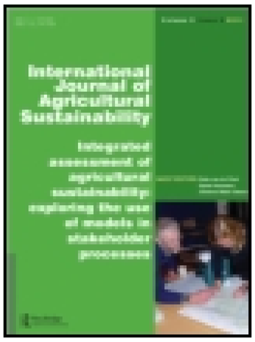

International Journal of Agricultural Sustainability

ISSN: 1473-5903 (Print) 1747-762X (Online) Journal homepage: http://www.tandfonline.com/loi/tags20

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To cite this article: N. Templer, M. Hauser, A. Owamani, D. Kamusingize, H. Ogwali, L. Mulumba, R. Onwonga, B. T. Adugna & L. Probst (2018): Does certified organic agriculture increase agroecosystem health? Evidence from four farming systems in Uganda, International Journal of Agricultural Sustainability

To link to this article: https://doi.org/10.1080/14735903.2018.1440465

Published online: 20 Feb 2018.

INTERNATIONAL JOURNAL OF AGRICULTURAL SUSTAINABILITY, 2018
https://doi.org/10.1080/14735903.2018.1440465

Routledge
Taylor & Francis Group

Does certified organic agriculture increase agroecosystem health? Evidence from four farming systems in Uganda

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ABSTRACT
Over the past decades, the number of certified organic farms have increased significantly in Uganda. One assumption is that certified organic agriculture contributes to economic, social and ecological health of agroecosystems. In the literature, however, there is thin empirical evidence to support such claims. We therefore developed health indicators and contrasted data from four Ugandan farming systems with principles and objectives of organic agriculture. We identified four health patterns (ecology-driven, economically struggling, socially-driven, and hanging in) demonstrating the impact of farm management on agroecosystem health and trade-offs between health domains. Ecological farm health is strengthened only if the conversion goes beyond ‘organic by default’. Market-oriented specialization can create lock-in situations if production strategies cannot be changed easily. Food shortages occur when additional income from certified production does not compensate for the reduced area and effort devoted to food crops. We conclude that the positive effects of organic certification on agroecosystem health cannot be taken for granted. Interventions promoting organic agriculture should acknowledge risks smallholder farmers take by converting to cash crop-oriented certified organic farming. A challenging question will be how aspects of wellbeing and social health can be translated into certification standards and thus product attributes.

KEYWORDS
Organic agriculture; agroecosystem health; farming systems; Uganda

1. Agroecosystem health and organic agriculture

Human life on earth depends upon the integrity of ecosystems for well-being and survival (Patz, Corvalan, Hortwitz, & Campbell-Lendrum, 2012). Agroecosystems are socio-ecological systems with communities of plants and animals interacting with their physico-chemical environments that have been altered by people for food and fibre production (Feld et al., 2007; Zhu, Wang, & Caldwell, 2012). Agroecosystems provide products and services that range from food and forage to support of biodiversity or regulation of water and soil quality (Power, 2010). They are major ecological units with flow and cycling of materials and energy rather than simple production units (Xu & Mage, 2001). Their structural composition and distribution vary among different types and at different scales (Smit & Smithers, 1993; Vadrevu et al., 2008). Safeguarding agroecosystems is critical especially for livelihoods in rural landscapes due to numerous direct as well as indirect benefits such as food security and income (Bommarco, Kleijn, & Potts, 2013; Millennium Ecosystem Assessment, 2010). However,

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agriculture (e.g. unsustainable intensification) can also be a key driver of ecosystem degradation (Dale & Polasky, 2007; Hoekstra, Boucher, Ricketts, & Roberts, 2005). The adequate understanding and management of agroecosystems are thus key to maintain or improve their structures and functions, hence safeguarding their sustainability (Almagro et al., 2016; Corbera, Brown, & Adger, 2007; Lobell, Schlenker, & Costa-Roberts, 2011; Parry, 2007; Power, 2010; Sandhu, Wratten, & Cullen, 2010).

Agroecosystem health describes the status of farming systems and communities against predefined indicators (Gitau, Gitau, & Waltner-Toews, 2008; Waltner-Toews & Kay, 2005; Waltner-Toews et al., 2000). The concept is multi-scalar with the farm being the basic unit (Jabbar, Peden, Mohamed-Saleem, & Pun, 2000; Waltner-Toews & Kay, 2005) and can be envisioned in four dissimilar perspectives: agroecosystem structure, function, organization, and dynamics (Xu & Mage, 2001). Healthy agroecosystems allow communities to respond to emerging challenges such as climate change or other higher-level trends, such as changing consumer preferences (Altieri & Koohafkan, 2008; Vignola et al., 2015; Wezel et al., 2014; Zhu et al., 2012). While agroecosystem health overlaps with comprehensive concepts of sustainability, we find that it has the metaphorical quality to intuitively create a systemic understanding of complex socio-ecological phenomena visible on farms. This is especially helpful for the participatory assessment of agroecosystems by farmers, researchers and students, since all of them have some concept of human health that can be used as a starting point to specify and also describe the health of an agroecosystem.

Organic agriculture has been recognized as one of the practices that can improve the health and sustainability of agroecosystems (Giovannucci & Ponte, 2005; Pretty, 2008). As defined by Mannion (1995), organic agriculture does so by focusing on the beneficial use of the complex interactions of farm biota, their growth and development, and the responses to external pressure. As a holistic practice, organic agriculture pays attention to the 'logical association and/or synchronization' of systemic elements (Scofield, 1986), such as water, soils, crops, and livestock. The aim of organic agriculture is to create viable socially, environmentally, and economically integrated agroecosystems (Lampkin, 1994). In the words of the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) (2007): 'Organic agriculture is a holistic production management system which promotes and enhances agroecosystem health, including biodiversity, biological cycles, and soil biological activity. (…). This is accomplished by using, where possible, cultural, biological, and mechanical methods (…)'. Beyond the crop production level, organic agriculture aims to achieve environmental goals (e.g. soil and water conservation, protection of biodiversity and animal welfare), social goals (e.g. fair distribution of benefits, food security and sovereignty), and economic goals (e.g. improved income opportunities, market access, and ability to save).

The popularity of organic agriculture is mainly anchored around environmental and human health-related concerns (Biao, Xiaorong, Zhuhong, & Yaping, 2003). Indeed, organic practices were suggested to reduce the dependency on external farm inputs, such as mineral fertilizers, synthetic pesticides and herbicides, and counter environmental degradation (Horrigan, Lawrence, & Walker, 2002; Parrott & Marsden, 2002; Scialabba & Müller-Lindenlauf, 2010). Beyond the farm, organic agriculture was found to contribute to the development of alternative food systems, which have expanded rapidly over the past several years (Avery, 2007; Biao et al., 2003; Stockdale et al., 2001).

Across sub-Sahara Africa, notably civil society organizations have promoted organic agriculture as a pathway for sustainable intensification of crop production with the potential to increase production by more than 50% in 2030 (Scialabba, 2007). In Uganda, the FAO found that sustainable intensification is of particular concern since 83% of the population live in rural areas, agriculture employs 72% of the labour force and contributes 25% to the overall gross domestic product (FAO, 2016). As the population continues to grow, the average farm size has decreased among the middle income and poorest households (Tumushabe, Ruhweza, Masiga, & Naturinda, 2007). Uganda's National Environment Management Authority found that predominant farming practices are the leading cause of decreasing soil quality and related environmental degradation (NEMA, 2010). At the same time, food security continues to be a concern – in the 2008/2009 agricultural census, with more than half of the agricultural households (56.7%) reported having recently suffered from food shortages. According to the Uganda Bureau of Statistics (UBOS, 2011), farmers attribute food losses and insufficient production as main reasons for food shortages (71.4%); to a lesser extent, farmers also quoted lack of capital (19.3%) or land (10%).

Organic agriculture started in Uganda during the economic and political crisis in the late 1980s (Jacobsen, 2009; Walaga, 2004). Low productivity and liberal policies opened up a window of opportunity for organic agriculture (Adebiyi, 2014; Hauser & Lindtner, 2017). Numerous non-governmental and community-based organizations have continuously promoted organic agriculture for the 'sustainable intensification of farming' (Walaga, 2004). As international demand for certified organic produce from tropical countries rose, the organic sector in Uganda became increasingly market-oriented and focused on export (Taylor, 2006; Walaga & Hauser, 2005; Walaga, Hauser, Delve, & Nagawa, 2005). Between 2004 and 2010, certified organic agriculture in Uganda expanded dramatically – from about 40,000 ha of certified area to more than 180,000 ha (Namuwoza & Tushemerirwe, 2011; Willer & Kilcher, 2010; Willer & Lernoud, 2016; Willer, Lernoud, & Kilcher, 2013; Willer & Yussefi, 2006) In 2016, Uganda had the largest certified organic area and the largest number of organic farms in Africa. In more recent years, the growth of the sector has slowed down to a rate that corresponds to the international average (Willer & Lernoud, 2016). Despite the positive momentum, organic agriculture as a pathway for Ugandan agriculture has been critically discussed at different levels. Regarding the productivity potential, the yield gap between organic and conventional farming continues to be fiercely debated, although organic practices would most likely improve productivity as compared to current farming systems (Connor, 2013; Ponisio et al., 2015; Tittonell & Giller, 2013; Walukano et al., 2016). Recent studies confirm that Ugandan farmers do not use enough fertilizer and improved seeds to maximize locally-attainable yields in a conventional system (Mbowa & Mwesigye, 2016). Another major concern regarding organic agriculture is the control of pests, weeds, and diseases (Chongtham, de Neergaard, & Pillot, 2010; Nalubwama et al., 2014). The complex and costly certification has been a major constraint for the expansion of organic agriculture. The dependency on exporters for certification has also jeopardized potentially empowering effects of converting to organic agriculture (Araki, 2007). Participatory certification schemes have tried to address these challenges but are of limited relevance in the export-oriented sector. While certified organic households seem to be more food secure, the effects on gender and intra-household power relations are not sufficiently understood (Aigelsperger, 2007; Ayuya et al., 2015; Gibbon, Bolwig, Odeke, & Taylor, 2008). While earlier studies have thus addressed the impact dimensions of organic agriculture in Uganda in isolation to each other, we integrate economic, social, and ecological aspects to explore the effects of certified organic agriculture on agroecosystem health. We refer to Rapport (2007) and Vadrevu et al. (2008) and define healthy agroecosystems as free from 'distress syndrome', while coping with disturbances and sustainably maintaining their production potential. The concept of health allowed us to operationalize an integrated set of indicators including economic, social, and ecological aspects to create a rich picture of organic farms. Our research interest lied in developing site-specific health indicators and contrasting the results of an agroecosystem health assessment with the principles and objectives of organic agriculture. The working hypothesis was that practicing certified organic agriculture increases economic, social, and ecological health of farming systems.

2. Analytical framework

An analytical framework to explore agroecosystem health has to incorporate economic, social, and ecological dimensions (Fletcher, Saunders, & Herbert, 2011; Rapport, 2007; Rapport, Costanza, & McMichael, 1998; Rapport & Mergler, 2004). Moreover, since agroecosystems are highly context-specific and influenced by a complexity of factors (Felipe-Lucia & Comín, 2015; Hayati, Ranjbar, & Karami, 2010; Reed, 2008; Seufert, Ramankutty, & Foley, 2012), we decided to translate the conceptual approach of agroecosystem health into an analytical framework that allows for site-specific variation. In developing the analytical framework (Table 1), we drew on relevant earlier conceptual and empirical work on assessing the status of farm systems (Bockstaller et al., 2009; Cabell & Oelofse, 2012; Friis-Hansen, 2008; López-Ridaura, Masera, & Astier, 2002; Sadok et al., 2009; Van Der Werf & Petit, 2002). Depending on the respective study site, the analytical framework was adapted at the indicator level for each study site. Following Heink and Kowarik (2010), we define an indicator as a component or measure of relevant phenomena. While the developed indicators are mainly descriptive, some have a normative background (e.g. gender equality, animal health). Indicators are important as communication tools, breaking down complex realities into digestible

Table 1. Analytical domains and dimensions to assess agroecosystem health.

Domain	Dimension	Examples of indicators
Ecological	General	Natural features, resource recycling
	Soil	Nutrients, organic matter, erosion
	Plant	Diversity, intercropping
	Animal	Animal welfare, feed provision
Economic	General	Land tenure, hired labor
	Income	Yield, market access
	Expenditure	Input costs, trade-offs
	Investment	Farm investment, savings
Social	Human development	Housing, education
	Food security	Food availability, utilization
	Social relations	Decision making, integration

Based on Bockstaller et al. (2009); Cabell and Oelofse (2012); Friis-Hansen (2008); López-Ridaura et al. (2002); Sadok et al. (2009); Van Der Werf and Petit (2002).

messages at the science-policy interface (Heink & Kowarik, 2010; Müller & Burkhard, 2012).

3. Methods

3.1. Study sites and sampling

The study was conducted in Uganda over a period of four years in Ntungamo (2011), Mbale (2012), Busembatia (2013), and Bushenyi (2014) (see Figure 1, Table 2) as research part of the International Training Course on Organic Agriculture (ITCOA). The ITCOA is a programme for graduate students organized annually for three weeks in Uganda. 183 households were surveyed using participatory rural appraisal tools, a structured questionnaire, and soil sampling to capture information on ecological, social, and economic indicators.

3.2. Data collection

For each of the four study sites, we trained participants of the ITCOA in data collection and data analysis. During the fieldwork periods, teams of four to five students worked with the sampled farmers to assess the health of their farms. Each field team assessed at least six farms to ensure consistency. The study combined participatory rural appraisals to structure the interaction and facilitate data collection. The tools used included transect walks, farm mapping, seasonal calendars, daily clocks, matrix scoring and a mobile soil test kit. While biophysical data could be objectivized, we relied on self-assessments to examine farmers' perception of the status of economic and social health domains. With the participants' consent, the responsible team member recorded the data relating to the defined indicators on the reporting protocol. Each field team included a member able to translate from the respective local language (Ntungamo and Bushenyi: Runyankore; Mbale: Lugishu, Masaba; Busembatia: Lusoga) to English and vice versa. At the end of a fieldwork period, the data was presented and discussed in a feedback workshop and with each farmer individually.

3.3. Indicators

We referred to the eleven dimensions of the analytical framework to develop agroecosystem health-indicators. In each of the four years and as part of a participatory learning process, development practitioners, scientists and graduate students in cooperation with farmers and other stakeholders complemented the core set of indicators with indicators specific to the respective farming system at every study site (Table 3). Although the variation of indicators reduces the comparability of the results, it increased the relevance of the agroecosystem health assessment to the respective farming community and enabled them to draw site-specific management conclusions. To allow for comparison, the indicators were indexed across domains and dimensions and the scaling standardized from 0 to 100 with 100 representing the optimum.

3.4. Data analysis

For data analysis, the SAS and SPSS statistical software packages were used. In addition to standard descriptive procedures, we applied hierarchical clustering (Ward's method) and k-means clustering using Euclidean distance to classify farms based on the three health domains. The number of clusters that yielded the highest Cubic Clustering Criterion (CCC) value in the

Figure 1. Study sites in Uganda (illustration based on Open Street Map data).

hierarchical clustering was selected for the k-means procedure. To show the difference between clusters regarding the three health domains, we used one-way ANOVA (not to be considered a validation of the clustering) to allow for more detailed interpretation. For measuring associations between categorical variables, we used chi-square tests and controlled family-wise error rates with the Bonferroni correction in case of multiple testing. To interpret significant associations, we calculated standardized residuals.

4. Results and discussion

The sampled farms in the four locations were all assessed for agroecosystem health using the generic and site-specific indicators. We first summarize the site-specific results, before we develop clusters to draw more general conclusions.

4.1. Site-specific results

4.1.1. Ntungamo

The sampled soils among farms belonging to the 'Pineapple Innovation Platform' in Ntungamo on average showed a pH of 5.13, which is appropriate for pineapple production. Soil nutrient levels (NPK) and soil organic matter varied strongly, and in relation to pineapple demands were only of medium level. The hilly pineapple plantations were monocultures and measures to minimize erosion were usually not

Table 2. Study sites and samples.

Site	Description	Samples
Ntungamo	The town lies approximately 360 km Southwest of Kampala, at 1400 m a.s.l. in the Western banana-coffee-cattle agro-ecological zone (Mwebaze, 2006). Ntungamo experiences a tropical climate with bimodal rainfall that peaks in April and November with an annual mean of 1258 mm. The average temperature is 20.1°C. Soils are dominantly Lixic Ferralsols with an average low pH of 4.8, and low levels of organic matter and nitrogen (Nyombi, 2013).	The study population comprised of members of the 'Pineapple Innovation Platform', which was established in 2009 in the course of the Sub-Sahara Challenge Programme. The platform introduced the production of certified organic pineapples for the international market, and certification by CERES (Germany) according to EU and the United States National Organic Program (NOP) standards was obtained. 35 farmer members from Ruhaama and Ngoma sub districts were randomly sampled and participated in this study. The typical crop farm size was 3.5 acres, and main other crops grown included banana (matoke) and beans.
Mbale	Mbale is located approximately 245 km Northeast of Kampala, at 1145 m a.s.l. in the medium altitude intensive banana-coffee agro-ecological zone (Mwebaze, 2006). The region experiences a montane type of climate. Two rain seasons occur whereas average annual precipitation totals around 1500 mm; the mean monthly temperatures range between 15°C and 27°C. The catchment is highly influenced by past volcanic activities and the soil is very variable. The impermeable nature of most of the rocks makes the adjacent areas of Mt. Elgon vulnerable to landslides during wet seasons. Generally, the soils in the highlands are clays, while those in the midlands and the lowlands are clay loams or sandy (Mugagga, Kakembo, & Buyinza, 2012).	The population considered for sampling comprised of members of the 'Bufumbo Organic Farmers Association'. The members mainly produce organic Arabica coffee for the export market, but also beans and vanilla. First obtaining certification in 2008, the association holds certificates by CERES (Germany) for EU and NOP standards. 53 randomly sampled farmers in Bubyangu, Bukonde, Makonde and Bufumbo sub-counties participated in the study. The average farm size was 3.7 acres.
Busembatia	Busembatia is located in Iganga District, approximately 145 km Northeast of Kampala, at 1110 m a.s.l. The highland area is at the border of the intensive banana-coffee and the banana-millet-cotton agro-ecological zone (Mwebaze, 2006). Mean annual temperatures range from 25°C to 35°C. Soils are generally sandy; most of the land is dry land, the rest being wetlands/swamps with annual rainfall ranging between 1250 and 2200 mm (Mwaura, Katunze, Muhumuza, & Shinyekwa, 2014)	The sampling population considered for our study were members of the Nsinze Tuzuuke Organic Farmer's Association (NTOFA), which was established in 2003 with the support of the National Organic Agricultural Movement of Uganda.
Bushenyi	Bushenyi is located in Western Uganda at 1500 m a.s.l, approximately 330 km from Kampala in the banana-coffee-cattle agro-ecological zone (Mwebaze, 2006). The average temperature is 19.3°C and the soils are grouped under the sandy clay loams with alluvial parent rock. The area receives a bimodal rainfall (September to December and February to April) between 1000 and 1200 mm per annum (Muzoora, Turyahabwe, & Majaliwa, 2011).	The sample population consisted of farmers in the Kyeizooba and Mutara sub-counties growing organic Robusta coffee as cash crop and banana (matoke) and cassava as main food crops. 48 member farmers of the Ankole Coffee Farmers' Cooperative Union were selected through random sampling and participated in the study. The association has been inexistence since 2006 and holds a certificate by CERES (Germany) for EU and Fairtrade standards. The average farm size was 5.8 acres.

Table 3. Domains and indicators usage and descriptions.

Domain	Dimension	Indicator	Specification	Ntungamo	Mbale	Busembatia	Bushenyi
Ecological	General	Resource recycling	Systematic composting	●			
		Adaptability to climate change	Measures to counter climate variability and change			●	
		Drinking Water Quality	Access to safe drinking water		●		
		Waste Management	Separation and disposal of waste		●	●	●
		Natural Features	Number of features with additional value for the ecosystem				●
	Soil	Soil acidity	Crop appropriate pH	●	●	●	●
		Soil organic matter	Level of soil organic matter	●	●	●	●
		Soil nutrients	NPK level	●	●	●	●
		Soil erosion/degradation	Prevalence of gullies and rills	●	●		●
		Soil aggregate quality (0–20 cm)	Shape and texture of soil aggregates			●	●
		Soil Depth of A-Horizon	Soil depth of A-horizon			●	
	Plant	Crop Health	Share of plants showing disease or nutrient deficiency	●	●	●	●
		Crop/Plant biodiversity	Number of different crops (species) / unit area of land			●	●
		Leguminous Plants	Use of leguminous plants on farm			●	
		Intercropping/Multipurpose trees	Number of beneficial trees	●	●	●	●
	Animal	Animal Feed	Share of feed produced on-farm	●			●
		Animal Welfare	Health, condition and housing of animals on farm	●	●	●	●
		Animal Health	Signs of ill health or mistreatment		●	●	●
		Animal Waste Management	Waste management strategy				●
Economic	General	Intensity	Percent of land under agricultural production		●		
		Hired Labour	Ability to hire labour for farm work		●	●	●
		OvertimeLlabour	Amount of extra work hours needed in a given period	●			
		Land Tenure	Type and ratio of tenure		●		●
		Storage Capacity/Facilities	Type of on-farm storage facilities			●	●
	Income	Income Diversification	Access to skilled off-farm work		●		
		Need for External Income	Necessity to work off-farm to sustain the household	●		●	
		Casual Labour	Time spent in unskilled casual labour arrangements		●	●	
		Market Access and Stability	Stability and number of marketing channels	●	●	●	●
		Market Information	Knowledge about current market prices			●	
		Power to Negotiate	Farmer influence on farm gate price			●	
		Value Addition	Ratio of produce processed before selling		●	●	●
		Profit Trend	Yield compared to input cost over the past 3 seasons		●		
		Yield	Yield per acre, specific to crop and region	●	●	●	●
		Yield Trend	Change in yield over the past 3 years				●
	Expenditure	Expenditure Trade -offs	Competition between food, health and education	●			
		Need for External Inputs	Share of off-farm inputs				●
		External Input Cost	Total cost of external inputs / farm size	●	●		
		Inputs Cost Trends	Change of input costs over past 3 years				●
	Investment	Access to Credit	Availability and cost of credit				●
		Investment	Amount invested in the farm over a given period	●		●	
		Animal Ownership	Number of livestock units		●	●	
		Savings	Ability of the household to save	●	●	●	●
		Debts	Debt per household member	●			
Social	Human	Education of Children	Percentage of children who receive primary education		●		●

(*Continued*)

Table 3. Continued.

Domain	Dimension	Indicator	Specification	Ntungamo	Mbale	Busembatia	Bushenyi
	Development	Housing Conditions	Type of construction material		●	●	●
		Housing Separation	Degree of sharing housing with farm animals				●
		Energy Access	Access to electricity and cooking technologies		●		
		Sanitation	Handling of human waste			●	●
		Drinking Water	Type of water source and water-related diseases			●	●
		Human Health	Absence from work due to illness	●		●	
	Food Security	Food Availability	Prevalence of food shortages	●	●	●	●
		Food Utilization	Dietary composition of food	●	●	●	●
	Social Relations	Household Decision-making	Control of financial and natural resources	●	●	●	●
		Workload Distribution	Workload share between males and females		●	●	●
		Child Labour	Days per season children miss school for farm work	●	●	●	●
		Farmer Association	Activity and transparency of farmer association	●	●	●	●
		Agricultural Information Access	Type of information sources the farmer has access to			●	
		Ageing Agriculture	Age of the household head and spouse		●		
		Household Head	Marital status and gender		●		

implemented. Typically, farmers would use some plant residues and animal manure for composting, while the condition and housing standard of livestock was poor. Although the pineapple yields were only at 50%–75% of the regional average, on-farm agricultural activity was the only income for most of the households. The majority of households had to prioritize either health or education expenditures, and were not able to make substantial savings. Accordingly, the level of investment in the farm had been low over the past five years. 27.8% of the households had experienced food shortages for more than three months over the past year, and 22.5% could maintain a balanced diet throughout. Men usually took important decisions in the household after consulting the women, and the children's schooling had priority over farm work. The farming association in Ntungamo was active and farmers participated regularly.

4.1.2. Mbale

The farms were integrating coffee and food crop production with livestock and poultry rearing in an intensive agroforestry system. Although situated on the steep slopes of the Western foothills of Mt. Elgon, there were mostly no signs of erosion in the cropping areas. On average, the soil pH was below the optimum for coffee production, while the availability of soil nutrients was adequate and the soil organic matter was very high. The livestock (cattle, goats) were typically kept in zero-grazing units, with solid manure and organic household waste spread on-farm. For the typical household, the cash crop yield was stable at approximately the regional average, while profits over the last three years decreased slightly. More than 70% of the households owned cattle or oxen, and around 50% could afford to hire external labour once per season during workload peaks. Farming was the only source of income for 49% of households; 26.5% had a low, entry-level source of non-agricultural income, 24.5% a high-entry level source of non-agricultural income. The farms had stable market access through an organic buyer and conventional buyers. 20.8% of the households had experienced food shortages within the last year that lasted two months or more, and 17% could add meat to their diet less than once a month. Children were only expected to help at the farm when it did not interfere with their education. The male head of household primarily controlled cash crop income. In 37.7% of the cases, the age of both the head of household and the wife were above 55 years. The farmers' association was meeting at least every 3 months, but decisions were not necessarily taken in a process that was transparent and/or the function of members was not clear.

4.1.3. Busembatia

Farmers in Busembatia grew mangoes and Robusta coffee as cash crops along maize and other staple crops. The majority of farmers did not practice intercropping or using leguminous plants, and experienced substantial nutrient deficiency/pest and disease problems in their cash crop plantations. On average, the soils were rich in organic matter and showed moderate nutrient levels, but the soil pH was clearly below the optimum for coffee and mango plantations (measured separately). Most of the households owned cattle or oxen, which was usually kept on short tethering. Only a few farmers composted crop residues and elaborately managed organic waste. For the average household, cash crop yields were not stable and had declined from the previous season, so that farmers were not able to save. About 50% of the farmers engaged in non-agricultural off-farm labour because the farm did not create a sufficient income. The majority of farmers sold their produce unprocessed, 37.2% had permanent access to an organic buyer, while the remaining farmers had only irregular sales arrangements or frequently sold their produce to conventional buyers. In addition, the majority had access to price information only through buyers and acted as price takers. 46.8% of the households had experienced periods of food shortage within the last year that lasted two months or more, but the majority of households were able to maintain a balanced diet at the time of the study. Human disease was considered a serious challenge, with 61.7% of the heads of household refrained from work for three or more times during the previous year. Using the labour of children at the expense of schooling was not an option for any of the households. The daily clock exercise showed that women tend to work up to a third more hours per day than men, but the majority of households stated that decisions are taken jointly. The involvement in the farmers' association varied strongly, and the majority of farmers attended less than six meetings a year.

4.1.4. Bushenyi

The soils on the organic farms in Bushenyi on average showed a pH value of 4.5, which is slightly below the optimum for Robusta coffee, the main organic commodity in the study area. While phosphorus and potassium levels were sufficient, soil nitrogen and organic matter levels were only moderate. On the main cropping area, coffee was planted adjacent to staple crops, but intercropping was not a common practice. Signs of erosion such as gullies and rills were visible, but only outside of the main cropping area. Organic waste and livestock manure were largely collected and/or transferred to the top of slopes. The housing of farm animals was largely poor and outbreaks of farm animal diseases were common. The average farmer had experienced more than two months of feed shortage for farm animals within the last year. Crop yields were below the average in the last cropping season and varied strongly over the past three seasons. Accordingly, the households' abilities to collect savings and make investments were diverse, as input costs increased and 41.2% had no access to credit facilities. When needed, 45.1% of the households were able to hire external labour. The typical farmer in the study area dried and graded the coffee produced, and was in a contract farming arrangement (60.8%) with no influence on farm gate prices. 20.8% of the households had experienced substantial food shortages over the past year, while 33.3% had not experienced shortages. 47.2% of the households were not able to maintain a well-balanced diet throughout the year. The household workload was not evenly distributed, as in 68.7% of the cases women worked at least three hours more per day than men did. Men in consultation with women usually made decisions, and the children's education was prioritized over farm work. Only half of the respondents were continuously active in the farmers' association.

4.2. Site comparison

Overall, organic farms in Mbale scored highest in the ecological agroecosystem health domain (Table 4) considering that general ecological, soil, plant, and animal health scores were 70 points and above for all cases reviewed. The lowest scores were found in Busembatia for all except soil health. The same pattern was observed in overall economic health i.e. highest in Mbale and lowest in Busembatia. Bushenyi scored highly in social health for all but social relations. Busembatia scored lower compared with other areas but had a high rating in the human development capacity.

To further address the hypothesis of the study ('practicing certified organic agriculture increases

Table 4. Agroecosystem health scores (domains and dimensions) of organic farms: mean (SD).

Domain	Dimension	Ntungamo (*n* = 35)	Mbale (*n* = 53)	Busembatia (*n* = 47)	Bushenyi (*n* = 48)
Ecology		60.4 *(9.1)*	76.9 *(11.6)*	50.0 *(10.0)*	63.5 *(9.6)*
	General	54.1 *(26.0)*	73.5 *(19.4)*	43.6 *(28.8)*	53.1 *(22.8)*
	Soil	73.6 *(11.5)*	77.1 *(19.1)*	60.4 *(15.7)*	71.9 *(14.8)*
	Plant	52.7 *(15.6)*	77.7 *(20.0)*	44.7 *(15.4)*	73.4 *(12.3)*
	Animal	48.6 *(33.2)*	78.8 *(17.1)*	39.2 *(29.7)*	44.2 *(20.6)*
Economic		61.8 *(12.0)*	68.8 *(10.7)*	48.0 *(14.6)*	55.9 *(13.0)*
	General	63.6 *(33.4)*	73.8 *(19.6)*	41.0 *(31.5)*	74.0 *(19.4)*
	Income	77.8 *(16.0)*	69.9 *(14.5)*	45.3 *(15.9)*	46.6 *(20.8)*
	Expenditure	66.1 *(22.8)*	74.9 *(32.0)*	*	54.2 *(22.7)*
	Investment	47.6 *(26.3)*	55.6 *(26.2)*	60.3 *(26.1)*	51.3 *(32.8)*
Social		71.0 *(12.7)*	68.9 *(11.6)*	67.8 *(13.1)*	78.4 *(11.4)*
	Human Development	72.4 *(23.1)*	65.6 *(20.5)*	78.2 *(16.4)*	85.4 *(14.3)*
	Food Security	53.9 *(25.3)*	55.7 *(28.4)*	53.2 *(26.4)*	73.3 *(20.8)*
	Social Relations	81.9 *(18.0)*	75.2 *(12.0)*	64.8 *(17.3)*	73.2 *(16.0)*

*no data recorded.

economic, social, and ecological health of farms') and to explore possible patterns in the dataset, we performed a cluster analysis across all cases with the agroecosystem health domains as clustering variables. Four clusters yielded the highest CCC-value in the hierarchical clustering (Ward's method), so that we set the number of clusters to four in the following k-means clustering.

Figure 2 visualizes summary statistics and dispersion of ecological, economic, and social health scores of the four clusters. For each cluster, we chose a name that represents its most characteristic feature.

Cluster 1 comprises farms that scored highly in the ecological and economic domain, whereas social health scores were average. We call this cluster 'ecology-driven'. Farms in cluster 2 scored lowest in the economic domain, with average scores in the ecological and above average scores in the social domain. We call this cluster 'economically struggling'. In cluster

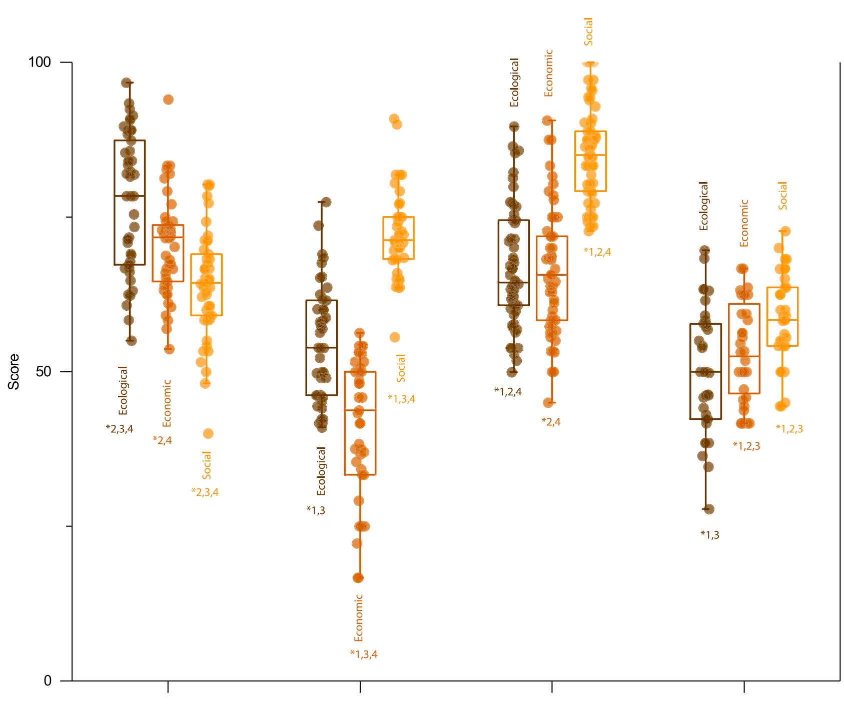

Figure 2. Plot of ecological, economic, and social health scores of four identified clusters (* denotes significant differences to other clusters).

Table 5. Standardized residuals of the cross-tabulation site*cluster.

	Cluster			
	1	2	3	4
Ntungamo	−.9	−.4	.3	1.2
Mbale	6.2	−2.4	−1.4	−2.6
Busembatia	−3.1	2.4	−2.3	3.9
Bushenyi	−2.6	.5	3.5	−2.1

3, farms scored highly in the social domain with a balanced scoring for the ecological and economic indicators. We call this cluster 'socially-driven'. The last cluster (4) scored lowest in the ecological and social domain but maintained average scores in the economic domain. We call this cluster 'hanging in'.

For analysing the association between clusters and study sites, we used cross tabulation with Pearson's chi-square test (Bonferroni corrected). There was a significant association between the study site and the clustering variable: $\chi^2(9) = 115.55$, $p < .001$. To further interpret the association, we interpret the standardized residuals of the cross tabulation as *z*-scores (Table 5). Scores that do not fall between −1.96 and 1.96 were considered as significant.

The results show that the distribution of Ntungamo farms across the clusters does not deviate significantly from expected counts. Farms in Mbale, however, are highly overrepresented in the 'ecology-driven' cluster, and significantly underrepresented in the 'economically struggling' and 'hanging in' clusters. Farms in Busembatia were significantly more likely to be 'hanging-in' or 'economically struggling' than being 'ecology-driven' or 'socially-driven'. Bushenyi farms were significantly more likely to be 'socially-driven' and unlikely to be 'ecology-driven' or 'hanging in'.

5. Discussion

In the following section, we discuss the contribution of certified organic agriculture to the ecological, economic, and social health of agroecosystems. We structure the discussion along the results of our cluster analysis.

5.1. Ecology-driven farms

Our hypothesis was that practicing certified organic agriculture would increase and balance agroecosystem health, including the ecological domain. Taking into account that the indicators in the ecological domain were mostly referring to agricultural practices rather than ecological preconditions, our findings do not support the hypothesis. Farms in the ecological cluster (1), mainly located in Mbale, are at the outset favoured by fertile soils (Mugagga et al., 2012) and the local climatic conditions. This, however, does not explain why farms differed significantly in all domains of ecological health across the study sites. Rather, we attribute the difference to the fact that only farms in the ecology-driven cluster were applying key strategies of organic agroforestry: shading and mulching in an integrated cropping system. Earlier studies found that such practices contribute significantly towards lower soil temperatures as well as soil nitrogen recycling and increased soil organic matter (Imru, Wogderess, & Gidada, 2015; Mafakheri, Siosemardeh, Bahramnejad, Struik, & Sohrabi, 2010; de Notaro, de Medeiros, Duda, Silva, & de Moura, 2014; Tumwebaze, Bevilacqua, Briggs, & Volk, 2012). The farmers, particularly in clusters 2 and 4, made little effort to control erosion and nurture soil health, which are main principles of organic agriculture (Hanson, Dismukes, Chambers, Greene, & Kremen, 2004; Pimentel, Hepperly, Hanson, Douds, & Seidel, 2005). Intercropping or crop rotation using leguminous plants were not used, as cash and food crops were grown on separated mono-culture plots. On such farms, the pest/disease pressure was reported to be higher and the soil nutrient status was not optimal. Although Aigelsperger (2007) and Adebiyi (2014) found that Ugandan farmers increased the diversity of crops when converting to organic agriculture, Aigelsperger (2007) also showed that focusing on single cash crops in contract schemes can reduce the resilience of the farming system and the stability of food availability. In general, it is problematic to maintain positive nutrient balances in tropical organic agriculture (Patil, Reidsma, Shah, Purushothaman, & Wolf, 2014) – focusing on closed nutrient cycles, on-farm fixation, and mobilization, and is therefore all the more important. Farms in the ecology-driven cluster explicitly integrated livestock into the farm system – they used solid and liquid manure in combination with composting to improve soil fertility. The crucial role of livestock in tropical organic agriculture is firmly established in the literature (Melse & Timmerman, 2009; Miele, Veissier, Evans, & Botreau, 2011). We conclude that certified organic agriculture can contribute to the ecological health of farms if the transition process is conducive to the implementation of key organic agricultural practices. However, the market-led pathway to organic agriculture may focus on certification requirements only and thus encourage 'organic by default', characterized by refraining from chemical input use. In combination with the typical specialization in cash-cropping, this may not improve the ecological health of smallholder farms in Uganda or may even put them at risk.

5.2. Economically-struggling farms

The main development strategy in the Ugandan organic sector has been to generate additional income through the export of certified produce to international markets (Adebiyi, 2014; Aigelsperger, 2007; Rundgren & Lustig, 2007). Bolwig (2012) and Jacobsen (2009) established that Ugandan farmers' income had increased since converting to organic agriculture. Since a substantial domestic market has not evolved, this impact is largely determined by the stability of demand and access to international markets. In the economically-struggling cluster, the cash crop yields were unstable and the producers were price-takers in variable relationships with buyers. Further, more farmers than in other clusters sold their produce unprocessed. We thus suggest to add nuance to the argument of increased income through certified organic agriculture: yield, market demand, and bargaining power are some of the specific factors that dynamically affect farm income.

In particular, the yield gap between conventional and organic agriculture has spurred a lot of debate in the past and was summarized in a number of meta-studies (Ponisio et al., 2015; De Ponti, Rijk, & Van Ittersum, 2012; Seufert et al., 2012). Generally, even conventional farms in Uganda may attain less than half of the locally-attainable yield (Tittonell & Giller, 2013) – consequently, well-managed organic farms could perform relatively better than current conventional systems. For typical organic cash crops such as fruits and coffee, the assumed yield gap is smaller than for that of cereals, roots, and tubers. Reaching the optimal yield for a specific organic system in a given area would however require an investment in labour-intensive organic farming strategies (e.g. nutrient management, weed control) – this investment was low in the economically-struggling cluster.

For marketing purposes, groups of organic smallholder farmers in Uganda are typically linked to a trading company or project, which holds the certificate on their behalf due to the high cost of certification. This underlines the powerful role of trading companies or development projects when farmers attempt to translate organic production standards into added value (Araki, 2007) – participatory certification schemes have been an attempt to address this issue but are of limited relevance in the export-oriented organic model. At present, certified organic farmers have little room to ascertain their position towards traders.

In our sample, the typical strategy to cope with the insufficient farm income for farmers was to engage in casual off-farm labour – which further limits the ability for households to engage in labour-intensive organic practices. This may in turn lead to a lock-in situation when struggling farms cannot move into a state in which they can benefit from organic certification. Indeed, households in the economically-struggling cluster were also stating a lower ability to collect savings and make investments.

Our conclusion is that organic certification alone does not guarantee economic health for smallholder farmers and can create lock-in situations if a farm is struggling and cannot easily change its type of production. Certification thus needs to be complemented by establishing a resolute market position, an investment in the ecological base of the farming system and by savings and loan institutions. Policies and interventions promoting organic agriculture should take this into account and acknowledge possible risks smallholder farmers take by converting to cash crop-oriented certified organic farming.

5.3. Socially-driven farms

The proponents of organic agriculture posit benefits beyond ecological and income effects – including improved health, better working conditions and social cooperation (Allen & Kovach, 2000; Mishra, Deep, & Choudhary, 2015; Pretty, Morison, & Hine, 2003; Shreck, Getz, & Feenstra, 2006). Earlier studies have shown that organic agriculture can create social capital, contribute to community development and increase interactions through its institutional requirements, support, and subsequent adaptation (Altenbuchner, Larcher, & Vogel, 2016; Jouzi et al., 2017; Khosla, 2006; Qiao, Halberg, Vaheesan, & Scott, 2016; Reganold & Wachter, 2016). In East Africa, group certification schemes through internal control systems are a key institutional mechanism (EuropeAid, 2012; Preißel & Reckling, 2010). Farmers and the community at large are normally able to gain knowledge and skills in these forums (Kelly & Metelerkamp, 2015). Other studies found moreover that organic certification can increase food security and dietary quality for smallholder farmers in Uganda (Aigelsperger, 2007; Chiputwa & Qaim, 2016; Gibbon et al., 2008). Regarding gender relations, the literature indicates two possible effects of certification: on the one hand, trainings and implemented standards may empower women – on the other hand, the workload for women may increase (Chiputwa & Qaim, 2016; Jouzi et al., 2017).

Our findings showed that farms in the socially-driven cluster performed better in the key domain of food security, the workload was shared more equally and farmers were more active in associations. At the same time, ecological and economic performances were only average. This allows for several interpretations: a trade-off may exist between a more complete implementation of organic agricultural practices and equal workload distribution – as suggested by earlier studies. Moreover, and as evident from the results of the economically-struggling cluster, social agroecosystem-health does not seem to correlate with economic health. In fact, social cooperation may increase when communities cope with economic challenges. The fact that across all clusters food shortages in certified organic farms prevailed is a general cause of concern.

In conclusion, we agree with Reganold and Wachter (2016) that farm-system research on social aspects – both in conventional and organic systems – is suffering from a lack of data, probably due to conceptual and methodological challenges. Accordingly, we propose to devote resources and efforts to further develop concepts of social health in farm system research. An even more challenging question will be how aspects of wellbeing and social health can be translated into certification standards and thus product attributes.

5.4. Hanging-in farms

The notion of 'hanging-in' was introduced by Dorward (2009) to describe livelihood strategies in development mainly 'concerned to maintain and protect current levels of wealth and welfare'. In our study, farms in the cluster we consider as hanging-in scored lowest in the ecological and social domain but showed average scores in the economic domain. We suggest that farms in this cluster maintain a fair economic status, but face ecological and social trade-offs.

The agronomic practices in this cluster did not go beyond 'organic-by-default', just barely ensuring compliance with organic standards, lacking composting, and intercropping, which are considered key nutrient management strategies in organic agriculture (Villio & Arrouays, 2001; Wszelaki, Saywell, & Broughton, 2012). The suboptimal soil conditions, fluctuating yields, and increasing pest and disease pressure characterized both cash and food crop production. The main social challenge in this cluster was the prevalence of food shortages and a lack of dietary diversity. A plausible explanation may be that households were not able to compensate for reduced food crop production through higher cash crop income (Bolwig & Odeke, 2007). As Aigelsperger (2007) observed, certified organic farmers in Uganda tend to prioritize inputs and efforts away from food crops, which can create risks when the (monoculture of) cash crops fails.

In conclusion, certified organic agriculture can contribute to a disintegration of farming systems and put food security at risk if the additional income is not sufficient to compensate for the reduced area and effort devoted to the production of food crops. This underlines the need for full-farm conversion and comprehensive implementation of organic principles to safeguard food security.

6. Conclusion

Considering the need for a robust understanding of the effects of certified organic agriculture on agroecosystem health, we contrasted data from four farming systems in Uganda with principles and objectives of organic agriculture. Our main finding is that certified organic farming per se does not guarantee the maintenance and/or enhancement of agroecosystem health.

- Ecological health was largely determined by the extent to which farmers applied key strategies of organic agroforestry. However, a large proportion of farms only practiced 'organic by default' to comply with certification standards.
- Economic health was mainly determined by the stability of cash crop yields and access to international markets. The typical coping strategy in case of insufficient income was to engage in casual off-farm labour. Struggling farms may be locked-in when they are not able to make sufficient investments in their ecological base or change crop production strategy.

- Social health did not explicitly correlate with other aspects of agroecosystem health. Food shortages occurred in all study sites, being a general cause of concern.

We conclude that the effects of certified organic agriculture on agroecosystem health are ambiguous, and emerge from an interplay of location, market, institutional setting, and management practices. More information on the costs and returns of a conversion to organic agriculture in different agroecosystems would help interventions promoting organic agriculture to draw a realistic picture of the risks and opportunities for farmers. Finally, future research should address how organic agriculture standards and their implementation could better capture agroecosystem health in its complexity.

Acknowledgements

We used first-last-author-emphasis to determine the order of authors. The other co-authors are ordered by relative contribution. We are grateful for the funding received for this research by the Austrian Commission for Development Research. The International Training Course on Organic Agriculture whose participants collected the data was supported by the Biovision Foundation and the Karl Kahane Foundation. The donors did not influence the research process at any stage.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by Austrian Commission for Development Research; Biovision Foundation; Karl Kahane Foundation.

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