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COMPARISON OF SOIL QUALITY AND YIELDS IN ORGANIC AND CONVENTIONAL CULTIVATION SYSTEMS

A pedological and qualitative case study in Makuutu subcounty, East Uganda

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Front page: Mutesi Hadija and her husband, Makuutu subcounty, Uganda. Author's photo.

Abstract

Organic agriculture has been proposed as a viable solution to declining soil quality and yields in no- or low-input cultivation systems typical for smallholder farms in Uganda. This study investigated the differences in selected soil quality parameters in organically cultivated soils as compared to conventionally cultivated soils in a case area in East Uganda. Based on interviews regarding cultivation practices and land-use history, 16 maize fields (eight fields for each system) were selected representing the organic and conventional cultivation systems employed in the area. Employed practices were found to be similar, although organic fields had limited inputs of nutrients through manure and compost, while conventional fields had no nutrient inputs. Generally, sampled fields had been cultivated continuously with maize for 10 years without crop rotation. Soil samples were collected in 10 and 20cm depths and analysed in terms of physical (soil water retention, bulk density, texture) and chemical (pH, soil organic carbon, total nitrogen, permanganate oxidable carbon) properties. No significant differences were found between the organic and conventional cultivation systems for any of these properties. Reported yield levels were also similar between systems. No measured soil property was significantly correlated with yield levels, indicating that unquantified factors such as drought conditions, presence of weeds and pests were more important. Long-term monoculture conflicts with key principles within organic agriculture, therefore this study questions whether selected organic fields in reality satisfy such principles.

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Preface

This thesis finalizes my Master's Degree in Geography and Geoinformatics with focus on Global Environmental Soil Sciences and Climate Changes from Department of Geosciences and Natural Resource Management (IGN), University of Copenhagen. The basis of my thesis was two months of fieldwork in Makuutu subcounty, Iganga District, Uganda in November and December 2017 followed by two months of intensive laboratory work at IGN.

First and foremost, I want to thank Associate Professor Thilde Bech Bruun, my supervisor, for her good and personal supervision of my work. It has been a pleasure working with her.

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Abbreviations

A2N	Africa 2000 Network
Al	Aluminium
BS	Base saturation
C	Carbon
C:N-ratio	Ratio between total carbon (C) and total nitrogen (N)
CCS	Conventionally cultivated soils
CEC	Cation Exchange Capacity
CO	Conventional
ECOSAF	Empower civil society and strengthen food security for farmer families
FAO	Food and Agriculture Organization of the United Nations
FC	Field Capacity
Fe	Iron
FFLG	Family Farming Learning Groups
IFOAM	The International Federation of Organic Agriculture Movements
IPCC	The International Panel on Climate Change
ISSS	International Soil Science Society
K	Potassium
N	Nitrogen
OCS	Organically cultivated soils
OD	Organic Denmark
OLS	Ordinary Least Squares
OM	Organic matter
OM-related properties	Organic matter-related properties, i.e. SOC, total N, Pox-C
OR	Organic
P	Phosphorus
PAW	Plant Available Water
rpm	Revolutions per minute (rotations around a fixed axis per minute)
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SWR	Soil Water Retention
USDA	The United States Department of Agriculture
WP	Wilting Point
ZPC	Zero Point of Charge

1 Introduction

Declining soil quality has been recognized as a major challenge in sub-Saharan Africa leading to decreased yields (Esilaba et al., 2005; Pender and Mertz, 2006; Sanchez and Swaminathan, 2005; Waithaka et al., 2007). Apart from being limited by inherent soil characteristics (Brady and Weil, 2014; Pender and Mertz, 2006), inadequate nutrient replenishment, exhaustion of soil's organic carbon pool and soil erosion as a result of anthropogenic influence are major reasons for this decline (Hilhorst and Muchena, 2000; Waithaka et al., 2007). Furthermore, agriculture depends heavily on precipitation, which is becoming increasingly unpredictable and is highly variable (Niang et al., 2014; Sanchez and Swaminathan, 2005). The consequences are food insecurity and poverty, especially amongst the rural population primarily consisting of smallholder, subsistence farmers strongly dependent on soil's ability to sustain agricultural production (Adamtey et al., 2016; Nkonya et al., 2004; Okalebo et al., 2007).

In East Africa, increasing population pressures, limited access to land and implementation of conservation policies, have led to the replacement of shifting cultivation with permanent agriculture, with reduced fallow periods or overall omission of fallowing having largely negative environmental consequences (Hilhorst and Muchena, 2000; Nkonya et al., 2004; Okalebo et al., 2007; Pender and Mertz, 2006; van Vliet et al., 2012). Farming systems practiced by the average farmer today are generally based on very low if any nutrient input from manure, compost or inorganic fertilisers (Chikowo et al., 2014; Sanchez and Swaminathan, 2005; Waithaka et al., 2007). Under these circumstances, organic agriculture has been suggested as a convenient approach to restore or sustain soil quality and improve farmer livelihood (Adamtey et al., 2016). Several studies found that conversion to organic agriculture have the potential to increase yields in smallholder farming systems of East Africa (Badgley et al., 2007; Gibbon et al., 2007; IFAD, 2002; Pretty et al., 2003; Willer and Lernoud, 2017), or as Willer and Lernoud (2017) put it:

> ”*The fact that traditional African agriculture is based on low external inputs provides an excellent foundation upon which organic agriculture can enhance productivity, resilience, and the profitability of smallholder farming in Africa. It is, therefore, an ideal development option for Africa*”

Thus, Badgley et al. (2007) suggested a yield ratio between organic and non-organic agriculture for grain products of 1.57 in developing countries in general, whereas ratios from East African countries for maize ranged from 1.46 to 3.49.

While being low on external inputs, the typical cultivation system in East Africa, as it has developed from traditional practices, falls short on the sustainability parameter with declining soil quality as a result (Hilhorst and Muchena, 2000; Merckx, 2002; Nkonya et al., 2004). Having this as the baseline, a conversion to organic cultivation practices may manage shortcomings through improved circulation and addition of nutrients, augmenting soil's ability to hold water and building up healthy biological activity in soils from a holistic perspective (Parrott et al., 2006; Scialabba et al., 2002; Willer and Lernoud, 2017). (John Dixon et al., 2001) stated that conversion to organic agriculture is a form of "*intensification of existing production pattern*", and certainly some of the organic cultivation practices are comparable to basic principles of shifting cultivation.

Plenty of literature describes the beneficial effect of organic cultivation practices on soil quality (e.g. Adamtey et al., 2016; Giller et al., 1997; IFAD, 2002; Mäder et al., 2002; Watson et al., 2002). However, to the knowledge of the author of the present study, literature has not assessed and quantified the difference in soil quality between organically and conventionally cultivated soils directly in an East African context. Using a case area, where farmers have converted to organic agriculture, this study aimed to investigate differences between organic and conventional cultivation systems and the changes that these may have caused in cultivated soils.

Organic Denmark and ECOSAF

Organic Denmark (OD) is a Danish associated organisation with a member base consisting of companies, organic farmers and consumers. They promote development of organic agriculture and products and believe that this is the way towards a more sustainable food production (Kaad-Hansen, 2017), while being a possible solution towards improving food security in the developing world. ECOSAF (Empower civil society and strengthen food security for farmer families) was a development project initiated by OD in 2013. The project established the Family Farming Learning Groups (FFLGs) approach in Uganda (Rasmussen, 2013). FFLGs bring together farmers who are interested in exchanging farming experience with others aiming to convert to organic cultivation practices, increase food security, improving livelihoods and domestic gender equality (Rasmussen, 2015, 2013). A number of partner organizations are now working together with OD in the second part of the project ECOSAF2.

The expectation of OD is that organic cultivation practices have the potential to increase yields considerably in Uganda where agriculture as it is typically practiced by smallholder, subsistence farmers is unsustainable resulting in low yields as presented above. The impression is that the involved farmers gained higher yields following conversion, while organic fields also withstand drought to a higher degree (Organic Denmark, 2017; Rasmussen, 2017). The case area of the present study was selected based on the areas where ECOSAF has been implemented.

1.1 Scope of the study

This study defined organic agriculture as one that applies cultivation methods that apply to the principles formulated by the International Federation of Organic Agriculture Movements (IFOAM), thus, the term organic cultivation practices in this study shares several characteristics with those of biodynamic agriculture, conservation agriculture, nature farming and agro-ecology to mention a few (Parrott et al., 2006). In practice fields were considered organic, if the relevant farmer considered him- or herself an organic farmer. Thus, farms are not required to be certified organic to be included under this definition of organic agriculture.

The term conventional is used to indicate that farming has developed in step with 1) the introduction of new cultivation technologies (e.g. ploughing remedies), and 2) a gradual transition of cultivation methods away from those used in shifting-cultivation as the traditional cultivation system. External inputs such as artificial fertilizers and pesticides are only used by a minority of conventional farmers – and in limited amounts. Thus, 'conventional' cultivation pratices as applied by farmers in Uganda differ considerably from what carries this term in, for example, Europe.

The study exclusively investigated soils cultivatied with maize on the time of sampling, because maize is an important food and cash crop in Uganda, while also being the investigated crop in many agricultural scientific studies.

1.2 Research questions

This study aims to investigate how organic cultivation practices impact soil properties potentially resulting in better soil quality as compared to conventional agriculture. The study combined pedological investigations with qualitative methods. A study area in mid-eastern Uganda was selected for the purpose through conversations with OD, while investigated soils were limited to maize-cultivation. The following research questions were formulated to cover the topic:

1. How does conventional and organic agriculture differ in the study area?
2. According to local organic farmers, what are the advantages of converting to organic cultivation practice – if any?
3. Is soil quality better in organically cultivated soils compared to conventionally cultivated soils? Focus on soil properties such as soil structure, plant-available water, soil organic carbon (and a certain part of this – labile carbon), total nitrogen and pH
4. Do inputs of nutrients (nitrogen (N), phosphorus (P) and potassium (K)) balance export of nutrients on field level?

The investigation consisted of numerous interviews with local farmers to get an overview of deployed cultivation practices. The interviews also constituted the basis for selecting 16 maize fields (eight conventional, eight organic) from which soil samples were collected to examine selected soil properties. Selection of fields was based on the criterium that the fields should be comparable in cultivated crops (maize being the primary crop, while intercropping/crop rotation should also be similar). At the same time, the selection aimed to represent typical practices within conventional and organic agriculture in the study area.

1.2.1 Hypotheses

Based on literature, hypotheses were constructed covering the expected findings. The hypotheses use the aim of the study as the point of departure, thus hypothesizing that organic soils have higher soil quality:

Hypothesis 1: Soil organic matter. Building up the soil pool of organic matter through addition of mulch, organic manures and compost is central in organic cultivation practice, and therefore soil organic carbon, total nitrogen and labile carbon fractions are expected to be greater in organically cultivated soils.

Hypothesis 2: Soil water retention. The amount of plant-available water is expected to be significantly higher in organically cultivated soils due to better soil structure and increased proportion of medium-sized soil pores caused by the assumed higher content of organic matter.

Hypothesis 3: pH. The assumed increased content of organic matter in the soil improves soil's buffering capacity. Therefore, the pH of organically cultivated soils is hypothesized to be significantly higher than that of conventionally cultivated soils.

2 Theory

The following section presents the typical soils of eastern Uganda and the associated soil characteristics. Focusing on these, the term soil quality is introduced, while describing the constituting soil properties – their relations to soil quality directly as well as their interrelations. Additionally, the concept of organic cultivation practice is presented with its intended effect on soil quality.

2.1 The soils of Eastern Uganda

Soil's intrinsic fertility is typically the cause of low yields all over Africa, where cultivation practices in addition often involve few or no external inputs (Brady and Weil, 2014; Feller and Beare, 1997; Okalebo et al., 2007). Major causes for soil degradation include nutrient deficiencies (especially nitrogen and phosphorus), soil acidity, water inadequacy and soil salinity (Gachene and Kimaru, 2003; Okalebo et al., 2007; Place et al., 2003). Another is the drastic fall in the length of fallow periods that has occurred in the region during the past decades (Pender and Mertz, 2006). The continent of Africa has the second largest area of degraded agricultural land in the world with 65%, second only to Central America's 74% (Brady and Weil, 2014).

Eastern Uganda is dominated by strongly weathered soils with low nutrient-holding capacity and high contents of kaolinitic clay as well as oxides of iron and aluminium, e.g. Ferralsols, Acrisols, and Nitisols. Nitisols constitutes the most productive soil of the three with its good soil structure and high water holding capacity, while also having the highest CEC due to high clay content and soil organic matter (SOM) (Driessen, 2001; IUSS Working Group WRB, 2015). The mineral composition of these soils results from the hot and wet climate of the tropics which accelerates weathering (Brady and Weil, 2014; Jones et al., 2013).

2.2 Soil quality

The term soil quality has been defined in numerous ways (e.g. Acton and Padbury, 1994; Borggaard and Elberling, 2013; Brady and Weil, 2014; Weil and Magdoff, 2004), but in general it is stated as a soil's capability to sustainably support ecological functions such as plant growth and storage and recirculation of water, nutrients and energy. Soil quality, thus, both concerns the soil functions connected to sustainable crop production in agricultural connection and environmental sustainability, as highlighted by Acton and Padbury (1994).

However, it is important to emphasize that the definition of good soil quality necessarily depends on the function or use that the soil in question should facilitate. High contents of nutrients may be good for plant growth but possesses a risk of leaching to surrounding waterbodies possibly causing pollution of aquatic environments. Thus, optimally the soil conditions should accommodate all its functions at once in a sustainable manner – 'a happy medium'.

Important properties related to plant growth include, but is not limited to, sufficient and balanced supply of nutrients, available water for plant respiration, and aeration to support root respiration and microbial decomposition processes (Brady and Weil, 2014; Lima et al., 2013; Shukla et al., 2006). Soil structure is an important determinant for both water availability and aeration, because it affects root penetration, soil porosity and permeability (Borggaard and Elberling, 2013), while also being important in controlling soil erosion. The latter is a frequent problem in Uganda (due to the combination of poor soil structure with periodic high-intensity rains, decreasing vegetation covers, and/or sloping surfaces), which can cause loss of nutrients by removing the top soil (Karamage et al., 2017). Ferralsols and Nitisols are generally thought to have good soil structure, while Acricols are easily eroded (Driessen et al., 2001).

The effect of soil structure on water availability, aeration and root development can be illustrated through the *bulk density*, thus being an important soil property from an agricultural viewpoint and one that is easily measured. Optimal bulk densities of agricultural soils are 0.9-1.5 g cm^{-3} in clay and silt loams and 1.25-1.75 g cm^{-3} for sandy loam and sand. High bulk densities typically cause restricted root growth and penetration, poor aeration and poor water availability (Brady and Weil, 2014).

The porosity, i.e. the volumetric proportion of a body of soil that does not consist of solids such as mineral particles or organic material, constitutes the storage for water and air. 10-20% of the pore space in the soil should be filled with air to secure good aeration (Brady and Weil, 2014), while as much of the remaining pore space under optimal conditions is filled with water to secure easy plant-uptake for plant roots. The composition of soil pore sizes and the permeability determines the soil's ability to hold water, termed the *soil water retention* (Jensen and Jensen, 2001).

2.2.1 Nutrients

A distinction is made between nutrients that plants need in large amounts of more than 1g kg^{-1} plant tissue dry mass (macronutrients) and those needed in small amounts of less than 0.1g kg^{-1} plant tissue dry mass (micronutrients) (Schjørring, 1999). An overview is given in Table 2.1, which also shows the plant-available ions. Some sources also consider carbon, oxygen and hydrogen as nutrients, but these are not denoted as such here. Sources of nutrients include decomposition of organic matter and weathering of minerals, while a minor part comes from precipitation.

Table 2.1 Overview of plant-essential nutrients and their plant-available ions (Brady and Weil, 2014; Marschner, 2002).

	Nutrient	**Plant-available ion**
Macronutrients	Nitrogen (N)	NH_4^+ (ammonium) or NO_3^- (nitrate)
	Phosphorous (P)	HPO_4^{2-} or $H_2PO_4^-$ (phosphate)
	Potassium (K)	K^+
Micronutrients	Boron (B)	BO_3^{3-} or $B(OH)_4^-$ (borate)
	Calcium (Ca)	Ca^{2+}
	Chloride (Cl)	Cl^-
	Copper (Cu)	Cu^+ or Cu^{2+}
	Iron (Fe)	Fe^{2+} or Fe^{3+}
	Magnesium (Mg)	Mg^{s2+}
	Manganese (Mn)	Mn^{2+} or Mn^{4+}
	Molybdenum (Mo)	MoO_4^- (molybdate)
	Nickel (Ni)	Ni^{2+}
	Sulphur (S)	SO_4^{2-} (sulphate)
	Zinc (Zn)	Zn^{2+}

As mentioned earlier, especially nitrogen and phosphorus constitute nutrients that are in shortage. The prevailing soil degradation in Sub-Saharan Africa leads to a decrease in soil's ability to hold water, and the presence of nitrate (the dominant form of nitrogen in agricultural soils) depends greatly on the water-holding capacity of soils. At the same time, these soils are often quite acidic (low pH) leading to the formation of insoluble iron and aluminium phosphates, where phosphorus is kept unavailable for plant uptake (Brady and Weil, 2014; Driessen, 2001; Gachene and Kimaru, 2003).

2.2.2 Soil particles and their effect on soil properties

Texture and properties connected to particle fraction

The term *soil texture* describes the distribution of sand, silt and clay in a body of soil (Table 2.2). The proportion of different particle sizes determines the *textural class* of the soil as described by FAO's Guidelines for Soil Description (FAO, 2006).

The clay fraction has immense importance for soil properties. For East Ugandan soils this fraction includes kaolinite (a silicate clay), aluminium and iron oxides (typically found as the crystalline gibbsite and goethite, respectively, while Fe-oxides are also found as amorphous ferrihydrite), and humus (organic material). Certain properties are connected these particle types (Table 2.3) (Brady and Weil, 2014). These particles are important for chemical properties of soils through their ability to retain nutrients due to their relatively high surface charges, while also affecting physical properties of the soil.

Table 2.2 Particle-size classes used by the United States Department of Agriculture (USDA) (FAO, 2006).

Particle	Particle size (µm)
Sand	63-2000
- Very coarse sand	1250-2000
- Coarse sand	630-1250
- Medium sand	200-630
- Fine sand	125-200
- Very fine sand	63-125
Silt	2-63
- Coarse silt	20-63
- Fine silt	2-20
Clay	0-2

Particles within the clay fraction: soil colloids

Kaolinite, being the dominant clay mineral in East Ugandan soils, possesses properties that impact plant growth (positively as well as negatively) due to its 1:1-layer structure (one octahedral layer and one tetrahedral layer). A consequence of this structure is that adsorption to this mineral is limited to its external surface area, while isomorphic substitution is negligible, resulting in a very low *cation exchange capacity* (CEC) (soil's total negative charge per unit of weight of soil). Additionally, the hydroxyls of the octahedral layer can release or uptake H^+ dependent on pH, thus making CEC dependent on pH with increasing pH leading to higher CEC.

A positive consequence of the dominance of kaolinite is that this clay mineral has low malleability, stickiness, shrinkage/swelling and cohesion, causing these soils to have a good structure for cultivation purposes. However, kaolinite's ability to adsorb water is low compared to other clay minerals resulting in poor water holding capacity of soils (Brady and Weil, 2014).

Aluminium and iron oxides (Al- and Fe-oxides, respectively), also termed **sesquioxides**, consist of octahedral layers connected with an Al^{3+} or Fe^{3+} cation exhibiting low malleability and low stickiness. Their external surface areas are larger than kaolinite, while their ion exchange capacities vary from slightly positive to negative. Thus, sesquioxides may both adsorb anions and cations. Oxygen and hydroxyl-groups at the surface of the particles provide the exchange spaces as was the case for kaolinite.

Humus is an organic soil colloid having very high positive and negative charge per unit mass, while net charge remains negative. Net charge depends on pH becoming increasingly negative with increasing pH (section 2.2.3), while being higher than any clay mineral (Borggaard and Elberling, 2013; Brady and Weil, 2014; Krogh et al., 2000). Thus, decreasing soil organic carbon (SOC) with 1 g kg^{-1} results in a decrease of effective CEC by 4.3 mmol kg^{-1} in soils with kaolinitic clay such as those in Uganda (Lal, 2006). Again, the pH-dependent charge results from (different types of) hydroxyl groups. In addition, humus can adsorb large amounts of water having a positive effect on soil's water retention capacity. Organic material and its effect on soil properties is described further in section 0.

Nutrient availability is closely related to the presence of these mentioned colloids. Kaolinite and sesquioxides are important adsorbents of nutrient ions, while humus both function as adsorbent and releaser of nutrients as mineralization takes place.

Table 2.3 Properties connected to the most dominant particles within the clay fraction in East Ugandan soils (Brady and Weil, 2014). Negative ion exchange capacities correspond to CEC, which is given in brackets.

	External surface area, m^2 g^{-1}	Ion exchange capacity (CEC), $cmol_+$ kg^{-1}
Kaolinite	5-30	-1 to -15 (1-15)
Al-oxides (Gibbsite)	80-200	+10 to -5 (0-5)
Fe-oxides (Goethite and ferrihydrite)	100-300	+2 to -50 (0-50)
Humus	Variable	-100 to -500 (100-500)

2.2.3 Soil charge and pH

pH is a very important parameter in determining soil quality for many reasons. First of all, pH strongly influences the surface charge of the soil colloids mentioned above, thus being an important determinant for the soil's net charge and thereby its ability to adsorb essential plant nutrients in plant-available form.

As described above, the net charge of soil colloids in East Ugandan soils is largely pH-dependent, while only a minor part is permanent charge. The latter results from isomorphic substitution happening to a very limited extent, thus CEC is very positively correlated to pH. Kaolinite clay, sesquioxides and humus each have proportions of 95%, 100% and 90% pH-dependent charges (Brady and Weil, 2014). pH-dependent charges develop as a result of 1) the protolytic properties of hydroxyl groups on organic and inorganic soil colloids, and 2) charged edges on clay particles that are no longer balanced by binding to a silicon (Brady and Weil, 2014; Jensen and Jensen, 2001). At high pH the hydroxyl group will release an H^+ ion leaving a negative charge behind, while low pH results in uptake of H^+ neutralising the charge or, alternatively, a release of OH^- leading to a positively charged adsorption space. The point where a pH-dependent charge shifts between being positive and negative, i.e. the point where it is neutral, is called the *zero point of charge* (ZPC) (Borggaard and Elberling, 2013). A consequence of these soil colloids' high proportion of pH-dependent charge sites is that the soils have relatively low CEC in general, while having relatively high *anion exchange capacities* (AEC) – a feature of soils that have been subject to intermediate to strong weathering intensity, which is typical for East Uganda due to high precipitation and high temperatures (Brady and Weil, 2014). Dominant presence of pH-dependent charges in these soils increases the importance of maintaining a soil pH that secures good soil quality. A pH of 5.5-7.0 supports good availability of most nutrients, while the optimal pH range for maize production is slightly more acidic being ~4.8-6.5 (Brady and Weil, 2014).

2.2.4 Soil water retention and water-availability to plants

Soils' ability to hold water is termed *Soil water retention* (SWR) and is a result of both soil texture and structure, because these determines soil's porosity and permeability. Soil porosity determines the amount of water than can be stored in the soil, while the retention of water is determined by permeability. In the perspective of agriculture, the amount of *plant-available water* (PAW) is interesting, defined as the difference in volumetric water content at *field capacity* (FC) and *wilting point* (WP) and found in middle-sized soil pores with radius 0.1 to 15μm (Jensen and Jensen, 2001). Figure 2.1 illustrates the relation between PAW and texture.

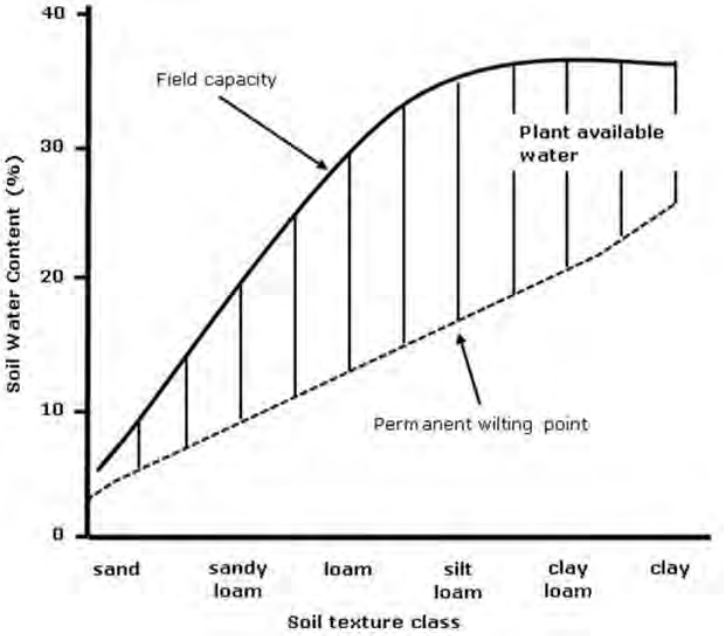

Figure 2.1 The relation between soil texture and amount of plant-available water (O'Geen, 2013).

SWR is illustrated with a *retention curve* where the pF-value, being the logarithm of the height (cm) of the water column needed to create a sufficient level of pressure, is a function of the soil water content as expressed by Eq. 2.1.

Eq. 2.1) $pF = log_{10}(cm\ water\ column)$ (adapted from Borggaard and Elberling, 2013)

Field capacity (FC) at pF2.0 corresponds to a water column of 100cm corresponding to the soil water content held back post-saturation, when free drainage after 2-3 days has become insignificant assuming zero evaporation (Romano and Santini, 2002). The wilting point (WP) at pF4.2 is a 15,000cm water column. At higher pressure water becomes unavailable to plants. With decreasing soil water content (approaching WP) water becomes less accessible for plants, since it is primarily stored in the soil's smallest pores. pF3.0 constitutes the border between the slowly available water (pF.3-pF4.2) and the easily available water (pF2.0-pF3.0). Soil structure is especially important at low pF values (pF0.0-3.0; low tension values), while texture is more important at higher pF-values (pF3.0-pF4.2; high tension values) where adhesion is the primary force retaining water (Jensen and Jensen, 2001).

The pressure potential (the energy the plant must spend to extract water from the soil) is inversely related to pore size. As a consequence, clayey soils – as the ones in East Uganda – have high WP, retaining a relatively large amount of water unavailable to plants (Figure 2.1: amount of water below the line indicating WP), although lower amounts than would be the case if other clay minerals had been dominant – kaolinite adsorbs less water than, for example, smectite, illite or vermiculite clays. Aggregation of soil particles improves soil structure and reduces the proportion of small soil pores, thus increasing PAW. SOM works as an agent for aggregation of soil particles, thus increasing the proportion of medium-sized soil pores storing PAW (Weil and Magdoff, 2004). Thus, the presence of SOM becomes important in such soils.

2.2.1 Soil organic matter

SOM consists of dead plant and animal remains as well as living organisms living within the soil (Borggaard and Elberling, 2013). The proportion of SOM which is no longer identifiable as plant tissue is termed *humus*, and this is the fraction that is important for soil quality (Murage et al., 2000; Shukla et al., 2006; Weil and Magdoff, 2004). A distinction is typically made between the active, the slow and the passive pools of SOM, each of them affecting soil properties differently (Table 2.4).

45-60% (normally assumed to be 58%) of SOM is made up by carbon and is termed SOC (Borggaard and Elberling, 2013). Thus, SOC refers strictly to the carbon content of SOM, while SOM include the whole mass of organic soil constituents.

As Table 2.4 indicates, SOM is important for a number of soil properties. Firstly, SOM affects water availability directly due to organic matter's high water-holding capacity resulting in higher contents of water with higher SOM content of the soil (Brady and Weil, 2014; Lal, 2006).

Secondly, SOM works as a 'glue' in soils improving structure of the soil through aggregation of soil particles. Aggregation increases the proportion of medium soil pores able to detain plant-available water, while decreasing the bulk density (Weil and Magdoff, 2004). The active pool is primarily responsible for the effect SOM has on soil structure (Brady and Weil, 2014).

Thirdly, the mineralization of SOM within the soil results in a release of nutrients that are readily available for plant uptake (Lal, 2006). Mineralization increases with increasing temperatures. The active and the slow SOM are the main sources of nutrients through decomposition (Weil and Magdoff, 2004). Additionally, SOM is an important adsorbent of nutrients in soils due to the colloidal properties of the passive pool of SOM (*humus*), thus increasing CEC as described in section 2.2.2. Macro- and micro-organisms, feeding on carbon obtained through decomposition, are vital for soil quality, because they are largely responsible for nutrient cycling and aid soil aggregation (Bot and Benites, 2005). Therefore, in cultivation of soil, procedures must accommodate a consideration of the living pool of SOM as well.

Lastly, through its protolytic properties SOM molecules buffer pH. If pH is increasing, the carboxyl sites will release H^+ to obtain equilibrium in the soil solution, while H^+ will be taken up in case of decreasing pH (Brady and Weil, 2014; Weil and Magdoff, 2004). Mineralization of SOM has a direct acidifying effect on pH, when H^+ is released as a biproduct.

Table 2.4 Properties connected to the active, slow and passive pools of SOM (Brady and Weil, 2014).

	Active SOM	**Slow SOM**	**Passive SOM**
C:N-ratio	15-30	10-25	7-10
Half-life	A few days to a few years	Decades	Hundreds to thousands of years
Proportion of SOM	10-20%		60-90%
Primary functions in terms of soil quality	• Nutrient source • Food for soil microbes • Structural stability of the soil (aggregation)	• Nutrient source • Functions connected to the active and passive pools	• Colloidal properties: adsorbs nutrients and is related to CEC

As appears from the description of relations between SOM and soil quality, the active, slow and passive pools of SOM, have significantly different roles. Therefore, when analysing SOM as an indicator of soil quality the analyses must differentiate between these pools. The *labile C fraction* has been used as a proxy of important soil chemical and physical properties and is largely connected to the biologically active C pool. This is the part of SOM that is most sensitive to management practices and has been proposed to be closely connected to soil quality (Bot and Benites, 2005; Culman et al., 2012; Murage et al., 2000; Weil and Magdoff, 2004; Weil et al., 2003). Weil et al. (2003) developed a simple laboratory method using potassium permanganate ($KMnO_4$) to estimate the active carbon pool as a better measure of microbial activity and other indicators of soil quality.

Long-term cultivation of soil typically leads to a decrease in SOM, especially in the active and to some degree the slow pool, resulting in a poorer soil structure (increased bulk density) and reducing other beneficial qualities connected to SOM as described above (Dixon et al., 2001; Weil and Magdoff, 2004). SOC, which constitutes the main part of SOM, has been suggested to be positively related to yield levels due to decreased nitrate leaching and soil's improved response to nutrient inputs (Lal, 2006). Therefore, it is important to return the amount of SOM which has been depleted as part of the cultivation through adding of crop residues, compost or organic manure (Brady and Weil, 2014; Lal, 2006). Cultivated A-horizons typically hold 2-4 weight-percent SOM (Jensen and Jensen, 2001), and agricultural management should pursue keeping the content in the high part of this range with a high C:N-ratio (Weil and Magdoff, 2004).

2.3 The concept of organic cultivation practice

The term 'organic' in organic cultivation practice refers on the one hand to the processes through which the outcome is produced, which are strictly organic (biological and ecological). On the other hand, the term also refers to the perception of the farm as an *organism* where the components (animals, microorganisms, plants, soils, people etc.) interact in a form of living system (Brady and Weil, 2014; USDA, 1980). The International Federation of Organic Agriculture Movements (IFOAM) formulated what they call *the principles of organic agriculture* (IFOAM, 2005; Kristiansen, 2006):

1. *Health*. Organic agriculture should avoid the application of agricultural inputs such as inorganic fertilizers, pesticides, animal drugs and food additives that may harm the health of any part of the environment being soil, plants, animals or humans, and that organic agriculture at all times will make efforts towards sustaining or improving the health of these entities.
2. *Ecology*. Organic agriculture bases itself upon ecological, naturally occurring processes, and thus strongly depends on the local conditions in terms of ecology, climate, soil etc. while also taking culture and scale of the farm system and society into account. Cycling within the system and biodiversity are considered important measures in following this principle.
3. *Fairness*. Organic Agriculture must ensure fairness among people and between people and other living things. Thus, the principle of fairness implicates that social sustainability is an intrinsic part of organic agriculture.
4. *Care*. Organic Agriculture should always aim to be sustainable in both time and space through responsible management taking necessary precautions. Management, therefore, must happen in agreement with the most recent scientific knowledge relevant to protect humans and environment supplemented with practical experience.

Thus, organic agriculture is based on a holistic production system striving to take account of both the well-being of humans, animals and nature through methods ensuring sustainability. This requires a constant consideration of prevailing, local factors such as climate, biodiversity, soil characteristics and existing farming systems as well as social structures of the area (Kristiansen, 2006). However, systems terming themselves 'organic' have several times been shown to be unsustainable (Oelofse et al., 2010b; Parrott et al., 2006).

2.3.1 How can organic farming contribute to improved soil quality?

Organic cultivation practices have shown to have positive effects on soil quality and yields in development countries (Brady and Weil, 2014; Watson et al., 2002). In the course of this study some practices employed by organic farmers to improve soil quality in the area were emphasized, and these are described here:

- *Mulching* – decreases erodibility of and evaporation from the soil surface, while also increasing SOM content, adding nutrients, contributing to soil particle aggregation, and improving soil water retention (Brady and Weil, 2014; Giller et al., 2006; Mulumba and Lal, 2008). The mulch can consist of crop residues from the same or different locations, which are added on the soil surface
- *Application of organic manure and compost* – contributes with nutrients in step with a gradual mineralization (Wang et al., 2017)
- *Intercropping* – increases the net yield (while potentially increasing food security through different timing of crop maturation), while potentially increasing soil quality through increasing SOC and soil organic nitrogen (Cong et al., 2015)
- *Crop rotation* – increases yield and maintains good soil fertility, while potentially minimizing problems with pests, diseases and weeds (Watson et al., 2002)
- *Trenching* – decreases soil erosion and retains water for plant growth
- *Nitrogen-fixing crops* – take up nitrogen directly from the atmosphere (in the form of N_2). Part of the stored N is released when the dead plants are mineralized in the soil (Giller et al., 1997)

2.4 Weeds and pests – impeding maize production

A number of biotic stresses impede maize production in Africa (VIB, 2017). The most important of these – in terms of economic consequences – are the pests stem borer and Fall Armyworm, and the weed Striga. The presence of these strongly depends on the general state of the soil and the maize plant itself, with poor soil quality and abiotic stress factors such as drought making maize crops more susceptible (Berner et al., 1997; Rich and Ejeta, 2008; VIB, 2017).

Infestation of **stem borers** (*Chilo partellus* and *Busseola fusca*) in maize may result in yield decreases of 20-50% (Gressel et al., 2004; VIB, 2017). This pest affects the maize plant from germination to harvest. The name comes from its characteristic ravage inside the plant stem, which mostly occur in older plants (VIB, 2017).

The pest **Fall Armyworm** (*Spodoptera frugiperda*) was first officially detected in Africa in 2016, where it has made its entry in almost all countries in sub-Saharan Africa by January 2018 (Wild, 2017). There are only few natural enemies to the armyworm in Uganda as it is, because the pest originates from America. Factors such as late planting or varying sowing time within small areas may increase the infestation degree of Fall Armyworm (FAO, 2018a).

Striga weed (*Striga hermonthica*) is a parasitic plant deriving part of or all its nutrients from a maize plant (Rich and Ejeta, 2008), while spreading through infected maize seeds, wind or agricultural equipment to mention a few (VIB, 2017). Striga's presence is related to infertile soils following from poor agricultural management such as monocropping over an extended period, allowing Striga to gain strength and increasingly take over the field. Effective countermeasures include the rotation of legumes in-between potential host crops such as maize, because these cannot host Striga while improving soil fertility (Berner et al., 1997; VIB, 2017).

3 Methods and materials

Fieldwork was carried out in a study area in Uganda to investigate potential differences in specific soil fertility parameters of organically cultivated soils compared to conventionally cultivated soils. The fieldwork included semi-structured interviews with local farmers and soil sampling. The interviews aimed to establish the land-use history of the area and get an overview of employed cultivation practices to make a basis for selecting eligible fields for soil sampling. Soil sampling was executed in order to represent soil quality of organically and conventionally cultivation maize fields that are representative for the case area.

Firstly, the study area is described in terms of climate, soil types and agriculture. Secondly, the fieldwork process is presented in terms of interviews and selection of fields for sampling including the practical strategy for the soil sampling. Lastly, the soil analyses representing soil quality parameters are described followed by an explanation of the statistical methods used to process the results.

3.1 Study area

The fieldwork was carried out in Makuutu subcounty (0°29’52N, 33°35’32E) in the district of Iganga, located in the south-eastern part of Uganda, approximately 60 km west of the Kenyan border and 30 km north of Lake Victoria (Figure 3.1). The study area is situated in an altitude of 1090-1160 m.a.s.l. Land-use in the subcounty is strongly dominated by subsistence agriculture (Karamage et al., 2017) with only small trading centres (cluster of houses with a number of small shops) consisting of 20-30 houses.

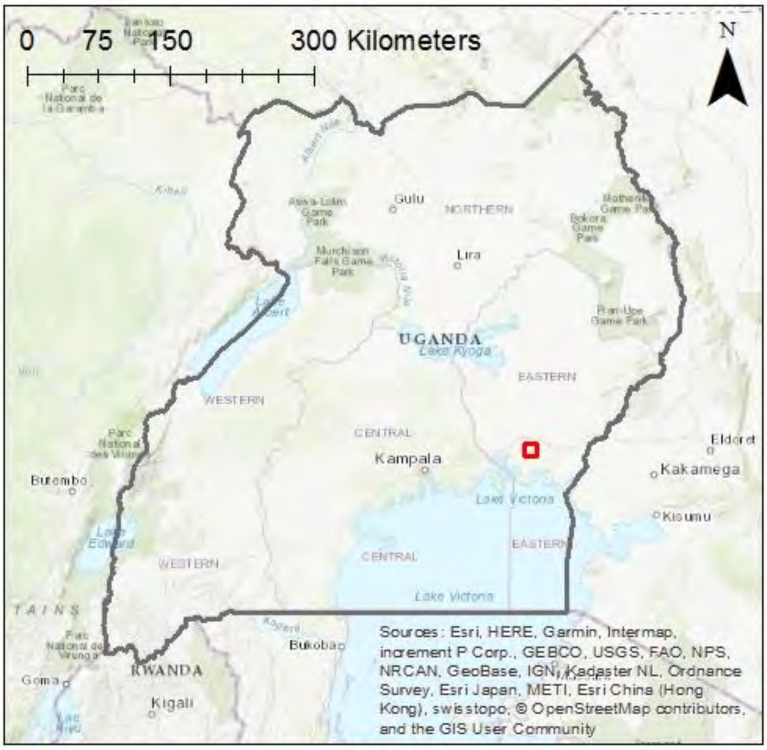

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Figure 3.1 Overview of the location of the study area in eastern Uganda.

The population of Iganga district increased from 355,500 people in 2002 to 504,200 in 2014 – an increase of almost 42% in 12 years (Uganda Bureau of Statistics, 2016). Local data (Appendix 1) also indicates a rapid population growth within the two parishes Makandwa and Makuutu being part of this study, which is increased a total of with 4000 people from 2014/15 to 2016/17 (Table 3.1).

Table 3.1 Population of the parishes which are part of this study in 2014/15 and 2016/17 (Appendix 1).

Parish	2014/15	2016/17
Makandwa	5285	7448
Makuutu	7264	9108

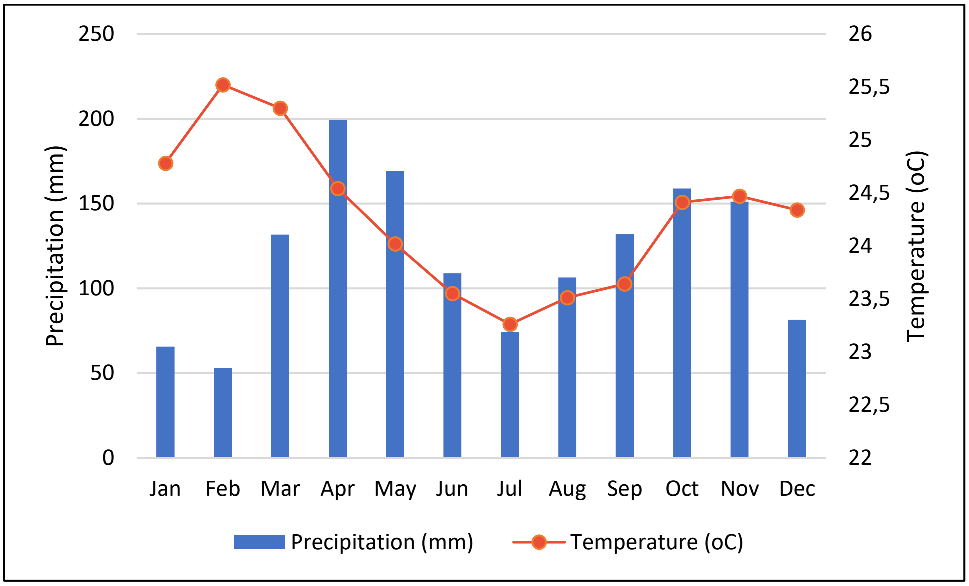

Figure 3.2 Average monthly precipitation and temperature in Uganda for the period 1991-2015 (World Bank, 2018).

3.1.1 Climate

Figure 3.2 shows the precipitation and temperature patterns of the Ugandan climate according to the period 1991 to 2015 (World Bank, 2018). Precipitation showed a bimodal pattern over the year having two rain seasons – one in March-May and one September-November. Average monthly precipitation ranged between 53 mm (February) to 199 mm (April), while the average annual precipitation was 1430 mm. Temperatures were lowest in July and highest in February with 23,3 and 25,5ºC. respectively. Thus, variation is very limited due to the proximity to Equator (app. 55 km).

According to the Köppen-Geiger Climate Classification, the climate of the study area is *equatorial monsoon* (Am) with an average temperature of more than 18 ºC for all months and distinct dry and rainy seasons (Kottek et al., 2006).

3.1.2 Soils

The following section describes the soil properties generally for the area according to Jones et al. (2013). The soil temperature regime of the study area is *isohyperthermic* having a mean annual soil temperature of more than 22 °C, while the difference between mean summer and winter temperatures is less than 5 °C. Soils are typically acidic with low CEC (4-20 cmol kg^{-1}).

The major soil type found in the study area is *Orthic Ferralsol* (Figure 3.3) (IUSS Working Group WRB, 2015). This translates to *Oxisol* in the Soil Taxonomy characterisation system (Brady and Weil, 2014).

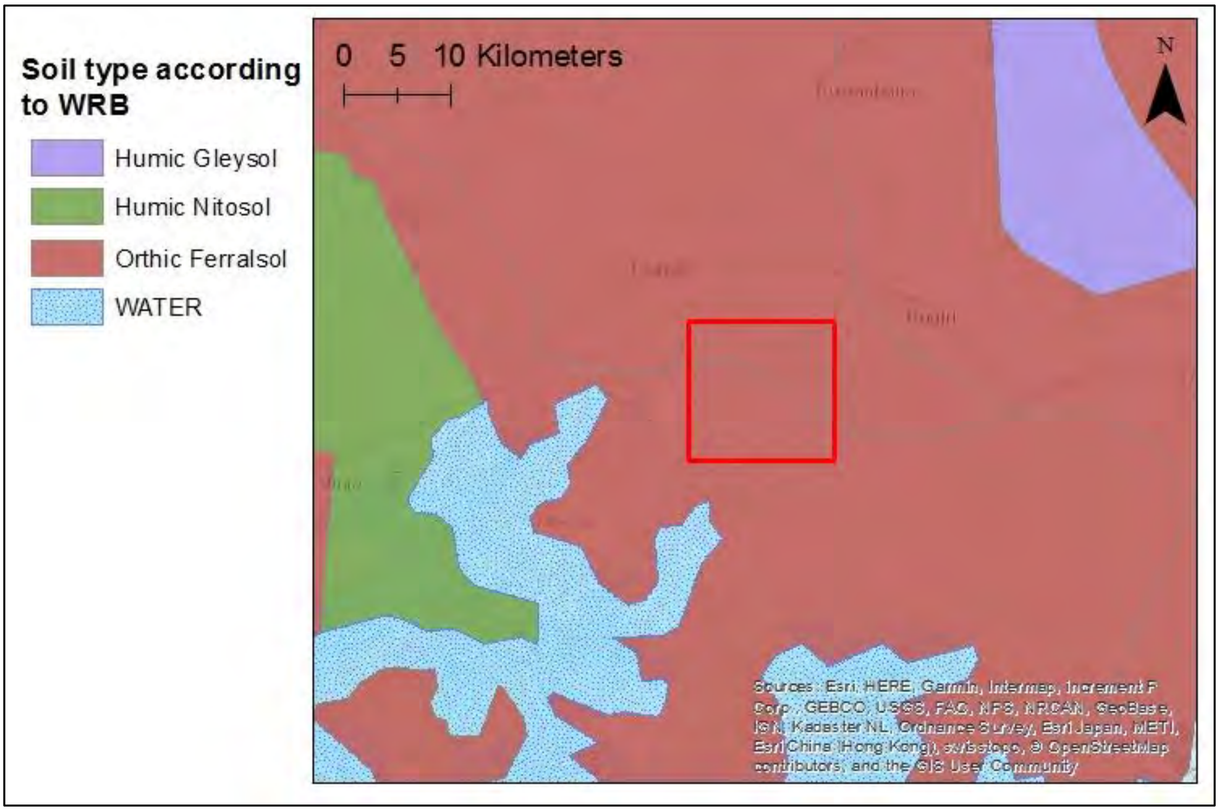

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Figure 3.3 Soil types of the study area (shown with the red square) according to IUSS Working Group WRB (2015).

3.1.3 Agriculture in the case area

The majority of inhabitants in Makuutu subcounty are either fulltime or part-time farmers, mainly cultivating maize, sweet potato, groundnuts, cassava, sugarcane, banana, pineapple and different types of beans (NEMA Uganda, n.d.; Appendix 3). The relatively high temperatures and bimodal precipitation pattern makes the basis of two growing seasons per year. The first growing season runs from February to June and the second from September to January (FAO, n.d.; Local farmers, 2017). The area has high potential for crop production due to the advantageous climate, but disregarding soil quality (Ruecker et al., 2003). Most farmers have less than 5 acres (2 ha) of land at their disposal, making it necessary to cultivate the whole area without leaving much land for fallow according to locals. The cultivation practices vary from conventional farming (see definition, section 1.1), without external inputs over conventional farming with some external inputs, to organic farming with different organic inputs such as organic manure, mulching and homemade pesticides. The National Environment Management Agency of Uganda stated soil erosion and declining soil fertility to be the major contributors to land degradation, both being related to the growing population of the area, poor farming methods, bush farming and overgrazing (NEMA Uganda, n.d.).

According to FAO, crop production in Iganga district has suffered from increasing drought for the past 15 years to a larger extent than Uganda as a whole (Figure 3.4). Especially the first growth season was impacted; for example, in 2004 93% of arable land in Iganga district was affected by drought as expressed by the Agricultural Stress Index (ASI), while 81% was affected in 2011 (FAO, n.d.).

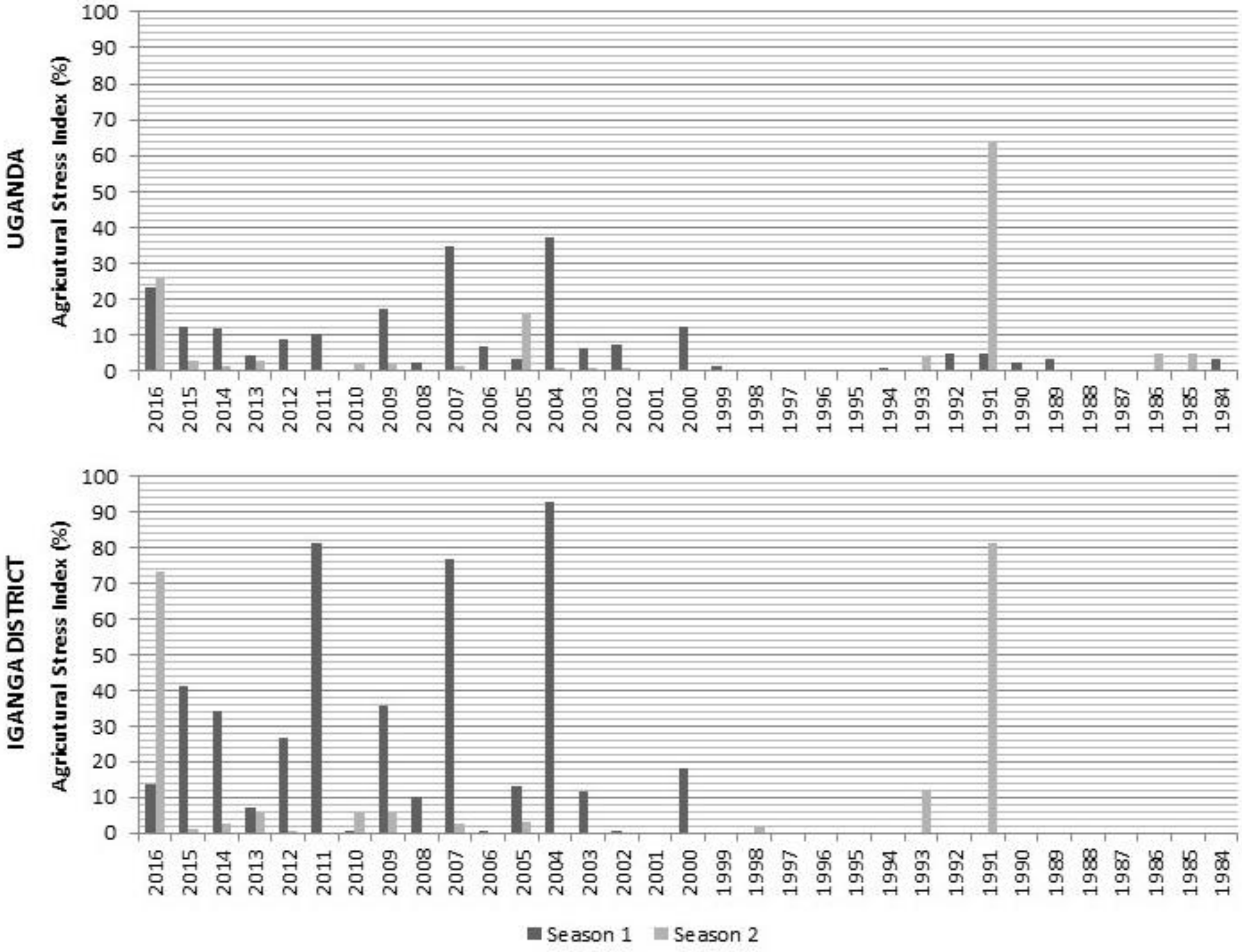


Figure 3.4 Agricultural Stress Index (ASI) in Iganga district, Uganda, in the period 1984-2016 (FAO, n.d.). ASI is the percentage of arable land with a Vegetation Health Index < 35 through the growing seasons in both spatial and temporal dimensions. The temporal dimension considers the duration and intensity of drought periods within crops' growth cycles, while the spatial dimension calculated the spatial extent of the drought event (FAO, n.d.).

3.2 Fieldwork

The fieldwork was carried out in the period 8th November to 22nd December 2017, which is close to the end of the second season of the year.

An introductory interview was carried out with the contact person in Africa 2000 Network (A2N), Yusuf Wesonga, who is working to implement ECOSAF in Iganga district. The interview concerned conventional and organic farmers' practices and their knowledge about soil quality. A transcription is shown in Appendix 3.

Bamulambe Roman was attached the project as an interpreter during the whole period of fieldwork. He is a local farmer residing in the village Makandwa in Makuutu subcounty and has been an *external facilitator* under ECOSAF for the past 10 years, while also being an organic farmer himself. Therefore, Roman has sound knowledge of organic cultivation practice. An *external facilitator* is charged with facilitating discussions and experience sharing in the individual *Farmer Family Learning Groups* (section 1). Through this Roman had relations to most of the organic farmers interviewed.

The following section introduces the field selection criteria employed and the interview approach. Subsequently, the strategy for soil sampling is described for field samples and soil profiles.

3.2.1 Selection of fields for soil sampling

16 fields were chosen for soil sampling. Eight of these were under conventional cultivation, while the remaining eight were cultivated organically (see section 1.1 for definitions). The selected fields were distributed between four villages (Makuutu, Makandwa, Kinabirye and Buswiriri) in Makuutu subcounty with two conventional and two organic farmers in each village. Criteria for selection of fields developed sequentially with increasing knowledge about cultivation practices and conditions.

The eligibility of fields was assessed through semi-structured interviews with the owner (Appendix 2). All fields used for sampling must fulfil the following criteria:

1. Maize must have been the **main crop** on the field for both of the two growing seasons of 2017. Yield levels were obtained based on the first season of 2017 (March-August). Additional information about the basis of this criteria below.
2. The location of the field should be in a distance of what farmers refer to as 'swamp' that ensures that the **field is not flooded on a regular basis**, since flooding can impact the nutrient base of the soil, which cannot be distinguished from nutrients relating to cultivation practice.
3. The field must not be situated on a **sloping surface** causing regular soil erosion. However, some slope is allowed if the farmer does not consider erosion to be a problem for the field in question.
4. The field must have been under the **interviewee's ownership for the past 10 years**. This ensures that it is possible under guidance of the farmer to describe the land-use history in the 10-year period.
5. The field must have **undergone ox-ploughing for the two seasons of 2017** (March and August) to ensure that the depth of top soil mixing is approximately the same.

The major challenge in selecting fields for sampling was to ensure that they for each cultivation system (organic vs conventional) represented the general methods within the system. This challenge was addressed through the interviews by asking about land-use and making a flow diagram in cooperation with the farmer. For each cultivation system there were some additional criteria for field eligibility which are presented below.

Criteria and decisions on exclusion

Some criteria developed in the course of the interviews. Initially, the criteria about cultivated crops on the fields in 2017 (criteria no. 1 above) was undecided; an overview of the usual cultivation patterns (crop rotation and intercropping) had to be obtained before making this decision. Having conducted 30 interviews covering 64 fields, it was decided to use fields that were cultivated with maize only in both growth seasons of 2017. The basis of this decision is shown in Table 3.2.

Firstly, maize had to be the primary crop in both seasons to obtain yield level estimates from the first season, while maize should also be the primary crop at the time of sampling. Therefore, fields with crop rotation within 2017 were excluded from sampling.

Secondly, intercropping with N-fixing crop(s) in either first and/or second season of 2017 was present in only 25% of the fields registered at the time (excluding fields with crop rotation or intercropping of non-N-fixing crops from the statistic). Additionally, if intercropped fields were to be included in the soil sampling, 16 fields with the same intercropping pattern had to be found, i.e. crop type and timing should be identical (for example, intercropping with g-nuts in the first season should be consistent for all 16 fields). In general, intercropping was applied more among conventional farmers than organic farmers with some variation between villages.

Table 3.2 Percentages of conventional (CO) and organic (OR) fields and combined that use the practices of intercropping and crop rotation (only with N-fixing crops) or none of these in the study area.

		Average ***(n = 64)***
% fields only maize	CO	74%
	OR	63%
	All	68%
% fields intercropped	CO	26%
	OR	23%
	All	25%
% fields crop rotated	CO	0%
	OR	15%
	All	8%

Conventional cultivation

The aim here was to represent the *average* conventional farmer. After having conducted the first part of the interview (i.e. excluding land-use timeline and flow diagram) with 30 non-organic farmers, it was decided to exclude farmers applying inorganic fertilizers or pesticides to their fields, since these made up only 14% (2 of 14) of conventional farmers interviewed at the time.

Organic cultivation

The organic fields that were selected for sampling had all been cultivated organically for 8-10 years. This time period was chosen as a criterion to ensure that the soils would be had been subject to the cultivation practices for long enough for soil properties to have altered due to a changed cultivation practiced (Breuning-Madsen, 2017; Bruun, 2017). The time period of 8-10 years was established after estimating that an adequate number of organic farmers matched this criterion.

3.2.2 Interviews

The semi-structured interviews were, in compliance with the recommendations by Kvale and Brinkmann (2014), executed aiming to ask short and simple questions, to give time for spontaneous, specific and relevant answers, and to follow up on potential misunderstandings during the interview, while verifying the interviewer's interpretation of the information given by the interviewee.

The interviews consisted of two parts (interview guides are found in Appendix 2): The first addressed the criteria for field selection that were formulated in advance, while at the same time giving an overview of the area, the practices employed and challenges faced by local farmers. The second part focused on land-use history of the individual field as well as the construction of a flow diagram (Appendix 2). This part elaborated on the information given during the first part, while also contributing with knowledge that could be important for the interpretation of the results emerging from the soil analyses. All parts of the interview were introduced with a short briefing about the purpose of the interview (Kvale and Brinkmann, 2014). Organic farmers were specifically inquired about their view on advantages with organic farming practices and the type of farming practices they started to employ after conversion.

The first part of the interview was executed with 42 local farmers, while the second part (land-use and flow diagrams) included 23 farmers. 16 maize fields were selected for sampling amongst these 23 farmers. The interpreter's knowledge of local conditions and people contributed greatly to finding interviewees.

Selecting and finding interviewees

Interviewees were selected based on a combination of different sampling strategies that are all non-random (Mosley, 2013):

1) *Purposive sampling* where the selection aimed to find farmers within the two groups of conventional and organic cultivation practice.
2) *Convenience sampling* where selection of interviewees depended to some degree on personal relations of the interpreter, who as a local farmer also worked as a form of guide. Additionally, convenience sampling in this context implied that selection of interviewee somewhat depended on the farmer being available at relevant times.
3) *Snowball sampling* where the interviewee was selected based on recommendations from earlier interviewees, typically relatives or neighbours.

In the initial phase of interviewing *purposive sampling* was the dominant sampling strategy. With time only one or two farmers from each village that met the selection criteria was missing to complete the field selection. From this point convenience and snowball sampling became more important, because the search for eligible fields had become very targeted and time was limited.

Charting land-use history

The land-use history is an important factor, because it may contribute with details affecting the soil. In this case it was deemed sufficient to describe the land-use for the past 10 years to give a good impression of factors having had influence on soil fertility.

Charting of land-use history was visually presented to the farmer as a timeline covering the past 10 years, 20 growing seasons, having chosen growing seasons as an appropriate time scale. The history was described using the ongoing growing season as the point of departure and going back in time. The farmer was specifically inquired about the selection criteria to ensure that these were met, while also aiming to capture details that may have affected the soil or yield levels such as challenges for his/her agricultural practices (e.g. weeds, pests, climate). An example of a land-use timeline is shown in Appendix 8.

Field-level flow diagrams

Flow diagrams (inspired by the procedure described by Defoer and Budelman, 2000) were constructed on field-level for the first season of 2017 to obtain a full overview of the cultivation practices employed on the field during the growth season, i.e. all potential inputs and outputs. A conceptual flow diagram is shown in Figure 3.5. The flow diagram was sketched for the farmer initially, the basic principles explained, and then details were filled in with the interviewer as facilitator. While the visual part was mainly a tool to make the interview tangible for the farmer, the flow diagrams contained important information concerning nutrient inputs, timing of weeding, seeding and harvest within the cultivation cycle, removal of weeds and crop remains and yield destinations (domestic use or sold on market). An example of a flow diagram as drawn during an interview is shown in Appendix 8.

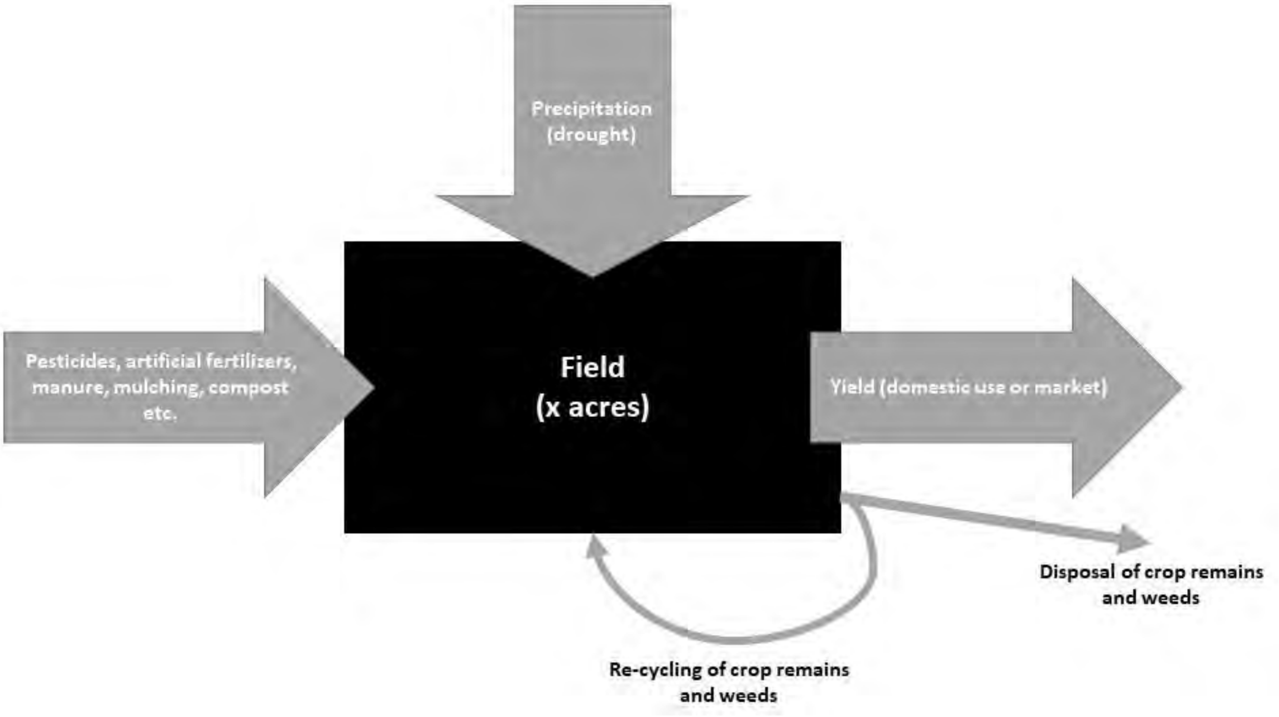


Figure 3.5 The concept of the flow diagram as presented to the interviewee.

3.2.3 Focus group interviews about soil quality

Two short focus group interviews were conducted about farmers' perception of soil quality (interview guide Appendix 5). Here, factors indicating good and bad soil quality were discussed with two groups of both organic and conventional farmers. The participants disclosed the sensuous signs they look for when determining whether a soil is good or bad as well as the causes for inclining or declining soil quality. These focus group interviews were held within the first week of the fieldwork.

3.2.4 Soil sampling strategy

Field top soils

Soil sampling was carried out in 10x10 m quadratic sample plots established centrally on each field, ensuring that the plot only include maize crops (and potential weeds) and that the distance to foot paths or surrounding fields was more than 1 meter to reduce risk of contamination or edge effects. The upper 30 cm was thought to represent the Ap-horizon, because ox-ploughing disturbs the top-soil down to this depth (Bamulambe, 2017; Wesonga, 2017). Therefore, three pits of approximately 30 cm depth were dug on a diagonal line within the sampling plot, see Figure 3.6. The distance between the pits was app. 2.8 m, each hole placed minimum 2 m from the border of the sample plot. The geographical coordinates of the individual fields and field areas were collected using a GPS, which also gave an indication of the slope of the field. This sampling strategy resulted in a total of 96 field topsoil samples. During sampling visible or perceivable characteristics of the soil were noted down

Volume specific samples (~100cm^3, slightly varying ring sizes) were collected at depths 10 cm (~7.5-12.5 cm depth) and 20 cm (~17.5-22.5 cm) along with small loose soil samples of approximately 30-

60 g at the same depths. The rings for this sampling were constructed of metal tubes at a local metal workshop in Iganga town. However, the metal tubes easily corroded, thus differing from scientifically approved soil water retention rings.

The purpose of digging three pits was to represent the variability within the field. In the statistical analyses each field is represented by two averaged values, one averaging measurements of the three samples taken in a depth of 10cm, and one for 20cm.

Soil samples were stored in zipper plastic bags at room temperature, since neither freezing or refrigerating conditions were available, nor were controlled conditions for drying the samples. Therefore, the plastic bags remained closed from sampling until arrival and subsequent drying in the laboratory in Denmark, a period of three weeks to 1.5 months.

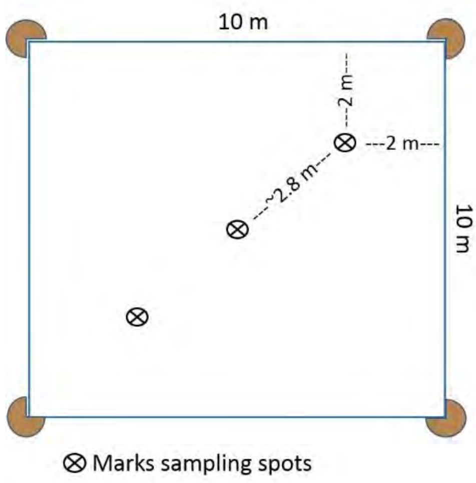


Figure 3.6 Drawing of sampling strategy. Blue square marking the sampling plot (10x10 m) that is placed centrally on the field.

Soil profiles

One soil profile was dug per village, while the location of these was sought to be central compared to the farmers from the relevant village. Geographical coordinates of the soil profiles were established with GPS, while notes were made of land-use, relief and vegetation.

The depth of the individual soil profiles was determined partly by soil profile development, and partly by the strength needed to dig. When the profile with increasing depth did not show significant changes in colour, structure or texture, i.e. distinct horizons, and the digging became increasingly hard due to high content of gravel and stones or compaction, the digging was stopped. However, all profiles exceeded the depth of 70 cm.

One sample was taken in the middle of each horizon. The horizons were described according to FAO (2006). For profiles where horizons were indistinct through colour or texture, samples were taken at regular depth intervals covering the whole profile. The colours of distinct horizons were determined using Munsell Soil Color Chart (2000). Where horizons were not present or indistinguishable, the soil colour was determined at the depth of the sample. Equipment for field analyses were not available, therefore, leaving description of horizon characteristics to those detectable to the human sensory system.

3.2.5 Limitations

During the interviews, interviewees were inquired about yield and field sizes, as well as amounts of manure, mulch etc. they may have applied to their fields. Sometimes being asked a couple of times about the same quantitative estimates during the interview it became clear that some farmers found it difficult to recall the numbers – a tendency that have been observed by other studies (e.g. Wortmann and Kaizzi, 1998).

Measuring the size of selected sampling fields confirmed the suspicion about estimated field sizes – that they were considerably different than reality in most cases; on average farmers estimated their fields on average to be three times bigger than the GPS-measured size. Both total land size owned by each farmer as well as the size of the individual fields chosen for sampling were initially estimated by farmers. However, total land size could not be verified, and should, therefore, be considered with caution.

Farmers' reported yield levels in some cases varied somewhat from time to time. Asking about yield development (increasing, decreasing, stabile) over the past five years, farmers reported yields per acre five years ago and today. However, acre-based estimates were not used for quantification of yield development, thus only registering the direction of yield developments.

3.3 Laboratory work

Table 3.3 lists the laboratory analyses that were carried out on samples from field top soils and soil profiles, while Table 3.4 summarizes preparatory procedures connected to each analysis. There were 96 field topsoil samples (16 fields *x* three holes *x* two sampling depths) and 16 profile samples. The laboratory procedures are presented below.

Table 3.3 List of laboratory analyses executed on soil samples from fields' top soils and soil profiles, respectively.

Field top soil samples	Soil profile samples
Soil texture	Soil texture
Bulk density	pH
Soil water retention	Total carbon (C) and nitrogen (N)
pH	
Total carbon (C) and nitrogen (N)	
Permanganate oxidable carbon (Pox-C)	

Table 3.4 Preparatory procedures connected to different soil analyses in terms of drying temperature and time as well as particle fractions used in the analyses

Analysis	Dried (temp/amount of time)	Fraction	Amount (g)
Soil texture	25°C / 7 days		
Bulk density	105°C / 24 hours		
Soil water retention	105°C / 24 hours		
Pox-C	25°C / 7 days	< 2mm	2.5 (±0.01)
pH	25°C / 7 days	< 2mm	5.0 (±0.05)
Total C and N	25°C / 7 days	< 2mm	5.0 (±0.05)

All analyses were conducted in the laboratory at Department of Geosciences and Natural Resource Management, University of Copenhagen (Øster Voldgade 10, 1350 Copenhagen K, Denmark), except for soil water retention, which was carried out at Department of Plant and Environmental Sciences, University of Copenhagen (Thorvaldsensvej 40, 1871 Frederiksberg C, Denmark).

3.3.1 Soil texture

Soil texture was determined by sieve analysis of the particles above 1 mm, while the fraction below 1 mm was determined using the Mastersizer 2000 (Malvern, UK) laser diffractometer which can detect particle sizes in the range 0.02-2000 µm.

Sieve analysis was executed according to the procedure described by (Flint and Flint, 2002) with the exception of the following: 1) Soil samples were dried at 105°C for at least 24 hours (instead of air-drying), 2) soil aggregates were gently broken apart using a porcelain mortar (instead of a wooden rolling pin) during sieving, and 3) inconsistent with the method description, sieving of particles below 2 mm was executed as a dry-sieve procedure. The samples were sieved in the following fractions: >4mm, 2-4mm, 1-2mm and <1mm.

Conversion of SOC to SOM was executed using Eq. 3.1 assuming a carbon content of SOM of 58%. This calculation was the basis for determining whether it was necessary to remove SOM prior to exposing samples to laser diffraction in connection with texture analysis. 10 of 112 samples exceeded 5% SOM, which usually is considered the limit over which removal of SOM should take place. However, the procedure was ignored, since values remained low (< 6.16%) and in consideration of the time horizon of laboratory work (Andersen, 2018).

Eq. 3.1) $\%SOM = 1.72 * \%SOC$ (Borggaard and Elberling, 2013)

Laser diffraction was employed on the particle sizes below 1000 µm (1mm) on the recommendation of Andersen (2018). Preparation of soil samples (<1mm-sized particles) for laser diffraction analysis included dispersion through the addition of 0.01M tetra-sodium pyrophosphate ($Na_4O_7P_2$-$10H_2O$) and subsequent exposure to ultrasound for two minutes using Bandelin SONOPULS HD 2200 ultrasonic homogeniser. Each sample was exposed to 5 replicate measurements, and an average of at least three of these (serious outliers were excluded) was used as the result.

Laser diffractometry is known to underestimate the clay fraction, and therefore, it was decided to use an upper grain size of 8µm for clay instead of 2µm, as proposed by Konert and Vandenberghe (1997). The 8µm grain size when being analysed by the laser diffractometer corresponds to 2µm when using the pipette method. The most optimal method of correction had been to compare laser diffraction results to pipette results for a random part of the samples and then using the difference between clay fractions of the two methods to find a correction factor. However, this would have been a time-consuming approach and was therefore omitted.

Determination of the soil textural class, only concerning the fraction <2mm, was done based on the particle-size classes defined by USDA (Table 2.2). However, in this study sand fractions (very fine, fine, medium, coarse and very coarse) were not discriminated between.

3.3.2 Soil bulk density

Soil bulk density (*D_b*), defined as the mass per unit volume of soil (Brady and Weil, 2014), was determined by dividing the dry weight of the ring soil samples with the inner volume of the soil water retention rings used for sampling:

Eq. 3.2) $D_b\ (g\ cm^{-3}) = soil \frac{weight}{(\pi * radius_{ring}{}^{2} * height_{ring})(cm^{3})}$

3.3.3 Soil water retention

SWR was determined for the wilting point at pF4.2 (15.6 bar) and pF3.0 (1.0 bar) using pressure membrane apparatus. Additionally, field capacity at pF2.0 was determined using sand boxes (08.01 Sandbox from Eijkelkamp Soil&Water) with an air-entry value at ~120 cm water column. For pF3.0 and pF2.0 ring samples were used, while loose samples (neither dried nor sieved) with unknown volumes were used for pF4.2.

The samples were exposed to a pressure equivalent to the pertinent pF-value for sufficient time (Table 3.5). Subsequently, the samples were weighed two times: 1) after pressure exposure and 2) after being oven-dried at 105°C for a minimum of 24 hours. The difference of the two weights determines the water content for the pertinent pF-value. The results of these measurements made up the basis of the construction of water retention curves. The method was consistent with the procedure described by Jensen and Jensen (2001).

Table 3.5 Specifications about sample type, equipment, equilibration time for the different pF-values.

pF	Term	Soil sample	Laboratory equipment	Equilibration time	Pressure
2.0	Field capacity	Ring	Sand bath	3 days	0.1 bar
3.0		Ring	Pressure vessels	2 weeks	1.0 bar
4.2	Permanent wilting point	Loose soil	Pressure vessels	3 weeks	15.6 bar

Eq. 3.3 shows the calculation of soil porosity corresponding to pF0.0:

Eq. 3.3) $Porosity\ (\%) = (1 - \frac{D_b}{D_p} * 100\%)$ (Flint and Flint, 2002)

The soil particle density, *D_p*, defined as the mass per unit volume of soil solids (Brady and Weil, 2014), is stated to depend on the contents of organic matter and calcium carbonate ($CaCO_3$) in the soil sample. According to Breuning-Madsen (2018) the $CaCO_3$ content can be assumed to be zero in a cultivated soil in the case area, while the content of organic matter can be estimated based on the total C content. The density of silicates is assumed to be 2.65 g cm^{-3} (Breuning-Madsen, 2018).

Volumetric water contents at pF2.0 and pF3.0, $\theta_{2.0}$ and $\theta_{3.0}$, respectively, were calculated as the difference in mass (*M*) between wet and dry soil for the respective pF-values multiplied by 100 and divided by the volume of the ring sample, V_{sample}, see Eq. 3.4. The volumes are specific for the individual samples.

Eq. 3.4) $\theta_{pF2\ or\ 3} = \frac{(M_{wet\ soil} - M_{dry\ soil})}{V_{sample}} * 100\%$

The calculation of volumetric water content at pF4.2 differed from Eq. 3.4 due to the unknown volume of these samples. The gravimetric moisture content was calculated as the mass of water in samples exposed to a pressure equivalent to pF4.2 divided by the mass of the dry soil. The gravimetric moisture content is multiplied with D_b divided by the density of water, D_w, which in this case is 1 g cm^{-3}.

Eq. 3.5) $\theta_{pF4.2} = w * \frac{D_b}{D_w} * 100\%$ (Petersen et al., 2016)

The proportion of plant-available water (θ_{AWP}) was calculated as the difference in volumetric water content at FC (θ_{FC}) and WP (θ_{WP}) as shown here:

Eq. 3.6) $\theta_{PAW} = \theta_{FC} - \theta_{WP}$ (Romano and Santini, 2002)

3.3.4 pH_{H2O}

pH was measured potentiometrically in a solution of soil and distilled water in the ratio 1:2.5 according to the procedure described by Reeuwijk (2002). The only deviations from the described method were 1) the shaking time (at 125 rpm) was reduced from two to one hour according to the procedure applied in the used laboratory, and 2) that the amount of soil applied was reduced from 20g to 5g in consideration of the limited amount of soil available for analyses. Reading of the pH-meter was consistently done after 1.5 minutes.

3.3.5 Permanganate Oxidable Carbon (Pox-C)

This analysis produces estimates of the labile carbon pool of the soil, i.e. the accessibility of easily degradable organic material, thus working as an integrated indicator of aggregate stability, effective CEC and microbial activity (Gruver, 2015; Weil et al., 2003). The method is based on the assumption that the bleaching of permanganate ($KMnO_4$), equivalent to a reduction in absorbance, is proportional to the soil's content of oxidable carbon.

The method and its advantages is described by Weil et al. (2003): A stock solution was prepared with 0.02M $KMnO_4$ mixed with 0.1M $CaCl_2$ obtaining pH7.2. Three standards of 0.005, 0.01 and 0.02 M $KMnO_4$ were used to construct a standard curve which made the basis of the Pox-C calculation (Figure 3.7). 2ml 0.02M $KMnO_4$ was added to each soil sample (2.5 ± 0.01 g) with 18ml milliQ water. This was hand-shaken for 2 minutes and subsequently left to settle for 10 minutes. The supernatant was diluted and measured on a spectrophotometer (Biochrom Libra S12) at a wavelength of 550nm.

The amount of oxidable C was determined using Eq. 3.7, where *0.02 M* corresponds to the concentration of the initial solution, *abs.* is the absorbance reading, while *a* and *b* are the intercept and slope of the standard curve, respectively. *9000 mg C* is oxidized when consuming 1 mol MnO_4, *0.02 l* is the volume of $KMnO_4$ reacted, and *0.0025 kg* is the amount of soil used.

Eq. 3.7) $MnoxC\ (mg\ kg^{-1}) = \left(0.02\ M - (a + b * Abs)\right) * 9000\ mgC\ mol^{-1} * (0.02\ l/0.0025\ kg)$

Since the spectrophotometer employed made a reverse standard curve (putting the concentration on the x-axis and absorbance on the y-axis) and this was not realized during the running of samples, the absorbance values of one of three runs (it took three runs spread over three days to get through all 96 samples) was used to construct a standard curve giving the required concentration values. Thus, this curve (Figure 3.7) was used on all samples, even though the absorbance of standard samples varied slightly across rounds. Appendix 6 shows the standard curves produced by the spectrophotometer software. They showed that variation in measured absorbance of standards between runs was minimal, making this approach admissible.

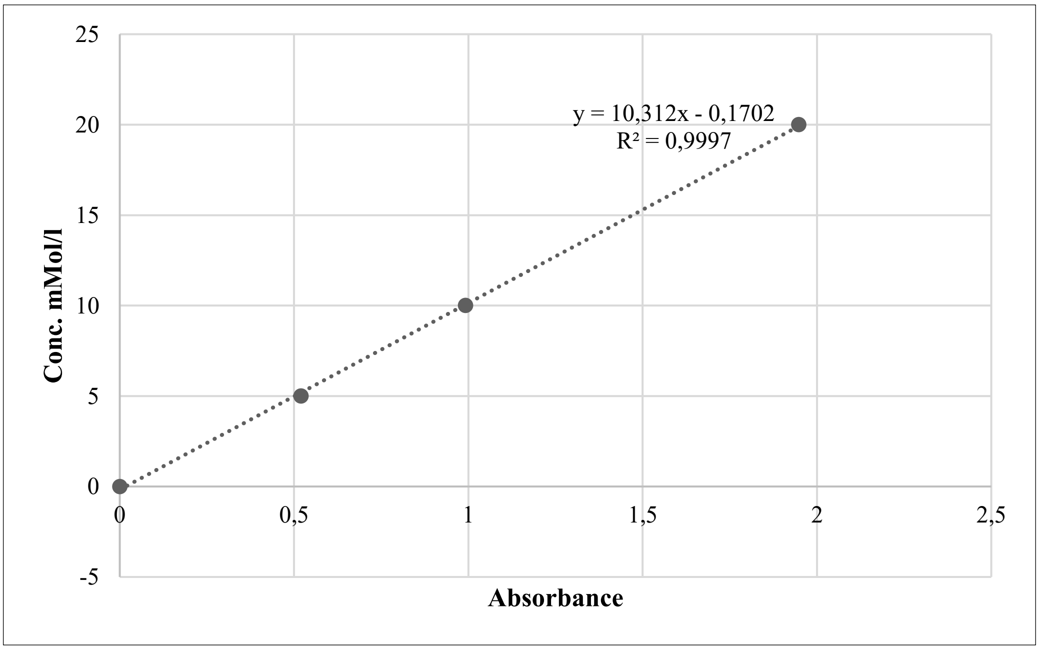


Figure 3.7 Standard curve used for calculation of concentration of Pox-C.

3.3.6 Total carbon and nitrogen contents

Subsamples of 5 g were picked from each of the topsoil samples for homogenization, which was done in agate mortars using a planetary ball mill (Fritsch planetary ball mill, pulverisette 5) with 250 rpm for 10 minutes. 5g greatly surpassed the amount needed for the analysis of total carbon (C) (equivalent to SOC), total nitrogen (N), and isotopic ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$, but was necessary to make sure that the grinded subsample is representative for the sample.

10-15 mg is taken from the grinded samples into tin combustion cups, and then measured by Dumas combustion (~1700 ºC) on an elemental analyser (Flash 2000, Thermo Scientific, Bremen, Germany) coupled in continuous flow mode to a Delta V Advantage isotope ratio mass spectrometer (Thermo Scientific, Bremen, Germany). Loamy soil standards (Elemental Microanalysis, Okehampton, UK) were used for instrument calibration. One standard sample was made per 10 samples with 5 additional standard samples, i.e. a total of 17 standard samples. The standard samples varied in weight from 8 to 20 mg to create a calibration curve covering the whole range of measuring. CO_2 and N_2 as pure gases worked as standard for isotope ratio analysis, calibrated against certified reference materials of ^{13}C-sucrose and $^{15}N\text{-}(NH_4)_2SO_4$, respectively (IAEA, Vienna, Austria). This analysis was supervised by professor Per Ambus from Centre for Permafrost (CENPERM), University of Copenhagen.

The relation between soil carbon and nitrogen, the C:N-ratio, was calculated as total content of C divided by total content of N.

3.4 Nutrient budget calculations

Nutrients are often highlighted as a limited resource in sub-Saharan soils. Therefore, simple nutrient budgets for N, P and K were calculated to indicate whether the field systems had net losses or net gains of these nutrient as a result of the cultivation practices (Oenema et al., 2003).

The basis for the budgets ($B_{nutrient}$) are knowledge of inputs and outputs from the system as described by farmers in the flow diagrams (section 3.2.2). Eq. 3.8 was used for the calculation.

Eq. 3.8) $B_{nutrient} = \sum inputs - \sum outputs$ (Oelofse et al., 2010a)

Values for the nutrient content of inputs were based on the USDA's Crop Nutrient Tool (USDA, 2009), where the crop type *Corn-Field, for grain (shelled, yellow dent, grade #1)* was used with a moisture level of 13.52% (default value of the tool) as recommended by Oelofse et al. (2010). Soil erosion was disregarded based on the assumption that it was very limited as stated by interviewees. Atmospheric deposition was also disregarded, although this contributes to the soil nutrient base (section 5.3). Thus, calculated nutrient budgets only considered inputs and outputs given by interviewees.

N, P and K contents of manure were based on Zake et al. (2010), who examined manure quality in what they termed a *semi-intensive management system*, which is comparable to the organic cultivation system of Makuutu subcounty (section 5.2.4). They presented values representing the quality of manure in rainy and dry seasons, respectively, as well as how the quality changed after 4 weeks of manure composting (

Table **3.6**). Part of the manure was collected during the rainy season and the rest during the dry season, which makes the distribution between these affect the nutrient content of the final manure product that is applied on the field. For the second season of 2017 (the time of sampling) the manure applied at the beginning of the season was collected during the first season of 2017. The monthly distribution between rainy and dry season in the first growth season is February and July-August are dry (3/6 months) and March-May are rainy (3/6 months) (Zake et al., 2010) (Figure 3.2). Therefore, the manure applied is assumed to consist of 50% manure from dry the season, 50% from the rainy season, giving the applied nutrient values of manure (Table 3.6).

A limitation of the calculation of nutrient budgets was that compost and mulch applied by some organic farmers could not be included in the calculation, since interviewees were not able to be precise in their description of compost composition and amounts of mulch.

Table 3.6 Values of N, P and K contents in cattle manure for wet and dry seasons of fresh cattle manure and the same manure after four weeks of decomposition (Zake et al., 2010). The right column 'Applied values' assumes that three fifths (3/5) of collected manure was collected during the wet season and two fifths (2/5) during the dry season.

	Rainy season	Dry season	Applied values
Fresh cattle manure			
C (kg t^{-1})	194.0	179.0	186.5
N (kg t^{-1})	15.0	9.0	12.0
P (kg t^{-1})	6.1	5.7	5.9
K (kg t^{-1})	4.85	5.1	5.0
After 4 weeks of composting			
C (kg t^{-1})	119.0	114.0	116.5
N (kg t^{-1})	5.3	3.8	4.6
P (kg t^{-1})	2.9	2.6	2.8
K (kg t^{-1})	7.0	6.9	7.0

3.5 Statistical data analyses

In order to determine whether a significant difference exists in soil properties of organically and conventionally cultivated soils two-tailed independent t-tests were applied on measured soil parameters. All statistical tests are carried out with a significance level of 5%. The software used for statistical tests was *IBM SPSS Statistics 25*.

The investigated soil properties were all tested for normality using the Shapiro-Wilk Normality test. This was done separately for the data from organic and conventional fields, where a significance value > 0.05 indicated normal distribution (Lærd statistics, 2013). If data showed to deviate significantly from a normal distribution, the non-parametric Mann-Whitney U Test (Wilcoxon Rank Sum Test) was employed instead of an independent t-test. In few cases, where the difference between medians seemed high, a non-parametric *median test (k samples)* was carried out to explore whether this difference was significant in cases where the averages were not.

The data of some soil properties (Pox-C and PAW) was normalized to eliminate the effect of texture. Normalization was done by dividing the soil property with the value of that property whose effect is sought eliminated, which in this case was clay percent (McGrew and Monroe, 2009).

Correlations between variables were tested using Pearson's Correlation Coefficient with a two-tailed test of significance.

3.5.1 Regression analyses

A regression analysis was carried out aiming to explore the degree to which investigated soil properties could explain yield sizes, i.e. yield levels were given as the dependent variable. Initially, the *Exploratory Regression Tool* (ERT) of ArcGIS was used to find combination(s) of variables resulting in a model that met the criteria defined by the tool (ESRIa, n.d.; ESRIb, n.d.). Following soil properties were given as independent variables: Aeration, PAW, water contents at pF4.2 and pF2.0, Pox-C, SOC concentration, total N concentration, pH and size of clay fraction for both 10cm and 20cm depths. Furthermore, field size and number of plants per square meter were included to represent practices that were not soil-related. The ERT uses *ordinary least squares* (OLS) *regression*, a type of linear regression (Mitchell, 2009), which quickly allows you to get an overview over the dataset.

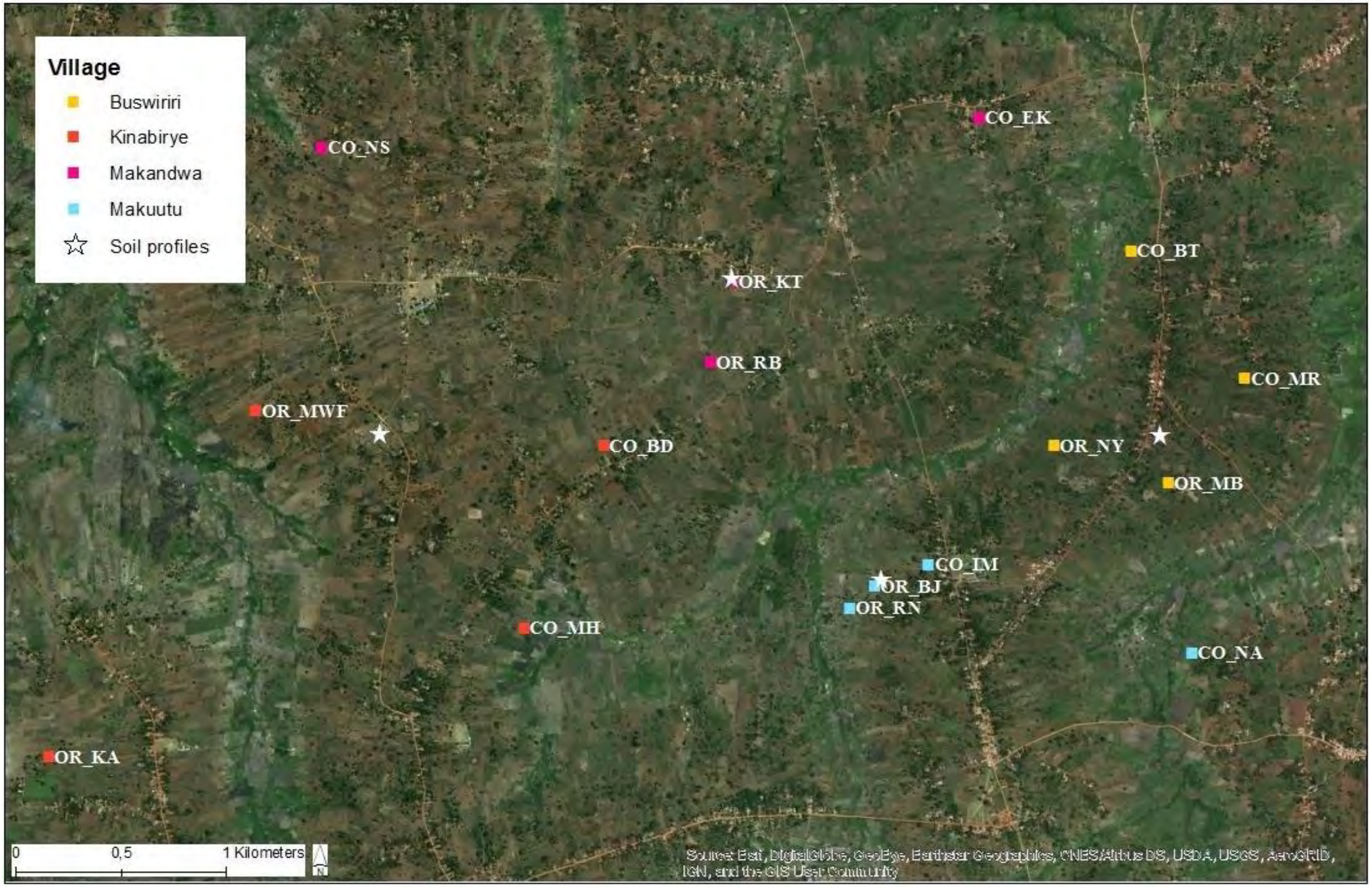
When the best model was found, the ArcGIS tool *Ordinary Least Squares* (OLS) *linear regression* was run (with default settings) using the independent variables of the best model in explaining yield levels. Finally, potential spatial autocorrelation (if field values are clustered, dispersed or random) was investigated with *Global Moran's I* and *Local Moran's I*. The global statistic gives one statistic for the whole dataset, while the local statistics compares every field to its neighbours (Mitchell, 2009). However, it must be emphasized that a dataset of at least 30 features is recommended as 'best practice' (ESRIc, n.d.), but this recommendation was ignored since the regression analysis only aimed to give an overview of the degree to which investigated variables could explain yield levels.

4 Results

This section describes the outcome of the study: Initially, the soil profiles give an overview of the soil diversity of the area. Secondly, the result of the interviews held with local farmers is presented. The third part concerns local farmer's perspective on soil quality, which leads into the third part dealing with the soil analysis data investigating soil properties in conventional and organic cultivation systems as described by the hypotheses presented in section 1.2.1. Finally, correlations between soil properties and quantifiable cultivation practices are explored. Table 4.1 presents villages and the farmers representing these, as well as cultivation system, fields' locations, altitude, field size and texture. Figure 4.1 maps fields' locations.

Table 4.1 Overview of the 16 farmers whose fields were sampled. The initials show whether the farmer is organic (OR) or conventional (CO) and are used to indicate features connected to individual farmers' cultivation or statements in the text. For organic farmers are number of years as organic given in brackets. Texture was noted for samples in depths of 10cm and 20cm, respectively.

Village	Interviewee	Initials	Date of sampling	Coordinates (decimal degrees)	Altitude (m.a.s.l.)	Field size (ha)	Texture	
							10cm	20cm
Buswiriri	Byakwaso Twaha	CO_BT	02-12-2017	N0.52368 E33.60032	1112	0.19	Loam	Loam
	Mutesi Rehema	CO_MR	01-12-2017	N0.51823 E33.60516	1120	0.12	Clay	Clay
	Mukabili Bakali	OR_MB (10 y)	02-12-2017	N0.51376 E33.60189	1124	0.48	Clay loam	Clay
	Nyende Yakubu	OR_NY (10 y)	01-12-2017	N0.51534 E33.59703	1123	0.22	Clay loam	Clay loam
Kinabirye	Basiliirwa David	CO_BD	08-12-2017	N0.51534 E33.57773	1155	0.39	Clay loam	Clay loam
	Mutesi Hadija	CO_MH	08-12-2017	N0.50755 E33.57433	1138	0.43	Loam	Loam
	Kagere Ahmed	OR_KA (10 y)	09-12-2017	N0.50205 E33.55399	1155	0.55	Loam	Sandy loam
	Mambya Waiswa Faisal	OR_MWF (10 y)	09-12-2017	N0.51684 E33.56285	1145	0.39	Loam	Clay loam
Makandwa	Edube Kuzaifa	CO_EK	11-12-2017	N0.52938 E33.59380	1133	0.09	Loam	Loam
	Nakisuyi Salama	CO_NS	11-12-2017	N0.52809 E33.56566	1147	0.26	Loam	Loam
	Kibwiika Thomas	OR_KT (10 y)	11-12-2017	N0.52237 E33.58326	1095	0.06	Clay loam	Clay loam
	Roman Bamulambe	OR_RB (10 y)	10-12-2017	N0.51892 E33.58232	1157	0.15	Clay loam	Clay loam
Makuutu	Isac Muledo	CO_IM	29-11-2017	N0.51028 E33.59166	1136	0.06	Loam	Clay loam
	Nandago Annet	CO_NA	28-11-2017	N0.50649 E33.60290	1124	0.21	Loam	Loam
	Buuza Janipher	OR_BJ (10 y)	29-11-2017	N0.50935 E33.58933	1138	0.06	Sandy loam	Loam
	Rose Namukose	OR_RN (8 y)	29-11-2017	N0.50840 E33.58828	1136	0.84	Sandy loam	Sandy loam



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 4.1 Overview of field locations connected to farmer-initials and colours indicating village. The locations of soil profiles are shown with white stars.

4.1 Soil profiles

An overview of location, terrain, vegetation cover and depth is given in Table 4.2, and photos with indication of sampling depths are shown in Figure 4.2.

Table 4.2 Overview of the four soil profiles – one for each village.

Village	Date	Coordinates (decimal degrees)	Altitude (m.a.s.l.)	Max depth (cm)	Terrain	Vegetation
Buswiriri	07-12-2017	N0.51580 E33.60155	1121	85	Flat	Maize (harvested). yam and cassava
Kinabirye	10-12-2017	N0.51585 E33.56815	1162	95	Flat	Sorghum. maize. tomatoes
Makandwa	11-12-2017	N0.52251 E33.58321	1138	95	Flat	Banana. cassava. coffee. mango etc.
Makuutu	30-11-2017	N0.50960 E33.58960	1126	85	Flat	Bare soil with sporadic elephant grass

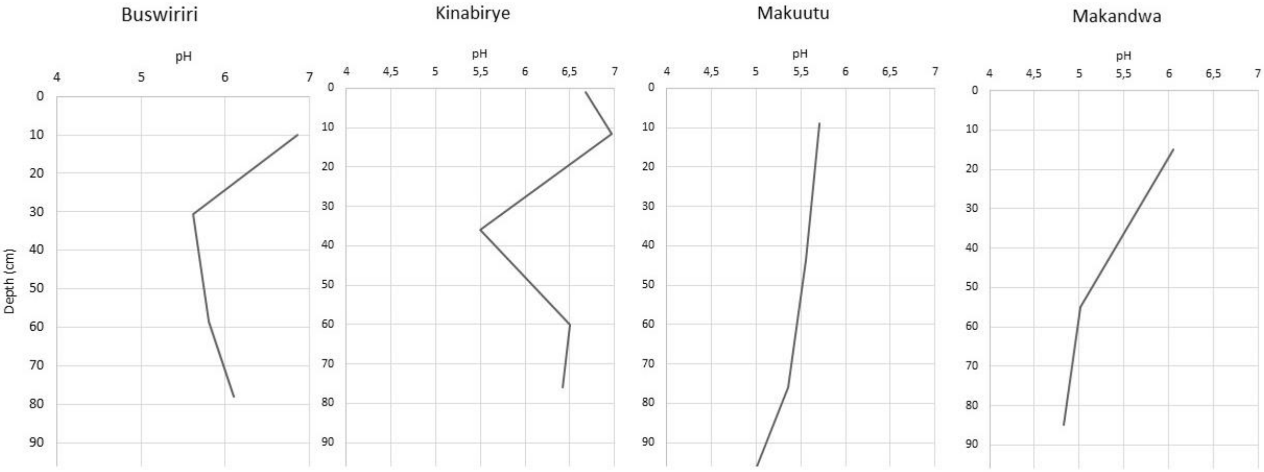


Figure 4.2 pH of samples taken from soil profiles in each of the villages.

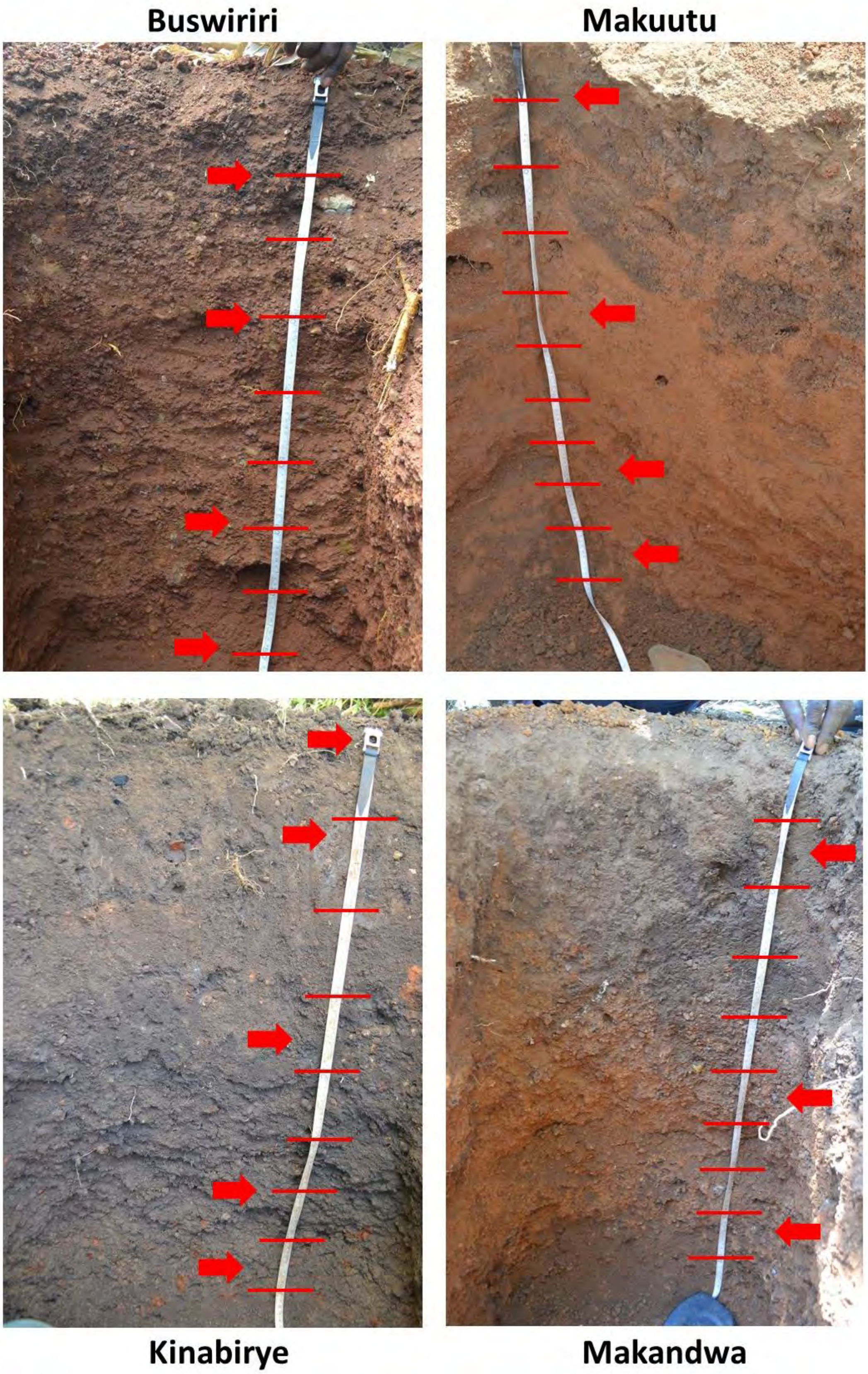


Figure 4.3 Photos of profiles in the four villages. Red lines indicate every 10cm, while red arrows show the depths from which samples were taken.

4.1.1 Buswiriri

Table 4.3 Description of profile in Buswiriri. Soil texture is indicated as well as colour and depth of identified horizons.

Depth (cm)	Horizon	Colour	Description
0-15	A	2.5YR 2.5/3	Loam. Gravel fraction (18 weight%) consisted partly of charcoal and gravel. Farmer confirmed that charcoal was produced at this location. No visible organic matter apart from living roots. Clear, smooth border.
15-45	B1	2.5YR 3/6	Sandy clay loam. Gravel fraction constitutes 32 weight% of the bulk soil. Roots were found to a depth of 45cm. Aggregates disintegrated easily. From depth of 15 cm, gravel fraction became bigger and coarser. Clear, smooth border.
45-68	B2	2.5YR 3/6	Sandy clay loam. Gravel fraction constitutes 39 weight% of the bulk soil. Lighter areas (10YR 6/8) found within the horizon. Aggregates disintegrated easily, but digging was hampered by the high gravel fraction. Below 70cm gravel particles sizes 4x5cm constituted app. 10% of the gravel fraction. Gradual, smooth border (68-73cm).
From 73	B3	2.5YR 3/6	Silt loam. Gravel fraction constituted 41 weight% of the bulk soil.

pH was highest (6.9) in the top sample (9-11cm), then decreasing to 5.6 in 29-32 (Figure 4.2), which can be considered the bottom of the ploughing layer (Figure 4.3). Below here pH increased to 5.8 (57-60cm) and further up to 6.1 (77-79cm) (Figure 4.2).

Clay illuviation appeared from the A horizon to B1 with clay fractions of 22 and 25 weight%, respectively (Table 4.3). Below this point the clay fraction decreased constituting 15 weight% in the deepest sample (77-79cm) (Table 4.3) (Appendix 7). The gravel fraction increased with depth, but was high even in the topsoil (Table 4.3), and consisted primarily of pisolithes and iron nodules.

Throughout the profile so-called ‘rotten stones’ were found characterised by being so physically weathered that they disintegrate under light pressure. The stones were irregular and fragmented.

All sampled fields in Buswiriri were found within 1.0km of the soil profile location.

4.1.2 Kinabirye

Table 4.4 Description of profile in Kinabirye. Soil texture is indicated as well as colour and depth of identified horizons.

Depth (cm)	Horizon	Primary colour	Description
0-2	A1	7.5YR 2.5/2	Loam. High content of organic material in the form of roots and newly dead plant material. Contained hard aggregates requiring a mortar to be crushed. Diffuse, smooth border.
2-20	A2	7.5YR 2.5/2	Loam. High content of gravel (20 weight% of bulk soil). Charcoal found down to 10cm depth, while pieces of bricks were found down to 20cm. These are signs that the location was previously used for brick production. High presence of roots, of which some are > 15mm broad. Diffuse, smooth border.
20-65	B1	7.5YR 2.5/1	Loam. High content of gravel (was 37 weight% of bulk soil) of which some particles are characteristic nodules (Figure 4.4). Within this horizon the soil matrix becomes very sticky. Little presence of 1mm roots. Diffuse, smooth border.
65-85	B2	7.5YR 3/1	Loam. High content of gravel (37 weight% of bulk soil). High presence of breakable aggregates which may at first sight appear as large gravel particles. Diffuse, smooth border.
From 85	C	2.5YR 4/8	Loam. Gravel constituted > 70%. Matrix was coloured 5YR 4/2. Matrix was somewhat sticky.

The pH profile varied considerably with depth in this soil profile (Figure 4.2): pH was highest (7.0) in 11.5cm, decreasing to 5.5 in 36cm, then increasing to 6.5 at the bottom of the profile.

The clay and sand fractions increased consistently with depth, while silt decreased constituting 51 weight% in 0-2cm and 32 weight% in 75-77cm (Appendix 7). Iron nodules were found in several depths through the profile becoming more frequent with depth in step with increasing gravel content (Table 4.4). A nice example of a nucleic nodule was found in 35-37cm (Figure 4.4). At the bottom of the profile, gravel made up the main part of the bulk soil with differing colours between gravel particles and matrix (Table 4.4). The main part of gravel particles was pisolithes.

Three of the four sampled fields in Kinabirye were situated within 1.1km of the soil profile location, while the last field (OR_KA) was found within 2.2km.

Figure 4.4 Nucleic iron nodule found in a depth of 35-37cm in the Kinabirye soil profile.

4.1.3 Makandwa

Table 4.5 Description of profile in Makandwa. Soil texture is indicated as well as colour and depth of identified horizons.

Depth (cm)	Horizon	Colour	Description
0-35	A	7.5YR 2.5/3	Clay loam. A bit heavy. The soil did not stick together. Gradual, irregular border.
35-70	B	7.5YR 4/4	Clay loam. Gravel: rounded, small stones about 5mm diameter. Gravel fraction constituted 43 weight% of bulk soil. The soil did not stick together, but particles between gravel particles were somewhat sticky. Single big, somewhat hard aggregates were breakable and resembled the rock layer below 74cm depth. Roots were visible down to 65cm. Clear, wavy border.
70-95	C	7.5YR 3/4	Clay loam. Gravel fraction constituted 44 weight% of bulk soil. Sticky clay between gravel particles.

pH decreased with depth, being 6.1 in depth of 15cm and 4.8 in 85cm (Figure 4.2).

The clay fraction showed signs of clay illuviation with 32 weight% in the top sample (14-16cm) increasing to 35 weight% below (54-56cm) (Appendix 7). The gravel fraction (primarily pisolithes) constituted 44 weight% of bulk soil in the bottom of the profile, while seeing a rapid increase from 14-16cm sample where gravel made up 14 weight% to 43 weight% in 54-56cm depth (Table 4.5, Appendix 7).

Sampled fields in Makandwa were situated within 2.1km of the location of the soil profile, with the closest two within 0.5km.

4.1.4 Makuutu

Table 4.6 Description of profile in Makuutu. Soil texture is indicated as well as colour and depth of identified horizons.

Depth (cm)	Horizon	Colour	Description
0-15	A	10YR 3/3	Clay loam. Heavy, incoherent soil. Roots were many but small (<1mm). No visible organic matter apart from living roots indicated high decomposition. Presence of few, small (1-2mm) red spots coloured 10YR 4/8. Sharp, irregular border (15-30cm).
30-85	B1	5YR 3/4	Clay loam. Soil was more heavy and aggregated than above. Compaction seemed high. Sticky. Roots are still present. Single dark-brown (10YR 3/3) spots of 2-3mm diameter. Some of them with vertical direction of 2cm length. Presence of holes made by moles. Diffuse, smooth border.
From 85	B2	5YR 4/6	Clay. Very compact and aggregated. Very sticky.

pH decreased towards the bottom of the profile, being 5.7 in depth of 9cm and 5 in 96cm.

Particles in the gravel fraction remained absent in this profile, thus making it different to the other three profiles (Table 4.6, Appendix 7). Clay content was high throughout the profile with 32 weight% in the top sample (8-10cm) increasing to 50 weight% (42-45cm) indicating that clay illuviation took place. The clay fraction decreased from here to the bottom of the profile with 38 weight% at the bottom. Border between B1 and B2 was conditioned by textural changes (Table 4.6).

Three of the fields sampled in Makuutu were located within 0.5km from the soil profile, while the last field (CO_NA) was situated 1.7km away.

4.2 Presentation of maize cultivation systems

This section introduces the cultivating systems of organic and conventional farming in Makuutu subcounty. Trade of seeds and other agricultural products across cultivation systems was not an issue, since pesticides was only used by few farmers. Organic certification was done for single products (organic pineapple production was big in the area) and thus such considerations were only needed for the specific product. Information on the number of organic farmers in the area that are certified was not available.

Table 4.7 Profile of organic versus conventional farms in terms of the size and yield of selected sampling fields, number of plants on the field (based on information on spacing between plants), household information and total land size as estimated by the farmer. *n = 16*.

	Organic		**Conventional**	
	AVG (ST.DEV)	**Range**	**AVG (ST.DEV)**	**Range**
Field size (ha)	0.3 (± 0.26)	0.06 – 0.84	0.2 (± 0.13)	0.06 – 0.43
Reported yield (t ha-1)	3.2 (± 1.76)	0.6 – 6.3	3.2 (± 1.23)	0.9 – 4.9
Number of maize plants m^{-2}	3.1 (± 1.22)	1.3 – 5.4	3.6 (± 1.78)	1.3 – 7.2
Household. adults	4.5	2 – 10	3.8	2 – 6
Household. children	5.8	0 – 10	4.9	2 – 10
Estimated total land size (ha)	6.9 (± 4.36)	4 – 39	2.6 (± 1.60)	2.5 – 15

Yields ranged from 0.6 to 6.3 t ha^{-1} for organic fields and 0.9 to 4.9 t ha^{-1} for conventional fields with averages of 3.17 and 3.24, respectively (Table 4.7; Appendix 8). Yields of organic and conventional fields are not significantly different ($P = 0.93$). On average, organic farmers directed 50% of their maize yield to domestic use and 50% to be sold. For conventional farmers, this was 70% and 30%, respectively. Farmers generally reported maize to be an important cash crop as well as an important part of the local diet.

The average number of maize plants (based on information about spacing between plants) was 3.1 plants m^{-2} for the organic cultivation system, while it was 3.6 m^{-2} for the conventional system. The difference between systems was not significant ($P = 0.519$). Yield levels did not depend on the number of plants since the correlation between average number of plants per square meter and yields was not significant ($P = 0.052$).

Average size of selected organic fields was slightly larger than conventional fields (Table 4.7), although this was not significant ($P = 0.270$). However, total land sizes were significantly larger for organic farmers with an average of 6.9 ha per farmer against the conventional farmers' average land size of 2.6 ha ($P = 0.029$) (Table 4.7).

All fields but one were cultivated with maize with no form of intercropping or fallowing from 2008 up to and including 2017 (OR_MB cultivated maize since the second season of 2012). This was a consequence of the selection criteria (the two seasons of 2017 had to be maize only). All selected fields were ox-ploughed in both seasons of 2017, while most fields were ox-ploughed every season for the past 10 years with few exceptions.

All farmers but one incorporated maize residues from the previous season as part of the preparation of soil for sowing. CO_BD burned the maize residues instead. OR_RN deviates from the other farmers by uprooting the maize residues, moving them to another location while ox-ploughing of the field takes place, then moving residues back after ploughing and mixing them with soil using a hand-hoe (Figure 4.5). Consequently, mixing of soil and residues is shallower compared to ox-ploughing, 10-15cm and ~30cm, respectively. Improved (hybrid) seeds play a minor role among interviewees of whom the far majority produce their own seeds. However, after years of seed barters and intermixture of hybrid and local seeds in fields, farmers stated that what is now termed 'local seeds' is not strictly free of hybrid seeds.

All farmers mix weeds with soil as part of the weeding process during the growth season. Weeding typically took place twice between sowing and harvest, strategically timed to prevent weeds from outpacing maize germination and growth. This was done with hand hoes; thus, the mixing is only done in the upper 10-15cm.

Figure 4.5 Woman with hand hoe that farmers use to weed and for mixing soil.
Photo: Tine Engedal.

4.2.1 How is the organic cultivation system different from conventional?

Organic farmers were asked to mention some practices that they started to employ after conversion to organic agriculture. The practices mentioned by most farmers were application of animal manure (cow dung) (89%), mulching (63%) and trenches (63%) (Figure 4.6). Timely weeding, application of compost and using own produced seeds were mentioned by more than 30% of the respondents. In an interview about local farmers' perception of soil quality, application of manure was emphasized as the most important action to improve soil fertility (section 4.3). Organic farmers generally considered the organic cultivation system to be more labour-intensive, but also more profitable.

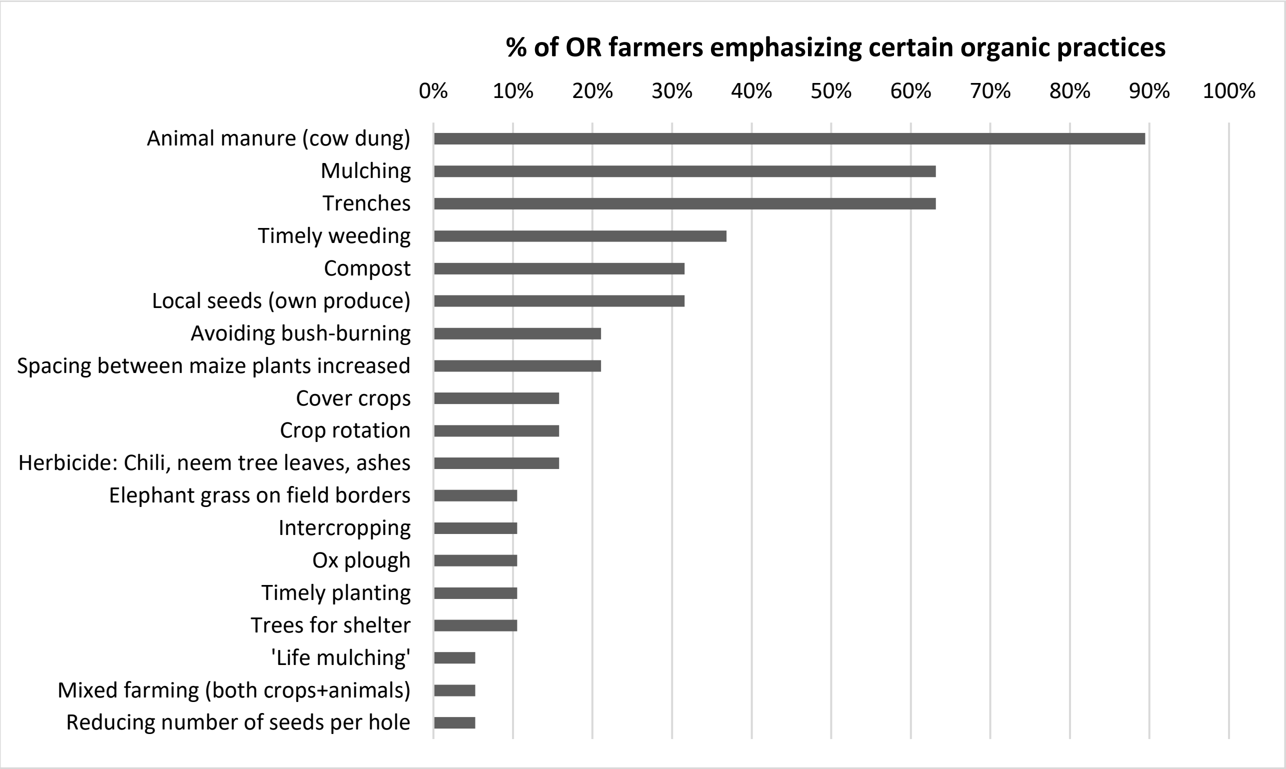


Figure 4.6 Percentages of interviewed organic farmers emphasizing listed organic practices, when asked how their practices changed after conversion. *n = 19*.

The differences between conventional and organic cultivation practices related to maize were limited. All organic farmers whose fields were sampled applied manure (cow dung), six of eight added compost, and two of eight added mulch (Table 4.8). Apart from incorporating maize residues and weeds, conventional farmers deployed no further practices to add nutrients.

The addition of organic manure varied between 103 kg ha^{-1} to 5162 kg ha^{-1}, corresponding to an average application of 2000 kg ha^{-1} (Table 4.8). Farmers were not inquired specifically about handling of manure from collection to application, but observations indicated that cow dung was collected during the growth season and stored in a heap near every organic farmer's home until it was applied on the field immediately before sowing. The cattle providing the manure primarily grazed on common land or farmers' pastures, thus the main source of food was made up by grass.

Compost application (amongst the farmers using it) amounted to an average of 1918 kg ha^{-1} (Table 4.8), ranging from 297 to 4491 kg ha^{-1}. Compost was reported to contain 'household wastes', which can consist of a wide variety of organic residues and household wastes. Therefore, it may have had different effects on soil quality. Composting took place in constructed depressions in the ground placed in the shade of trees near the farmhouse.

Two of eight organic farmers applied mulch (Table 4.8): OR_NY in the form of above-ground biomass residues of 1 acre (farmer's estimate) of soya beans, while OR_BJ mulched with elephant grass (*Pennisetum purpureum*). OR_BJ was the only farmer among those whose fields were sampled to state that soil erosion was a challenge. The farmers could not specify the amount of mulch.

Yields were not significantly correlated with amount of applied manure among organic fields (*P = 0.274*) (Figure 4.7A), and the same was the case with yields and compost application (*P = 0.261*) (Figure 4.7C). Negative correlations were found between application of organic manure and field size (*P = 0.040*) (Figure 4.7B) and between compost application and field size (*P = 0.028*) (Figure 4.7D), i.e. farmers tended to apply less cow dung with increasing field size.

Table 4.8 Amounts of added organic manure (cow dung), compost and mulching. Standard deviation is given in brackets, while the number of farmers using the specific factors was indicated with X/8, i.e. X of 8 farmers employed this practice.

	Manure application (kg ha^{-1})	Compost application (t ha^{-1})	Mulching
Organic cultivation system	2000 (±1470) 8/8	1920 (±1810) 6/8	2/8
Conventional cultivation system	-	-	-

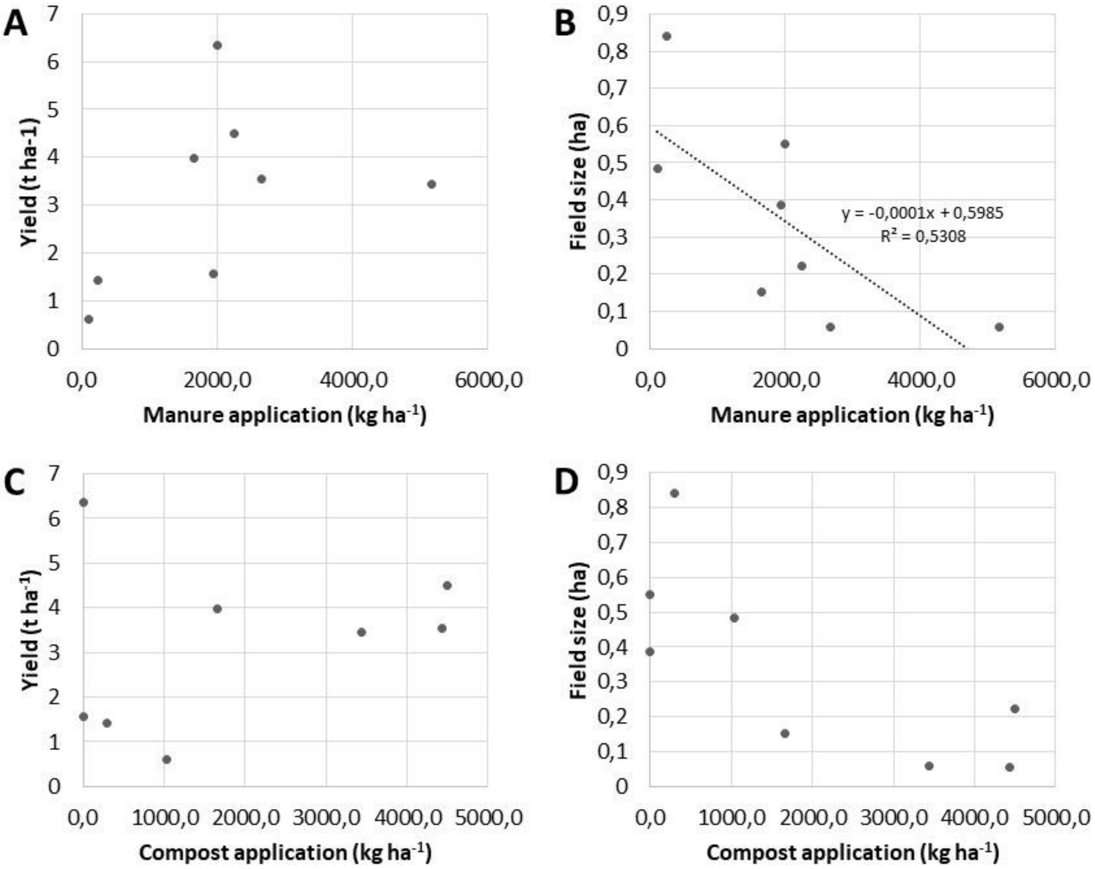


Figure 4.7 A) Application of manure and yield size were not correlated (*P = 0.274*). B) Negative correlation between application of cow dung and field size (*P = 0.040*). C) Application of compost and yield size were not correlated (*P = 0.261*). D) Negative correlation between application of compost and field size (*P = 0.028*).

The most frequently emphasized advantage of organic cultivation practice was increased yields (74%, Figure 4.8). In the interviews 94% of organic farmers (n = 18) reported to have experienced increased yields immediately following conversion to organic cultivation practices (data not shown). Reduced expenditure for farming (inorganic fertilisers, pesticides, hybrid seeds and/or transportation) as well as increased soil fertility were also important (26% and 24%, respectively, Figure 4.8).

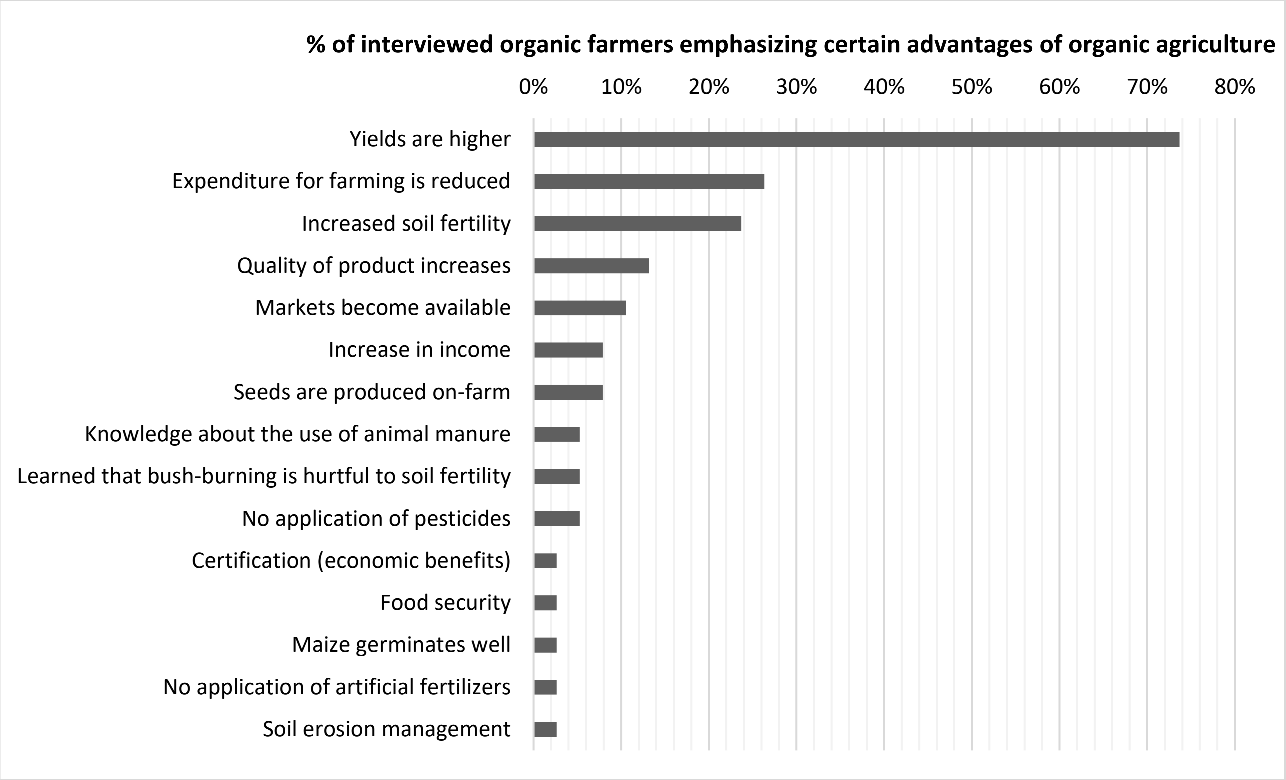


Figure 4.8 Proportion of organic respondents emphasizing certain advantages of organic agriculture. *n = 19*.

4.2.2 Challenges faced by farmers

Farmers were asked to highlight the challenges they have been facing in cultivation of maize in recent years (Figure 4.9). The challenges highlighted by organic farmers were not different than those mentioned by conventional farmers, therefore, one joint graph is shown. Three factors were strongly dominant: Drought (93%), Fall Armyworm (*Spodoptera frugiperda*) (83%), and Striga weed (*Striga hermonthica*) (80%). Soil infertility was mentioned by one farmer only. Although sampled fields were troubled by armyworm and striga to a variable extent, observations did not indicate that one of the cultivation systems was in a better position in this aspect; both cultivation systems were seriously troubled by these challenges.

Questioned on yield development the past five years, all but two interviewed farmers (*n = 42*) – conventional and organic – stated that yields decreased during this period. The last two farmers had converted to organic cultivation practices three years ago, upon which they saw increasing yields.

Drought

Selected fields for sampling are situated within an area of 15 km^2 without significant differences in altitude and are hence expected to have been subject to similar weather conditions. Different resistances towards drought stress must therefore be assigned seed quality and pedological conditions, thus also affected by cultivation practices. The area has experienced some drought in recent years, as described in section 3.1.3. Farmers expressed frustration as to the timing of sowing, which was sought coincident or immediately succeeding the first precipitation of the rainy season. The transition between dry and rainy season has become less foreseeable.

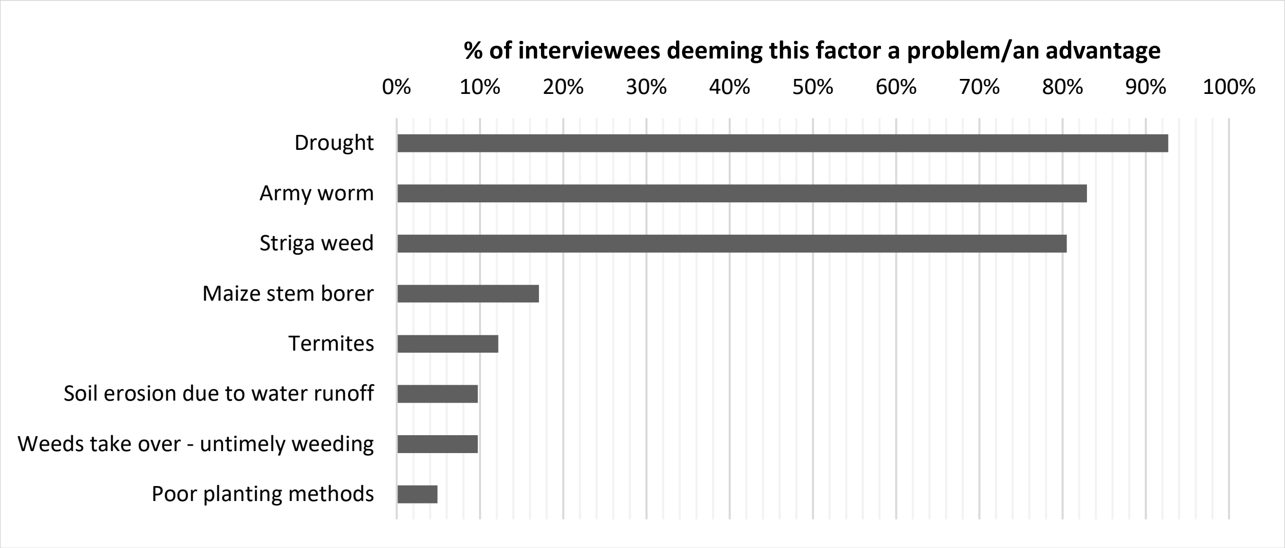


Figure 4.9 Negative factors affecting yield levels as perceived by farmers (only including those mentioned by more than one farmer). *n = 41.*

Fall armyworm

Figure 4.10 shows infected maize plants. According to locals, farmers in Makuutu subcounty encountered Fall armyworms for the first time in 2015 (OR_NY, CO_BT). Only OR_KA did not detect armyworm in his field at the time of sampling. Farmers reported that the presence of Armyworm seems to be related to drought – a relation that is caused by plants' reduced resilience related drought events.

Organic farmers combated the Armyworm using a homemade mixture of leaves from the Neem tree (*Azadirachta indica*), mixed with ashes from the fireplace, piri piri (chili) and water (Figure 4.10). However, only OR_MB mentioned to have used this on the maize field in question.

Figure 4.10 Left: The maize can get striped and holed leaves and cones are damaged. Middle: A leave full of armyworm-inflicted holes. Right: Piri-piri and neem leaves are two of the four ingredients used in the home-made mixture that organic farmers use to combat armyworm. Ash and water are the remaining ones.

Striga weed

Farmers generally found Striga a somewhat insurmountable challenge due to its vigorous growth (Figure 4.11). However, a common opinion was that Striga more easily was coped with if the plants were uprooted before blooming, since that impedes some spreading of Striga seeds, although the weed also spreads through other channels (section 2.4).

Figure 4.11 Left: An example of how striga weed is a root parasite of maize, growing from the same spot through “stealing” the maize plants nutrients. Right: Field where striga thrive amongst maize plants. This shows how striga also outgrow other weeds.

4.3 Soil quality as perceived by farmers

Two focus group interviews about soil quality were conducted with two different groups of farmers consisting of both organic and conventional farmers. The following presents the results of the focus group interviews (Appendix 5), while being supplemented with information obtained through other interviews and conversations with locals.

Farmers stated properties such as weight and colour as important indicators of soil quality, saying that a fertile soil is heavy and dark, while rapid growth of both crops and weeds were also highlighted as good signs. Overgrazing, monocropping and bush-burning were given as causes of declining soil quality, while signs of soil erosion and the presence of Striga weed were stated to be signs of bad soil quality.

Listing practices that may improve soil quality, farmers highlighted trenches, crop rotation, mulching, applying manure, cover crops and nitrogen-fixating crops. The answers given by conventional and organic farmers were somewhat different when asked about the most important practices in improving soil quality: Conventional farmers stressed deep-ploughing (app. 30cm with ox-plough) and mixing weeds into the soil upon weeding. Organic farmers declared that the application of cow dung was the most important practice in improving soil quality. Fallowing was no longer a part of the farming system among conventional farmers, while organic farmers used it to a lesser extent as pasture today.

4.4 Soil quality in conventionally and organically cultivated soils

This section describes the soil properties measured in conventionally cultivated soils (CCS) and organically cultivated soils (OCS) focusing on the hypotheses given in section 1.2.1. Averaged results for each cultivation system (Table 4.9) are introduced (see averaged data on field-level in Appendix 9). Subsequently the outcomes of statistical analyses are presented. Correlations between soil properties were investigated and is presented at the end of this section.

Table 4.9 Analysed soil properties for organically (OR) and conventionally (CO) cultivated soils in depths of 10 and 20cm. Averages (with standard deviations in brackets) and ranges are given.

Soil property	***OR* avg 10cm**	**CO avg 10cm**	***OR* range 10cm**	**CO range 10cm**	***OR* avg 20cm**	***CO* avg 20cm**	***OR* range 20cm**	***CO* range 20 cm**
SOC%	2.1 (± 0.1)	1.8 (± 0.2)	0.7-3.1	1.2-3.0	1.7 (± 0.2)	1.5 (± 0.2)	0.7-2.6	1.1-2.1
Total N%	0.2 (± 0.0)	0.2 (± 0.0)	0.1-0.3	0.1-0.3	0.2 (± 0.0)	0.1 (± 0.0)	0.1-0.2	0.1-0.2
C:N ratio	11.0 (± 0.3)	10.7 (± 0.2)	10.0-12.2	9.4-11.8	10.8 (± 0.4)	10.6 (± 0.4)	9.7-12.1	9.5-11.7
Pox-C (mg kg^{-1})	376.2 (± 34.6)	351.9 (± 39.9)	76.4-563.9	243.4-481.5	276.8 (± 30.3)	292.6 (± 62.6)	37.0-451.3	164.5-412.4
Pox-C of SOC (%)	1.8 (± 0.4)	2.0 (± 0.3)	1.0-2.3	1.6-2.6	1.6 (± 0.4)	1.58 (± 0.4)	0.6-1.9	1.6-2.7
Bulk density (g cm^{-3})	1.2 (± 0.1)	1.2 (± 0.1)	1.1-1.4	1.1-1.4	1.3 (± 0.1)	1.3 (± 0.1)	1.2-1.5	1.2-1.5
pF4.2 (vol%)	13.7 (± 1.2)	13.6 (± 1.3)	4.8-18.9	8.9-17.7	13.4 (± 1.3)	13.8 (± 1.2)	5.8-17.6	11.0-17.5
pF3.0 (vol%)	18.3 (± 1.2)	19.0 (± 1.4)	9.5-23.5	15.5-23.3	20.5 (± 1.3)	21.2 (± 1.5)	11.2-27.2	17.7-27.5
pF2.0 (vol%)	26.1 (± 1.8)	27.2 (± 1.8)	18.0-31.3	24.6-30.3	27.5 (± 1.6)	29.8 (± 1.4)	20.5-32.7	26.3-33.7
PAW (vol%)	12.3 (± 1.0)	13.6 (± 2.3)	10.0-14.2	11.1-17.2	14.1 (± 1.4)	16.0 (± 1.3)	11.9-15.2	11.9-21.8
Porosity (vol%)	52.0 (± 3.4)	51.7 (± 2.2)	47.4-55.9	45.3-58.6	48.9 (± 3.1)	48.0 (± 2.3)	43.3-53.2	42.8-54.8
Aeration (vol%)	25.9 (± 5.1)	24.5 (± 3.9)	23.0-30.9	17.9-30.3	21.3 (± 4.3)	18.2 (± 3.1)	18.0-25.3	10.5-25.5
pH	6.0 (± 0.1)	6.0 (± 0.2)	4.8-7.0	5.2-6.6	5.9 (± 0.1)	6.0 (± 0.2)	4.8-7.1	5.5-6.3

4.4.1 Hypothesis 1: Soil organic matter

SOC concentration was slightly higher in OCS than CCS averaging 2.1% and 1.8%, respectively, in the depth of 10cm and 1.7% and 1.5% in 20cm (Table 4.9). However, the difference was not significant (10cm: $P = 0.502$; 20cm: $P = 0.497$, Table 4.10), while being consistently higher in the upper samples (10cm) compared to the lower samples (20cm) for both cultivation systems (Appendix 9). The lowest SOC concentration was found at 0.7% for OR_RN's field for both 10 and 20cm depth, while the highest (3.1%) was found in 10cm in the field of OR_RB.

Total N concentration showed the same pattern as SOC with slightly higher contents in 10cm compared to 20cm. The lowest N concentration was found with OR_RN at 0.07% in 10cm and 0.06% in 20cm (Appendix 9). The difference between OCS and CCS was not significant (10cm: $P = 0.624$; 20cm: $P = 0.523$) (Table 4.10).

The labile C pool, Pox-C, for OCS and CCS were 376.2 mg kg^{-1} and 351.9 mg kg^{-1} in 10cm samples, while being 292.6 mg kg^{-1} for CCS and 276.8 mg kg^{-1} for OCS in 20cm (Table 4.9). Pox-C tended to be higher in 10cm depth compared to 20cm with few exceptions (Appendix 9). The difference between OCS and CCS was not significant in neither depth (10cm: $P = 0.290$; 20cm: $P = 0.105$) (Table 4.10). The range of values was considerably wider for organic farmers, due to very low Pox-C in OR_RN's field. The median of 10cm samples from OCS was 454.4 mg kg^{-1} compared to that of CCS of 346.9 mg kg^{-1}, while it was more similar in 20cm (OR: 292.2 mg kg^{-1}, CO: 301.7 mg kg^{-1}). The difference in medians was not significant in neither depth (10cm: $P = 0,619$; 20cm: $P = 1.000$). In 10 cm depth Pox-C constituted 1.8 and 2.0% of the SOC in OCS and CCS, respectively – a nonsignificant difference (10cm: $P = 0.290$; 20cm: $P = 0.105$).

The C:N ratio decreased with depth from 11.0 in 10cm to 10.8 in 20cm for OCS, and from 10.7 to 10.6 for CCS (Table 4.9). This difference was, however, not significant (10cm: $P = 0.418$; 20cm: $P = 0.708$) (Table 4.10).

Table 4.10 P-values of statistical tests testing whether the averages of OCS and CCS are significantly different in terms of soil properties connected to the organic pool in soils.

Soil property	**Depth**	
	10cm	**20cm**
SOC	0.502	0.497
Total N	0.624	0.523
C:N ratio	0.418	0.708
Pox-C	0.717	0.779
Pox-C of SOC	0.290	0.105^{M}
Normalized Pox-C using clay fraction	0.540	0.645^{M}

^{M} Mann Whitney U test performed instead of t-test due to data not passing test of normality.

None of the investigated soil properties connected to organic matter in soils was significantly different between OCS and CCS (Table 4.10), therefore, hypothesis 1 was rejected: In terms of soil properties related to organic matter and the composition thereof, OCS and CCS are similar in the study area.

Based on the investigated properties, it cannot be concluded that soil quality was better in soils under organic cultivation.

4.4.2 Hypothesis 2: Soil water retention and aeration

Measured bulk densities were similar in both cultivation systems, ranging from 1.1 to 1.4 g cm^{-3} in 10cm samples and from 1.2 to 1.5 g cm^{-3} in 20cm (Table 4.9). Differences between average bulk densities for OCS and CCS were not significant (10cm: $P = 0.678$; 20cm: $P = 0.828$) (Table 4.11). Aeration was generally good (Appendix 9); only CO_MH and CO_BT stood out as low (10.5% and 11.2%, respectively).

In general, OCS had lower water contents at all measured pF-values (except pF4.2 in 10cm), giving CCS a slightly lower porosity (Table 4.9) (not significant, Table 4.11). PAW for OCS was 12.3 against 13.6 vol% in CCS in 10cm samples, and 14.1 against 16.0 vol% in 20cm samples; differences tested to be non-significant (10cm: $P = 0.200$; 20cm: $P = 0.114$, Table 4.11). Attempting to eliminate the effect of the clay fraction, PAW was normalized as described in section 3.5, however, the difference between OCS and CCS remained non-significant (10cm: $P = 0.678$; 20cm: $P = 0.828$, Table 4.11).

None of the soil properties related to soil water retention and structure were significantly different between OCS and CCS as shown by the P-values all exceeding 0.05 (Table 4.11). On this basis hypothesis 2 was rejected not showing any indication that the practices used on OCS in the study area increases soil quality.

Table 4.11 P-values of statistical tests testing whether OCS and CCS are significantly different in terms of soil properties related to soil water retention.

Soil property	**Depth**	
	10cm	**20cm**
Bulk density	0.678	0.828
pF4.2	0.926	0.834
pF3.0	1.000^{M}	0.784
pF2.0	0.587	0.247
Porosity	0.881	0.671
PAW	0.200	0.114
Aeration	0.451	0.129
Normalized PAW using clay fraction	0.574^{M}	0.505^{M}

^{M} Mann Whitney U test performed instead of t-test due to data not passing test of normality.

4.4.3 Hypothesis 3: pH

Average pH of OCS and CCS were similar in depths of both 10cm (6.0 and 6.0) and 20cm (5.9 and 6.0) (Table 4.9). The range was somewhat bigger for OCS in both depths. OR_RN had the lowest pH in both 10 and 20cm (4.8), while OR_MB had the highest in 10cm (7.0) and 20cm (7.1) (Appendix 9).

pH is not significantly different between the organic and the conventional cultivation system either for 10cm depth (*P = 1,000*) nor 20cm (*0,928*) (Table 4.12). Hypothesis 3 is hereby rejected.

Table 4.12 P-values of statistical tests testing pH difference between OCS and CCS.

Soil property	**Depth**	
	10cm	**20cm**
pH	1.000	0.928

^{M} Mann Whitney U test performed instead of t-test due to data not passing test of normality.

4.5 Nutrient budgets

Nutrient budgets, based on manure nutrient contents presented by Zake et al. (2010), resulted in either positive or negative values, indicating net gain or net loss of N, P and K. Export of nutrients from both OCS and CCS were limited to harvested maize. Only OCS had input of nutrients in the form of manure, while inputs of compost and mulch were disregarded.

For fresh manure, nutrient budgets were negative for OCS in N (-22.0 kg ha^{-1}), while P and K were positive (3.0 kg ha^{-1} and 0.3 kg ha^{-1}, respectively) (Table 4.13). After four weeks of manure composting, the quality of manure in terms of nutrient contents had declined considerably resulting in budgets for both N (-36.9 kg ha^{-1}) and P (-3.3 kg ha^{-1}) showing net export, while the relative amount of K increased after composting (4.2 kg ha^{-1}) now showing net import. At field scale, budgets ranged widely for all three nutrients in OCS as a result of the size of yields removed and manure applied.

Table 4.13 Nutrient budgets (kg ha^{-1}) for nitrogen (N), phosphorus (P) and potassium (K) in organically cultivated soils (OCS). Budgets were given for both fresh manure and after four weeks of composting. Negative values indicate net export of nutrients from the field system, while positive values indicate import.

OCS		**Avg (st.dev.)**	**Range**
Fresh manure			
	N	-22.0 (± 23.8)	-68.1 – 12.1
	P	3.0 (± 7.9)	-5.8 – 20.9
	K	0.3 (± 6.9)	-9.4 – 15.2
After 4 weeks of composting			
	N	-36.9 (± 23.4)	-83.0 – -8.5
	P	-3.3 (± 4.8)	-12.1 – 4.7
	K	4.2 (± 9.2)	-5.5 – 25.4

For CCS, there was a net loss of N (-47.0 kg ha^{-1}), P (-9.0 kg ha^{-1}) and K (-9.9 kg ha^{-1}), while ranges were narrower than OCS (Table 4.14) due to removed harvest being the only factor affecting these calculations.

The amounts of N exported from CCS were significantly higher than that of OCS when using budgets based on fresh manure (*P = 0.043*), while not being significantly different after four weeks of composting (*P = 0.379*). P budgets in CCS and OCS were significantly different for both fresh manure (*P = 0.0.002*) and four weeks composting (*P = 0.022*), and the same applied to K (*P = 0.004*; *P = 0.002*, respectively). In summary, composting of manure had considerable influence on the difference in N, P and K budgets for OCS and CCS which showed to approach each other as the nutrient contents of manure declined.

Table 4.14 Nutrient budgets (kg ha^{-1}) for N, P and K in conventionally cultivated soils (CCS). Negative values indicate net export of nutrients from the field system, while positive values indicate import.

CCS	**Avg (st.dev.)**	**Range**
N	-47.0 (± 17,8)	-71.2 – -13.4
P	-9.0 (± 3.4)	-13.6 – -2.6
K	-9.9 (± 3.7)	-15.0 – -2.8

4.6 Correlations between soil properties

Measured soil properties and quantifiable features such as yield levels, field size and number of plants per square meter were tested for statistically significant correlations in samples from depths 10cm and 20cm (Table 4.15). Having concluded that no significant differences exist in investigated soil properties between OCS and CCS, the correlation analysis was conducted independent of cultivation system.

Table 4.15 Correlations between soil properties across cultivation systems differentiating between samples collected from depths 10 and 20cm. Clay-normalised properties are shown with "/clay%", while clay%, % and sand% denote the amounts of these textural fractions. Significant correlations were highlighted in bold fond. *n = 16*.

	SOC%	***Total N***	***Pox-C***	***Pox-C/clay%***	***PAW***	***PAW/clay%***	***pH***	***Clay%***	***Silt%***	***Sand%***
10cm										
SOC%	1	**,962****	**,874****	0,156	0,137	**-,684****	**,665****	**,794****	0,048	**-,807****
Total N	**,962****	1	**,864****	0,038	0,135	**-,747****	**,732****	**,881****	0,055	**-,896****
Pox-C	**,874****	**,864****	1	0,370	0,119	**-,777****	**,723****	**,844****	0,001	**-,837****
Pox-C/clay%	0,156	0,038	0,370	1	0,222	-0,061	0,291	-0,151	0,306	0,021
PAW	0,137	0,135	0,119	0,222	1	0,324	-0,031	0,015	**,653****	-0,291
PAW/clay%	**-,684****	**-,747****	**-,777****	-0,061	0,324	1	**-,676****	**-,834****	0,372	**,669****
pH	**,665****	**,732****	**,723****	0,291	-0,031	**-,676****	1	**,636****	-0,050	**-,609***
Clay%	**,794****	**,881****	**,844****	-0,151	0,015	**-,834****	**,636****	1	-0,191	**-,910****
Silt%	0,048	0,055	0,001	0,306	**,653****	0,372	-0,050	-0,191	1	-0,232
Sand%	**-,807****	**-,896****	**-,837****	0,021	-0,291	**,669****	**-,609***	**-,910****	-0,232	1
20cm										
SOC%	1	**,981****	**,908****	0,052	-0,112	**-,702****	**,680****	**,741****	**,500***	**-,800****
Total N	**,981****	1	**,898****	-0,008	-0,063	**-,722****	**,735****	**,802****	**,532***	**-,863****
Pox-C	**,908****	**,898****	1	0,338	-0,070	**-,667****	**,760****	**,631****	**,626****	**-,747****
Pox-C/clay%	0,052	-0,008	0,338	1	0,392	0,293	0,059	-0,419	0,284	0,267
PAW	-0,112	-0,063	-0,070	0,392	1	**,542***	-0,191	-0,304	0,078	0,235
PAW/clay%	**-,702****	**-,722****	**-,667****	0,293	**,542***	1	**-,716****	**-,849****	-0,355	**,845****
pH	**,680****	**,735****	**,760****	0,059	-0,191	**-,716****	1	**,694****	0,403	**-,728****
Clay%	**,741****	**,802****	**,631****	-0,419	-0,304	**-,849****	**,694****	1	0,276	**-,949****
Silt%	**,500***	**,532***	**,626****	0,284	0,078	-0,355	0,403	0,276	1	**-,566***
Sand%	**-,800****	**-,863****	**-,747****	0,267	0,235	**,845****	**-,728****	**-,949****	**-,566***	1

*Correlation is significant at the 0.05 level.

**Correlation is significant at the 0.01 level.

SOC concentration, total N and Pox-C – all soil properties that are related to soil organic matter (from here termed *OM-related properties*) – were positively correlated with each other at the 0.01 significance level in both 10 and 20cm samples (Table 4.15). Additionally, these properties were positively correlated to pH and clay content, while correlating negatively with clay-normalised PAW and sand content. The clay-normalised Pox-C, however, did not correlate with any of the presented soil properties.

PAW was positively correlated with silt content in 10 cm depth, while not having any other significant correlations (Table 4.15). Clay-normalised PAW, on the other hand, was correlated to a number of properties: It was negatively correlated with the OM-related properties, pH and clay content, while being positively correlated to sand content. pH was positively correlated with the OM-related properties and clay content while negatively correlated with sand content (Table 4.15).

Furthermore, positive correlations at the 0.01 significance level were found 1) between OM-related properties and water content at all pF-values (pF4.2, pF3.0 and pF2.0), and 2) between pH and water content at all pF-values. Negative correlations appeared 1) between bulk density and water contents at all pF-values, and 2) between bulk density and OM-related properties with exception of C:N ratio. These correlations were not shown.

No correlations were found among yield level, field size and number of plants per square meter, and the same applied to correlations between these three and any measured soil property. Therefore, the results of these analyses are not shown.

4.7 Regression analysis

Using the *Exploratory Regression Tool*, the best model found (*adjusted R^2 = 0.50*) used four independent variables: 1) PAW (10cm depth), 2) total N concentration (20cm), 3) field size and 4) amount of clay (10cm) to explain yield levels in Makuutu subcounty. Subsequently, *OLS regression* revealed the coefficients of each variable (Table 4.16), showing that increasing PAW, total N and field size would result in decreasing yields (*adjusted R^2 = 0.50*), while yields would increase with 0.1 kg per percent increase in clay. The negative coefficient of PAW and total N was surprising, since positive coefficients would be expected. However, only one variable, field size, came out significant in explaining yields. According to OLS, the independent variables had consistent relationships to yields in both geographical and data space (ESRId, n.d.). *Nota bene*: Yield levels were given in kg ha^{-1}, thus, shown coefficients indicate the number of kg ha^{-1} yields would increase/decrease per unit of the explanatory variable.

Neither *Global Moran's I* or *Local Moran's I* found significant spatial autocorrelation in residuals, i.e. residuals were spatially random (ESRId, n.d.).

Table 4.16 OLS results showing coefficients of each variable in explaining yield levels (kg ha^{-1}) and the connected P-value indicating whether the variable was significant.

	Coefficient	P-value
PAW, vol% (10cm)	-0.6	0.06
Total N, % (20cm)	-39.0	0.06
Field size, ha	-7.1	0.01*
Clay, % (10cm)	0.1	0.18

*Significant at the 0.05 level.

4.8 Summary

Soil profiles from each of the villages were described showing that the Makuutu profile stood out by having no gravel throughout the profile compared to relatively high gravel contents of the other three profiles. pH ranged from 5.7 to 6.9 in the top samples and developed differently with depth. Soil colours were generally reddish, especially below the A-horizons.

The difference between employed practices on OCS and CCS was limited to include inputs of manure, compost and mulch, which were only part of organic cultivation practice. Thus, the systems were similar in the following aspects: Generally, all farmers ploughed down crop residues from the previous season, while using the hand hoe to mix weeds into the soil in the course of the growing season. Main problems were drought, presence of Fall Armyworm and Striga weed. Many farmers stated one or more of these factors to have been the primary cause(s) for decreasing yield during the previous five years. Organic farmers largely stated that yields increased following conversion from conventional cultivation practices.

Hypotheses 1 and 2 were rejected, because no soil properties connected to soil organic matter or soil water retention and structure, respectively, were significantly different between OCS and CCS. Hypothesis 3 expecting similar pH in both cultivation systems was accepted, since the null hypothesis was retained: pH of OCS and CCS were not significantly different.

Nutrient budgets showed that composting of manure had significant influence on the difference in N, P and K budgets for OCS and CCS which showed to approach each other as the nutrient contents of declined in composted manure. CCS experienced N, P and K export with harvested maize, while OCS had net export of N and P if applying composted manure, while there was a net import of K.

SOC concentration, Pox-C and pH, which are all soil properties known to be related to soil quality, were generally positively correlated. An OLS regression analysis was able to explain 50% of the variation of yields using four variables of which three had negative coefficients (PAW, total N, field size) and one positive coefficient (amount of clay), while only one of the variables came out significant.

5 Discussion

The findings of this study are discussed in the following, suggesting possible explanations as to why no significant differences were found between investigated soil properties. Additionally, it is discussed whether the organic cultivation system justifiably is being referred to as such.

5.1 Soil profiles' representability for soils below fields

The purpose of digging a soil profile in each of the four villages from where sampled fields were selected was to get an impression of the soil below the ploughing layer. The following assesses whether the soil profiles correspond to characteristics of Ferralsol as the classified soil type in the area (section 3.1.2). Texture, pH and SOC concentration were the only properties available for soil type characterization.

Despite high contents of pisolithes in Buswiriri, Kinabirye and Makandwa profiles, these cannot be classified as *Plinthosols*, as the pisoplinthic horizon (≥ 40% pisolithes/nodules) did not start within 50cm from the soil surface (IUSS Working Group WRB, 2015). Classifying the soil profiles as *Nitosols* can also be dismissed, because no *argic* horizons in any of the profiles were found.

Ferralsols are known to have diffuse horizon boundaries, which for a large part correspond to what was observed in Makuutu subcounty; soil colours below the A-horizon were generally reddish, and soil felt sandy due to aggregation (Jones et al., 2013). However, pH profiles did not indicate strong acidification as is normally related to Ferralsols and are high for this soil type (Breuning-Madsen, 2018b; IUSS Working Group WRB, 2015).

Certain implications follow when cultivating Ferralsols. Major changes in vegetation cover (for example when converting forest to cultivated land) will quickly result in declining soil quality in the form of nutrient depletion, acidification and phosphorus fixation, thus Ferralsols have very low resilience (Stocking, 2003). Sampled fields were relatively flat, and interviewees did not consider soil erosion a large issue on selected maize fields, which corresponds with the soil type having moderate sensitivity compared to other tropical soils (Stocking, 2003).

In conclusion, it appeared to be a reasonable assumption that the profiles represented the general soil development with depth in Makuutu subcounty, since no major differences existed in pH ranges, although some textural differences were observed. However, it is important to emphasize that considerable variations in soil types can occur within small distances, and since fields could be situated up to 2.2 km from the nearest soil profile, it cannot be ruled out that such variation existed. On the other hand, consulted soil type classifications of the area (ISRIC, n.d.; Jones et al., 2013) did not indicate that the area should be diverse in soil types.

5.2 Soil properties in conventionally and organically cultivated soils

Hypotheses of this study were based on an expectation that organic cultivation practices after 8-10 years would result in improved soil quality. All three hypotheses were rejected, since soil properties related to soil quality were not significantly different between OCS and CCS in selected fields. The following suggests possible causes as to why no significant differences were found between cultivation systems.

The soil properties investigated in this study were selected because they are related to soil quality (Murage et al., 2000; Shukla et al., 2006; Weil and Magdoff, 2004; Weil et al., 2003). They covered both physical (SWR, porosity, bulk density), chemical (SOC, total N, pH) and biological (Pox-C) dimensions of soil quality, although measurements of additional properties would have provided valuable information about the state of soil quality as well. For example, levels of plant-available P could indicate whether N or P was the limiting nutrient within the area.

5.2.1 Soil organic matter and related soil properties

Hypothesis 1 concerned soil organic matter and properties related to this such as total N and the labile C pool (as indicated by Pox-C). The application of organic manure, compost and mulch was expected to result in higher values of the mentioned properties in OCS compared to CCS, however such difference was not found in practice. Following may explain the absence of differences:

1. *Amounts of organic input*. The applied amounts of organic matter were too small to make a significant contribution to the soil organic pool on organic fields.
2. *The timing of sampling.* Sampling was carried out in November and December 2017 – app. 3 months after sowing and relatively close to the time of harvest.
3. *Other inputs of organic matter*. Other factors than the amount of manure/compost/mulch applied on organic fields determined the SOC concentration and total N while also affecting Pox-C in both OCS and CCS, such as inputs of organic matter from trees surrounding or within the field.

The applied amounts of manure on organic sampling fields were relatively low compared to recommendations (section 5.4.1). These inputs may simply have been too small to deflect significantly on SOC, total N and Pox-C values, although the nutrient budgets imply a better situation in OCS compared to CCS (section 4.5). Additionally, soil's organic constituents would have undergone some alterations since sampling in the form of mineralization and/or immobilisation depending on the C:N ratio of applied manure and compost. If the applied organic matter was easily degradable, a lot of plant-available nutrients were released rapidly and then taken up by plants or removed from the soil system as losses such as leaching or volatilization (see section 5.3). If mineralization rates exceeded plants' nutrient demands, substantial leaching of N may have taken place (Rufino et al., 2006), especially considering the timing of manure application at the beginning of the rainy season. This mechanism could perhaps explain the absence of significant differences in OM-related properties between conventional and organic cultivation systems, although composted manure (as that applied here) is suggested to have a more long-term effect on soils (Okalebo et al., 2007). However, information about the degradability of applied manure in Makuutu subcounty was not available.

Topsoil Pox-C is a useful indicator of the effect of different management practices, as it is more sensitive to changes in management compared to SOC (Culman et al., 2012; Gruver, 2015; Weil et al., 2003). In the present study, the difference between Pox-C in OCS and CCS was nonsignificant, which may strengthen suspicion that the applied organic matter on OCS have not impacted soil properties to a measurable extent.

The only conclusion that can be made is that neither yields or soil quality-related properties or OCS apparently benefitted from the addition of manure and compost.

Differences in SOC and total N concentration as well as Pox-C were not related to differences in practices between conventional and organic cultivation systems, as they were not correlated with manure or compost applications. Thus, differences must be caused by factors crossing the defined systems. Such factors could be fields' surroundings, such as the presence of trees. Adjacent trees have been suggested to make considerable contribution to SOC through littering and decay of roots. Trees can reach nutrients that are below the reach of maize plants while effectively decreasing nutrient losses from the system (Bayala et al., 2007). Several of the sampled fields had trees around and/or within the field, and therefore, such fields are likely to have been affected. Regrettably, number and proximity of trees was not a factor recognized to this degree during fieldwork.

5.2.2 Plant-available water (PAW) and soil structure

Hypothesis 2 described an expected higher PAW as a result of the assumed higher SOM in OCS. The correlation between PAW and soil's content of organic matter due to the beneficial effect of SOM on soil structure is well-known (Emerson, 1995; Lal, 2006), thus making soils under organic cultivation more resilient to water stress assumed that organic cultivation results in increased SOM (Rasul and Thapa, 2004; Scialabba et al., 2002). No significant difference was found in amounts of PAW between OCS and CCS, which was consistent with the absence of difference in OM-related properties. Properties such as bulk density as well as water contents at FC and WP were also similar across cultivation systems, indicating that soil structure was similar.

Nyamangara et al. (2001) studied the effect of manure application on soil water retention in a Zimbabwean *Haplic Lixisol*, which had been fallowed for a minimum of six years. Manure application rates (12.5 t ha^{-1} year in three years and one application of 37.5 t ha^{-1}) were significantly higher than those seen in the present study. The increase in PAW after this treatment was not significant after three years, although *readily available water* (defined as amount of water between 0.05 bar and 2 bar) was significantly increased. The highest effect was found at low tension values, because soil aggregation is more important here (Nyamangara et al., 2001), however, in the present study water contents at FC were not significantly different in OCS and CCS where improved soil aggregation would be apparent.

5.2.3 Soil pH

Hypothesis 3 about pH was based on the assumption that OCS would have a higher content of organic matter, which would increase the soil's buffer value counteracting the release of H^+ as a biproduct of decomposition of the added organic matter. However, the average pH was 6.0 in both cultivation systems. The found pH levels are comparable to pH levels reported by other studies in the area. For example, Wortmann and Kaizzi (1998) found an average pH of 5.8 in Ferralsols in Imanyiro subcounty situated ~20km from the study area, while Zake et al. (2010) found average pH of 6.0 in Wakiso, another subcounty ~140km from Makuutu subcounty.

5.2.4 Critical limits for good soil quality

Having determined that no significant differences exist between soil properties in organically and conventionally cultivated soils, it is interesting to examine the state of soil quality in sampled fields.

Critical limits for good soil quality have previously been determined for cultivated soils in East Africa based on local farmers perceptions (Lal, 2006; Murage et al., 2000; Zake et al., 2010). The soil properties for which critical limits in similar soils were found included SOC, total N and pH, which can be compared to the findings of this study. The results of the studies by Zake et al. (2010) and Murage et al. (2000) are central in the following discussion and are briefly presented here:

Zake et al. (2010) investigated the status of soil fertility of maize fields in Wakiso District, Uganda, situated ~140 km from the study area with similar climate and altitude (Kottek et al., 2006). Soils were Ferralsols under continuous cultivation. The semi-intensive cultivation system investigated by Zake et al. (2010) is comparable to the organic cultivation system of farmers in Makuutu subcounty: Farmers apply cattle manure from cattle that were largely fed on open range. Grazing was supplemented with crop residues.

Soil quality indicators were also investigated in smallholder's fields in Kiambu District, Kenya (~1600 m.a.s.l.), based on soil samples representing the depth of 0-20cm (Murage et al., 2000). The climate here is temperate (i.e. colder) with precipitation distributed throughout the year (Kottek et al., 2006), while soils were *Humic Nitisols* expected to possess higher soil quality compared to Ferralsols (IUSS Working Group WRB, 2015). Kiambu is situated ~450 km from Makuutu.

Soil organic carbon concentration and labile carbon

Yield levels have been suggested to be linearly correlated with SOC concentration of the soil medium up to a concentration of 2% above which the effect of further increase on yield levels becomes less significant (Lal, 2006). This underlines the importance of focusing on SOC in cultivation practices. Using a limit of 2% SOC concentration, 11 of the 16 fields in Makuutu could potentially increase yields if increasing SOC to 2% or above, while only five fields had clay contents below 20%.

Murage et al. (2000) found soils with SOC concentration above 2.4% to be productive, while a concentration below 1.9% was indicative of non-productive soils. Only two fields met this requirement of productive soils for both 10 and 20cm samples (OR_RB and OR_NY), while 10 fields would be characterised as unproductive according to Murage et al. (2000) (Table 5.1).

Zake et al. (2010) used a critical limit of 3% SOM, and found that a cultivation system comparable to organic cultivation in Makuutu generally fell slightly below this limit with 2.9% SOM. Applying a conversion factor of 1.72 (Eq. 3.1), the majority of sampled fields in Makuutu fell below this limit in on or both sample depths, while five fields had sufficient SOM concentrations in both 10 and 20cm samples. A critical level of 3% SOM is however, considerably below the SOC limits proposed by Lal (2006) and Murage et al. (2000).

In a highly weathered and leached soil (termed Ultisol according to Soil Taxonomy) in Thailand, local farmers' perception of soil quality showed that Pox-C levels below 442 and above 588 mg kg^{-1} indicated bad and good soil quality in 0-5 cm depth, respectively (Bruun et al., 2017). Since soil samples were collected deeper in Makuutu subcounty, the values must be expected to be somewhat lower. Considering the 10cm sample, however, 11 of the 16 sampling fields fell below 442 mg kg^{-1} with five fields below 300 mg kg^{-1}.

However, in the present study no significant correlation was found between yield levels and SOC concentration nor Pox-C levels, which may indicate that other factors not directly related to the effect of SOC impacted production more under current conditions.

Total N

A critical limit of total N was proposed at 0.2% (Okalebo et al., 2002; Zake et al., 2010). Five fields had higher total N, however some of the remaining fields were considerably lower; OR_RN's field had 0.06% total N averaging over 10 and 20cm samples, while OR_BJ and OR_KA had 0.10%. The latter had the ultimately highest yield among respondents of 63.5 t ha^{-1} despite soil's low total N levels (Table 5.1). If it is the case that another nutrient than N limits crop growth, crops take up less N hence increasing the risk of N being leached from the soil system (Giller et al., 2006).

pH

Zake et al. (2010) used a critical pH limit of 5.5 below which toxic cations (primarily Al^{3+}) and low P availability constrain plant productivity (Okalebo et al., 2002). Findings indicated that what they termed *semi-intensive system*, which was comparable to organic cultivation systems in Makuutu subcounty, did not fall underneath the critical limit. In Makuutu subcounty, two fields had average pH below 5.5: OR_RN with 4.8 in both sampling depths, and CO_BT with 5.2 in 10cm and 5.5 in 20cm.

Murage et al. (2000) proposed critical limits for pH indicative of productive and unproductive soils with pH above 6.26 and below 5.56, respectively. Consequently, apart from the aforementioned having bad soil quality, three fields sampled in Makuutu can be described as good quality soils in terms of pH when averaging the 10 and 20cm samples: CO_BD (6.4), OR_MB (7.0) and OR_NY (6.8). The remaining 11 fields fell in-between limits of productive and unproductive soils (Table 5.1).

In general, pH values were in the upper range of the appropriate conditions for maize growth (4.8-6.5) (Brady and Weil, 2014). Consequently, perceiving soil quality for the purpose of the soil as a growth medium for maize, soils in Makuutu subcounty generally offered good pH conditions.

In summary, the soil quality status of fields sampled in Makuutu subcounty varied depending on the soil property underlying the assessment. However, two fields fell out as having bad soil quality on all properties examined here; OR_RN's and CO_BT's fields had insufficient concentrations of SOC, SOM and total N, while pH was so low that it may have negatively affected plant health (Table 5.1).

Continuous cultivation of soils, especially without crop rotation or intercropping, is reported to result in decreasing SOC concentration, total N, CEC and BS, including degrading soil structure (Jones et al., 2013; Lemenih et al., 2005; Moebius-Clune et al., 2011). Since the majority of fields in Makuutu have been cultivated with maize continuously for the past 10 years, such effects are very likely to have taken place here. Thus, declining soil quality is likely to be part of the explanation that farmers experienced decreasing yields.

Table 5.1 Overview of the degree to which farmers' fields were above or below critical limits determined by different studies. + indicates that measured values were above the limit, while – indicated that values were below. *o* indicated that value fell between limits proposed for productive or unproductive fields.

	SOC[1]		**Pox-C**[2]	**Total N**[3]		**pH**[4]	
Farmer initials	**10cm**	**20cm**	**10cm**	**10cm**	**20cm**	**10cm**	**20cm**
CO_BD	+	o	o	+	+	+	+
CO_BT	-	-	-	-	-	-	-
CO_EK	-	-	-	-	-	o	o
CO_IM	-	-	-	-	-	o	o
CO_MH	-	-	-	-	-	o	o
CO_MR	-	-	-	-	-	o	o
CO_NA	-	-	-	-	-	o	o
CO_NS	-	-	-	-	-	o	o
OR_BJ	-	-	-	-	-	o	o
OR_KA	-	-	-	-	-	o	o
OR_KT	+	-	o	+	-	+	o
OR_MB	+	o	o	+	+	+	+
OR_MWF	o	-	-	+	-	o	o
OR_NY	+	+	o	+	+	+	+
OR_RB	+	+	o	+	+	o	o
OR_RN	-	-	-	-	-	-	-

[1] Murage et al., 2000. + is above 2.4%, - is below 1.9%. o indicates values falling between the limits.
[2] Bruun et al., 2017. + is above 588 mg kg^{-1}, - is below 442 mg kg^{-1}. o indicates values falling between the limits.
[3] Zake et al., 2010. + is above 0.2%, - is below 0.2%.
[4] Murage et al., 2000. + is above 6.29, - is below 5.56. o indicates values falling between the limits.

5.3 Nutrient budgets

Assessing the nutrient budgets of fields in the study area are important, since particularly nutrient deficiencies have been highlighted as being largely responsible for declining soil quality and yields (Esilaba et al., 2005; Okalebo et al., 2007; Waithaka et al., 2007). Such budgets can contribute greatly to an understanding of the cultivation system, while being central to the sustainability criteria of organic farming (Oelofse et al., 2010a).

Manure was the only input taken into account in nutrient budgets, thus, ignoring inputs from compost and mulch (cf. section 3.4). Especially compost would add more nutrients to OCS than indicated in budgets. Applied amounts of manure were not sufficient to make the field systems sustainable in N and P if comparing OCS when manure was composted with CCS. Negative nutrient budgets in smallholder farming systems with no or very limited fertilizer use have been found by several studies in the East African region (Adamtey et al., 2016; Wortmann and Kaizzi, 1998), possibly due to restricted access to and quality of manure and compost.

Good levels of available K in soils have shown to improve crops' resistance towards drought (Wang et al., 2013). Sources in OD and the local organisation A2N perceived organic fields in Makuutu to be more drought resilient, although neither yield data or measured SWR indicated that such resistance existed, despite a positive K balance in OCS (section 4.5). K is easily leached from soils, particularly where pH is low (Brady and Weil, 2014), while waste amounts of K may be removed with soil erosion (Wortmann and Kaizzi, 1998). Such factors may undermine the potential effect of increased K in OCS.

P has been found to be the most frequently limiting nutrient in Imanyiro (Wortmann and Kaizzi, 1998), a nearby subcounty situated ~20km from the study area and for similar soils. Therefore, this is likely to also be the situation in the study area. Manure is generally low in P for which reason supplementary P fertilizing may be necessary (Nziguheba, 2007; Zake et al., 2010). While maize growth on CCS depended on P released through mineralization of maize residues, weeds mixed into the soil and weathering of minerals, OCS received an additional input through manure, compost and mulch. The input from manure was not sufficient to create a positive P balance after composting. Additionally, P released through these mentioned processes is rapidly fixed, primarily adsorbed to insoluble metal oxides such as gibbsite and goethite, although pH levels in sampled fields support a relatively high proportion of plant-available P (Brady and Weil, 2014). P-fixation is a widespread challenge in East Africa (IUSS Working Group WRB, 2015; Jones et al., 2013; Nziguheba, 2007).

Budgets showed large export of N from both OCS and CCS. Particularly leaching and volatilization are important when assessing N movements in and from soil. The warm climate may cause volatilization of N as NH_3, while precipitation events can result in leaching of NO_3^- (Rufino et al., 2006; Snijders et al., 2009) – a problem that may be of high importance since manure is added as the beginning of the rainy season when vast amounts of precipitation falls in short amounts of time. The timing of manure application is a difficult practice to change, because this is the only time ox-ploughs can be used to incorporate manure into the soil. Alternatively, manure should be added in several steps during the growing season and be incorporated with hand-hoes to avoid damaging crops – a considerably more laborious sequence of work. The extent of these losses depend on the pace of mineralization, which, in turn, depends on C:N-ratios of organic matter, which is discussed further in section 5.3.1.

Measured levels of total N did not reflect differences between OCS and CCS as indicated by nutrient budgets. The addition of manure (as well as compost and mulch), apparently, did not increase N pools in soils or result in increased yields of organic cultivation systems, although budgets indicated a smaller export of N, P and K. Part of the explanation for this may be due to the quality of applied manure (section 5.3.1).

Soil erosion would impact losses of all mentioned nutrients, but was not considered an important problem by farmers, while selected fields exhibited limited slope. Thus, erosion was assumed to be negligible. However, in many studies soil erosion is suggested as one of the most important reasons for nutrient loss in Uganda (Mulumba, 2004; Nkonya et al., 2004; Wortmann and Kaizzi, 1998), and for a nearby subcounty average soil losses were estimated at 4.4 t soil ha^{-1} $year^{-1}$ (9.2, 2.4 and 11.9 kg ha^{-1} $year^{-1}$ N, P and K, respectively) (Wortmann and Kaizzi, 1998).

Atmospheric deposition of N also constitute an input of N on a given location, whereas atmospheric deposition of P and K are negligible (Eickhout et al., 2006; Nkonya et al., 2004; Wortmann and Kaizzi, 1998). For annual crops, atmospheric deposition has been estimated to 4.1 kg N ha^{-1} $year^{-1}$ in the area (Wortmann and Kaizzi, 1998), roughly corresponding to an additional input of N in calculated nutrient budgets of 0.8 kg ha^{-1} per growing season. Thus, considering the size of N exports in budgets, including atmospheric N input would only have minor effect on the balance.

As losses of nutrients take place through several mechanisms as described here, input of nutrients into field systems will not all benefit plant productivity. Such losses were not considered in calculated budgets, which only included inputs and outputs identified by farmers. Soil productivity may decline more than indicated by negative nutrient budgets, because decreasing nutrient base implicate a proportionally lower amount of plant-available nutrients (Wortmann and Kaizzi, 1998).

5.3.1 Manure quality

Assessing the differences in budgets between fresh manure and composted manure, it is evident that the quality of manure in terms of N and P contents declined during four weeks, assuming that the development is similar to that found by Zake et al. (2010) resulting in low quality manure (Palm et al., 1997). Supposing that farmers exhaust their storage of manure at the beginning of every growing season, collection of manure is initiated immediately to accumulate as much as possible for the following growing season. Thus, stored manure would be composting for up to six months, while the final manure heap, which is applied on the field, will consist of excreta that has been exposed to varying degrees of decomposition with only a limited proportion having been composting for four weeks or less. Assumed that nutrient contents continue to decline after the initial four weeks' composting, the manure applied by organic farmers in Makuutu subcounty was possibly of poorer quality than that used in calculating nutrient budgets, thus presented nutrient budgets are likely to overestimate the input of nutrients in OCS.

The content of nutrients in animal manure can vary due to a number of processes connected to the handling from cattle fodder to practices connected with application on the field (Bayu et al., 2004; Oelofse et al., 2010a; Rufino et al., 2006; Snijders et al., 2009; Waddington et al., 1998; Watson et al., 2002):

- Variation in fodder sources and utilization by animals
- Collection (stalled or grazing cattle)
- Storage (shelter, burial, cover…)
- Processing of manure (composting time, turning, addition of ash/water/greens…)
- Method of application to the field (added on soil surface, mixed with soil…)

Interviewees were not inquired about handling of manure and the following discussion is, therefore, solely based on observations from visits to farms. Manure quality in terms of N will be the main focus, while the importance of P and K are also recognized.

The **utilization of fodder** by cattle determines the nutrient contents of faeces and urine. Fodder produced during the dry season has been shown to contain less N while also being somewhat scarce resulting in a high utilization degree with cattle (Schlecht et al., 1995). Thus, manure excreted during the dry season tends to be of lower quality in terms of total N content (Rufino et al., 2006; Schlecht et al., 1995) as also shown in the nutrient values of fresh manure used in this study as presented by Zake et al. (2010) showing that this also applied to P, while the opposite was the case for K. The primary food source for cattle in Makuutu subcounty was grass from rangelands.

Collection of manure was carried out during the growing season. Since urine cannot be collected from grazing cattle, this fraction of N must be considered lost (Rufino et al., 2006). The proportions of manure collected during rainy and dry seasons were assumed to be 50%-50%, however this is speculative (section 3.4). The manure was **stored** in heaps on bare ground close to the farmhouse. Although farmers were not interviewed about manure handling, observations indicated that manure heaps were uncovered, which previously has been found to be typical amongst on small-scale farms (Lekasi, 1998). Losses of N include volatilization of NH_3, denitrification if anaerobic conditions form in the heap, or leaching of soluble N which may be considerable for uncovered manure heaps (Rufino et al., 2006; Snijders et al., 2009). During storage the heaps were turned on a regular basis (Wesonga, 2017), which has been shown to cause considerable losses of N through volatilization of NH_3 (Rufino et al., 2006). Additional factors that may have affected the quality of manure include 1) the degree to which the heap is placed in the shadow (high temperatures increase decomposition, which possibly increase loss of nutrients), and 2) potential addition of straw or other plant residues which lead to immobilization of N during composting and hence increased N-losses (Rufino et al., 2006). These are some of the mechanisms that may have caused the quality decline as observed by Zake et al. (2010).

Finally, the method of application to the field also affected the degree to which OCS benefitted from manure. Mixing cattle manure into the soil may decrease potential volatilization losses of N (Rufino et al., 2006; Snijders et al., 2009). Farmers reported that manure was incorporated using ox-plough before sowing, but it is uncertain whether the incorporation took place immediately, which would prevent major volatilization losses of N.

The C:N ratio of manure can be used as a chemical quality parameter affecting the mineralization rate. An increasing C:N ratio from fresh manure to four weeks' composting of 16 to 26 show that the content of N decreased relative to C (Table 3.6). An N concentration of 18-22 g kg^{-1} has been suggested as the transition range between mineralization and immobilization (Palm et al., 1997). N concentration in manure after four weeks' composting was 5.3 and 3.8 g kg^{-1} for rainy and dry season manure, respectively, against that of fresh manure of 15.0 and 9.0 g kg^{-1} (Table 3.6). These values indicate that crop growth may be restricted since C:N ratios of added manure resulted in immobilization (Rufino et al., 2006) – even more so if C:N ratios increase further with increased composting time. In general, organic inputs with low N and P levels may immobilise soils' nutrient stocks (Hilhorst and Muchena, 2000). However, the C:N ratio alone may not serve as a good predictor of mineralization-immobilization patterns (Delve et al., 2001; Palm et al., 1997), since manures with low C:N ratios also have been found to result in N immobilization (Nyamangara et al., 1999).

Of course, the basis for the discussion of manure quality and the reliability of nutrient budgets could have been strengthened further with more precise information about handling, while analysis of manure samples had provided more reliable estimates of the effect of seasonality, composting time and manure handing practices.

5.4 The difference and similarities between organic and conventional cultivation practices in the study area

Conventional and organic cultivation of maize in Makuutu subcounty yielded on average 3.2 (± 1.8) and 3.2 (± 1.2) t ha^{-1}, respectively, compared to past yields of up to 3.5-7 t ha^{-1}. Current yield levels, however, are not low compared to yields of infertile soils in other parts of East Africa according to literature. For example, the average maize yield of no nutrient-input cultivation of Ferralsols in 12 sub-Saharan countries was 2.0 t ha^{-1} (Sileshi et al., 2010), which is the same amount as was estimated for maize yields in Uganda based on government statistics (Wortmann and Kaizzi, 1998).

Differences in employed practices on organic compared to conventional maize fields were, as described in section 4.2.1, largely limited to organic farmers applying manure to their maize fields (some also applied compost and/or mulch), while conventional farmers applied no nutrient inputs. Findings by Wortmann and Kaizzi (1998) show that by the mid-90's most farmers in a nearby subcounty had left the practice of burning residues, since 75% of farmers where incorporating residues *in situ*. The practice of removing maize residues for burning was only deployed on one of the sampled fields in the study area today (CO_BD), and the farmer declared during the final interview that residues would be incorporated in the soil henceforth.

To the question why farmers chose to cultivate maize on selected sampling fields, answers alternated between 1) the field in question having good soil fertility, or 2) maize being an important cash and food crop for which space had to be found. These findings agree with those of Murage et al. (2000), who found that Kenyan farmers cultivated maize in both productive and unproductive areas due to its importance for diet and income.

Land use history of selected sampling fields could indicate that farmers tend to grow maize on the same fields year after year, since the result of the selection criteria – that maize should have been the primary crop in 2017 – resulted in a general tendency: Almost all sampling fields had been cultivated with maize as sole crop for 10 or more consecutive years. Organic farmers did not change this practice after conversion, although long-term monocropping without any form of crop rotation oppose organic principles (IFOAM Organics International, 2013; Scialabba et al., 2002; Watson et al., 2002). Inevitably this had consequences for the outcome of the study.

5.4.1 Conversion to organic agriculture

Literature describe strong arguments for conversion to organic cultivation practices. These included 1) higher yields, 2) reduced expenses for artificial inputs, and 3) increased market access and increased income (IFAD, 2002; Oelofse, 2010; Parrott et al., 2006). The potential of organic cultivation to increase yields is recognized by a large body of literature (Badgley et al., 2007; Oelofse, 2010; Parrott et al., 2006; Pretty et al., 2003; Willer and Lernoud, 2017). This was also the most frequently highlighted advantage amongst interviewees in Makuutu subcounty (74%). Such claimed yield increases were, however, not evident when comparing collected data on yield levels from conventional and organic maize fields; they were not significantly different. Reasons to this are discussed in below. Reduced expenses for external inputs were emphasized by 26% (figure R, section R). The study area generally has high market access (Ruecker et al., 2003), while 11% of interviewed organic farmers reported to have experienced increased market access since conversion. Export demand mainly concerned horticulture products, while maize trade took place locally.

Farmers' reported yield increases after conversion

Yield increases that organic farmers claimed took place after conversion were not apparent in recent yield levels when comparing organic and conventional cultivation systems. This give cause for the consideration whether yield increases occurred immediately after conversion on a temporary basis, i.e. over the long-term the reported yield increase following conversion may not have been permanent.

The term *priming effect* arises from short-term incline in mineralization following addition of easily decomposable organic substances contributing with potentially limiting nutrients that rapidly increase productivity (Kuzyakov, 2010; Kuzyakov et al., 2000). Since organic farmers reported increased yields after conversion to organic cultivation practices, priming effects may explain this sudden yield increase triggered by the addition of manure. Application of manure was the most frequently mentioned organic practice that farmers started using after conversion (highlighted by 89% of organic farmers, Figure 4.8). Mulching and compost most likely also contributed to the effect, however, fewer farmers highlighted these practices (63% and 32%, respectively). Part of the pool of organic matter in the soil present before diverse applications of manure, compost and mulch would be mineralized due to the priming effect. With time, the size of this pool decreases resulting in a proportionally smaller release of nutrients although the addition of material remains the same, and the system reaches a new equilibrium, similar to a tendency observed by Probert and Okalebo (1992) as cited by Okalebo et al. (2007). This short-term effect of the application of especially manure and compost on soils that previously had no nutrient input, may explain the initial yield incline reported by organic farmers, and, thus, also explain why the effect of such applications was not permanent. However, no data of the precise development in application of manure, compost and mulch since conversion is available. Therefore, it is not possible to rule out that the yields on organic and conventional fields approached each other over the years as a result of a decline in application amongst the organic farmers, although this is not the impression given by organic farmers in interviews.

Characterization of farmers choosing to convert to organic cultivation practices

The significant difference between total land size owned by organic compared to conventional farmers gave cause for reflection. What drives the motivation for conversion to organic cultivation practices? Artificial inputs were only applied by a minority of conventional farmers who afforded the expenses connected with application of such. For this reason, these farmers were excluded from the study as part of an effort to represent the average conventional farmer (section 3.2.1). The fact that organic farmers indicated that they had reduced expenses for such inputs after conversion may implicate that these farmers previously belonged to the more economically affluent conventional farmers. This suspicion was further strengthened by organic farmers owning significantly more land, although some organic farmers had increased their land since conversion (section 4.2). If the choice of converting to organic cultivation practices was more likely amongst farmers that were relatively well-off, it may have affected their priority in terms of cultivation practices. However, total land size and proportion of maize yield sold on the market were the only factors that could be considered indicators of economic standpoint, of which the latter was not significantly different between organic and conventional fields.

Introduced practices in connection with conversion

The application of manure (ranging from 0.1 to 5.2 t ha^{-1}, average of 2.0 t ha^{-1}) was low compared to manure applications found amongst smallholder farmers in other parts of East Africa. In Machakos District, Kenya, farmers applied 38-168 t ha^{-1} (Probert et al., 1995), while application amounted to 40 t ha^{-1} in Zimbabwe (Nyamangara et al., 2003). On the other hand, Waithaka et al. (2007) found lower manure inputs of 0.2 t ha^{-1} in Vihaga district, Kenya. Hilhorst and Muchena (2000) reported manure inputs of 0.5 t ha^{-1} in Embu, Kenya, to be causing soil quality to decline due to a negative nutrient budget. Zake et al. (2010) found application rates of up to 2.5 t ha^{-1} in Wakiso district, Uganda. According to Sanchez et al. (1997) a maize yield of 4 t ha^{-1} can be maintained with a nutrient input of 100 kg N, corresponding to an input of fresh manure of 3.4 t ha^{-1} (using the nutrient contents presented in Table 3.6) on fields in Makuutu without taking the declining quality of manure with composting time into consideration.

A negative correlation was found between compost application and field size as well as between manure application and field size on organic fields (section 4.2). Collection and handling of manure and compost are laborious processes (Badgley et al., 2007; Parrott et al., 2006; Place et al., 2003; Pretty et al., 2003; Zake et al., 2010). The availability of labour force on field-level may have had an effect on the amount of manure and compost collected and applied (Nkonya et al., 2004). Furthermore, the number of cattle providing manure may be limited (Tittonell et al., 2005). Regrettably, farmers were not inquired about the size of their herd. Considering the potentially poor quality of manure (discussed in section 5.3), the negative correlation between field size and manure was unfortunate, because it results in manure of rather poor quality being dispersed over large areas. Consequently, the effect on soil properties and yields may be vanishingly small. Optimally, the manure application rate would reflect the quality of manure. A better strategy might be to focus on optimizing handling of manure to improve its quality.

There was no correlation between manure application on sampling fields with total land size. This does not exclude that the relation between manure application and total land size exist – it may simply need an 'extra dimension' to be significant. Such dimensions could be distance from field to homestead (Giller et al., 2006), while household wealth also has been shown to impact resource allocation on field level (Tittonell et al., 2005).

Resources tend to be allocated to fields closer to the homestead (Giller et al., 2006; Vanlauwe et al., 2007) where nutrients are stored or nutrient sources are located (Place et al., 2003). Such tendencies may impact the application of manure and compost on fields in the study area. Thus, OR_KT, whose field was situated within 20 meters of the family home, applied 5.2 t ha^{-1} being the only farmer to apply more than 3.4 t ha^{-1} while the remaining seven organic farmers applied 2.7 t ha^{-1} or below. This negative relation between manure application and distance from homestead may have affected the disclosed applications with organic farmers in Makuutu. However, the distances between fields and farmers' homes were not registered in this study.

5.5 Farmers' challenges in cultivation of maize

Maize yields have been shown not to be determined by the investigated cultivation systems, and analysed soil properties did not indicate that OCS had better soil quality compared to CCS. Furthermore, no significant correlations were shown between soil quality related soil properties and yield levels. The regression analysis showed that the only variable that was significant in explaining yield levels was field size. Apparently, yield levels were determined by factors that were not quantified during the investigation. Such factors may be management-induced, yet not connected to the cultivation systems. Maize has been found to be more susceptible to biotic and abiotic stresses (Rich and Ejeta, 2008) and may be severely affected by threats such as Striga weed, Fall Armyworm and drought causing yield loss of up to 70-100% (VIB, 2017).

In general, farmers knowledge about Striga's spreading channels seemed somewhat limited. Weeding was the primary strategy to combat the weed, but maize crops may be affected already before the weed is visible. Furthermore, maize seeds can be contaminated and should be discarded (VIB, 2017).

However, farmers depend on their own production of maize seeds, therefore, making such an approach difficult.

Although organic farmers spoke of homemade pesticides to control Fall Armyworm, few actually applied it. OR_KA had the highest yield of all fields (both organic and conventional) of 6.3 t ha^{-1}, and was the only farmer reporting that Fall Armyworm had not infested his field. He had not done anything specific to avoid infestation, but the pest did not seem to have reached this part of the subcounty. Farmers' emphasized that the occurrence of Armyworm was coincident with droughts congruent with findings by Hruska and Gould (1997), who found greater yield loss caused by Armyworm when coinciding with drought stress.

Diversification of maize fields in the study area through intercropping and crop rotation would possibly reduce the problem of Striga and Fall Armyworm (Altieri et al., 1978; Berner et al., 1997). Successful pest and weed management go hand in hand with biodiversity, since a high diversity creates a broader prey-predator base (Altieri, 1999; Root, 1973). Furthermore, biodiversity is at the centre of organic principles as a natural instrument in improving resistance towards weeds and pests (IFOAM Organics International, 2005; Scialabba et al., 2002). Implementation of practices to improve diversity in field systems may contribute to recovering yield levels in the study area. However, the presence of Striga and Armyworm may result in farmers giving lower priority to severely attacked fields (Nkonya et al., 2004), thus, creating a vicious circle of poor management degrading soil quality, which in turn increases the problem of weeds and pests. In this respect, the current maize monocropping of both OCS and CCS probably deteriorate the situation, while also decreasing systems' resistance towards drought.

There are several possible solutions to farmers' challenges in the study area. Some of these solutions – intercropping, crop rotation, application of organic matter – are integrated parts of a 'organic thinking' as presented in ECOSAF (Vaarst et al., 2016) and were to some extent employed in the study area (Table 3.2). The challenges may be partly responsible for the yield levels of sampling fields, while possibly blurring the beneficial effect of organic cultivation practices. It is a condition of the success of organic cultivation that the system is recognized holistically; limiting factors such as infestations of Striga and Fall Armyworm and drought may be remedied before the end product (yield levels and soil quality) benefits (Watson et al., 2002).

5.6 The basis of comparison of organic and conventional cultivation systems

Based on the description of applied practices on sampled organic maize fields, it should be considered whether the systems can be considered organic in respect to IFOAM's four principles of organic farming (section 2.3). The land-use history of organic fields in this study indicated that diversity was not made an integrated part of the cultivation practices, since monocropping was the most widely deployed maize cultivation practice. Supporting biodiversity through cropping practices such as intercropping and crop rotation, preferably including N-fixing crops, are central to the ideology of organic farming (IFOAM Organics International, 2005; Scialabba et al., 2002; Watson et al., 2002), while increasing diversity also increase SOC and total N concentrations of soil (Sanchez et al., 2004). Additionally, maintaining or improving biodiversity is a prerequisite for the productivity of organic cultivation systems, for example due to the systems resistance towards infestations as described above

(Altieri, 1999; Altieri et al., 1978; Scialabba et al., 2002). The present investigation revealed that organic farmers did not include such practices in the cultivation of their fields to a higher degree than conventional farmers during the past 10 years as shown by sampled fields' land-use histories.

Calculated nutrient balances also indicated that the investigated field systems were unsustainable (when only considering inputs and outputs described by farmers), despite nutrient cycling and nutrient base maintenance being important contributors to good soil quality.

Such discrepancies between the cultivation system that farmers considered themselves belonging to and the practices they employed have been observed by several studies (IFOAM Organics International, 2013; Oelofse, 2010; Oelofse et al., 2011; Parrott et al., 2006), although the problem there seems to be more prevailing within certified organic agriculture, where focus is on economic returns. Certified organic production mainly concerned horticulture products for export in Makuutu subcounty, while trade with maize was locally based. Thus, commercialism is not the determining component for the practices that farmers chose to deploy on selected maize fields. On the contrary, one might speculate that the cultivation of maize in the area was determined more by old habits, since the practices that organic farmers have learned through the ECOSAF project (section 1) were deployed to such a limited extent.

In summary, one might say that the selected 'organic' fields were labelled so based on an expectation of practices employed within a holistic, sustainable system as the one living up to IFOAM's five key principles (section 2.3). However, in reality the cultivation system should be defined by the practices actually employed – and the consequence of this is that the differences in yields and soil properties of fields in Makuutu subcounty were found to be insignificant, while the organic cultivation system did not live up to IFOAM's principles about organic agriculture.

5.7 Interview and selection biases and criticism of the fieldwork process

Fieldwork is an instructive process through which one quickly learns that things rarely go as planned and where one must adapt according to circumstances. One of the most difficult parts of such a process may be to constantly relate to one's project as being scientific, which sets certain requirements as to how obstacles can be overcome. Awareness of potential weaknesses or biases connected to methodological priority is important throughout a process to maintain an acceptable scientific standard. Such weaknesses and biases identified during fieldwork are discussed in the following.

Firstly, the selection of interviewees was strongly influenced by the interpreter's personal acquaintances (section 3.2.2). The interpreter was aware of the purpose of the study, while being personally involved in promotion of organic cultivation practices himself. He had spent the past 10 years teaching local farmers about organic practices and how this could benefit their soils and increase their yields. While the selection of organic farmers seemed rather targeted towards people with relation to the interpreter, the selection of conventional farmers was more randomized, partly because they constituted the vast majority of farmers in Makuutu subcounty. Such selection biases may have affected the representativity of described organic and conventional cultivation practices based on conducted interviews.

Secondly, the interpreter in his position as the 'teacher' and facilitator of group discussions among farmers possibly affected the answers given by interviewees, especially amongst the organic farmers, due to his position and knowledge. Furthermore, the actual *interpretation* of information from interviewer to interviewee and vice versa was inevitably influenced to some degree by the interpreter as a subjective human-being (Berman and Tyyskä, 2011). It should be stressed that the interpreter's knowledge of local people and conditions was also a valuable asset during interviews, for example, because he contributed to the creation of an immediate degree of confidence between interviewer and interviewees.

Thirdly, among organic farmers there seemed to be a narrative about the potential of organic agriculture that affected the given answers. This narrative could originate from the way that organic cultivation practices are presented to farmers previous to their decision on converting. It is worth noticing that 74% of organic interviewees responded that increased yields were one of the main advantages with organic practices compared to conventional practices, when this advantage was not apparent in collected data – as if this answer was connected to the narrative more than reality. However, the frequency of answers like this may also have been incited by an underlying positivity towards organic agriculture on the interviewer's part – a type of bias that may be comparable to *acquiescence bias* describing a culture-induced tendency of interviewees to agree with the interviewer (Bowling, 2005).

In the process of conducting the 42 interviews the approach was altered along the way. Initially, farmers were asked to list all their fields with associated crops. First of all, this gave an overview of major crops in the area, while also indicating the degree to which farmers employed intercropping. However, it was also a very time-consuming process which seemed somewhat unnecessary considering the study aim. The approach was changed so farmers then listed maize fields only with potential crop rotation or intercropping within the two growing seasons of 2017, and this made the basis of the decision that sampling fields would be chosen amongst sole maize cropped fields (section 3.2.1). Choosing these fields for sampling was based on the observation that maize monocropping was more common than intercropping and crop rotation. Had time and resources allowed it, a more comprehensive study could have selected fields representing the practices within organic and conventional cultivation, but such an approach would demand a far bigger dataset, i.e. a considerably higher number of fields.

5.8 Summary

The differences between cultivation practices employed on conventional and organic fields were very limited. Organic farmers applied manure to their fields, and some also compost and mulch. The hypothesised positive effects of organic cultivation practices on soil nutrient deficits and poor water holding capacities were absent in the study area, thus all hypotheses were rejected showing that there was no significant difference in measured soil properties. There was an incongruity between these findings and the nutrient budgets that indicated that the net export of nutrients from CCS was considerably larger than that from OCS, which would be expected to show in soil properties. Suggested reasons for this incongruity included:

1. Applied amounts of manure were too low to alter investigated soil properties at the end of the growing season
2. The quality of manure was poor due to inappropriate handling methods

Organic farmers highlighted increased yields as one of the main advantages of converting to organic cultivation practices, while all stating that their yields increased immediately after conversion. Such yield increases were not evident in reported yield levels for the first growing season of 2017. Increased mineralization rates following application of manure (so-called *priming effect*) may contribute to higher yields initially, but the long-term effect may not be higher yields from organic fields. The difference in yields must be caused by 1) management, which is not determined by the designated cultivation system (organic or conventional), but rather to the energy put into weeding, and the degree to which farmers are troubled by Striga weed and Fall Armyworm, and/or 2) water was limiting factor maize production – drought has been an increasing problem in recent years.

It is debatable whether the organic cultivation system as described practiced on sampling fields can be considered organic, since manure, compost and mulch (apparently without effect on soil properties and yields) were the only practices separating the two cultivation systems. No other practices were deployed to increase or maintain soil quality, and most fields had been under long-term monocropping, thus, did not live up to organic ideals/principles.

6 Conclusion

The purpose of this study was to investigate differences in selected soil properties between organic and conventional cultivation systems. In literature, organic cultivation practices have been shown to increase several soil quality parameters (for example through increasing SOM, which improves soil structure, supply of nutrients and PAW). 16 maize fields were selected (eight organic, eight conventional) based on interviews regarding management practices. Cultivation practices proved to be similar in the two systems. However, limited addition of manure, compost and/or mulch characterized the organic fields, whereas conventional fields had no input of nutrients to replenish nutrients removed at harvest. Both conventional and organic maize fields had been cultivated with maize continuously for the past 10 years without crop rotation or intercropping. 40 of 42 interviewed farmers reported decreasing yields within the past five years, which may be a result of increasing problems with drought coinciding with infestations with Striga weed and Fall Armyworm severely impeding maize production in the area.

Organic farmers highlighted increased yields as the primary advantage of conversion to organic cultivation. However, reported yield levels of selected organic and conventional fields were not significantly different. Therefore, it was suggested that the yield increase stated by organic farmers was caused by a *priming effect* triggered by the addition of manure and compost. This effect causes yields to increase immediately after conversion, but not in the long term.

No significant differences were found between organically and conventionally cultivated soils in any of the investigated soil properties. Consequently, all hypotheses based on the assumption that employed organic cultivation practices would increase soil quality were rejected. A significant negative correlation between the addition of manure or compost per unit area and field size was found on organic fields, while no correlation was found between such nutrient inputs and yields.

Simple nutrient budgets, based on literature's estimates of nutrient contents of manure, indicated that employed practices within organic and conventional cultivation systems both resulted in net export of nitrogen and phosphorus. The export was smaller from organic fields, but this was not evident in measured soil properties. While applied amounts of manure were limited, the quality of manure in terms of nutrient content was suggested to be inferior due to poor handling practices. This suggestion was based on spontaneous observations during fieldwork, as farmers, regrettably, were not inquired about their handling of manure. Thus, there was no indication that organic farmers had improved soil quality through their practices, which can be ascribed limited nutrient input and the degrading effect of monoculture systems.

Long-term monocropping does not correspond with key principles within organic agriculture, where, *inter alia*, maintenance of a favourable soil nutrient status and biodiversity are central. Therefore, it is debatable whether the investigated 'organic' cultivation systems can actually be characterized as organic.

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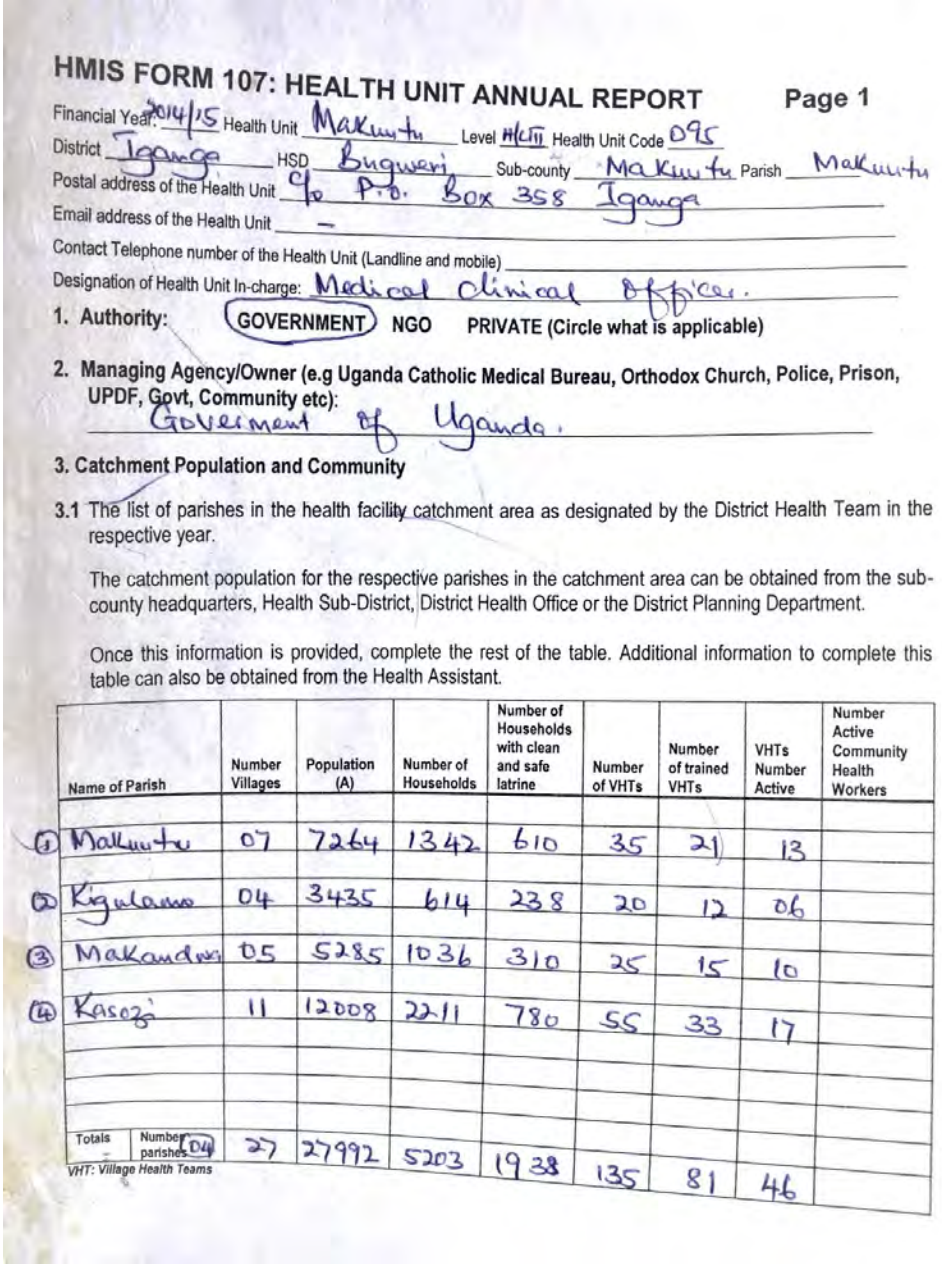
8 Appendix

Appendix 1: Local population data

Population data of Makandwa and Makuutu parishes in Makuutu subcounty from 2014/15 and 2016/17. Statements made by the government. Documents photographed when visiting the Makuutu subcounty office in December 2017.



HMIS FORM 107: HEALTH UNIT ANNUAL REPORT **Page 1**

Financial Year: 2014/15 Health Unit Makuutu Level H/CIII Health Unit Code 095
District Iganga HSD Bugweri Sub-county Makuutu Parish Makuutu
Postal address of the Health Unit C/o P.O. Box 358 Iganga
Email address of the Health Unit –
Contact Telephone number of the Health Unit (Landline and mobile)
Designation of Health Unit In-charge: Medical clinical Officer.

1. **Authority:** [✓ **GOVERNMENT**] **NGO** **PRIVATE (Circle what is applicable)**

2. **Managing Agency/Owner (e.g Uganda Catholic Medical Bureau, Orthodox Church, Police, Prison, UPDF, Govt, Community etc):**
Goverment of Uganda.

3. Catchment Population and Community

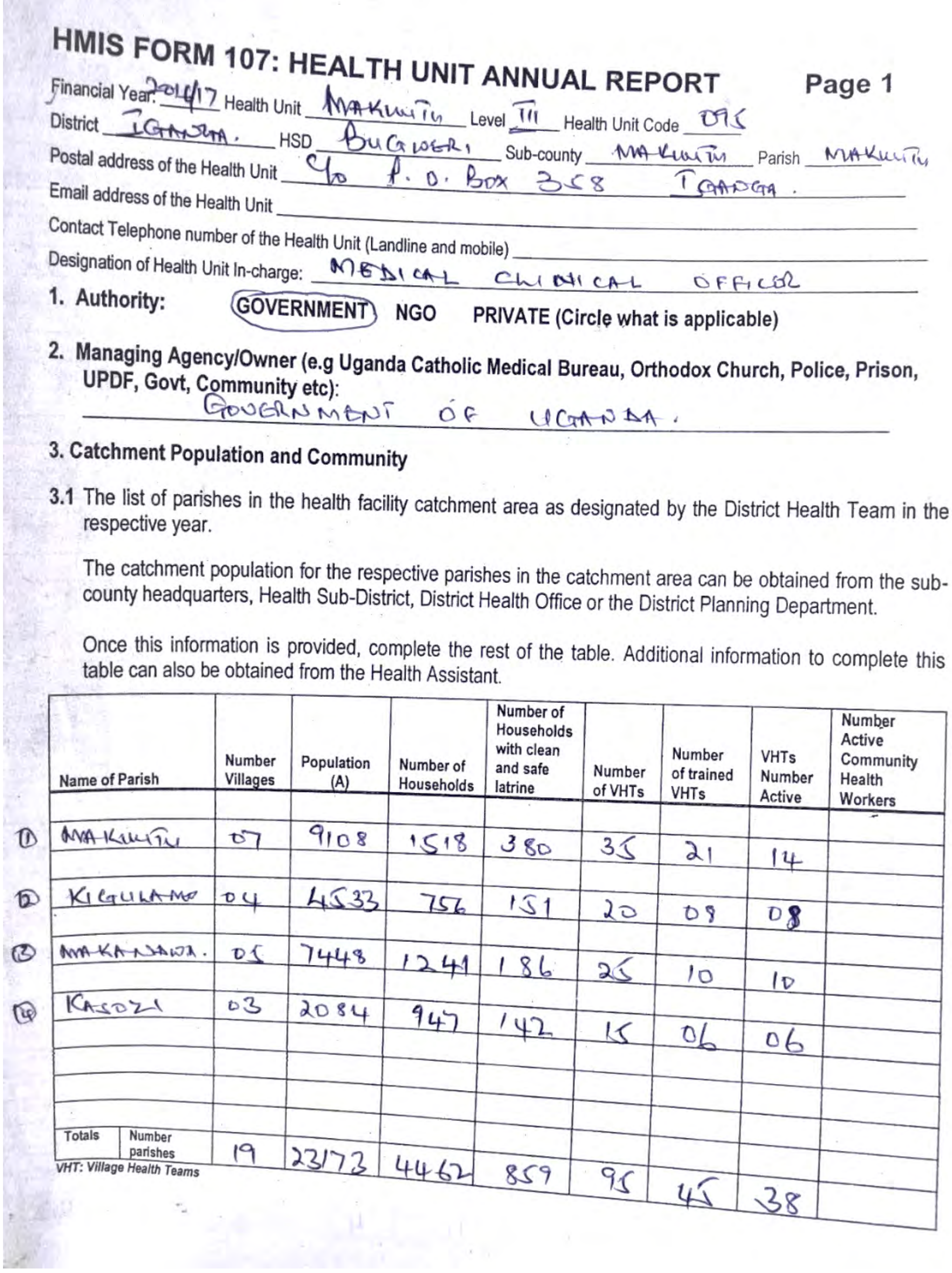
3.1 The list of parishes in the health facility catchment area as designated by the District Health Team in the respective year.

The catchment population for the respective parishes in the catchment area can be obtained from the sub-county headquarters, Health Sub-District, District Health Office or the District Planning Department.

Once this information is provided, complete the rest of the table. Additional information to complete this table can also be obtained from the Health Assistant.

Name of Parish	Number Villages	Population (A)	Number of Households	Number of Households with clean and safe latrine	Number of VHTs	Number of trained VHTs	VHTs Number Active	Number Active Community Health Workers
① Makuutu	07	7264	1342	610	35	21	13	
② Kigulamo	04	3435	614	238	20	12	06	
③ Makandwa	05	5285	1036	310	25	15	10	
④ Kasozi	11	12008	2211	780	55	33	17	
Totals – Number parishes 04	27	27992	5203	1938	135	81	46	

VHT: Village Health Teams



HMIS FORM 107: HEALTH UNIT ANNUAL REPORT

Page 1

Financial Year: 2016/17 Health Unit MAKUUTU Level III Health Unit Code 095

District IGANGA. HSD BUGWERI Sub-county MAKUUTU Parish MAKUUTU

Postal address of the Health Unit C/o P. O. BOX 358 IGANGA.

Email address of the Health Unit

Contact Telephone number of the Health Unit (Landline and mobile)

Designation of Health Unit In-charge: MEDICAL CLINICAL OFFICER

1. Authority: [✓ GOVERNMENT] NGO PRIVATE (Circle what is applicable)

2. Managing Agency/Owner (e.g Uganda Catholic Medical Bureau, Orthodox Church, Police, Prison, UPDF, Govt, Community etc):

GOVERNMENT OF UGANDA.

3. Catchment Population and Community

3.1 The list of parishes in the health facility catchment area as designated by the District Health Team in the respective year.

The catchment population for the respective parishes in the catchment area can be obtained from the sub-county headquarters, Health Sub-District, District Health Office or the District Planning Department.

Once this information is provided, complete the rest of the table. Additional information to complete this table can also be obtained from the Health Assistant.

Name of Parish	Number Villages	Population (A)	Number of Households	Number of Households with clean and safe latrine	Number of VHTs	Number of trained VHTs	VHTs Number Active	Number Active Community Health Workers
① MAKUUTU	07	9108	1518	380	35	21	14	
② KIGULAMO	04	4533	756	151	20	08	08	
③ MAKANAWA.	05	7448	1241	186	25	10	10	
④ KASOZI	03	2084	947	142	15	06	06	
Totals Number parishes	19	23173	4462	859	95	45	38	

VHT: Village Health Teams

Appendix 2: Interview guides

All-round introduction that will be presented to interviewees and other stakeholders:

I am investigating how soil properties change after conversion to organic agriculture. This is done by taking soil samples from organically cultivated fields and from traditionally cultivated fields. The fields that I sample from must fulfil certain criteria within which my investigation is focused, for example the fields must be cultivated with maize at the time of sampling, and they must have comparable soil characteristics as well as climate. In the end, I hope to figure out what makes a good agricultural soil for a farmer in Makuutu subcounty. If the advantageous parameters that make good quality soils can be found, the future the efforts towards increase and secure agricultural production can potentially be more targeted.

Semi-structured interview – selecting eligible fields

These semi-structured interviews aim to collect enough information about the individual farmers and their land to select the fields where sample plots can be established. These interviews will be conducted until 12-16 farmers (6-8 organic, 6-8 traditional / conventional) with comparable fields are found, while at the same time making sure that these farmers do not stand out from the crowd by coincidence. Thus, the interview should elucidate all potential factors that could affect the investigation. After having settled whether this farmer has converted to organic cultivation practice and when, the farmer will be asked to make a list of his/her fields (size, crop(s), slope, soil characteristics), which will work as the basis for the interview.

Main selection criteria:

- Maize – crop cultivated in both current and previous season (if possible)
- Comparable soil type (texture, moisture level etc.)
- Low or comparable slope of field
- Half of sample fields are cultivated organically – the other half traditionally

Introduction for the interviewee
With this interview I intend to find out whether your land is eligible to be part of my investigation. I have a number of criteria that must be fulfilled, because the sampled fields must be comparable in order to make tenable conclusions based on the soil analyses.

Information about interviewee
Name: ______________________________

Age: ______________________________

Location (village): ______________________________

Household size (adults / children): ______________________________

Land size: ____

Organic agriculture (Y/N) – how long? ____

Overview of fields
We will make a list of your fields concentrating on the crops you grow and characteristics connected to the soil. This will work as the point of departure for our conversation.

Field	**Current crop(s)**	**App. size**	**App. slope**	**Soil characteristics[1] (including distinct differences within the field)**	**Yield levels of previous season**	**Organic (how long?) or traditional / conventional**	**Previous season: crop(s)**
#1							
#2							
#3							
#4							
#5							

In the following I will ask you about the considerations you have had in connection with cultivation, while targeting the criteria mentioned earlier through my questions. I will also ask your opinion on the major factors impacting cultivation and yield levels.

1. One field or crop at a time: Why did you choose to grow this crop on this field? (location, slope, timing, demand, soil characteristics, economic consideration…)
2. Do you grow perennial crops (covering more than one season) on top of the seasonal crops?
3. In your opinion, what are the main factors that affect yield levels?
    a. Have you experienced single events that had devastating impact on the yields at the time? If yes, specify.
4. On field level, how were your yields last season?
    a. During the past 5 years or more, have they increased, decreased or remained somewhat stabile?

If organic
1. Did your yield levels change notably following the conversion to organic practice?

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[1] Characteristics: Texture, water content, gravelly, compaction…

2. Mention 5 key things that you are doing differently now compared to before conversion to organic cultivation practice?
3. As you see it, are there advantages with organic compared to traditional/conventional agriculture?

Land-use history

We will chart the land-use history as a timeline, starting today and going back as long as possible or to a maximum of 10 years.

1. How long have you cultivated this land? (basis of timeline, preferably to cover the past 10 years)
2. Find a common temporal scale that both interviewee and interviewer can relate to. Divided by seasons? Important events that are clear in interviewee's memory and that have had influence on his/her cultivation practice / yields.
3. Go back in time, step by step. Focus on:
    - Crops (species, cash crops, food crops…) – more than one crop on the field at a time (*intercropping*)?
    - Inputs and outputs – factors that affected these
    - Ploughing method – how deep?
    - Irrigation
    - Was the field rented out during the period?
    - Fallowing – why?
    - Failed harvests? What caused these? (crop diseases, drought, flood…)
    - Shifts in availability of agricultural equipment / remedies? (ploughing, irrigation…)

Flow diagrams

Introduction for the interviewee

The following exercise aims to describe the cultivation cycle for the field, focusing on inputs to and outputs from the field for the growing season before the current one (specify). Inputs could be fertilizers, manure, pesticides, irrigation and old crop residues, and outputs are the yields and any removal of crops or weeds. Additionally, I am interested in the soil preparation methods such as ploughing and irrigation, including the timing of these.

We will illustrate the flows using a box depicting the field with arrows going in – inputs – and out – outputs (show the drawing of a flow diagram skeleton).

1. Field preparation: ploughing method, mulching (including types), irrigation, sowing
    a. Seeds – local / hybrid?
2. Inputs: amounts, types and source (internal/external):
    a. Fertilizers

    b. Manure (animal/human waste?)
    c. Compost
    d. Pesticides
    e. Irrigation (+ frequency)
    f. Old crop residues (ploughed down)
    g. Precipitation (cloudburst may have destructive effects on crops)
    h. Additional inputs?
3. Yield: amount (idea: destinations shown using pie chart to illustrate distribution)
    a. Proportion sold – income?
    b. Proportion for household consumption
4. During the growing season: Were you affected by
    a. Crop diseases
    b. Drought / floods
    c. Erosion or deposition (estimate amounts and source if relevant)

Appendix 3: Transcribed interview with Yusuf Wesonga, Africa 2000 Network

I gained contact with Yusuf through Per Rasmussen from Organic Denmark who has worked with Yusuf at several occasions.

Date: 10th November 2017

LC = Lærke Callisen, YW = Yusuf Wesonga

LC	The purpose of this interview is to gain some insight into the farmers' lives, and how they think about soil. And I would also like to ask a bit about the ECOSAF2 project. So first let me ask your age?
YW	I am 30.
LC	Okay. And your position in Africa 2000 Network?
YW	Field Extension Worker.
LC	Maybe let's start with you telling me a bit about Africa 2000 Network and what you do there.
YW	Africa 2000 Network (A2N) is a nongovernmental organisation (NGO) working in Uganda in 4 regions: eastern Uganda, northern Uganda, western and southwestern Uganda.
LC	What do you work with?
YW	We are working with different projects, but me, basically, I am attached to the ECOSAF project working with organic farmers in Eastern Uganda based in Iganga district. So I am working in 6 districts where we are implementing the ECOSAF project, and this project has 1,500 farmers who are organic farmers in the ECOSAF2 project. Amongst those farmers some 123 farmers are organically certified, and we want more farmers to be certified organically, because we are working with farmers who are growing a wide variety of horticulture. We want to provide a market for fruits. That is why some of our farmers

	are certified, so that we can tap the international market for farmers' product. By doing that we find that they will get at least fair income from when they sell their produce.
LC	Okay, so that is why you want the certification?
YW	Yes.
LC	But for internal markets, it is not so important?
YW	The internal market is there but it is not enough.
LC	How long have you been involved in organic agriculture?
YW	I have been working with A2N – this is my fifth year working with organic farmers. I started as a volunteer for two years, then I was confirmed as a field extension worker 3 years ago. Now it is approximately 5 years.
LC	In your opinion, a conversion to organic agriculture – what can that give the farmers that they don't have already? When they convert to organic agriculture, what to they get that they don't already have?
YW	Previously, farmers were in conventional agriculture, but when we came in to promote sustainable agriculture or organic farming (OF) they can draw the difference, because conventional agriculture today is more expensive in terms of acquiring artificial fertilizers. But when we came with the concept of OF they use the locally available materials to improve the soil fertility (SF) and then to increase the yield. Because when the SF is improved you expect better yields from the farm. So, there is a very big difference in terms of yield and soil fertility management (SFM) amongst the participating farmers. Because you clearly see the difference between an organic farmer and conventional or traditional farmer in terms of yields. Organic farmers are better than conventional farmers. They get higher yields.
LC	What about the market here – they do not really care whether they buy a conventional product or an organic product, do they?
YW	The market here is still small internally, because we do not have very many organic farmers, and you find that they are selling at the same price as conventional farmers, so the market is not so good. You find that the conventional farmer is selling his product at the same price as the organic farmer. But despite of that we have gone ahead to tap the market for organic farmers so that the organic products can be bought at a fair price compared to conventional farmers. And by doing that some organisations have come in to provide a market for organic products. An organisation like NOGAMU buys organic products from farmers at better prices. Then there is another one called FURANA is also buying organic products from farmers. At least to show the difference that for a farmer who is organic, her products are at least bought at a higher price, so that this price can attract the non-organic farmers also to join OF. So, we are trying to connect them to buyers who are interested in buying organic products. But locally, it is hard, but it is coming slowly.
LC	Okay, so you get a better price for the product, even though it is also cheaper to do the cultivation?
YW	Yes.
LC	Very good. So, in your opinion, which one do you think is more important: is it the convertion itself to a different cultivation practice aiming to increase the SF, or is it the training for these farmers that makes the big difference in the yields?
YW	It is organic agriculture (OA) the concept which is good coupled with training. You have to train farmers to understand the concept, and then after training they go and practice. After replicating they will go and realise their output. To me it is OA which is good. If you manage SF it will give you better results in terms of yields.

LC	Before the training these farmers do not know how to manage SF?
YW	Before the training they are doing it without knowing that it is OA. We have to take them through for more training so that they can understand it in the best way. We train them how to manage soil erosion, how to increase SF, how to mulch, how to use organic manure and how to make it also. But previously they were just making trenches and maybe kept shifting from one place to another to go and farm. Because the soil has lost fertility they will leave one place to go and open another area.
LC	This is what is called *shifting cultivation*?
YW	Yes, *shifting cultivation*. We advised them: Instead of leaving this place where the soil has lost fertility, we train them in SFM using organic manure, mulch, using nitrogen-fixing plants, plants velvet bean or jack bean, practice crop rotation, intercropping – and all these practices are being taught to farmers.
LC	So, the training is very important?
YW	Yes. The training is very important.
LC	Okay. What is the role of a facilitator in the Farmer Family Learning Groups (FFLGs)?
YW	The external facilitator is mobilising the farmers. In addition, they also facilitate the training in FFLGs based on the topics they have selected. With us in FFLGs we do not use the concept of training but of facilitating. We encourage every participant to participate and to contribute. We do not want it to be so that we all know everything, but we ask the facilitator to facilitate the process, so that each farmer participates in a certain discussion, where he can come up with challenges and solutions. The facilitator just guides and maybe adds on to what they have already said.
LC	A facilitator needs to be trained to be a facilitator.
YW	Yes. In the concept of FFLG we have two concepts: we have the external facilitator and internal facilitator. External comes from outside the group, the internal comes from within the group.
LC	So Roman could be an internal facilitator?
YW	Roman is an external facilitator, and there is also internal. I forgot to tell you that in ECOSAF2 my title is FFLG officer. This person trains the external facilitator, then the external goes and trains the internal at times. Then the external and internal facilitators go and train the group members.
LC	So as an FFLG officer you train the external facilitator, who then trains the internal facilitator, and then the external and internal together train the groups or facilitates the discussion.
YW	Yes, facilitate discussions.
LC	Okay, that seems like a good structure. How long does the training take of an external facilitator? Is it just one day? Three days?
YW	It depends where we want to train, but basically two days are enough. We mobilise all the externals, they come to one central place and we train them once. This way they can go back and train. At times it could be for one week, but it all depends on the resource envelope. Especially when the project is new. But when the project is not new, it is between 2-3 days. There are times where we come back for reflection meetings at every three months. External and internal come in, we join them for reflection meetings every three months, to share experiences they have transpired in the field, what are the challenges, achievements, lessons learned and other experiences and identify the gaps and come up with solutions through mutual learning.

LC	When putting together an FFLG, how do you find these farmers that are to take part in a group?
YW	The farmers have seen the benefit of working together, because they have seen the increase in yield. At least somebody can testify that in this season my yield has increased from maybe one bag to two bags in a quarter of an acre, like that, especially for maize. Then there is solidarity also, people work together because we encourage them to work as a team. Then you find that there is teamwork, and people share labour. We encourage them to go and work in such a norm so that maybe when we find that the challenge is that he lacks a peat latrine, let me say a toilet, in a home where the household lacks a bathroom we mobilise the group members and encourage them to work as a team, so they can go and go and establish that peat latrine or bathroom in that home. So, you find that people are working together, and this saves time. Another thing is that promoted hard work, because people are always challenges to work so that they have something to eat in the home. There is a difference between the people who are under FFLG and those who are not in the FFLG program – their home is totally different. You can see some changes in the household. Then another change is that you can see improvement in generations, because we encourage the gender aspect of it in the groups, where we encourage the man and the woman to work together in the family. So, you find that there has been reduced domestic violence in the homes, because the man is aware where the woman is going, and the woman is aware where the man is going. Some homes do not allow their women to get involved in development programs and that results in family breakdowns, but in our case, we have not observed it. So, there is improvement in the relationship. Also, in terms of feeding; because we encourage the farmers to grow a variety of crops, and you find that there is diversification of crops amongst our farmers – they do not depend on one crop. They have at least balanced diet, and when you go in the homes, you will find a home with a number of small vegetable gardens in the homes, so that they feed on greens instead of going to buy in the market. Those gardens have been established in the homes.
LC	Okay, that is really good. Are there certain criteria that people should fulfil in order to be part of an FFLG, or can they just do it if they want? Should they be poor, or should they be involved in some way?
YW	There are no criteria which are needed to be involved in an FFLG. It is just your interest and willingness to participate in the trainings.
LC	Okay, good. So, before they become part of an FFLG; what are the major problems that these farmers have?
YW	In terms of farming, the problem … before they had no information about OA, detailed information, the whole concept – they were not aware of it. And they were doing their poor farming practices. They had no knowledge about OA. That was the biggest challenge. They were declining in terms of SF, which led to poor yields, so those are the biggest challenges. From there, after identifying those problems, we went back home to train them and teach them about OA – what you can do to improve SF, improve productivity and production and all that is invested in organic agriculture.
LC	What things do you tell them? How do they improve SF for example?
YW	SFM. We ask them, what are the factors that lead to soil infertility. Then they will tell us poor methods of farming, including not planting in lines, not intercropping, not carrying

	out crop rotation, doing bush burning and monocropping, and soil erosion. Then we work on how to improve soil fertility, what are the good farming methods.
LC	It seems like they already know what their problems are, they just do not know how to handle these problems. That is interesting.
YW	Yes. For improving soil fertility, we tell them: If you have land which is on a slope, make sure to put trenches to trap runoff of water, mulch, use organic manure and we train them and we make it, use liquid manure, we train them, because all those improves soil. Practice good farming practices like crop rotation, intercropping, do not plant only one crop over seasons, planting of N-fixing plants (live mulching).
LC	So, before this project they did not do any mulching, and they did not add any organic manure?
YW	They did not.
LC	So, that is why the soil fertility is declining, because they just remove nutrients and they do not add any. This is one of the good things about organic agriculture – you think of the circulation of nutrients; when you take some out, you need to put some in.
YW	Yes, they are not adding back into the soil, and the soil also wants it.
LC	This is probably an important part of what they learn – that there is kind of a balance that you need to keep.
YW	People have started to shift from their areas to go and cut down forest, because that is where they saw that the fertile soils were. Here, the crops are not doing well, but when people leave the village and go to the forest and cut down the trees, anyone could get 40 bags, but where the soils have lost fertility you could not even get four. We teach them that they just need to improve their methods of farming, use organic farming, plant seeds – and you will get better yields.
LC	They see the forest soil is much better, but they do not understand why?
YW	Yes, and it was good enough that the government also stopped them. That is why we initialised this project with OA. But as much as we are promoting, but there are still conflicting interests – conflicting information by some of the stakeholders who promote conventional agriculture.
LC	Who are they?
YW	The government also comes with conventional agriculture. They have employed scientists to disprove. We have maintained our track. Despite of that we cannot be diverted, because we have fields with which we can testify that organic agriculture is better than conventional agriculture. As you go to Makuutu, Roman will take you to the fields of organic agriculture, and you will see – you will compare.
LC	You are saying that you can see the difference. (YW confirms) Do you know how you can see on a plant that it needs nitrogen or phosphorous? Did you know that you can actually see that?
YW	Yes, you can detect nitrogen deficiency from the sign of yellowing leaves while they are still young, with phosphorous you see purple leaves. You can detect in the field when you are there.
LC	I am going to see if I can find it.
YW	The signs are there.
LC	Participation in an FFLG does not include any economical support?
YW	It does not. It is voluntarily.
LC	Okay, so it has to be your own motivation.

YW	Yes, it is up to you to see the economic part of it.
LC	I wanted you to mention 5 important things that the farmers have changed in the way that they do farming. I think you have mentioned them already; you have said it is mulching?
YW	Mulching, SFM, trenching, use of organic manures, planting of nitrogen-fixing plants alongside the boundaries, diversification of crops instead of depending on two crops.
LC	You said a little about it already, but maybe you can help me to understand what kind of system it is that the traditional farmers use. You said that it is shifting cultivation.
YW	In traditional agriculture they would just move from one area to another thinking that this soil has lost fertility, and they need to get a virgin area where they can plant the crops so that they get better yields.
LC	Are they still doing that up to today?
YW	Now, it is not there because of the population pressure. The land has become scarce.
LC	What do they do now?
YW	Others are still practicing their methods of farming, like growing one type of monocropping, they have stuck with that one.
LC	Why is monocropping not good?
YW	Monocropping is not good because it also causes soil to lose fertility. Because one grows one type of crop season after season and in the end the soil will lose fertility, and it will not give you better yields. I think, basically, that is what traditional farmers are doing. What else? That is what they are practicing. Also, traditional farmers intercrop very many crops in one piece of land. It can be three crops in one place, which is not a very good method. They can intercrop maize, beans, sweet potato. It is not good because if you intercrop those crops that are not recommended they will compete for nutrients. They need to intercrop some crops that supplement each other.
LC	Beans and maize?
YW	Beans and maize, maize and groundnuts. Groundnuts supplements nitrogen. Maize wants nitrogen. You will find that some traditional farmers still practice their traditional methods of farming which are not good.
LC	So, some use intercropping, but intercropping in the wrong way? (YW confirms) You said maize, groundnuts and cassava. Are there other typical crops in this area?
YW	Those are the typical crops. Maize first which is the main crop, second one in this region would be sweet potato, the third one is beans, and the fourth is cassava, groundnuts comes next. Millet is not here on a large scale.
LC	Next, I would like to ask you about the terminology that farmers use. You already told me that converting to organic agriculture has a big effect on yields.
YW	Yes, yields and in terms of soil fertility.
LC	Is it the yields for all these crops? Both maize, sw.pot., beans, cassava – they all get better yields?
YW	Yes.
LC	When you talk to farmers about what factors in soil that control their yields, what do they mention?
YW	When you talk to them, they will tell you about the soil properties. They will say soil texture -
LC	- will they call it soil texture?
YW	There you have to speak in the local language, but I will call it soil texture. They will see how it looks. Soil properties are the ones that can determine whether the soil is fertile or not.

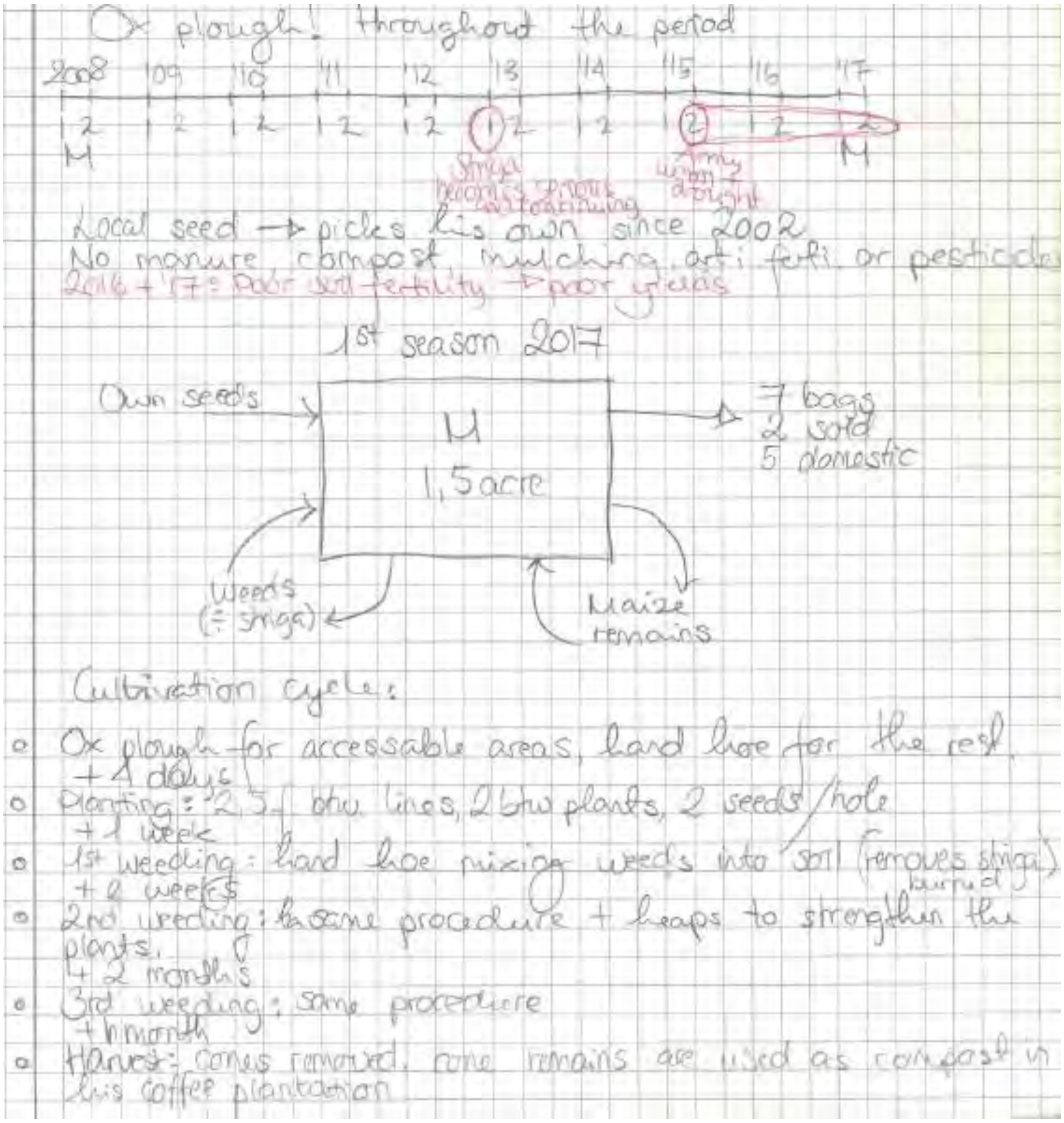
LC	They do not look into what things in the soil that makes it fertile or not, they just know if it is high or low?
YW	For the farmer, it is hard to say for him to tell you if this soil is fertile. He or she will tell you that a soil which is fertile has some small insects in it, it is blackish in colour, and the farmer can even tell you that the soil that is fertile is where you find *elephant grass* or *latama camala* trees. I will show you! Where you find those trees, there is good soil.
LC	Do they have things, they look for?
YW	They have things they look for, and they will tell you that this soil is fertile. But it is not the same scenario which is in Karamoja. For Karamoja the soils are reddish, when they are also fertile. Here, they are black in colour. It is not science, but they can tell you from a every man's view that when you find this and this kind of tree the soil is good.
LC	As soon you go somewhere else, they will look for different things. (YW confirms) The farmers never talk about nutrients?
YW	They talk of nutrients. They talk about N and P. You gather and make compost, which is full of P and N and K. They cannot tell if they are getting N from those trees, it is up to us to tell them. But they know now. This compost has N, P and K. We tell them to mobilize those trees where we can extract those nutrients which the plant wants.
LC	Is this a result of the training, or did they also think about nutrients before?
YW	It is a result of the training.
LC	A few practicalities in the end. Is there any specific reasons that you choose Makuutu subcounty to be the case area?
YW	That is where we started from. That generation had its interest. This is where we found the problem of low fertility. With the backup of ECOSAF we increased the coverage into other districts. Makuutu's soils were declining in fertility, because they were used to growing only maize, maize, maize – season after season. The yields were declining, so we came in and trained them on good agronomy practices using organic agriculture.
LC	But there are still many people in this area that are not part of the project?
YW	Yes. But others are joining. Africans believe by seeing, so a number of them are joining to do organic agriculture. We started with a few people, but now in Makuutu alone we have like 400 farmers – we started with 100. You can draw a difference from the farmer using organic agriculture and the ones not using organic agriculture – in terms of yields. Even food security. For a farmer who is depending on only one crop is not food secure, but our participating farmers are food secure, because they are growing more than three crops. You find that these ones that are not under the program, they are the ones bringing insecurity in the village by going to steal these people's food. Therefore, the only way is to encourage them and to bring them onboard.
LC	How often do these groups meet?
YW	Some meet every week, others after a month. For saving groups, they meet every week. Groups that are not saving can meet twice a month.
LC	They save up money?
YW	Yes, to support them in buying seeds, buying hoes…
LC	Everyone contributes with the same amount of money?
YW	They have their way of working, maybe every person pays 4000 UXS at every seating. With a total number of 30 members, then that money is given to another person, who then brings a small profit of 10 or 1%. Then they share.
LC	Does the subcounty of Makuutu differ from surrounding subcounties, for example when it comes to soil – is the soil in Makuutu different than the subcounties around?

YW	It is not very different. It is kind of sandy. Not clay, but fertile.
LC	It is actually good soil?
YW	Yes, we just need to mobilize farmers to utilise it very well by encouraging them to carry on organic farming practices. So it can gain its fertility in full swing.
LC	Is the land owned by one farmer in the same location just around his/her house, or could it be a bit here and a bit there?
YW	Some is just around the house, some is a bit far, like two or 3 km.
LC	You said that one growing season is from August up to December or January. The first season?
YW	The first season starts from March up to July or August. Due to climate change you may find that the seasons are changing now. We expected the rain in March, but rains came in June.
LC	That was a very long time without the rain.
YW	In this season we expected the rains to come in August/September. It has just come in November. This will affect the farmers. During the flowering state the rain was not there. Maize can at least survive, but beans and groundnuts died. Sweet potato also survived.
LC	After such a drought, is there a difference between the situation of a traditional farmer and the situation of the organic farmer?
YW	Yes, you will find that the organic farmer will have at least something to harvest despite the drought. Take for example bananas; for a farmer who mulched very well the bananas are doing very well compared to one who did not mulch. Even maize also – same scenario. At least there is a difference. That is why organic farmers put trenches – in times of rain like this, trenches will conserve water. Two feet down. This is also a way to manage soil erosion.

Appendix 4: Example of a flow diagram and a land-use timeline

The timeline for CO_BT's field is shown at the top. Capital 'M' at each end of the timeline indicate that maize was the main crop, and that nothing was grown in the time between the first growing season of 2008 up to the last growing season of 2017. Red writing indicates the farmer's highlighted challenges during the 10-year period.

The flow diagram made in cooperation with OR_BT is shown. Below the flow diagram the cultivation cycle has been described in order to capture all practices that could have impacted soil properties.



Ox plough! throughout the period

Local seed → picks his own since 2002
No manure, compost, mulching, arti ferti or pesticid
2016 + '17: Poor soil fertility → poor yields

1st season 2017

Cultivation cycle:

- Ox plough for accessable areas, hand hoe for the rest.
  + 4 days
- Planting: 2,5 ft btw. lines, 2 btw plants, 2 seeds/hole
  + 1 week
- 1st weeding: hand hoe mixing weeds into soil (removes striga) buried
  + 2 weeks
- 2nd weeding: the same procedure + heaps to strengthen the plants.
  + 2 months
- 3rd weeding: same procedure
  + 1 month
- Harvest: cones removed, cone remains are used as compost in his coffee plantation

Appendix 5: Farmers' perception of soil quality

The tables below show both asked questions and respondents answers.

First focus group interview, date: 13-11-2017

Participants: Basoula William, Nyumba Samuel, Mutesi Edith, Nandago Fatina, Aida Namujasi, Roman Bamulambe.

Village: Makandwa

What characterizes a soil of good fertility?	- Soft and a bit heavy (good soil moisture) - Black - The plants on top grow well – sometimes the weeds can be an indicator of fertility. The appearance of water grass is a good sign.
Signs of declining soil fertility	- Aida: Striga weed shows declining fertility – yields become lower - Fatina: Overgrazing an area - Edith: Soil erosion - William: Soil erosion, when one fails to dig trenches
Ranking (from worst to least bad) the practices or constraints that cause fertility to decline	1) Monocropping is the worst one, causing fertility to drop at the most rapid rate. 2) Lacking trenches to prevent soil erosion 3) Overgrazing
Soil fertility incline: signs and causes – what practices can contribute to increase soil fertility?	Signs are: - Edith: rapid growth of weeds - Soils become darker → black Causes: - William: Applying manure → darker soils - Fatina: Mulching - Crop rotation → nitrogen-fixating legumes - Cover crops against soil erosion
Rank (from best to good bad) the practices that contribute to increasing soil fertility	1) Manure 2) Mulching 3) Cover crops 4) Crop rotation
Why are some farmers better at maintaining and improving soil fertility than others?	William: Some farmers do not adapt. It takes long for them to change their mindset. Roman: The culture for producing certain crops in certain areas is difficult to change.

Two organic farmers who are also men. It seems that the organic farmers know more about fertility of soil, but it may also just be due to their sex – the women do not dare to say as much when men are present. This tendency was clear in the answers, for example in the question concerning ranking of practices increasing fertility, where practices employed by organic farmers end up in the top-ranking.

Second focus group interview, date: 14-11-2017

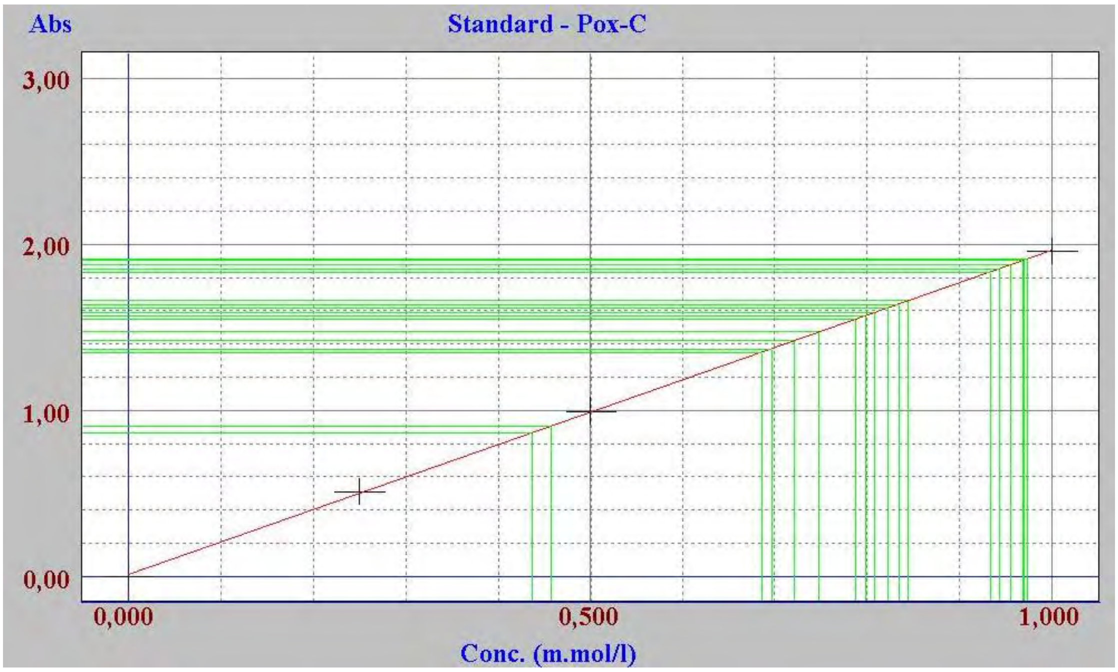
Participants: George Batuuaula, Thomas Igegere, Buuire Steven, Nanatale Jalia, Kitaluu Moses, Ullaisuua Faluku, Kasango Yusuf, Ouuino Johannes, Gaikilo Souuede

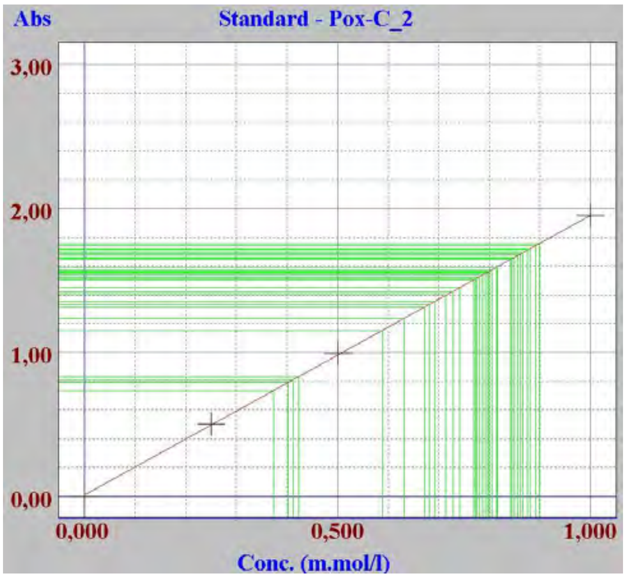
Village: Makandwa

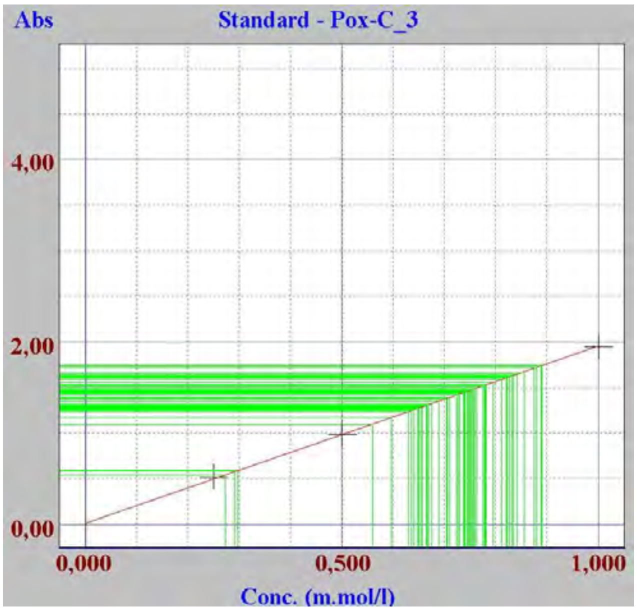
What characterizes a soil of good fertility?	- Grass grows on top of the soil → good soil - Black, heavy → indicates water, soft.
Signs of declining soil fertility	Signs: - Becomes light, grass becomes yellow - Soil erosion – if you fail to put trenches and cover crops Causes: - Bush burning → destroys microbes, overcutting trees → removing potential organic material to contribute to soil fertility, overgrazing. - Monocropping
Ranking (from worst to least bad) the practices or constraints that cause fertility to decline	1) Soil erosion 2) Bush burning 3) Monocropping
Rank (from best to least good) the practices that contribute to increasing soil fertility	Organic and conventional farmers diverge when saying what they think is the most important measure to improve soil fertility: Conventional farmers say deep ploughing and ploughing weeds into the soil are the most important ones, while organic farmers declare the application of cow dung to be most important. Common: 2) Trenches 3) Crop rotation 4) Mulching Fallowing is only applied to a limited extent. One of the conventional farmers use it to revive soil fertility, while the organic farmers use it for pasture.
The challenges	Organic farmers: 1) Striga, 2) armyworm, 3) drought Conventional farmers: 1) drought, 2) striga, 3) army worm, 4) soil erosion, 5) thieves

Appendix 6: Faulty standard curves

Faulty standard curves produced by the spectrophotometer software in connection with Pox-C measurements. Crosses on the graph represent the absorbance of standard samples. The difference between these is minimal.







Appendix 7: Profile data

Data from soil profiles dug in each village.

Village	Top depth	Bottom depth	pH	Clay (<2µm) %	Silt (2-63µm) %	Sand (>63µm) %	USDA texture	Gravel (>2mm) %	N % total	C % total
Buswiriri	9	11	6.9	21.5	32.6	45.9	loam	18	0.2	2.3
	29	32	5.6	24.5	27.0	48.5	sandy clay loam	32	0.1	0.9
	57	60	5.8	21.2	23.9	54.9	sandy clay loam	39	0.1	0.7
	77	79	6.1	14.7	21.0	64.3	sandy loam	41	0.1	0.6
Kinabirye	0	2	6.7	14.4	51.1	34.5	silt loam	12	0.3	3.3
	10	13	7.0	18.5	39.3	42.2	loam	7	0.2	2.5
	35	37	5.5	20.2	38.6	41.3	loam	20	0.2	2.0
	59	61	6.5	21.9	29.9	48.2	loam	37	0.2	1.5
	75	77	6.4	27.1	32.2	40.8	loam	37	0.1	1.5
Makandwa	14	16	6.1	32.2	37.4	30.4	clay loam	14	0.2	2.4
	54	56	5.0	34.9	28.7	36.4	clay loam	43	0.1	1.2
	84	86	4.8	34.7	31.4	33.9	clay loam	44	0.1	1.4
Makuutu	8	10	5.7	32.4	38.7	28.9	clay loam	0	0.1	1.2
	42	45	5.6	50.0	24.5	25.5	clay	0	0.1	0.6
	75	77	5.3	36.9	22.6	40.6	clay loam	0	0.1	0.5
	95	97	5.0	37.9	24.6	37.5	clay loam	0	0.1	0.5

Appendix 8: Flow diagrams

Summary of the output of flow diagram interviews.

									Circulation			Input						Output
Farmer	**Village**	**Field size estimate (ha)[1]**	**Measured field size (ha)**	**Estimate deviation**	**Line dist (foot)[2]**	**Plant dist (foot)[2]**	**Max number of plants**	**Seeds pr hole**	**Maize residues (Y=1, N=0)[3]**	**Maize cones destination[4]**	**Weeds (Y=1, N=0)[3]**	**Seeds (own/ local/ hybrid)**	**Manure Type**	**Manure (kg ha^{-1})**	**Mulch type**	**Compost (kg ha^{-1})**	**Homemade pesticide application (Y=1, N=0)[5]**	**Yield (kg ha^{-1})[7]**
CO_BD	Kinabirye	0.40	0.39	4%	2	1.5	1293	2	0		1	Hybrid 'Long10h'	None	0	None	0.00	0	2062.1
CO_BT	Buswiriri	0.61	0.19	69%	2.5	2	373	2	1	C	1	Own	None	0	None	0.00	0	3753.6
CO_EK	Makandwa	0.81	0.09	88%	3	1	314	2	1	F	1	Own	None	0	None	0.00	0	4250.6
CO_IM	Makuutu	0.20	0.06	70%	2	1	305	2	1	F	1	Own	None	0	None	0.00	0	4914.5
CO_MH	Kinabirye	0.81	0.43	47%	2.5	2	866	3	1	F+C	1	Own	None	0	None	0.00	0	924.2
CO_MR	Buswiriri	0.40	0.12	70%	4	2	152	3	1	F	1	Own	None	0	None	0.00	0	2471.1
CO_NA	Makuutu	0.81	0.21	74%	2	1.5	707	3	1	F	1	Own	None	0	None	0.00	0	3773.1
CO_NS	Makandwa	1.62	0.26	84%	1.5	1	1750	2	1	F	1	Own	None	0	None	0.00	0	3808.9
OR_BJ	Makuutu	0.20	0.06	72%	2	1.5	188	2	1	C	1	Own	Cow dung	2659	Elephant grass	4431.29	0	3545.0
OR_KA	Kinabirye	0.81	0.55	32%	2.5	1.5	1470	2	1		1	Own	Cow dung	1996	None	0.00	0	6349.9
OR_KT	Makandwa	0.20	0.06	71%	2.5	2	116	2	1	C	1	Own	Cow dung	5162	None	3441.51	0	3441.5
OR_MB	Buswiriri	0.40	0.48	-20%	4	2	606	2	1	C	1	Own	Cow dung	103	None	1031.18	1	618.7
OR_MWF	Kinabirye	0.40	0.39	4%	2.5	2	774	2	1	C	1	Own	Cow dung	1939	None	0.00	0	1550.8
OR_NY	Buswiriri	0.81	0.22	72%	2.5	1	891	2	1	F	1	Own	Cow dung	2245	Soya bean residues	4490.75	0	4490.7
OR_RB	Makandwa	0.40	0.15	63%	2	1	755	1	1		1	Own	Cow dung	1655	None	1654.64	0	3971.1
OR_RN	Makuutu	1.01	0.84	17%	2.5	1.5	2244	2	1	M	1	Own	Cow dung	238	None	297.15	0	1426.3

[1] Field size as estimated by farmers. [2] Line dist = distance between lines, Plant dist = distance between plants on lines. [3] Whether maize/weeds residues are circulated back into the soil system after harvest, yes = 1, no = 0. [4] The destination of maize cones, which are also removed as part of the harvest: C = compost, F = firewood, M = mulch. [5] Whether the farmer applied homemade pesticide, yes = 1, no = 0. [7] The yield size was originally given in 'bags' of 100kg and have been recalculated. This only includes the corn without cones.

Appendix 9: Field sampling results

Average values of all measured soil properties on field level. The averages represent the three replicate samples taken on each field, standard deviations are shown in brackets.

Table 8.1: OM-related properties: Labile C as represented by Pox-C, % of labile C out of SOC (%labile), total N and SOC concentrations, SOM concentration and C:N ratio.

Sample ID	Pox-C (mg C kg^{-1})	%labile	Total N%	SOC%	SOM%	C:N
10cm						
CO_BD	481.5 (± 37.7)	1.60%	0.28 (± 0.1)	3.0 (± 0.6)	5.2 (± 0.9)	10.8 (± 0.4)
CO_BT	243.4 (±12.1)	2.10%	0.13 (± 0.0)	1.2 (± 0.3)	2.1 (± 0.4)	9.4 (± 0.1)
CO_EK	377.8 (± 29.5)	2.60%	0.14 (± 0.0)	1.5 (± 0.0)	2.5 (± 0.1)	10.6 (± 0.2)
CO_IM	294.6 (±6.7)	1.80%	0.15 (± 0.0)	1.6 (± 0.0)	2.8 (± 0.1)	11.0 (± 0.0)
CO_MH	344.4 (± 51.5)	1.80%	0.17 (± 0.0)	1.9 (± 0.2)	3.3 (± 0.4)	11.1 (± 0.5)
CO_MR	309.2 (± 61.5)	1.70%	0.18 (± 0.0)	1.8 (± 0.2)	3.1 (± 0.3)	10.0 (± 0.1)
CO_NA	414.9 (± 39.1)	2.30%	0.16 (± 0.0)	1.8 (± 0.2)	3.1 (± 0.4)	10.8 (± 0.3)
CO_NS	349.3 (± 22.6)	2.20%	0.14 (± 0.0)	1.6 (± 0.2)	2.8 (± 0.3)	11.8 (± 0.2)
OR_BJ	244.9 (± 27.8)	2.30%	0.10 (± 0.0)	1.1 (± 0.0)	1.8 (± 0.1)	10.2 (± 0.5)
OR_KA	234.7 (± 42.3)	1.80%	0.11 (± 0.0)	1.3 (± 0.1)	2.3 (± 0.2)	11.6 (± 0.3)
OR_KT	563.9 (± 49.8)	2.10%	0.23 (± 0.0)	2.7 (± 0.4)	4.6 (± 0.6)	11.3 (± 0.4)
OR_MB	488.2 (± 8.3)	1.90%	0.25 (± 0.0)	2.5 (± 0.1)	4.4 (± 0.1)	10.0 (± 0.2)
OR_MWF	423.1 (± 37.5)	2.00%	0.21 (± 0.0)	2.1 (± 0.2)	3.7 (± 0.4)	10.3 (± 0.3)
OR_NY	485.7 (± 25.9)	1.70%	0.26 (± 0.0)	2.9 (± 0.0)	5.0 (± 0.0)	11.4 (± 0.2)
OR_RB	492.6 (± 20.9)	1.60%	0.25 (± 0.0)	3.1 (± 0.0)	5.3 (± 0.1)	12.2 (± 0.2)
OR_RN	76.4 (± 13.4)	1.00%	0.07 (± 0.0)	0.7 (± 0.1)	1.3 (± 0.1)	11.0 (± 0.3)
20cm						
CO_BD	329.5 (±33.4)	1.60%	0.20 (± 0.0)	2.1 (± 0.0)	3.5 (± 0.1)	10.1 (± 0.1)
CO_BT	164.5 (± 6.7)	1.60%	0.11 (± 0.0)	1.1 (± 0.1)	1.8 (± 0.1)	9.5 (± 0.2)
CO_EK	284.2 (± 33.0)	2.20%	0.12 (± 0.0)	1.3 (± 0.2)	2.2 (± 0.3)	10.3 (± 0.5)
CO_IM	238.0 (± 11.3)	1.70%	0.13 (± 0.0)	1.4 (± 0.1)	2.4 (± 0.1)	10.8 (± 0.3)
CO_MH	308.5 (± 27.2)	1.90%	0.15 (± 0.0)	1.7 (± 0.3)	2.9 (± 0.4)	11.6 (± 0.3)
CO_MR	412.4 (±170.2)	2.60%	0.16 (± 0.0)	1.6 (± 0.6)	2.7 (± 0.9)	9.6 (± 0.9)
CO_NA	298.1 (± 75.0)	2.20%	0.12 (± 0.0)	1.4 (± 0.4)	2.4 (± 0.6)	11.3 (± 0.3)
CO_NS	305.3 (± 41.5)	2.10%	0.12 (± 0.0)	1.4 (± 0.0)	2.5 (± 0.1)	11.7 (± 0.5)
OR_BJ	180.3 (± 17.6)	1.90%	0.10 (± 0.0)	0.9 (± 0.1)	1.6 (± 0.1)	9.8 (± 0.3)
OR_KA	186.7 (± 27.2)	1.70%	0.09 (± 0.0)	1.1 (± 0.1)	1.9 (± 0.2)	12.1 (± 0.5)
OR_KT	319.4 (± 36.2)	1.80%	0.17 (± 0.0)	1.8 (± 0.2)	3.1 (± 0.3)	10.6 (± 0.5)
OR_MB	378.3 (± 10.7)	1.80%	0.22 (± 0.0)	2.2 (± 0.1)	3.7 (± 0.1)	9.9 (± 0.3)
OR_MWF	264.9 (± 55.5)	1.60%	0.17 (± 0.0)	1.7 (± 0.4)	2.9 (± 0.6)	9.7 (± 0.5)
OR_NY	451.3 (± 37.0)	1.80%	0.22 (± 0.0)	2.5 (± 0.1)	4.4 (± 0.2)	11.3 (± 0.8)
OR_RB	396.6 (± 21.7)	1.60%	0.21 (± 0.0)	2.6 (± 0.2)	4.4 (± 0.3)	12.0 (± 0.1)
OR_RN	37.0 (± 2.7)	0.60%	0.06 (± 0.0)	0.7 (± 0.1)	1.2 (± 0.1)	10.9 (± 0.4)

Table 1.2: Soil water retention (SWR) values and other structure related variables.

Sample ID	**Bulk density (g cm^{-3})**	**pF4.2 (vol%)**	**pF3 (vol%)**	**pF2 (vol%)**	**Porosity (vol%)**	**Aeration (vol%)**	**PAW (vol%)**
10cm							
CO_BD	1.1 (± 0.1)	15.4 (± 1.5)	23.0 (± 1.0)	30.3 (± 1.0)	55.1 (± 2.3)	24.8 (± 3.2)	14.9 (± 0.5)
CO_BT	1.3 (± 0.1)	13.9 (± 2.0)	17.8 (± 1.9)	29.8 (± 1.5)	50.1 (± 3.0)	20.3 (± 4.4)	15.9 (± 0.5)
CO_EK	1.4 (± 0.0)	15.5 (± 1.1)	17.9 (± 0.8)	27.3 (± 1.2)	45.3 (± 1.4)	17.9 (± 2.6)	11.8 (± 0.8)
CO_IM	1.2 (± 0.1)	10.3 (± 0.5)	18.1 (± 0.9)	24.6 (± 1.9)	54.9 (± 2.5)	30.3 (± 4.5)	14.3 (± 1.8)
CO_MH	1.4 (± 0.1)	12.3 (± 1.9)	18.0 (± 3.1)	25.0 (± 2.9)	46.3 (± 2.0)	21.3 (± 4.9)	12.7 (± 1.0)
CO_MR	1.1 (± 0.0)	17.7 (± 0.3)	23.3 (± 0.6)	28.8 (± 1.0)	58.6 (± 0.4)	29.8 (± 1.4)	11.1 (± 1.0)
CO_NA	1.2 (± 0.0)	8.9 (± 1.5)	15.5 (± 1.7)	26.1 (± 3.3)	52.0 (± 2.0)	25.9 (± 5.2)	17.2 (± 2.0)
CO_NS	1.3 (± 0.1)	14.4 (± 1.6)	18.1 (± 0.9)	25.4 (± 1.7)	50.9 (± 3.7)	25.5 (± 5.4)	11.1 (± 0.6)
OR_BJ	1.4 (± 0.0)	8.5 (± 0.3)	14.2 (± 0.9)	22.7 (± 0.6)	47.4 (± 0.7)	24.8 (± 1.2)	14.2 (± 0.4)
OR_KA	1.3 (± 0.1)	10.8 (± 0.4)	13.7 (± 1.0)	20.8 (± 1.8)	49.4 (± 3.0)	28.6 (± 4.8)	10.0 (± 1.4)
OR_KT	1.1 (± 0.1)	17.9 (± 2.7)	22.7 (± 2.2)	29.9 (± 2.4)	54.7 (± 5.5)	24.9 (± 7.9)	12.0 (± 0.4)
OR_MB	1.1 (± 0.1)	18.9 (± 2.5)	22.6 (± 2.7)	30.1 (± 3.8)	55.9 (± 4.4)	25.8 (± 8.3)	11.2 (± 1.3)
OR_MWF	1.3 (± 0.1)	14.0 (± 0.6)	19.8 (± 0.2)	27.5 (± 0.9)	50.5 (± 3.8)	23.0 (± 4.8)	13.6 (± 1.1)
OR_NY	1.1 (± 0.1)	18.4 (± 0.3)	23.5 (± 1.1)	31.3 (± 1.7)	54.6 (± 2.3)	23.3 (± 4.1)	12.9 (± 1.5)
OR_RB	1.2 (± 0.1)	16.7 (± 2.0)	20.6 (± 1.0)	28.4 (± 1.9)	54.2 (± 4.2)	25.8 (± 6.1)	11.7 (± 0.3)
OR_RN	1.3 (± 0.1)	4.8 (± 0.5)	9.5 (± 0.5)	18.0 (± 0.9)	48.9 (± 2.9)	30.9 (± 3.7)	13.2 (± 1.3)
20cm							
CO_BD	1.2 (± 0.0)	13.4 (± 0.9)	23.4 (± 0.9)	29.3 (± 1.0)	54.8 (± 1.1)	25.5 (± 1.9)	15.9 (± 1.8)
CO_BT	1.5 (± 0.1)	14.5 (± 1.0)	19.9 (± 1.1)	32.4 (± 0.6)	42.8 (± 3.3)	10.5 (± 3.3)	17.9 (± 1.3)
CO_EK	1.4 (± 0.1)	14.4 (± 2.0)	19.3 (± 1.9)	26.3 (± 2.6)	45.9 (± 4.0)	19.6 (± 6.6)	11.9 (± 0.8)
CO_IM	1.4 (± 0.0)	14.6 (± 1.5)	22.0 (± 0.7)	28.8 (± 0.7)	47.6 (± 2.0)	18.8 (± 0.9)	14.1 (± 1.3)
CO_MH	1.4 (± 0.1)	11.0 (± 0.5)	20.3 (± 2.0)	32.9 (± 2.7)	44.0 (± 1.9)	11.2 (± 2.2)	21.8 (± 3.2)
CO_MR	1.2 (± 0.0)	17.5 (± 1.0)	27.5 (± 3.0)	33.7 (± 1.9)	53.5 (± 0.9)	19.9 (± 2.7)	16.2 (± 1.2)
CO_NA	1.4 (± 0.1)	11.4 (± 1.9)	17.7 (± 1.8)	28.7 (± 1.9)	47.3 (± 4.4)	18.6 (± 5.6)	17.3 (± 0.2)
CO_NS	1.3 (± 0.0)	13.7 (± 0.6)	19.3 (± 0.7)	26.8 (± 0.2)	48.1 (± 1.9)	21.3 (± 1.8)	13.1 (± 0.5)
OR_BJ	1.4 (± 0.1)	10.4 (± 0.9)	14.9 (± 0.9)	22.3 (± 1.0)	47.7 (± 3.7)	25.3 (± 4.7)	11.9 (± 1.2)
OR_KA	1.5 (± 0.1)	10.2 (± 0.6)	16.4 (± 0.1)	23.6 (± 1.4)	43.3 (± 2.9)	19.8 (± 4.3)	13.4 (± 0.8)
OR_KT	1.3 (± 0.2)	17.2 (± 3.8)	24.6 (± 3.5)	31.1 (± 3.0)	50.7 (± 8.4)	19.6 (± 11.5)	13.9 (± 1.2)
OR_MB	1.3 (± 0.1)	17.5 (± 1.3)	27.2 (± 1.0)	32.7 (± 2.1)	50.7 (± 2.2)	18.0 (± 2.7)	15.2 (± 3.1)
OR_MWF	1.3 (± 0.1)	13.3 (± 0.8)	21.0 (± 1.3)	27.4 (± 1.0)	47.7 (± 2.5)	20.3 (± 1.9)	14.1 (± 1.4)
OR_NY	1.2 (± 0.1)	17.6 (± 2.0)	26.0 (± 2.7)	31.7 (± 2.9)	53.2 (± 2.3)	21.5 (± 5.2)	14.1 (± 1.2)
OR_RB	1.2 (± 0.0)	15.6 (± 0.6)	22.9 (± 0.7)	30.7 (± 1.1)	53.1 (± 1.5)	22.4 (± 2.4)	15.2 (± 1.6)
OR_RN	1.5 (± 0.0)	5.8 (± 0.0)	11.2 (± 0.5)	20.5 (± 0.4)	44.5 (± 1.3)	24.0 (± 1.6)	14.7 (± 0.4)

Table 1.3: Texture results for clay, silt and sand fractions with the designated texture class according to USDA. pH results are also showed here.

	Clay (<2µm) %	**Silt (2-63µm) %**	**Sand (>63µm) %**	**USDA texture**	**pH**
10cm					
CO_BD	35.2 (± 1.2)	39.6 (± 1.6)	25.2 (± 0.8)	clay loam	6.6 (± 0.2)
CO_BT	17.0 (± 1.5)	44.2 (± 1.1)	38.8 (± 1.3)	loam	5.2 (± 0.3)
CO_EK	18.4 (± 1.9	39.0 (± 0.8)	42.6 (± 2.1)	loam	6.2 (± 0.2)
CO_IM	25.2 (± 2.8)	33.4 (± 3.6)	41.4 (± 6.3)	loam	5.9 (± 0.4)
CO_MH	21.1 (± 3.0)	42.0 (± 2.8)	37.0 (± 5.5)	loam	6.2 (± 0.3)
CO_MR	45.1 (± 4.3)	34.9 (± 4.1)	20.0 (± 5.9)	clay	6.0 (± 0.1)
CO_NA	13.5 (± 1.0	38.3 (± 2.6)	48.2 (± 3.6)	loam	5.9 (± 0.2)
CO_NS	20.8 (± 0.7)	40.4 (± 5.2)	38.8 (± 5.6)	loam	6.0 (± 0.2)
OR_BJ	14.6 (± 1.4)	31.6 (± 1.5)	53.9 (± 2.7)	sandy loam	5.7 (± 0.1)
OR_KA	15.7 (± 0.3)	32.8 (± 1.2)	51.5 (± 0.9)	loam	5.7 (± 0.1)
OR_KT	31.0 (± 0.8)	43.4 (± 3.4)	25.6 (± 3.3)	clay loam	6.3 (± 0.2)
OR_MB	37.0 (± 10.7)	41.5 (± 5.4)	21.6 (± 15.7)	clay loam	7.0 (± 0.1)
OR_MWF	26.9 (± 1.9)	38.3 (± 1.9)	34.8 (± 3.7)	loam	6.2 (± 0.1)
OR_NY	39.8 (± 1.5)	39.0 (± 1.6)	21.1 (± 2.7)	clay loam	6.8 (± 0.1)
OR_RB	28.1 (± 3.4)	39.0 (± 3.5)	32.9 (± 6.7)	clay loam	5.5 (± 0.1)
OR_RN	8.7 (± 0.8)	31.9 (± 1.6)	59.4 (± 1.6)	sandy loam	4.8 (± 0.1)
20cm					
CO_BD	38.3 (± 2.3)	34.9 (± 2.4)	26.8 (± 4.7)	clay loam	6.3 (± 0.2)
CO_BT	17.6 (± 2.9)	43.7 (± 3.1)	38.7 (± 6.1)	loam	5.5 (± 0.3)
CO_EK	21.3 (± 2.4)	36.6 (± 3.6)	42.0 (± 3.0)	loam	6.1 (± 0.4)
CO_IM	27.4 (± 0.9)	30.9 (± 1.3)	41.7 (± 1.7)	clay loam	6.1 (± 0.1)
CO_MH	21.4 (± 2.9)	42.4 (± 1.4)	36.2 (± 2.8)	loam	5.9 (± 0.1)
CO_MR	45.4 (± 5.2)	31.9 (± 4.0)	22.7 (± 6.2)	clay	5.8 (± 0.2)
CO_NA	15.9 (± 2.4)	41.9 (± 6.1)	42.1 (± 8.3)	loam	6.1 (± 0.4)
CO_NS	21.7 (± 2.3)	33.9 (± 3.5)	44.5 (± 3.4)	loam	5.9 (± 0.2)
OR_BJ	17.3 (± 0.8)	32.4 (± 2.0)	50.3 (± 1.9)	loam	5.7 (± 0.0)
OR_KA	16.5 (± 1.1)	26.1 (± 3.1)	57.5 (± 4.1)	sandy loam	5.6 (± 0.2)
OR_KT	33.3 (± 4.9)	37.6 (± 1.5)	29.1 (± 4.6)	clay loam	6.0 (± 0.3)
OR_MB	40.0 (± 2.8)	36.1 (± 1.6)	23.8 (± 2.3)	clay	7.1 (± 0.1)
OR_MWF	28.9 (± 3.4)	33.8 (± 0.7)	37.4 (± 4.0)	clay loam	5.9 (± 0.1)
OR_NY	38.9 (± 2.7)	33.4 (± 1.7)	27.7 (± 2.4)	clay loam	6.8 (± 0.1)
OR_RB	34.5 (± 2.5)	37.5 (± 2.7)	28.0 (± 5.1)	clay loam	5.6 (± 0.2)
OR_RN	8.8 (± 0.9)	36.5 (± 4.9)	54.8 (± 5.7)	sandy loam	4.8 (± 0.1)

Appendix 10: Nutrient budgets on field-level

Nutrient budgets on field level. Maize yield (only corn) constitutes the only output from the field systems, while manure were the only inputs considered in the calculation of nutrient inputs.

USDA’s Crop Nutrient Tool (https://plants.usda.gov/npk/main) employs bushel units for the category *Corn-Field, for grain (shelled, yellow dent, grade #1)*. A conversion of bu to kg (1 bu = 24.8 kg) was found in Table 3 at https://web.archive.org/web/20070525150336/http://extension.missouri.edu/xplor/agguides/crops/g04020.htm with a moisture content of 13.5%. The default moisture percentage of 13.52% was used in the Crop Nutrient Tool.

			Output (kg ha^{-1})			**Input (kg ha^{-1})**						
			EXPORT OF NPK IN YIELDS			**FRESH MANURE**				**COMPOSTED MANURE (4 WEEKS)**		
Farmer	**Village**	**Yield**	**N**	**P**	**K**	**Manure**	**N**	**P**	**K**	**N**	**P**	**K**
CO_BD	Kinabirye	2062.1	29.9	5.7	6.3	0	-29.9	-5.7	-6.3	-29.9	-5.7	-6.3
CO_BT	Buswiriri	3753.6	54.4	10.4	11.4	0	-54.4	-10.4	-11.4	-54.4	-10.4	-11.4
CO_EK	Makandwa	4250.6	61.6	11.8	13.0	0	-61.6	-11.8	-13.0	-61.6	-11.8	-13.0
CO_IM	Makuutu	4914.5	71.2	13.6	15.0	0	-71.2	-13.6	-15.0	-71.2	-13.6	-15.0
CO_MH	Kinabirye	924.2	13.4	2.6	2.8	0	-13.4	-2.6	-2.8	-13.4	-2.6	-2.8
CO_MR	Buswiriri	2471.1	35.8	6.8	7.5	0	-35.8	-6.8	-7.5	-35.8	-6.8	-7.5
CO_NA	Makuutu	3773.1	54.7	10.4	11.5	0	-54.7	-10.4	-11.5	-54.7	-10.4	-11.5
CO_NS	Makandwa	3808.9	55.2	10.5	11.6	0	-55.2	-10.5	-11.6	-55.2	-10.5	-11.6
OR_BJ	Makuutu	3545.0	51.4	9.8	10.8	2659.8	-19.5	5.9	2.4	-39.3	-2.5	7.7
OR_KA	Kinabirye	6349.9	92.0	17.6	19.4	1995.7	-68.1	-5.8	-9.4	-83.0	-12.1	-5.5
OR_KT	Makandwa	3441.5	49.9	9.5	10.5	5162.3	12.1	20.9	15.2	-26.4	4.7	25.4
OR_MB	Buswiriri	618.7	9.0	1.7	1.9	103.1	-7.7	-1.1	-1.4	-8.5	-1.4	-1.2
OR_MWF	Kinabirye	1550.8	22.5	4.3	4.7	1938.5	0.8	7.1	4.9	-13.7	1.0	8.7
OR_NY	Buswiriri	4490.7	65.1	12.4	13.7	2245.4	-38.2	0.8	-2.5	-54.9	-6.3	1.9
OR_RB	Makandwa	3971.1	57.6	11.0	12.1	1654.6	-37.7	-1.2	-3.9	-50.0	-6.4	-0.6
OR_RN	Makuutu	1426.3	20.7	3.9	4.3	237.7	-17.8	-2.5	-3.2	-19.6	-3.3	-2.7