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How is organic farming performing agronomically and economically in sub-Saharan Africa?

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ABSTRACT

The potential of organic agriculture and agroecological approaches for improving food security in Africa is a controversial topic in global discussions. While there is a number of *meta*-analyses on the environmental, agronomic and financial performance of organic farming, most of the underlying data stems from on-station field trials from temperate regions. Data from sub-Sahara Africa in particular, as well as detailed real-farm data is scarce. How organic farming is implemented in sub-Saharan Africa and how it performs in a smallholder context remains poorly understood. We applied a novel observational two-factorial research design, which allowed to evaluate the impacts of i) interventions for introducing organic agriculture and ii) specific organic management practices on 1,645 farms from five case studies in Ghana and Kenya, which we closely monitored for 24 months. Among the farmers who have been exposed to the interventions, we found heterogeneous adoption of organic agriculture principles, depending on the intervention. Furthermore, we found rather passive than active organic management among farmers. Most yields and gross margins under organic management remained at similar levels as the conventional values in four of the case studies. In one case study, however, coffee, maize and macadamia nut yields increased by 127–308% and farm-level gross margins over all analysed crops by 292%. Pooling our data across all case studies, we found significantly higher (+144%) farm-level gross margins on organically managed farms than on conventional farms. This indicates the potential of organic and agroecological approaches if implemented well. Based on our observations, we argue for improving the implementation of organic agriculture projects in settings with smallholder farmers. Limited capacities, lack of appropriate inputs and market access are major agronomic and institutional challenges to be addressed. Furthermore, we argue for supporting a differentiated debate about which types of organic farming are really desirable by classifying approaches to organic farming according to i) their intention to work organically and ii) the degree of following the organic principles. This will support the design and implementation of targeted policy interventions for stimulating sustainability of farming systems and rural development.

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1. Introduction

Organic agriculture (OA) is a globally-applicable environmentally-friendly alternative to conventional farming systems, which strives for the principles of health, ecology, fairness and care (Luttikholt, 2007). Its fundamental agronomic core characteristic is to aim at a circular system by reducing external inputs, in particular through the ban of chemical inputs such as synthetic pesticides and mineral fertilisers (Reganold and Wachter, 2016; Seufert et al., 2017). The environmental impacts are linked to the lower chemical input use and the agronomic practices that need to be implemented for compensating these inputs, such as a wider crop rotation, active nutrient management via compost, manure and nitrogen-fixing legumes and an increased use of preventive and biological pest management strategies. Therefore, many studies show clear environmental benefits in terms of biodiversity promotion, soil organic matter, reduced energy use as well as less greenhouse gas emissions, and decreased pollution of water, soil, and air (Gattinger et al., 2012; Lori et al., 2017; Mäder et al., 2002; Meier et al., 2015; Schader et al., 2012). By this, organic farming can contribute to addressing some of the global environmental challenges related to food production (Muller et al., 2017; Rockström et al., 2009; Steffen et al., 2015; Willett et al., 2019). However, the main drawback for organic farms are the often lower yields, which partly offset these benefits when environmental benefits are evaluated from a per-output perspective (Meier et al., 2015; Seufert and Ramankutty, 2017; Tuomisto et al., 2012; van der Werf et al., 2020).

Agroecological practices are compatible with the principles of organic agriculture and can enhance the agronomic performance and potential of the system to adapt to climate change (Sinclair et al., 2019). Unlike other agroecological approaches, the strict ban of chemical inputs as a clear minimum criterion, allows to evaluate whether farmers are working organically or not (Fouilleux and Loconto, 2017; Pekdemir, 2018; Seufert et al., 2017). From a food supply chain perspective, standards allow to communicate such a compliance, via globally applicable third-party certification systems. Such certification allows to generate financial benefits in terms of price premiums for farmers who comply with basic standards and contributed largely to the adoption of organic farming in many countries, particularly in Europe and the US (Crowder and Reganold, 2015; Willer et al., 2020).

In SSA, the uptake of conscious organic farming is still low with about 0.2% of the agricultural land (Willer et al., 2020). This is particularly interesting, as most conventional smallholder farmers in SSA often suffer from low productivity and marginal incomes from their farming activities (Collier and Dercon, 2014; McCullough, 2015). African farmers perceive organic farming often as a foreign farming system, as its rules are given by foreign organisations and crops are often produced for foreign consumers. This hampers adoption and ownership by smallholder farmers (Jouzi et al., 2017; Kamau et al., 2018; Vaarst, 2010). Currently, OA is implemented in SSA with diverse aims and rationales, which blur general statements that are often made about organic systems (Bennett and Franzel, 2013; Seufert et al., 2017; Willer et al., 2019). For instance, there are many non-certified OA projects in SSA, often established to supply healthy and safe food for local markets, while third party certified OA projects primarily aim at export markets in Europe or North America (Ibanez and Blackman, 2016; Reganold and Wachter, 2016). For OA to be accepted by farmers and to diffuse in sub-Saharan Africa, it needs to be manageable, productive (De Ponti et al., 2012; Muller et al., 2017; Seufert et al., 2012) and profitable (Crowder and Reganold, 2015; Meemken and Qaim, 2018; Seufert and Ramankutty, 2017).

The agronomic and economic performance of OA has been scrutinised by academics, with multiple shortcomings regarding methods and data availability. While meta studies have analysed comprehensive global datasets, there is little empirical data available for SSA (Crowder and Reganold, 2015; Seufert et al., 2012). Impact assessments of single projects in SSA have often studied success stories qualitatively, without providing a clear baseline or counterfactuals and without being able to clearly separate the effect of the agronomic system versus the accompanying training or further institutional measures (Bolwig and Gibbon, 2009; Meemken et al., 2017; Ssebunya et al., 2018). On-station field trials tend to disregard the context of smallholder farming (Adamtey et al., 2016; Crowder and Reganold, 2015; Ponisio et al., 2015; Seufert et al., 2012) by assuming the general availability of adequate agronomic knowledge, high-quality inputs and market access. This is despite the many studies showing that OA is highly knowledge and management-intensive and that access to both high-quality organic inputs and functioning markets can be challenging (Meemken and Qaim, 2018). Additionally, studies often focus on export-oriented certified crops (Bolwig and Gibbon, 2009; Ssebunya et al., 2018), disregarding the farming systems they are embedded in and neglecting various other forms of OA and their great diversity of agronomic practices and economic performances (Bolwig and Gibbon, 2009; Ssebunya et al., 2019; Tittonell et al., 2010; Tittonell et al., 2005).

Therefore, there is little evidence on the agronomic and economic performance of OA as implemented by smallholder farmers in SSA, with some evidence at times even biased (Porciello et al., 2020). Thus the controversial debate regarding OA in SSA is often more ideological than based on facts and empirical data (Meemken and Qaim, 2018; UNCTAD and UNEP, 2008). Consequently, for understanding the potential of OA in SSA as a basis for livelihoods of smallholder farmers and for achieving environmental and economic objectives, more evidence on the way OA is actually implemented on real farms and the resulting yields and economic performance are needed.

This study fills this gap through analysing how OA is implemented by smallholders and assessing its agronomic and economic impacts, for a large number of smallholder farms in East and West Africa, covering different agroecological zones and business contexts. The study's specific targets were i) to analyse how OA is implemented in different agroecological contexts and market rationales; and ii) to analyse the effect of organic farming practices on productivity and profitability at crop and farm level.

To achieve these two objectives, we developed an observational two-factorial evaluation framework and applied it to 1,645 farms in five case studies with different approaches to OA. Each case study consisted of a group of farmers that had been exposed to an intervention for changing their management practices to organic farming prior to the study and a control group that has not been exposed to this intervention. We classified the farms in each case study to a) whether they participated in the respective organic interventions (Organic Intervention Group vs. Control Group) and b) whether they were using mineral fertilisers and/or synthetic pesticides (Organic Management Group vs. Non-organic Management Group) (Fig. 1). This allowed for the evaluation of two effects:

A. For evaluating the **effect of the organic interventions on the adoption of organic practices**, we compare the Organic Intervention Group with the Control Group (Fig. 1, vertical comparison).
B. For evaluating the **effect of organic farming practices on productivity and profitability at crop and farm level**, we compared the Organic Management Group with the Conventional Management Group (Fig. 1, horizontal comparison).

2. Materials and methods

2.1. Case study selection

We chose a transdisciplinary approach to the design and implementation of this study, which purposefully included the opinions of external stakeholders in the selection of case studies and development of research questions. The rationale behind selecting the case studies was to cover the relevant agroecological (i.e. humid and semi-arid), agronomic (i.e. predominantly arable and predominantly perennial systems) and commercial contexts (i.e. focus on non-certified production for local

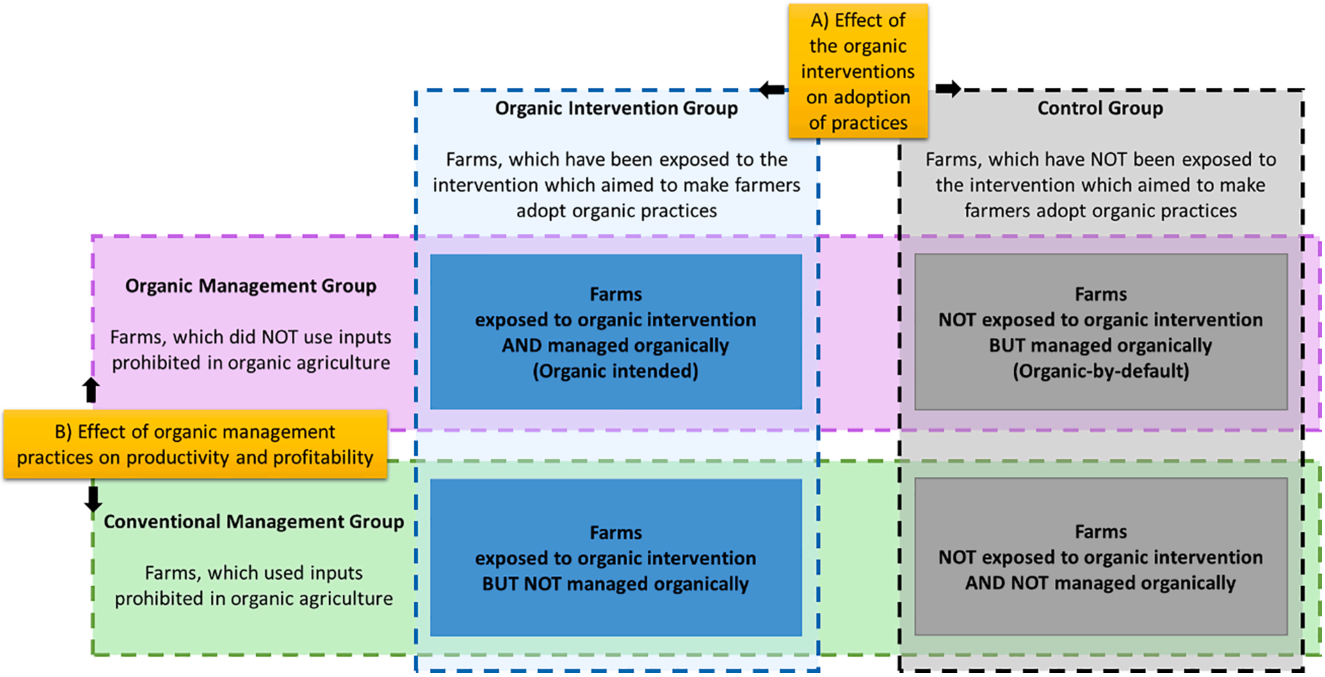
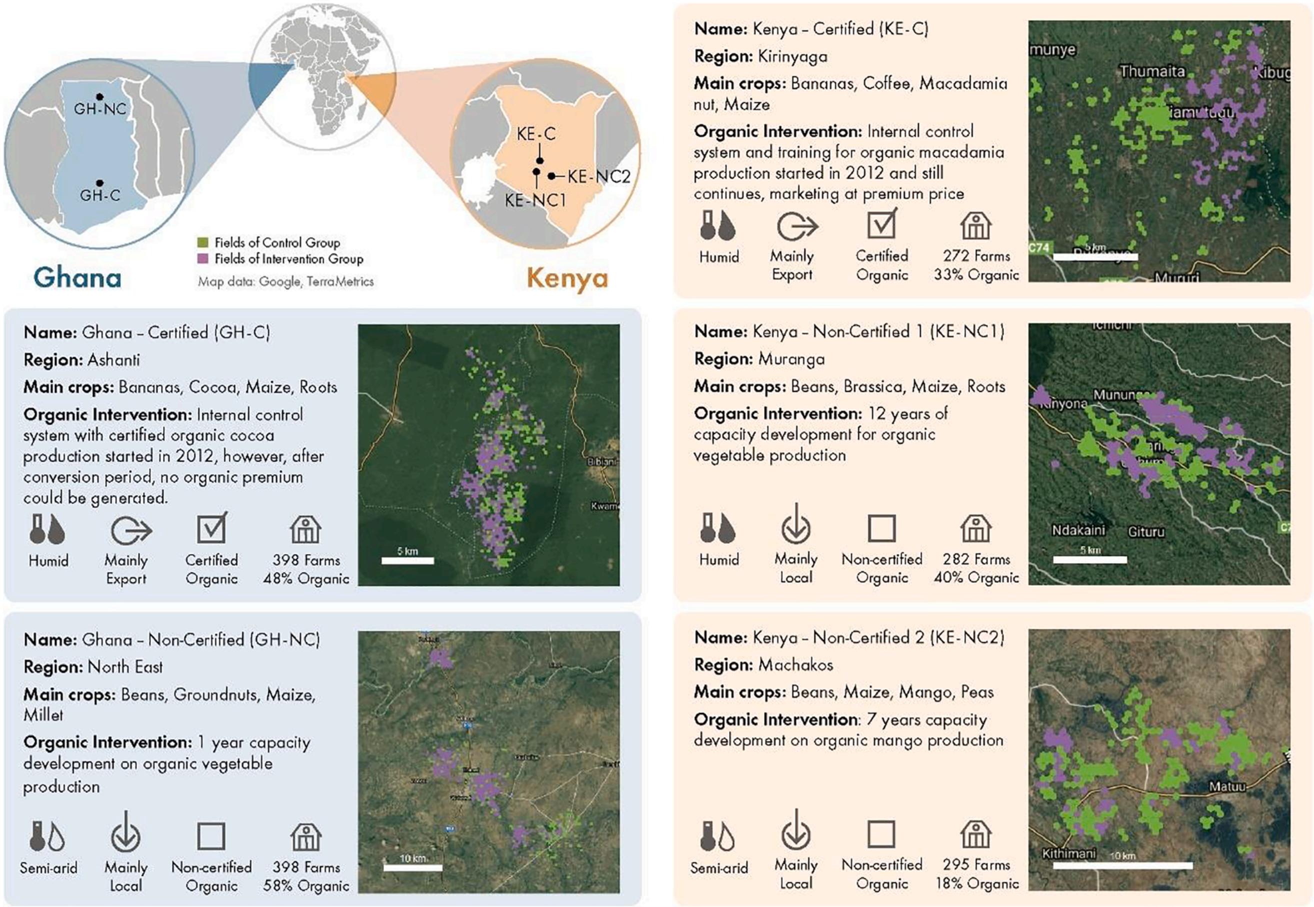


Fig. 1. Generic analytical framework for the evaluation of the effect of A) organic interventions on the adoption of organic management practices and B) the effect of organic practices on productivity and profitability of farms.



Name: Ghana – Certified (GH-C)
Region: Ashanti
Main crops: Bananas, Cocoa, Maize, Roots
Organic Intervention: Internal control system with certified organic cocoa production started in 2012, however, after conversion period, no organic premium could be generated.
Humid | Mainly Export | Certified Organic | 398 Farms 48% Organic

Name: Ghana – Non-Certified (GH-NC)
Region: North East
Main crops: Beans, Groundnuts, Maize, Millet
Organic Intervention: 1 year capacity development on organic vegetable production
Semi-arid | Mainly Local | Non-certified Organic | 398 Farms 58% Organic

Name: Kenya – Certified (KE-C)
Region: Kirinyaga
Main crops: Bananas, Coffee, Macadamia nut, Maize
Organic Intervention: Internal control system and training for organic macadamia production started in 2012 and still continues, marketing at premium price
Humid | Mainly Export | Certified Organic | 272 Farms 33% Organic

Name: Kenya – Non-Certified 1 (KE-NC1)
Region: Muranga
Main crops: Beans, Brassica, Maize, Roots
Organic Intervention: 12 years of capacity development for organic vegetable production
Humid | Mainly Local | Non-certified Organic | 282 Farms 40% Organic

Name: Kenya – Non-Certified 2 (KE-NC2)
Region: Machakos
Main crops: Beans, Maize, Mango, Peas
Organic Intervention: 7 years capacity development on organic mango production
Semi-arid | Mainly Local | Non-certified Organic | 295 Farms 18% Organic

Fig. 2. Overview of the locations and main characteristics of the five case studies in Ghana and Kenya and the interventions for introducing organic agriculture to farmers.

Table 1

A) Number of organic and conventional the intervention and control groups of each case study. B) share of farmers not using any inputs prohibited according to organic standards (based on EU Regulation EU Regulations 834/2007, 889/2008 and 1235/2008). C) Estimated average treatment effect on the treated regarding adoption of organic farming practices.

	GH-C	KE-C	GH-NC	KE-NC1	KE-NC2
A) Number of farms in organic and conventional farms in intervention and control groups					
Organic Intervention / Organic management (Organic intended)	59	83	38	47	15
Organic Intervention / Conventional management	134	7	194	66	39
Organic Intervention Group - Total	193	90	232	113	54
Control / Organic Management (Organic-by-default)	12	0	2	35	25
Control / Conventional management	193	182	164	134	216
Control Group - Total	205	182	166	169	241
Total number of farms	398	272	398	282	295
B) Proportion of farmers not using any inputs prohibited according to organic standards					
Organic Intervention group	30.6%	92.2%	16.4%	41.6%	27.8%
Control group	5.9%	0.0%	1.2%	20.7%	10.4%
C) Adoption of organic practices (Average effect of the treatment on the treated)					
Non-use of conventional inputs					
Non-use of mineral fertilisers	**0.12****	**0.41*****	0.09	**0.09****	0.07
Non-use of chemical pesticides (excl. Herbicides)	**0.27*****	**0.52*****	**0.01*****	**0.12****	**0.18*****
Non-use of chemical herbicides	0.03	**0.79*****	0.05	**1.00*****	0.02
Substitution of conventional weed, pest and disease management					
Application of non-chemical pesticides and fungicides	0.08	−0.03	−0.01	−0.02	0
Application of mechanical or manual weed control	−0.06	−0.03	0.01	−0.02	−0.08
Substitution of mineral fertilisers					
Application of organic fertilisers	−0.04	**0.12***	**0.11****	−0.04	**−0.09****
Use of cover crops	0.01	−0.05	−0.01	−0.02	0.02
Mulching	0.02	0.01	−0.10	0.00	−0.13
Incorporation of crop residues	0.00	0.01	**0.03***	−0.02	**−0.08***
Further agroecological and preventive practices					
Reduced tillage	0.07	−0.07	−0.01	−0.01	0
Diverse crop rotation	−0.04	**−0.24****	**0.01****	**0.13***	**−0.22****
Agroforestry	−0.07	−0.07	−0.02	0.00	0.05
Intercropping	0.04	0.06	**−0.03***	0.00	**0.05***
Application of measures to prevent soil erosion	0.01	−0.01	0.04	0.00	0.03

Significance levels: *** = $p<0.001$, ** = $p<0.01$, * = $p<0.05$.

markets, or on certified production for export markets) in which organic agriculture is implemented in SSA. Kenya and Ghana were selected as focal countries for the following reasons: i) in both countries, there is a substantial share of area under organic agriculture, ii) the existence of organic crop production for export, and iii) the existence of local scientific partners with whom prior experiences in collaboration existed and who could implement the study. In both countries, relevant organic farming initiatives (eight in Kenya, five in Ghana) were mapped, visited and evaluated according to the following criteria: a) a sufficient number of individual smallholder farms, which complied with the farm selection criteria (see below), b) the willingness of the organic initiative operators to cooperate with the research team, and c) coverage of a wide range of agroecological, agronomic and commercial contexts. Out of these 13 organic initiatives, we selected five, referred to as case studies hereafter. The selected case studies (two in Ghana, with one of them being certified (GH-C), and one non-certified (GH-NC), and three in Kenya, one of which was certified (KE-C) and two non-certified (KE-NC1, KE-NC2)) are described in Section 3.1 and Fig. 2.

2.2. Farm selection

As a first step, we characterized the population of organic farms in each case study area, according to the socio-demographic and agronomic data collected by the organic interventions and defined criteria for selection: farms had a) to be located not more than 50 km away from each other, b) to be exposed to the intervention, which aimed at the adoption of organic agriculture, at least three years prior to the start of the data collection period in July 2014, and c) to meet or exceed the minimum farm size (KE-C: 5 macadamia trees, KE-NC1: maximum of 3 ha of farm land, KE-NC2: 5 mango trees; for the case studies in Ghana, the maximum farm size was 10 ha).

In a second step, we stratified the organic farms according to village, and randomly selected organic farms in each stratum. In a third step, we randomly selected similar conventional farms in each stratum. These conventional farms needed to meet the same size criteria as the organic farms.

In total, the local research partners randomly selected 300 farms for each of the three case studies in Kenya and 400 farms for each of the two case studies in Ghana (see Table 1A for final numbers) and sensitized the farmers, in a series of workshops, on the study's objectives and the intensive data collection involved.

2.3. Data collection

In each case study, the research team assigned a data collection team with a site manager and a group of 10–20 enumerators. The enumerators were trained and monitored extensively in order to ensure homogenous, comparable and high-quality data. Data was collected for five cropping seasons from August 2014 to March 2017. Season 1 (August 2014 – March 2015) was used as a pre-test for training the enumerators and for tailoring the questionnaire contents and procedures to the research necessities. Farmers who were literate entered all relevant information into farmers' field books designed by the researchers. Less literate farmers were supported in keeping regular records of their farming activities by literate family members or farmers' secretaries (literate people from the village who were paid by the project). In Ghana, about 200 visits of an average of one hour each were paid to each farmer by the enumerators or farmers' secretaries. In Kenya, the enumerators transferred the information from farmers' field books fortnightly (about 100 times in total) to the electronic questionnaire for 2–3 h per visit over two years (four seasons).

The questionnaire was an electronic Excel file with an automatic upload function to a database in which all data was stored. The questionnaire contained 20 sheets comprising all the relevant information about each farm concerning inputs, outputs and processes. For each farm, fields were identified and marked on a sketch map. We measured the size of all fields on a farm using handheld GPS devices. Fields were subdivided into plots if several crops or intercropping patterns were found in one field. For each plot, all crops were documented. For each crop on each field, we documented inputs and outputs as well as which agronomic activities were performed. Finally, all inputs and outputs were documented in physical and monetary units (Figure S5). Physical quantities of yields were determined by using standardized measuring containers and calibrating the farmers' own containers (e.g. baskets, bags, wheelbarrows, buckets, tins, etc.) accordingly. This allowed the farmers to measure the quantities used and harvested with their own containers, yet allowed a standardization of these containers for comparability.

2.4. *Characterization and analysis of farm management practices*

To understand how farmers practiced OA, we analysed the rate of adoption of organic practices at two levels: first, we looked at the number of farms which did not use any conventional inputs (inputs prohibited in OA based on EU Regulations 834/2007, 889/2008 and 1235/2008) on any of their plots during any of the seasons over the two years, referred to from here on as "**Passive Organic Management (POM)**". Second, we investigated how farmers substituted these inputs by means of preventive measures and/or productivity-enhancing inputs which are permitted in OA or by agroecological practices, referred to as "**Active Organic Management (AOM)**". To understand the extent to which farmers implemented AOM, proxies were defined based on 23 farm-level indicators from the sustainability assessment method SMART-Farm Tool (RRID:SCR_018197) (Schader et al., 2016; Schader et al., 2019) implemented on the same farms as the productivity and profitability study (Table S7). The performance of each farm with respect to each indicator was evaluated according to a function defined within the SMART-Farm Tool. Indicator scores were aggregated and normalized using an equal-weight approach. A score of 0% means that a farmer did not use any practices associated with AOM at all, while a score of 100% means that a farmer fully implemented all AOM options.

2.5. *Analysis of productivity and profitability*

We used R (https://www.R-project.org/) for computing the parameters relevant for assigning productivity and profitability at farm, crop, field, and plot level. All physical flows into and out of the farm were allocated to crops, fields, plots or livestock activities. Additionally, we allocated all labour activities to specific fields, plots and crops or livestock activities. We collected farm-specific price data for labour, land, inputs and sales. For labour prices, based on the median of the data received and in order to ensure comparability between the farms, we fixed labour prices at the level for non-permanent employees above 18 years at 3.00 Ghanaian cedis (GHS) (GH-C), 37.50 Kenyan shillings (KHS) (KE-C), 1.67 GHS (GH-NC), 37.50 KHS (KE-NC1) and 46.43 KHS (KE-NC2). This set-up allowed calculating farm, crop, field and plot-specific key performance indicators such as quantities of physical inputs, labour, total input costs, yields, revenues, gross margins, land and labour productivity.

2.6. *Data management and verification*

Achieving high data quality standards with survey data from smallholder farmers is challenging. Therefore, we implemented a complex iterative data verification and correction process alongside the data collection to ensure complete, valid and consistently high-quality data (Figure S6). To minimize possible response errors, participating farmers and field secretaries were trained in record keeping prior to and during the data collection. Several other measures were applied to reduce respondent/farmer fatigue: interviews were kept brief (max 1.5 to 2 h), but were performed on a regular basis. To maintain farmers' motivation over the entire course of the project, all the participants received small yearly tokens of appreciation, which did not influence their farming practices. To reduce data entry errors, ongoing training of enumerators, together with support and supervision, were established in all five case study sites, including seasonal workshops, video tutorials and peer review sessions among the enumerators as well as regular checks of enumerators' performances. Carefully designed questionnaires, including instant validity checks were used to ease the data entry and reduce mistakes. Through this, enumerators were enabled to directly identify and correct errors. After data collection, the completed questionnaires were uploaded to the central Microsoft Access database and passed through multiple procedures for data quality, checking to detect syntactical, semantic and coverage anomalies within each questionnaire. Automated database queries were set up, resulting in enumerator-specific data quality reports, each encompassing greater than 50 validity checks. To also ensure the consistency between different questionnaires and identify enumerator biases, agronomic parameters such as yields, inputs and labour hours were calculated and compared between and within case studies as well as between enumerators.

We further established processes for identifying outliers for monetary parameters (output, labour and input prices) as well as for physical inputs and outputs (labour hours per ha, inputs per ha, yield per ha). Outliers were identified by calculating lower and upper fences (Q1-/Q3 + 3*IQR). Monetary outliers were replaced with the case study median. For the data entries that caused outliers in physical inputs and outputs, we followed a multiple imputation approach, applying the multivariate imputation by chained equations (MICE) method for replacing outliers (Royston, 2004) through the R-package "mice" (van Buuren and Groothuis-Oudshoorn, 2011). Predictive mean matching (PMM) was used as imputation model and 22 variables were included as predictors for output, labour and input quantity outliers. Five imputed datasets were generated through this method and analysed for differences through a MANOVA test. In a sensitivity analysis, the results proved to be stable (p greater than 0.993) and, consequently, the initial imputed data set was used for further analysis. The datasets and source code generated during and/or analysed during the current study are available from the corresponding author on request.

2.7. *Statistical analysis*

We used an entropy balancing approach (Hainmueller, 2012; Meemken and Qaim, 2018), to correct for potential selection bias in each case study with regards to participation in the OA interventions. The exact adjustment of covariate moments make it an appealing alternative to standard matching or reweighting methods when estimating causal effects from observational studies (Zhao and Percival, 2015). Farm-specific weights were generated in STATA (StataCorp. 2017. Stata Statistical Software: Release 15) using a large range of covariates covering the characteristics farms and farmers (Table S8). Unobservable characteristics, such as motivation or risk aversion, were assumed to be implicitly captured through family labour, gender, experience and other covariates.

Based on the entropy weights, key performance indicators reflecting immediate and intermediary outcomes were used to compare farms in the intervention groups with farms in the control groups at the crop and farm levels. More immediate outcome variables include compliance with minimum requirements for OA and the uptake of AOM practices. More intermediate outcomes include changes in yield and economic performance in terms of gross margins. As the weights were only assigned to untreated units in the control group through the data pre-processing, the entropy balancing produced estimates of the average treatment effect on the treated (ATT) (Meemken and Qaim, 2018). The effects were estimated using a probit regression for the binary compliance outcome. A generalized linear model (GLM) with a binomial family for the error distribution and a logit link for the dependent variable was used to estimate the effect for the AOM scores, as recommended for dependent variables scaled as proportions (Papke and Wooldridge, 1996). For the gross margin estimations, standard ordinary least square (OLS) regression was employed. For farm-level estimations of economic performance effects, the robustness of the method was tested by comparing the results generated by entropy balancing with the results produced through propensity score matching. This confirmed the findings.

For the impact analysis at crop level, we concentrated on four crops/crop categories in each case study, which were most commonly grown by farmers. Crops were aggregated to crop categories according to Table S9. The organic to non-organic yield ratio, input cost ratio, labour cost ratio, and gross margin ratio were calculated using a bootstrap procedure to estimate a single confidence interval on the ratio in medians. The systems were deemed significantly different from each other, if the 95% confidence interval of the ratio did not overlap one another. The analysis was implemented using the R-package boot and figures were produced using the R-package ggplot2. Gross margins are not displayed for those crops with different mathematical operator signs. The sensitivity analysis, with an assumed general price premium of 20% as a conservative estimate, was based on data from a *meta*-study (Crowder and Reganold, 2015). We, however, deducted estimated cost for maintaining a functioning internal control system and covering cost for external certification, as we did not want to overestimate potential profitability of the smallholder systems.

The productivity effects of AOM were assessed across all five case studies using a production function framework. In all cases, a Cobb-Douglas specification was used. Due to the large number of zero values for mineral fertiliser and synthetic pesticide. inputs, dummy variables associated with the incidence of zero observations were included in the analysis (Battese and Broca, 1997). In this article, we use the term "pesticide" as an umbrella term for fungicides, insecticides, herbicides and other plant protection substances, unless specified differently. The endogeneity of AOM was tested in all five cases and the significant correlation of error terms required the use of a regression model in order to treat this covariate as endogenous. Program participation and experience with organic management were employed as instruments in the first stage equation.

3. Results and discussion

3.1. Case study descriptions

We applied the evaluation framework to a broad set of case studies covering different agroecological and market contexts, as well as various types of interventions that had introduced OA to African smallholder farmers. Three of the selected case studies were in Kenya (KE) and two in Ghana (GH) (Fig. 2). In three of these case studies (KE-NC1, KE-NC2, GH-NC) the interventions aimed at implementing non-certified (NC) OA and in the other two, certified (C) OA was introduced (KE-C, GH-C). The implicit assumption behind the non-certified organic interventions is that they lead to a healthier environment and that farmers benefit from applying agroecological principles and technologies, avoiding the use of synthetic pesticides and mineral fertiliser (Altieri, 2018; Jensen et al., 2015). The certified organic interventions combine the capacity development efforts with a formal certification for securing price premiums for further improving farmers' livelihoods.

Each case study consisted of 280–398 smallholder farmers over the period April 2015 to May 2017. A proportion of these farmers had been exposed to interventions that introduced them to organic farming practices at least three years prior to data collection (organic intervention group), while the remaining farmers (control group) were selected from similar socio-ecological contexts (Fig. 2). Average farm sizes were 2–3 ha in Ghana and around or below 1 ha in Kenya. The most labour-intensive case study was KE-NC1, which was dominated by vegetable production (1,450–1,660 h/(ha*a)) and KE-C (517–583 h/(ha*a)). In the other case studies labour hours were between 55 and 147 h/ha*a. In GH-NC family labour was dominating (around 80%) compared to other case studies.

The main cash crops were cocoa in GH-C, coffee, macadamia nuts and bananas in KE-C, maize, millet and beans in GH-NC tea, maize and brassicas in KE-NC1 and maize, peas and beans in KE-NC. Fertiliser inputs were very low in GH-C (0.4 kg N/(ha*a)), GH-NC (32 kg N/(ha*a)) and KE-NC2 (8 kg N/(ha*a)), but very high in KE-C (169 kg N/(ha*a)) and KE-NC1 (240 kg N/(ha*a)) (Table S9).

Conventional farmers did not report using any herbicides in KE-NC1 while between 0.5 kg/(ha*a) (GH-C) and 2.4 kg/(ha*a) (KE-C) was reported in the other case studies. Synthetic fungicides were used in all case studies, but in GH-NC the use was very low, averaging 0.01 kg//(ha*a). The highest quantities of fungicides were used in KE-C (0.45 kg//(ha*a)). A large amount of organic fungicides (e.g. copper) was used by both conventional and organic farmers in KE-C. In terms of synthetic insecticide use, farms in KE-C were managed most intensively with about 1.1 kg/(ha*a), too among the conventional farmers, while the other case studies ranged between 0.03 (GH-NC) to 0.44 kg/(ha*a) on the vegetable plots in KE-NC1. Botanical insecticides (e.g. neem) which were allowed in organic were only reported from certified organic systems KE-C (2.4 kg/(ha*a)) and GH-C (0.1 kg/(ha*a)) (Table S9).

In all case studies, interventions that introduced OA provided training and organic inputs to encourage farmers to adopt organic practices. The training schedules covered crop rotation, compost making, preventive and natural pest and disease management and general farm management. However, the training concepts and the governance for fostering the uptake of OA, such as the availability of organic inputs, varied by case study (Table S11). While GH-C suffered from discontent of farmers because their organic cocoa could not generate appropriate price premiums during the course of our study, KE-C was equipped with a well-managed internal control system. Among the non-certified interventions, KE-NC1 had a well-functioning, long-term advisory service with staff committed to the principles of OA and able to communicate the potential benefits of organic farming to farmers, while KE-NC2 and GH-NC invested less efforts in capacity development (Table S10).

3.2. Implementation of organic farming practices

To understand how farmers practice OA, we analysed the rate of adoption of organic practices distinguishing between a) **Passive Organic Management (POM)**, i.e. farmers not using any conventional inputs and b) **Active Organic Management (AOM)**, i.e. farmers substituting conventional inputs by means of preventive measures and/or productivity-enhancing inputs, which are permitted in OA.

3.2.1. Effect of the interventions on passive organic management

All five organic interventions significantly reduced the number of farmers using conventional inputs, including synthetic pesticides (including herbicides) and/or mineral fertilisers, compared to the control groups (Table 1C). However, the share of farmers not using any conventional inputs differed substantially between case studies. In KE-C, 92% of the farmers who were exposed to the interventions did not use any conventional inputs, while in the control groups the share of farmers not using conventional inputs was low. The farmers in GH-C had low compliance rates with organic standards as the business partners of the cooperative failed to sell their produce on the organic market and thus did not receive the expected organic premium price. This contributed to a large number of farmers in the intervention group continuing to use mineral fertilisers and/or synthetic pesticides. In the non-certified case studies, rather small percentages of farms fully followed the rules of OA. In KE-NC1, the case study with the most promising approach, up to 42% of farmers worked organically, without any certification, while in GH-NC and KE-NC2 only 16% and 28% did, respectively.

Remarkably, in four case studies, the share of smallholder farmers in the control group that did not use conventional inputs (i.e. mineral fertilisers or synthetic pesticides) was below or around 10%. In KE-NC1, the rate was about 21% (Table 1B). This is contrary to literature, where organic-by-default is often indicated to be common among smallholder farmers in SSA (Jouzi et al., 2017; Sheahan and Barrett, 2017). This indicates the increasing availability and usage of conventional inputs as found by De Bon et al. (2014) and Andersson and Isgren (2021). Especially pesticide use among smallholders is far more widespread than commonly assumed (Bakker et al., 2021). Getting accustomed to conventional input use may lead to a decreased willingness of smallholder farmers to convert to an entirely organic system and agroecological principles (Sapbamrer and Thammachai, 2021). However, input use in SSA varies substantially between countries (Sheahan and Barrett, 2017), therefore these results cannot be extrapolated to other countries.

3.2.2. *Effect of the different interventions on active organic management*

Farmers replacing conventional inputs with either preventive or curative agroecological practices can address nutrient and pest management issues under organic management. These practices include, among others, applications of botanical pesticides, such as neem; preventive practices can involve a more diverse rotation, agroforestry or intercropping systems (Altieri, 2018; Sinclair et al., 2019). We specifically analysed whether the interventions led to an increased uptake of a) practices substituting conventional inputs for pest, disease and weed management, b) practices for substituting mineral fertilisers, and c) further agroecological practices.

Looking at the effect of the interventions on the uptake of AOM practices, our data shows no widespread systematic adoption in any of the case studies (Table 1C). Organic fertiliser application was slightly increased in KE-C and GH-NC while it was reduced in KE-NC2. Among the agroecological practices, only the diversity of crop rotations was affected positively in GH-NC and KE-NC1 while it was even less diverse in KE-C and KE-NC2. For the remaining components of AOM, we did not find consistent differences between the intervention and control groups.

While at least one of the interventions led farmers to adopt POM, AOM was not adopted widely in any of the case studies, despite that all of the interventions aimed at such an adoption. This shows the importance of considering innovation dynamics and transition timeframes when introducing organic agriculture to smallholder farmers, as their decision-making is dynamic, multi-dimensional and contextual (Hermans et al., 2021). Transferring information and skills to famers via group trainings is an important component of capacity development, but needs to be embedded in a long-term process and governance structure, which allows a group of smallholder farmers to learn and explore practices on their own farms and identify ways of combining practices that fit into their specific production system. Compared to applying mineral fertilisers, herbicides and pesticides, agroecological practices are usually knowledge-intensive and require understanding of complex ecological principles (Sinclair et al., 2019).

3.2.3. *Motivations and challenges for implementing organic agriculture*

In order to understand the low uptake rates of organic farming practices by farmers in the organic intervention groups, we analysed a) motivations to convert to organic agriculture and b) the implementation challenges as perceived by the farmers.

In the two certified organic case studies (KE-C and GH-C), high potential economic returns motivated farmers to practice organic farming (at least POM), while non-financial reasons (personal health related and a general conviction for organic farming) were less apparent. In the non-certified case studies, the primary motivation to practice organic farming was non-financial with the exception of GH-NC, where 54% of the responding farmers had primarily financial reasons. The differences in motivations and expectations are partly driven by the implementation approach of the intervention. For instance, in KE-NC1, much time was prior invested to make farmers aware of the non-financial benefits of organic farming such as human and environmental health. While in most case studies, little difference between the responses of adopters and non-adopters could be observed, farmers adopting organic management practices in KE-NC2 and GH-NC had a higher share of financial motivations (Table S3).

The most prominent challenges that the organic intervention farmers faced were: pest and disease damage during crop cultivation and post-harvest stages (74% of all farmers in the intervention groups perceived this as an important challenge), lack of stable markets (67%), inadequate training and extension services (57%), unavailability of inputs (54%) and additional labour required due to weeding (52%). The importance of the challenges was perceived differently in the various case studies. Generally, the Ghanaian farmers perceived the agronomic challenges as more important than the Kenyan ones. Furthermore, our assessment of uptake of farmers is reflected in severity of the challenges, as farmers in KE-C and KE-NC1 who were exposed to these interventions perceive the challenges as overall less severe (Table S10).

While there is only little empirical evidence reported in literature about motivations and challenges of organic farmers in SSA (Sapbamrer and Thammachai, 2021), the technical challenges, such as weed infestation and damage by pests and diseases, are similar to those found in Switzerland by Home et al. (2019) although the Swiss farmers in their study reported that these barriers were less severe than they had estimated before conversion to organic.

3.3. *Productivity and profitability of organic agriculture*

3.3.1. *Productivity and profitability of organic farming at crop level*

Following the analysis of the effects of the interventions on the adoption of practices, we analysed how OA, as a production system, performed. For this, we compared all farms in each case study, those who worked organically with those who did not, regardless of whether they were part of the intervention group or not (Fig. 1 – horizontal comparison). We analysed the differences in yields, inputs, labour and gross margins of the four most widely grown crops in each of the five case studies, using an entropy balancing approach for estimating a sound counterfactual (Fig. 3).

Among the total of 20 crops analysed from the five case studies, we found four organically managed crops with significantly higher and four crops (bananas in KE-C, baize and brassica in KE-NC1 and millet in GH-NC1) with significantly lower yields (Fig. 3A). Input cost was significantly higher for three crops each, while inputs were significantly lower for eight crops (Fig. 3B) and labour was lower for six crops (Fig. 3C). This resulted in higher gross margins for four organically managed crops, while only one crop (bananas in KE-C) had significantly lower gross margins under organic management (Fig. 3D).

Comparing the two certified case studies, farmers practicing OA performed very differently in their productivity and profitability. Except for reduced cocoa input costs (-100%), no significant differences in yields and gross margins between organically and conventionally grown crops could be observed in GH-C. Contrary, we observed higher yields for the economically most relevant crops (macadamia nut + 172%, coffee + 308%, maize + 127%), while banana yields were lower (-61%) in KE-C. Input cost was reduced (macadamia nut, bananas) or stayed similar, while labour cost was increased for coffee (+87%) and macadamia nut (+248%) in KE-C. Despite labour cost was higher, the gross margins of coffee and macadamia nut increased by 336% and 185%, respectively.

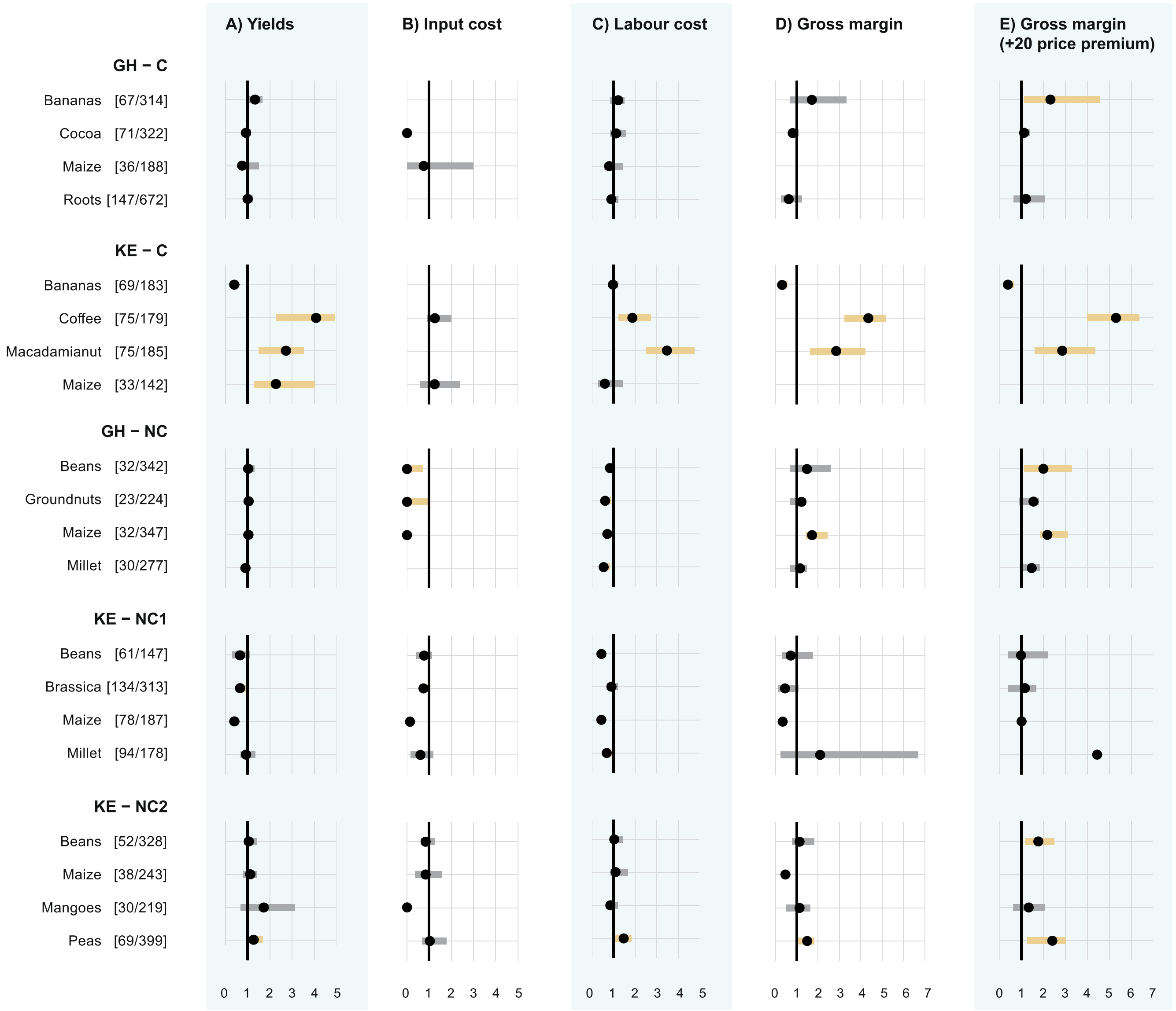


Fig. 3. Ratios of organic to non-organic A) yield (t/ha*a), B) input cost ($/ha*a), C) labour cost ($/ha*a), D) gross margin ($/ha*a) based on observed output prices and E) gross margin with an assumed price premium of + 20% for all crops grown organically. Data is weighted using entropy balancing to allow comparability. Dots indicate the ratio median estimates; bars represent the 95% confidence limits for the ratios. The systems were deemed significantly different from each other if the 95% confidence interval of the ratio did not overlap one (highlighted in orange). The number of observations in each group is shown in parentheses [organic system/non-organic system]. When no median input cost is displayed this is because it was zero for both conventional and organic crops. When gross margins are not displayed, gross margins for conventional and organic have different signs. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Estimated effect of organic management on total gross margins ($/ha) in the case studies and for the pooled dataset as average treatment effect on the treated (ATT) using entropy balancing with the dataset as observed and an assumed 20% price premium for all organic products as sensitivity analysis.

		POOLED	GH-C	KE-C	GH-NC	KE-NC1	KE-NC2
Potential outcome mean for conventional management		1095.7	403.7	2153.1	125.2	1595.4	208.2
as observed	Organic management	2644.8	401.0	8432.5	147.1	1474.4	238.3
	ATT	1549.1	-2.7	6279.4	21.9	-121.1	30.1
	Relative difference	**141%*****	-1%	**292%*****	17%	-8%	14%
20% premium for all organic products	Organic management	3159.3	520.6	9646.4	189.8	2092.2	350.3
	ATT	2063.3	116.9	7493.3	63.2	496.0	142.3
	Relative difference	**188%*****	**29%****	**348%*****	**52%****	31%	**68%****

Significance levels: *** = p<0.001, ** = p<0.01, * = p<0.05, ns=not significant.

Less pronounced differences were found in the non-certified case studies: in GH-NC, yields of organic farms were similar to conventional farms for the four crops, almost no purchased inputs were used and labour was reduced for maize (-29%), groundnuts (-40%) and millet (-46%). Gross margins of organically managed crops were at similar levels to their conventional counterparts, except in the case of maize (+72%). In KE-NC1, however, organically managed brassica and maize yields were lower than for conventional farmers (-35%, −60% and quite consistent trends with findings from on-station research (Adamtey et al. 2016) but other crops were not significantly affected. Maize input cost was significantly lower while labour costs were lower for beans, maize and roots. Overall, no significant differences in gross margins were observed in KE-NC1. On the other hand, in KE-NC2, pea (aggregate of pigeon pea and cowpea) yields were higher, while the other crops remained unaffected by organic management. In this case study, organic farmers significantly reduced input cost for mango while labour cost for peas was higher. In terms of gross margins, there were no significant differences, except for peas (+49%) (Fig. 3D).

Except for macadamia nut in KE-C, the organically grown crops in our case studies were not sold with/did not generate a price premium. To assess the importance of local and international markets for organic produce, we therefore tested the impacts of a general 20% price premium for the organic farmers for sensitivity analysis (see Fig. 3). Assuming an organic price premium, POM gross margins would be higher than the conventional counterpart for bananas (+131%) in GH-C, coffee (+429%) in KE-C, beans (+100%) and maize (+117%) in GH-NC, roots (+344%) in KE-NC1, and beans (+77%) and peas (+140%) in the case of KE-NC2.

The high variability of organic yields and gross margins through organic farming is mostly consistent with findings of *meta*-studies that are mainly based on data from high-income countries (Badgley et al., 2007; De Ponti et al., 2012; Ponisio et al., 2015; Seufert et al., 2012). The methodological difficulties of comparing organic smallholder producers in low-income countries and the resulting uncertainty resulting from the definition of a sound counterfactual led even to a higher uncertainty of impacts of organic agriculture on smallholder yield and profits. Some authors identify strong yield increases due to organic agriculture (Badgley et al., 2007; UNCTAD and UNEP, 2008), while others criticise methodological flaws (Meemken and Qaim, 2018).

3.3.2. *Profitability of organic farming at farm level*

We observed positive effects of organic farming practices at farm level productivity in one of the five case studies (KE-C + 292%). Higher farm level gross margins could neither be achieved in the other certified case study (GH-C) nor in the three non-certified case studies (Table 2). As, at least in GH-C, organic price premiums were originally supposed to be realised, the farm-level gross margins were analysed under the assumption that at least 20% of price premium could be realised due to the organic management. For the pooled sample over all five case studies, OA had significantly positive impacts on gross margins (+141%).

Under such an assumption, the organic farmers in four of the five case studies would have realised higher gross margins than the farmers who managed their farms conventionally. Besides KE-C, GH-C (+29%), GH-NC (+52%) and KE-NC1 (+68%) would also have performed better, while for KE-NC1, there was no significant difference observed. For the pooled sample, OA had significantly positive impacts on gross margins (+188% instead of + 141%).

Our results show that there is no one silver bullet for increasing profitability among smallholder farmers (Table S4). Profitability-

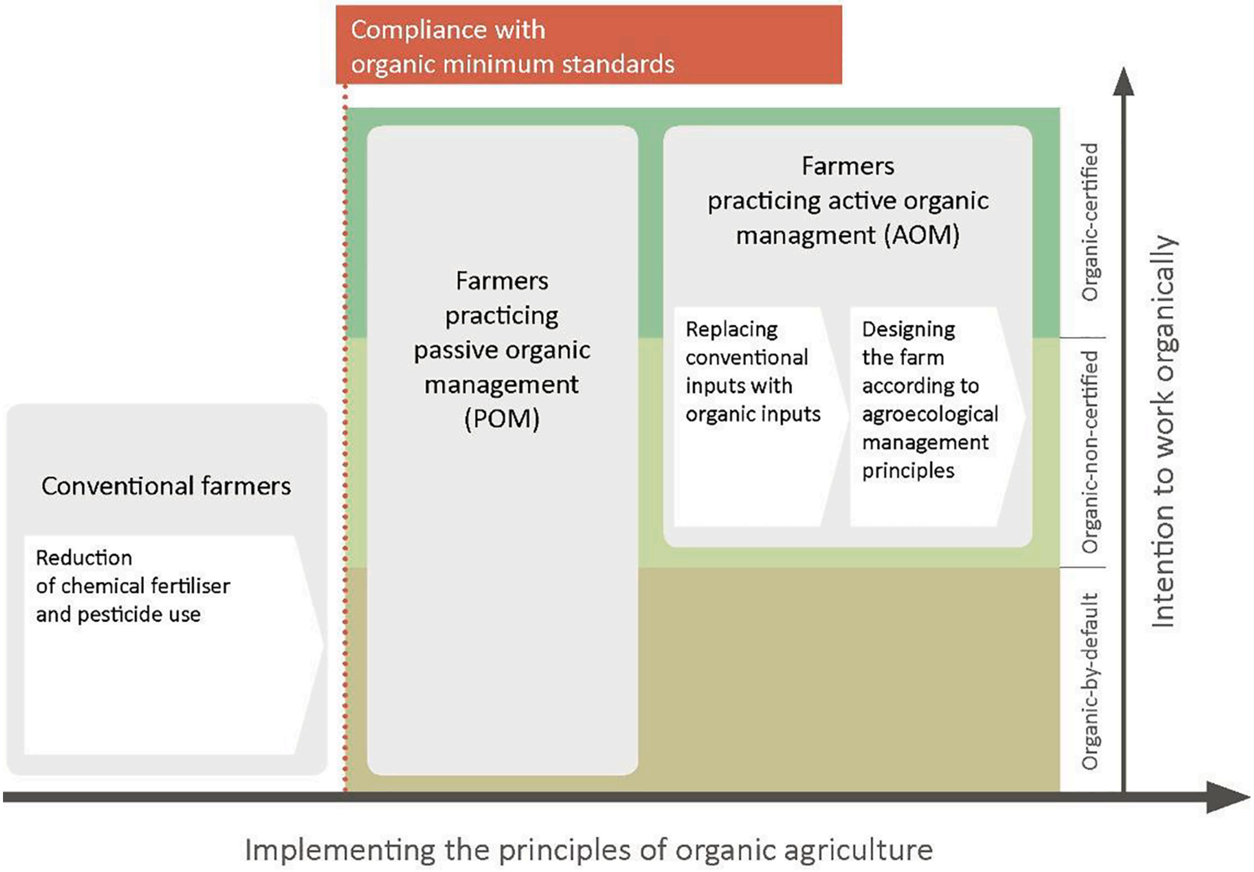


Fig. 4. Graphical classification of African smallholder farmers according to their organic management practices and their intention to work organically based on the findings from our study.

increasing effects observed over all the five case studies can be associated with labour input in general and specifically with the number of hours spent on pruning as one of the key specific good agricultural practices for the perennial crops such as macadamia nut, mango and cocoa. When used, the application of organic fertilisers had significantly positive impacts, while conventional fertilisers and pesticides affected the revenues rather negatively. Organic insecticides (pyrethrum, neem) did not have significant yield effects while copper did. Contrary to findings from field trials (Adamtey et al., 2016; Altieri, 2018), further organic and agroecological management practices resulted mostly in no remarkable economic benefits assessed for the farmers in our study (Table S5). This could signify that the levels of inputs and practices applied by farmers in our study were still low and not optimal as supported by on-station long-term trial findings in Kenya (Adamtey et al., 2016). Contrary to results from field studies and *meta*-studies, which report the productivity of organic agriculture crop-specifically (Ponisio et al., 2015; Seufert et al., 2012), our study shows that contextual factors such as the governance and capacities of smallholder cooperatives are important factors determining the agronomic and economic performance of OA, too.

Many authors suggest that capacity development measures, which are implemented alongside organic projects, are responsible for a large share of the revenue increases that were observed in other studies (Bolwig and Gibbon, 2009; Meemken and Qaim, 2018; UNCTAD and UNEP, 2008). In our study, we therefore, controlled for the number of training events from both government and non-governmental (NGO) organisers. Overall, organic farms had similar numbers of training events and extension visits by NGO and government agents in all case studies, except in KE-C, where the number of governmental and total trainings was even lower than for conventional farms (Table S6). Government trainings were generally rated lower by organic farmers than by conventional farmers in KE-NC1 and KE-C. On average, NGO trainings were rated better in terms of effectiveness compared to the governmental-based trainings. This indicates a potential for improvement and strengthening of trainings and extension services offered by governmental agents. This further indicates that there are large differences in the perceived quality of NGO training provided to the farmers.

3.4. *A management-based typology of organic farms in SSA*

There is a great diversity of smallholder farmers in Africa. Much of the on-going controversial discussion about OA is due to a lack of a clear classification and the very heterogeneous characteristics and performances that one can realise on farms that may all be called “organic” on a superficial level (Seufert and Ramankutty, 2017; Seufert et al., 2017). Therefore, based on the results from our study, we propose a terminology for organic farms that can bring more transparency in the debate and can be used to assess the current situation and design tailored public and private policy interventions.

Fig. 4 distinguishes organic farming systems according to a) the degree they follow the principles of OA (health, ecology, fairness, care) (Luttikholt, 2007) (horizontal axis) and b) the intention to work organically (vertical axis). The degree that farming systems follow the principles of OA can be represented as continuous scale, however, a clear line can be drawn between farmers who complied with the minimum requirements of organic standards (organic farmers) and those who do not (conventional farmers). On this scale, also conventional farmers can be by the extent to which they come close to the boundary of organic compliance, based on the amount and frequency of chemical inputs they use (Fig. 4).

Furthermore, organic farmers can be grouped according to whether they practice organic farming because they do not have access to chemical inputs (organic-by-default) or whether they practice organic farming intentionally (organic intended). In our case studies, organic-by-default farmers, which were in the control and not in the intervention groups, were rather uncommon, as most farmers used chemical inputs from time to time, even though some used them only in small quantities. Both groups practice organic farming intentionally and can be further distinguished as farmers who manage their farm only passively and those who manage their farm organically in an active way. Among the latter group, we can further distinguish between farmers who merely substitute conventional inputs by organic ones and those who actively follow agroecological principles and design their farm accordingly for a sound organic nutrient and pest management. While the latter group can be considered closest to implementing the principles of OA, according to our data it is the absolute minority among smallholder farmers in SSA. This emphasises the necessity to view organic agriculture as a farming system that requires a systemic shift beyond the view of single practices that is increasingly taken up by agroecology or regenerative agriculture (Altieri, 2018; Gosnell et al., 2019; Loconto and Fouilleux, 2019).

4. Conclusions

This study feeds empirical facts into a long-term debate with greatly diverging opinions about the potential of organic agriculture for sustainable intensification and food security in SSA. Using a large-scale dataset with a two-factorial observational research design, we were able to consistently analyse a) how different organic interventions enable farmers to practice organic agriculture and b) how organic agriculture comparatively performs in terms of productivity and profitability.

Given the large heterogeneity of organic farming systems, it is necessary to classify them into intended organic management and organic-by-default and according to the degree they follow the principles of OA. While passive organic management (POM) (i.e. just omitting prohibited inputs) is prevalent among all organic farmers, active organic management (AOM) is only present among farmers who intentionally practice OA and can be divided into a) the mere substitution of conventional inputs and b) substitution of conventional inputs plus an agroecological system design.

While OA aims at such an agroecological system design, our study shows that the reality in SSA looks very different. After being exposed to an intervention for introducing OA, most farmers do not fully adopt even POM and are even further away from sound AOM. We attribute this to, a) the limited knowledge and lack of capacities to manage the organic production system, b) the lack of suitable organic biomass and other organic inputs for soil fertility management, and effective plant protection inputs and c) the lack of markets which are sufficiently stable and allow for generating organic price premiums as additional incentives.

The farmers who managed their farms organically were mostly performing not substantially different from conventional farmers in terms of yields and profitability. The exception farmers in an organic certified case, in which an intervention introduced effective capacity development, including the provision of necessary organic inputs and an intensive and functioning monitoring and control system to allow for organic premium prices. Uptake of organic practices as well as most physical yields and profits of organic farmers were substantially higher than their conventional counterparts in that case study. However, even in this system, farmers did not substantially adopt AOM practices, neither could those who did derive significant economic benefits from it.

OA is operationalised by farmers mostly as a restriction in management. However, if the aim is to make farmers work according to organic or agroecological principles, organic farming needs to be reframed from a “do not use specific inputs” to a “do better agroecosystem management” approach and to be better adapted to a smallholder context in SSA. From field trials, we know that generally agroecological practices are effective in increasing yields (Altieri, 2018; Trabelsi et al., 2016). This could not be observed in any of our case studies and one likely explanation relates to poor implementation of the measures due to lacking capacities. Therefore, if the policy goal is to make farmers work increasingly according to the principles of OA and agroecology, the abovementioned agronomic and institutional challenges need to be addressed, not only by private initiatives. This would support idea of payments for ecosystem services and large-scale public investments into resilience of ecosystems and combating desertification in sub-Saharan Africa, such as the Great Green Wall.

The excellent agronomic and economic performance of organic agriculture in one of the five case studies with more than 290% increase in gross margins at farm level, indicates the potential that organic agriculture in SSA can have if the main challenges are addressed and the smallholder systems are managed well. Both governmental and non-governmental capacity development needs to be targeted to the main challenges of input availability, farmers' capacity development for agroecosystem management, and access to local and international markets with price premiums. Due to the partly poor governmental capacity development institutions, the role of private initiatives and standards is important to not only address issues specific to organic agriculture but also promote general good agricultural practices (Schoneveld et al., 2019; Thorlakson et al., 2018).

Contrary to previous studies, which were based mostly on field trial data (Crowder and Reganold, 2015; Seufert and Ramankutty, 2017; Seufert et al., 2012), we did find only sporadic indications for significantly lower yields and profitability in organic systems in SSA compared to current systems. Within the SSA context, improved agronomic management through organic interventions, e.g. the use of organic inputs which help to add organic matter to the soil, and tree pruning, can help to offset potential yield reductions as commonly reported for organic in developed regions of the world. It is, however, likely that smallholder conventional high-input systems would yield much higher returns if implemented well. The fact that particularly maize, millet and brassica were among the few crops performing lower under organic management in a few cases, draws attention to the importance of staple crops under organic management. Future research should therefore address the agronomic performance specifically of staple crops under organic management.

Finally, from a societal perspective, it should be considered that organic farming induces less external costs to society (e.g. for clean water, biodiversity protection and workers health), while delivering more expensive food to consumers (Seufert and Ramankutty, 2017). From a resource-economic perspective, the cost for providing public goods to society should not be borne by consumers as is currently the case for certified OA in SSA (von Braun and Birner, 2017). This is a typical free-rider problem - as only a limited number of consumers are ultimately likely to accept the higher costs for organic products, OA will globally not develop into a dominant system. Therefore, governments should either make efforts to internalise these external effects, and thus improve the relative competitiveness of organic farming practices, or facilitate and finance such capacity development and economic perspectives for the implementation of OA and enable smallholders to practice it.

CRediT authorship contribution statement

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Declaration of Competing Interest

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

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Appendix A. Supplementary data

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