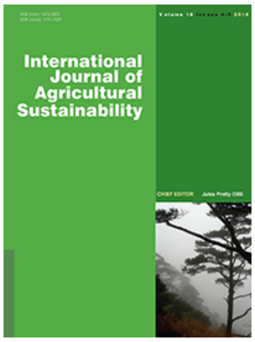

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Drivers of sustainable intensification in Kenyan rural and peri-urban vegetable production

Barnabas K. Kurgat[a,b*], Evans Ngenoh[c], Hillary K. Bett[d], Silke Stöber[a], Samuel Mwonga[d], Hermann Lotze-Campen[e,f] and Todd S. Rosenstock[g,h]

[a]Centre for Rural Development (SLE), Humboldt-Universität zu Berlin, Berlin, Germany; [b]School of Science and Applied Technology, Laikipia University, Kenya; [c]Department of Agricultural Economics and Agribusiness Management, Egerton University, Egerton, Kenya; [d]Department of Crops, Horticulture, and Soils, Egerton University, Egerton, Kenya; [e]Potsdam Institute of Climate Impact Research (PIK), Potsdam, Germany; [f]Department of Sustainable Land Use and Climate Change, Faculty of Life Sciences, Humboldt-Universität zu Berlin, Berlin, Germany; [g]CGIAR Research Program on Climate Change, Agriculture, and Food Security, Nairobi, Kenya; [h]World Agroforestry Centre (ICRAF), Kinshasa, the Democratic Republic of the Congo

ABSTRACT
Sustainable intensification promotes environmentally sound and productive agriculture. However, use of sustainable intensification practices (SIPs) is low in many sub-Sharan African countries. This study examined the adoption of SIPs in Kenyan rural and peri-urban vegetable production to understand the scale of and underlying factors in the use of SIPs. A multistage sampling technique was employed to randomly select 685 rural and peri-urban vegetable farm households. Household data was then collected and anaylsed for four practices namely improved irrigation, integrated soil fertility, organic manure and crop diversification using a pre-tested structured questionnaire. A multivariate probit model was run to model simultaneous interdependent adoption decisions. Adoption of organic manure and African indigenous vegetables (AIV) diversification was high in both rural and peri-urban areas. However, adoption of improved irrigation systems and integrated soil fertility management was low, and even significantly lower in rural areas than in peri-urban areas ($p < 0.041$). Similarly, adoption intensity of SIPs was lower in rural areas than in peri-urban areas. Furthermore, the findings also show complementarities and substitutabilities between SIPs. Market integration, the farm location and household income were the major factors heavily influencing the adoption of most SIPs. Policies and programmes that seek to build household financial capital base and integrate farm households into effective and efficient vegetable markets need to be formulated and implemented in order to enhance adoption of SIPs in AIV production.

KEYWORDS
Adoption; farm households; peri-urban; rural; sustainable intensification; vegetables; Kenya

1. Introduction

Agriculture in sub-Saharan Africa (SSA) needs to dramatically increase food production in response to increased demand and dietary changes as a result of a growing population, increasing urbanization and rising prosperity (Tilman & Clark, 2014). This challenge is complicated by environmental and social constraints, including land and water scarcity, declining soil fertility, climate variability and change (The Montpellier Panel, 2013; Vanlauwe, Tittonell, & Mukalama, 2007). At the same time, many practices aimed at increasing agricultural productivity degrade the environment such as contributing to global warming and water pollution (Kim, Thomas, Pelster, Rosenstock, & Sanz-Cobena, 2016; Vanlauwe et al., 2011).

Sustainable intensification (SI), an approach commonly promoted to support environmentally sound

CONTACT Barnabas K. Kurgat bkurgat@laikipia.ac.ke; bkurgat@yahoo.com
*Present address: School of Science and Applied Technology, Laikipia University, Kenya.

agricultural development, aims to produce more food from the existing land base with fewer environmental impacts (Godfray, 2015; Pretty, Toulmin, & Williams, 2011). Farm management practices such as integrated organic and inorganic nutrient management, conservation agriculture (CA), integrated pest management (IPM), crop diversification and sustainable water management (irrigation) have all been suggested as being indicative of sustainable intensification practices (SIPs) (Badgley et al., 2007; Dile, Karlberg, Temesgen, & Rockström, 2013; Okalebo et al., 2007). The adoption of such SIPs has been demonstrated to improve yields and nitrogen use efficiency, and to conserve resources under certain conditions (Pretty et al., 2011; Teklewold, Kassie, Shiferaw, & Köhlin, 2013). Despite the practices' potential to provide benefits to farm households and the environment, the adoption of SIPs generally remains low in SSA (Ajayi, Akinnifesi, Sileshi, & Chakeredza, 2007; Giller, Witter, Corbeels, & Tittonell, 2009; The Montpellier Panel, 2013).

Attempts to understand the determinants of households' decisions to adopt SIPs have been documented in a range of previous studies. Marenya and Barrett (2007) revealed that household size, the household structure and education level of the household head, the size of farmland owned, the value of livestock and off-farm income significantly influenced smallholder farmers in western Kenya in the adoption of integrated soil fertility management, use of manure and agroforestry. Kassie, Jaleta, Shiferaw, Mmbando, and Mekuria (2013) documented several factors, such as environmental constraints (rainfall, insect and disease problems), government effectiveness in the provision of extension services, the size and tenure status of plots, social capital, plot location as well as household assets as influencing farmers' decisions to use improved seed, conservation tillage and legume intercropping in smallholdings in rural Tanzania. Other studies have analyzed determinants of adopting SIPs, with household socioeconomic, institutional and environmental factors being the main determinants of SIP adoption (Kassie, Teklewold, Jaleta, Marenya, & Erenstein, 2015; Ndiritu, Kassie, & Shiferaw, 2014; Teklewold et al., 2013).

However, these studies largely focused on farming households cultivating cereal crops (maize) in rural areas of SSA. Only one study has focused on the adoption of safer irrigation technologies (*e.g.* sieving of irrigation water) and crop choices among vegetable farmers in urban Kumasi, Ghana, and found household and farm characteristics such as extension agents, education level of household head, farmers' organizations and cropping patterns to drive irrigation use (Abdulla, Owes, & Baking, 2011). Authors there analyzed factors influencing the adoption of safer irrigation technologies only, neglecting the possibility of simultaneously adopting a number of interrelated SIPs. There is no evidence concerning the scale of adoption of interrelated SIPs in smallholder vegetable production systems.

Furthermore, there is equally limited information on whether there are any significant differences in the level of adoption of SIPs between rural and peri-urban areas. There may be difference on the scale of adoption between these two production environments because farmers in peri-urban areas may have more access to better transport network, input-output markets, as well as credit and extension services, hence fostering adoption. On the other hand, peri-urban areas are more likely to offer good off-farm work opportunities with higher wages possibly making it difficult for farmers to adopt labour intensive SIPs, unless they also provide high returns on labour. Therefore, this comparison will provide more understanding on which SIPs or more practiced in rural and peri-urban areas in Kenya. It also helps the decision makers and other stakeholders to design specific policies and programmes for rural and peri-urban vegetable production.

Vegetable production, particularly African indigenous vegetables (AIVs), has attracted attention in Kenya's horticultural sector due to the potential offered by AIVs towards improving household food security and income (Abukutsa-Onyango, Amoke, & Habwe, 2010; Ngugi, Gitau, & Nyoro, 2007). Furthermore, most of the AIVs have also been reported to have low sensitivity to climate variability and change (Stöber et al., 2017). The growing importance of AIVs to Kenya's food security and smallholder household income is driving AIV intensification both in rural and peri-urban areas. For instance, the area allocated for AIV cultivation in the country has increased by 31%, rising from 27,102 ha in 2009 to 35,503 ha in 2014. In addition, AIV yields and value increased by 6% and 10% respectively between 2012 and 2014 (HCDA, 2014). Despite this increase in land area allocation and yields, AIV supply does not match market demand particularly during dry periods (Muhanji, Roothaert, Webo, & Stanley, 2011). This is partly due to increasing water scarcity to support year round production of AIVs, declining soil fertility, lack of good quality seeds and knowledge on best agronomic

Table 1. Sample size and distribution per county and climate characteristics.

Region	Counties	Temperature (°C) max	Temperature (°C) min	Rainfall (mm)	Sample size (*n*)
Rural	Kakamega	27	14	1942	197
	Kisii	25	15	2070	199
Total rural					*396*
Peri-urban	Kiambu	23	12	930	144
	Nakuru	25	11	960	145
Total peri-urban					*289*
Total					685

practices, and market barriers (Croft, Marshall, & Hallett, 2016; Muhanji et al., 2011; Onium & Mwaninki, 2008), factors that sustainable intensification aims to address. The deficit of AIVs is likely to widen given the projected increase in human population and rising prosperity. It is therefore, important to have a clear understanding on adoption rate of SIPs and the factors influencing their adoption in order to come up with potential viable options to sustainably intensify AIV production in Kenya. The following interrelated SIPs were examined: improved irrigation systems, organic manure, integrated soil fertility and diversification.

This study examined the adoption rate of interrelated SIPs and the factors influencing their adoption among smallholder farmers in Kenyan rural and peri-urban AIV production. Specifically, the research asked the following questions: (1) what is the extent of adoption of SIPs in Kenyan rural and peri-urban AIV production? (2), are there differences between rural and peri-urban areas? (3), which factors influence adoption? and (4) which, if any, of the interrelated SIPs complement or substitute one other?

2. Methodology

2.1. Study site

This study used data from a survey of smallholder farm households conducted in rural and peri-urban regions in Kenya in September-November 2016 by the Horticultural Innovation and Learning for Improved Nutrition and Livelihood in East Africa (HORTINLEA) project.

2.2. Data collection

Six hundred and eighty-five farming households were selected using a multi-stage sampling technique. In the first stage of the sampling procedure, two production locations were selected based on their AIV production potential: rural and peri-urban. Secondly, two counties were also selected from each production system: Kakamega and Kisii in rural areas and Kiambu and Nakuru from peri-urban areas.

Thirdly, five to ten divisions were randomly selected from each county depending on the intensity of AIV production and size of division. Finally, using proportionate to the size sampling approach (according to village household size), farm households were selected at village level and the number of households selected per county is presented in Table 1. Each household was given a structured questionnaire to characterize the household socio-economic status and production of AIV, including management practices such as adoption of SIPs (integrated soil fertility management, use of organic manure, improved irrigation systems and AIV diversification) and marketing data. Complementary data on assets, land and livestock ownership, income sources, access to credit and extension services, social networks and farmers' willingness to take production risks (based on farmer perception) were also collected.

2.3. Model

A multivariate probit (MVP) model was employed in this study to capture the decision process of farmers in the adoption of multiple SIPs instead of just relying on only a single strategy to optimize their AIV production. Moreover, the model facilitates the understanding of the interconnectedness of different SIPs through the assessment of their respective correlations. Studies that use univariate multinomial logit and probit models do not consider possible correlations of error terms of the adoption equations (Kassie et al., 2013). The weakness of these univariate models is that, they fail to correct for interrelations, which potentially leads to biased estimates (Lin, Jensen, & Yen, 2005).

A range of factors were considered that would influence farmers' decision to adopt four SIPs (improved irrigation, integrated soil fertility

Table 2. Description and summary statistics of variables used in multivariate probit model.

Dependent variables	Description of the variables	Mean	Std. Dev.
Improved irrigation system	Farmers using improved irrigation (1 = yes; 0 = no)	0.12	0.33
Organic manure	Farmers using organic manure (1 = yes; 0 = no)	0.66	0.48
Integrated soil fertility management	Households using both animal manure and inorganic fertilizers (1 = yes; 0 = no)	0.09	0.29
AIV diversification	Farmers growing more than one AIV on their farm (1 = yes; 0 = no)	0.83	0.38
Explanatory variables		Mean	Std. Dev
Household characteristics			
Household size	Total household/family size (numbers)	6.11	2.37
Household head is male	Household structure (1 = male; 0 = female)	0.82	0.39
Age of household head	Age of the household head in years	52.70	12.64
Education level	Education level of the household head (years of schooling)	8.47	4.66
Willingness to take risk	Household head willingness to take risk (1 = yes; 0 = no)	0.76	0.43
Asset endowment			
Natural logarithm of land size	Natural logarithm of household land size (acres)	0.28	1.07
Farming as main occupation	Household head with farming as main occupation (1 = yes; 0 = no)	0.62	0.49
Livestock ownership	Household owning livestock (1 = yes; 0 = no)	0.97	0.16
Farm ownership	Household land ownership (1 = owned; 0 = otherwise)	0.96	0.19
Natural logarithm total income	Natural logarithm of total household income (KSh)	9.43	0.79
Land fertility	Household land fertility (1 = Fertile; 0 = otherwise)	0.37	0.50
Market access			
Informal market integration	Household selling any of AIVs grown (1 = yes; 0 = no)	0.69	0.46
Formal market integration	Household participating in the formal market (1 = yes; 0 = no)	0.30	0.46
Natural logarithm of distance to market	Natural logarithm of distance to the nearest market (km)	0.63	0.70
Institutional factors			
Extension	Household accessing extension services (1 = yes; 0 = no)	0.64	0.48
Access to credit	Household accessing credit services (1 = yes; 0 = no)	0.24	0.42
Group membership	Household member belong to AIV farmer group (1 = yes; 0 = no)	0.37	0.48
Information on new agricultural technologies	Household access to information on new agricultural technologies and innovations (1 = yes; 0 = no)	0.38	0.49
Information on health benefits of AIVs	Household having information on health benefits of AIVs (1 = yes; 0 = no)	0.72	0.45
Information on health benefits of AIVs	Household having information on health benefits of AIVs (1 = yes; 0 = no)	0.72	0.45
Environmental constraints			
Crop pest	Households who faced crop pest attack (1 = yes; 0 = no)	0.07	0.25
Crop disease	Households who faced crop disease attack (1 = yes; 0 = no)	0.05	0.21
Water shortage	Water shortage during the growing season (1 = yes; 0 = no)	0.08	0.27
Unusual heavy rainfall	Unusually heavy rainfall in the growing season (1 = yes; 0 = no)	0.13	0.34
Drought	Households who faced drought events (1 = yes; 0 = no)	0.40	0.49
Farm location			
Peri-urban	Household is located in peri-urban area (1 = yes; 0 = no)	0.42	0.50

management, organic manure and AIV diversification). To describe the MVP model, let SIP_i denote a random variable taking on the values (1, 2, 3, 4) for a positive integer, in this case representing all the four SIPs, and let X denote a set of conditioning variables. Therefore, the SIPs chosen by any AIV farming household were represented by random variables (SIP_i). It was assumed that each farmer may consider a combination of SIPs, which was further assumed to depend on a set of the households' socio-economic, demographic and institutional characteristics as well as other factors (X). Therefore, the MVP model for this study was characterized by a set of binary dependent variables (SIP_{ipn}) such that:

$$SIP^*_{ipn} = \beta'_n X_{ipn} + u_{ipn}, \quad n = 1, \ldots, N \qquad (1)$$

and

$$SIP_{ipn} = \begin{cases} 1 \text{ if } SIP^*_{ipn} > 0 \\ 0 \text{ otherwise} \end{cases} \qquad (2)$$

where, β'_n is the corresponding vector of parameters to be estimated and SIP^*_{ipn} is the latent variable. Equation (1) assumes that a rational AIV smallholder farming household has a latent variable, SIP^*_{ipn}, that captures the unobserved preferences associated with the *n*th choice of SIPs. This latent variable was assumed in this study to be a linear combination of both household socioeconomic and institutional characteristics (X_{ipn}) that are observed to be influencing the simultaneous selection of SIPs, as well as the unobserved characteristics that are captured by the stochastic error term u_{ipn}. Owing to the nature of the latent variable, the estimations in this study were based on observable binary discrete variables SIP_{ipn}, which indicate whether or not an AIV farming household has selected a particular SIP.

2.4. Descriptive statistics of variables

The definition and descriptive statistics of variables used in the analysis are presented in Table 2.

2.4.1. Dependent variables

One of the SIPs considered was the use of improved irrigation systems, described here as the use of hosepipe-sprinklers fitted with electric-motorized pumps to pump water from wells/rivers and take it to vegetable fields. This irrigation system conserves water and is less labour intensive than the use of watering cans. Manual irrigation with watering cans is time consuming. Danson, Drechsel, Wiafe-Antwi, and Gyiele (2002) noted that manual irrigation takes 13% of the total cost (excluding family labour) or 38% of a farmer's time, and high water application rates (640–1600 mm yr^{-1}) in year-round irrigation of peri-urban vegetable production in Ghana. Additionally, the weight of water (10–15 litres per can) limits its use to fields close to water sources (Drechsel, Graefe, Sonou, & Cofie, 2006). Therefore, the use of improved irrigation systems conserves water and reduces production costs hence increases livelihoods gains (crop income). It is therefore assumed that adoption of improved irrigation systems has high probability of improving sustainability of AIV production.

Integrated soil fertility management is a soil management approach that emphasis combine use of organic and mineral fertilizer inputs with the goal of improving yields and fertilizer use efficiency (Pincus, Margenot, Six, & Scow, 2016; Vanlauwe et al., 2014). Chivenge, Vanlauwe, and Six (2011) indicate from a meta -analysis of studies from across SSA that, combined use of organic and mineral fertilizer input leads to greater yield response than either input on its own. In addition, Kurgat, Stöber, Mwonga, Lotze-Campen, and Rosenstock (2018) established that mixing animal manure with inorganic fertilizers optimizes livelihoods gains with minimal negative environmental impacts (less nitrous emissions) based on on-farm trials carried out in African nightshade cultivation fields in peri-urban areas in Kenya. Applying organic manure from livestock waste to croplands potentially leads to increased soil quality and soil biota by returning organic matter to the soil, improves soil water-holding capacity and increases the potential of soil to sequester carbon (The Montpellier Panel Report, 2013). Crop biodiversity is considered a cornerstone of long-term food security because it provides a wider range of genetic raw material that enables food crops to adapt to ever-changing environmental conditions, including emerging pathogens, evolving pests and climate change . AIV diversification – denoted by the number of AIVs grown by the farming household – was included in this study as an indicator of sustainable intensification (SI) of AIV production.

2.4.2. Explanatory variables and hypotheses

Several previous studies on farm technology adoption have supported the use of empirical models to determine factors influencing adoption or non-adoption (Kassie et al., 2013; Shiferaw, Okello, & Reddy, 2009; Teklewold et al., 2013). The following section therefore, contains a discussion about the explanatory variables that were selected as determining factors in decision-making and whether these variables have a positive, negative or inconsistent influence on the adoption of SIPs in AIV production.

(a) Household characteristics

Household characteristics were built into the model, controlling for household size, age, level of education and the household structure (household head being male or female). These four sociodemographic variables have also been used in previous studies to define decision-making in the adoption of farm technologies (Asfaw et al., 2014; Kassie, Zikhali, Pender, & Köhlin, 2010).

In terms of education, it is assumed that better educated farmers are more likely to receive off-farm income, which enables them to invest in new technologies and purchase, inputs and have better analysis regarding benefits of new technologies in solving farm production constraints. Conversely, better-educated farmers may be less willing to invest in labour-intensive technologies and would rather opt for off-farm jobs offering better returns on labour (Lee, 2005; Shiferaw et al., 2009). Half (50.8%) of the sampled households received 8.4 years of education on average, implying that the maximum education attained was primary level based on Kenyan education system.

From this study, the age of the household head ranged from 20 to 91 years, with a mean average age of 52.7 years. Concerning household structure, the data revealed that the majority (82%) of the sampled households were headed by men. Older farmers were likely to have been exposed to a wider range of production technologies and environments, accumulated more wealth, and built larger social networks, and hence there is a better chance of them adopting SIPs. However, old age is also associated with a loss of energy, risk aversion and short-term investment planning (Asfaw et al., 2014; Kassie et al., 2013). Women are often excluded from access to land, livestock and other assets, as well as markets and extension services due to the social and cultural perceptions of the role of women in African societies (Ndiritu et al., 2014). Therefore, the education level and age of household head have a countervailing effect on the adoption rates of SIPs. Household size is one proxy indicator for the availability of family labour. The average household size of the sampled households varied from 1 to 15 household member (s), with an average household size of 6 members. As soil conservation strategies are quite labour intensive, household size can positively influence the adoption of soil conservation strategies (Lee, 2005).

(a) Household asset endowment

Land size, total household income, land and livestock ownership were used to represent household asset (wealth) endowments. Households with a strong capital base are likely to invest in capital-intensive technologies and finance the purchase of inputs, such as chemical fertilizers. Households that lease land (tenants) are risk averse and are not likely to invest in capital-intensive SIPs as they might feel threatened by contract termination and eviction. Livestock provides manure as a side product that could be used in crop production (Kassie et al., 2013). However, livestock also competes for other resources such as water and family labour, and may negatively affect the adoption of certain SIPs. Households with more land may feel less need to intensify their production compared to households with less land. In the sample, agricultural land is generally small, with 96% of the respondents owning land which was on average size 0.28 acres. Of farmers surveyed, 62% were full-time farmers and almost all (97%) owned at least one or more livestock.

(a) Market access

In general, market imperfections such as structural constraints, failure to pay on delivery or lack of understanding of price differentiation in different market outlets limit the attractiveness of adopting and investing in SIPs (Chelang'a, Obare, & Kimenju, 2013; Lee, 2005). Farmers participating in market outlets and selling their farm products are likely to achieve better economic returns from their investments. Croft et al. (2016) reported that AIV famers selling their vegetables to formal markets[1] had a higher gross income than those supplying to informal markets.[2] This, in turn, may increase their likelihood of invest in SIPs. A dummy variable equal to one (and zero otherwise) was included if the household sold any of the AIVs produced. From the data, 69% of the households also produced AIVs for selling, and 31% were pure subsistence farmers. Another dummy variable was included if the household sold any AIV produce directly to any formal market. The survey shows 30% of farmers sold to supermarkets, hotels, restaurants or schools, and were therefore considered as being integrated into the formal market. The remaining 39% of farmers sold their AIV produce to informal markets, such as brokers or middle men, roadside kiosks or open market stalls. It was assumed that market integration in general, and formal market participation in particular, has a positive impact on the adoption of SIPs. Distance to market is another influencing factor in the adoption of SIPs because increasing distance means a rise in transaction costs due to reduced access to market information and inputs (Mbaga-Semgalawe & Folmer, 2000). Gotor and Irungu (2010) reveal that market information on AIVs decreases with increasing distance from Nairobi. Similar to this finding, this study expects market distance to have a negative impact on the adoption of SIPs.

(a) Institutional variables

Social capital emerges through bonding or bridging networks and has been denoted as an important determining factor in the diffusion of innovation as well as adoption theory and practices (Rogers, 2003). Social capital facilitates the exchange of information and enables farmers to access inputs and overcome credit constraints, particularly in areas where information sources are scarce or inadequate and there are imperfect markets with high transaction costs (Kassie et al., 2013). In this study, the households' social capital was operationalized as the household's membership of a producer and/or marketing group. In the present sample, 37% of the AIV producers were members of a group. It was assumed that being a member of a producer or a marketing group positively influenced the adoption rate of SIPs.

(a) Environmental constraints

Even though AIVs have been reported to tolerate a wide spectrum of weather variability, some AIV species are rather sensitive to pest and diseases as well as weather-related shocks such as dry spells or water logging caused by too little or too much rainfall (Stöber et al., 2017). Furthermore, Shackleton, Pasquini, and Dresher (2009) observed that AIVs can be harvested more than once per season. This intensive production requires good soil fertility management to sustainably maintain the crop productivity. Therefore, a dummy was used to estimate the soil fertility of AIV plots based on farmers' perceptions of land or plot fertility. It was assumed that the level of plot fertility had negative or positive impact on the SIP adoption rate. A set of dummies equal to one was included for various problems faced by the farming household, specifically AIVs infected by pests and diseases, water shortages, and the incidence of extreme weather events such as unusual heavy rainfall or dry spells in the growing season. It was assumed that pests and diseases, water shortages and exposure to weather-related shocks had a positive impact on the adoption rate of SIPs.

(a) Farm location

AIVs are highly perishable leafy vegetables that require a properly maintained cool supply chain to increase their shelf life. Cooling facilities, appropriate infrastructure and easy market access depends on proximity to the market. Therefore, AIVs produced in peri-urban areas are likely to reach the market fresher than those produced in rural areas (Weinberger & Pichop, 2009). Formal markets, such as supermarkets, demand high quality standards (for example, leaf size and appearance of freshness). AIV famers producing AIVs in peri-urban areas are more likely to penetrate these formal markets, fetching higher economic returns compared to AIV producers in rural areas. For instance, Indeche, Mensah, and Annor-Frempong (2017) found that AIV farmers in remote rural Kakamega lack knowledge on quality standards, especially with regard to the transaction costs attributed to formal market integration. Therefore, a dummy variable equal to one was included if the household produced AIVs in a peri-urban region (Kiambu, Nakuru), where 42% of the households were located, and zero for the remaining 58% residing in rural areas (Kakamega, Kisii). It was assumed that the per-urban production environment positively influences adoption of SIPs.

3. Results and discussion

3.1. Extent of adoption

The extent of adoption of SIPs varied considerably between practices and locations. The most widespread SIP was AIV diversification, with 83% of the households planting more than one AIV species. Diversification of AIV species was significantly ($p < 0.03$) more widespread in rural areas than in peri-urban areas. The application of organic manure was also a widely disseminated practice, with 66% of the farmers using organic (animal) manure on their AIV plots. This is fairly similar to the mean adoption level of 70% using animal manure documented for smallholder farmers cultivating maize in Kenya, but 30% less than the adoption levels for the same crop cultivated in Malawi, Ethiopia and Tanzania (Kassie et al., 2015). Furthermore, the present findings were slightly higher compared to the adoption level of manure application of approximately 50% reported by smallholder farmers cultivating maize in rural western Kenya (Marenya & Barrett, 2007). This suggests a higher adoption of organic manure in vegetable production compared to staple crops such as maize in SSA. Only a very small proportion of farming households used improved irrigation systems and integrated soil nutrient management, with an adoption level of 12% and 9% respectively. This low adoption levels of these two SIPs was even significantly lower in rural areas than in peri-urban areas (Table 3). These findings implies that while many farmers use

Table 3. Adoption levels as the share of the total number of households and per location.

	Share from total *N*		Production system (%)		
Type of SIPs	No of households	%	Peri-urban	Rural	Chi^2 (*p*-value)
Improved irrigation systems	85	12.4	90.6	9.4	93.20****
Organic manure	451	65.8	44.3	55.7	2.52
Integrated soil fertility management	62	9.1	59.7	40.3	8.55**
AIV diversification	566	82.6	40.1	59.9	5.80**

**** and ** indicate significance at $p < 0.001$ and 0.05 respectively.

and benefit from ecological benefits of organic manure, a larger number do not gain economic and environmental outcomes of using improved irrigation systems and integrated soil fertility management.

There is need therefore for stakeholders working on programmes that seeks to improve sustainable production of AIV to focus more on how to improve uptake of two these SIPs which low uptake levels.

3.2. Adoption intensities

Adoption intensity, defined here as the number of SIPs practised by the AIV producer, ranged from zero to four. Overall, the adopters of two SIPs were highest both in rural and peri-urban areas compared to adopters of one or three SIPs. 62% and 38% of farmers adopted two SIPs in rural and peri-urban areas respectively.

Adopters of one or two SIPs were slightly more widespread in rural areas, with 65% compared to 35% peri-urban adopters. However, the proportion of adopters practising three SIPs was higher in peri-urban areas (92%) compared to 7% in rural areas (Figure 1). None of the farmers in the rural areas adopted the highest intensity of four SIPs, and only one peri-urban farmer did so. These results indicate a slightly higher adoption intensity in peri-urban settings compared to rural areas. This suggest that AIV production in peri-urban areas is probably done using SIPs compared to in rural areas. This might be attributed to better market integration, more information about SIPs, and greater access to market prices and farm inputs in peri-urban areas that offer farm households higher economic returns from their investments, resulting in them being motivated to invest in more SIPs

3.3. Complementarities and substitutabilities

The alternative hypothesis of mutual interdependence among SIPs was statistically significant (likelihood ratio test (chi^2 (6)) = 163.609, $p < 0.000$). This supports the choice of the multivariate probit model in this adoption study. Additionally, four out of six coefficients of pairwise correlation were significantly correlated, demonstrating that some SIPs complement or substitute one other (Table 4). For instance, improved irrigation systems and integrated soil fertility management were positively correlated, as were use of organic manure and AIV diversification.

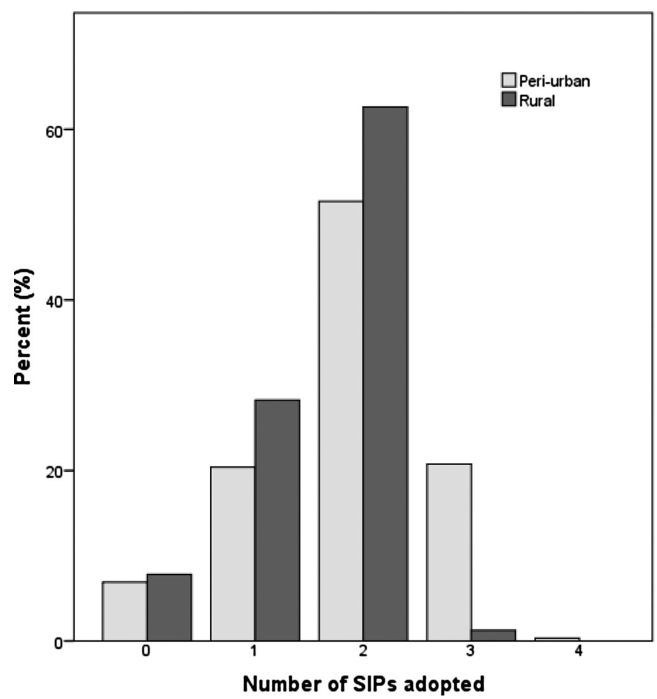

Figure 1. The percentage of farming households from rural and peri-urban areas who practiced either 1, 2, 3 or all the 4 sustainable intensification practices.

Table 4. Correlation coefficients of adoption of SIPs from MPV model.

	$\rho_{\text{improved irrigation system}}$	$\rho_{\text{organic manure}}$	$\rho_{\text{integrated soil fertility management}}$
$\rho_{\text{organic manure}}$	−0.117 (0.081)		
$\rho_{\text{integrated soil fertility management}}$	0.374 (0.094)****	−0.854 (0.046)****	
$\rho_{\text{AIV diversification}}$	0.128 (0.095)	0.326 (0.068)****	−0.151 (0.083)*

Likelihood ratio test of: $\rho_{\text{organic manure}} = \rho_{\text{improved irrigation system}} = \rho_{\text{integrated soil fertility management}} = \rho_{\text{improved irrigation system}} = \rho_{\text{AIV diversification}} = \rho_{\text{improved irrigation system}} = \rho_{\text{integrated soil fertility management}} = \rho_{\text{organic manure}} = \rho_{\text{AIV diversification}} = \rho_{\text{organic manure}} = \rho_{\text{AIV diversification}} = \rho_{\text{integrated soil fertility management}} = 0$; $X^2(6) = 163.23$****

**** and * indicate significance at $p < 0.001$ and 0.1 respectively.

The relationship between integrated soil fertility management and use of organic manure was negative, as was that between integrated soil fertility management and AIV diversification. One possible reason for this could be that households usually decide on just one distinct soil fertilization method. Moreover, if households have insufficient resources they potentially opt for organic manure because integrated soil fertility management is labour intensive and costly due to necessity of buying inorganic fertilizers.

3.4. Drivers and barriers of adoption of SIPs

The six categories of explanatory variables had different influence on the adoption and non-adoption of SIPs (Table 5). With regard to household characteristics, male-headed households with fewer members were more likely to adopt improved irrigation systems. This may be attributed to resource endowment characteristics and the higher labour availability of male-headed households. For instance Mulwa, Marenya, Rahut, and Kassie (2017) found that the availability of male family labour conditioned the adoption of soil and water conservation measures in Malawi. However, large households are likely to spend most of their income on food and other basic needs. This in turn reduces the household's ability to invest in improved irrigation systems, which are usually capital intensive. The education level of the household head however was an important factor determining the adoption of organic manure.

This result is consistent with the results of Waithaka, Thornton, Shepherd, and Ndiwa (2007) and Gelgo, Mshenga, and Zemedu (2016), who reported a similar positive relationship between the education level of the household head and adoption of organic manure among smallholder farmers in western Kenya and in Shashemene district in Ethiopia. This implies that more public and private investment on farmer training and education programmes are potential pathways to increase use of organic manure as well as achieve sustainable AIV production in Kenya.

Farmers' willingness to take production risks significantly affected the adoption of integrated soil fertility management as a means of SIP. This may imply that farmers consider investment in integrated soil fertility management a risky endeavour, perhaps due to higher investment costs and greater expected returns. Therefore, risk-taking farmers are likely to opt for integrated soil fertility management and expect higher economic returns. For organic manure it is the opposite since risk-takers do not adopt soil fertility management based on the use of organic fertilizers. Those claiming that their main occupation is full-time farming were more likely to adopt improved irrigation systems. They rely on income from farming to support their livelihoods, and therefore avoid the risk associated with rain-fed dependency or the workload of traditional irrigation systems for AIV production. Improved irrigation systems are less labour and water intensive and guarantee household income even in dry seasons. Land ownership conditioned the adoption of organic manure, which is consistent with previous studies by Kassie et al. (2013) and Asfaw et al. (2014). They reported a similar positive relationship between land ownership and adoption of manure among smallholder farmers in Tanzania and Malawi. Land ownership is associated with greater tenure security, which increases farmers' likelihood of adopting strategies that will capture the returns on their investment in the long run.

Livestock ownership negatively affected adoption of improved irrigation systems on AIV plots. Livestock compete with irrigation for water and labour. Furthermore, keeping livestock for milk production is a major enterprise for most smallholder households in Kenya and is often associated with higher economic returns. In this study area, farmers specialized in livestock production (allocating more household resources) instead of intensifying vegetable production through improved irrigation systems.

Household income significantly ($p < 0.0001$) determined the adoption of improved irrigation systems, use of organic manure and AIV diversification. This is consistent with the wider view that when access to credit is limited, better-off households are doubly advantaged by having more resources to invest in SIPs and at the same time enough liquidity to invest in SIPs that require cash payments upfront (Pender & Kerr, 1998). This shows the essence of cash in the early stages of adoption decisions, *i.e.* cash is needed to purchase irrigation equipment (motorized pumps and pipes), drill boreholes or wells, and pay for labour. The positive relationship between income and adoption of organic manure contradicts the findings of Waithaka et al. (2007) who reported an inverse relationship between increase in income and use of organic manure among smallholder farmers in western Kenya. This may be due to the fact that manure in rural western Kenya is not income dependent because most farmers keep their own livestock and the manure market is almost inexistent. However, in this study, particularly in peri-urban areas, organic manure is an external input bought from other counties.

Integrated soil fertility management is negatively correlated with household income. This may be due to the high share of off-farm and non-farm income in households with a higher income, and part-time farmers being less interested in investing in integrated soil fertility as the farm is not the primary source of livelihood. Farmers with a higher household income may prefer to invest their time, energy and cash in more risky enterprises that will earn them greater

Table 5. Parameter estimates from MVP model for estimating determinants of adoption of SIPs (standard errors in parenthesis).

	Dependent variables			
Explanatory variables	Improved irrigation system	Organic manure	Integrated soil fertility management	AIV diversification
Household characteristics				
Household size	−0.090 (0.042)**	−0.000 (0.024)	0.004 (0.034)	0.018 (0.029)
Household head is male	0.372 (0.225)*	−0.003 (0.141)	0.134 (0.185)	0.077 (0.160)
Age of household head	0.010 (0.006)	−0.001 (0.004)	−0.004 (0.005)	0.006 (0.005)
Education level	0.023 (0.018)	0.022 (0.011)*	0.001 (0.014)	−0.016 (0.013)
Willingness to take risk	0.263 (0.204)	−0.175 (0.125)	0.437 (0.198)***	−0.012 (0.144)
Asset endowment				
Natural logarithm of land size	−0.120 (0.079)	−0.046 (0.053)	−0.086 (0.072)	−0.017 (0.060)
Farming as main occupation	0.347 (0.018)*	0.083 (0.113)	−0.169 (0.150)	−0.013 (0.132)
Livestock ownership	−0.849 (0.388)**	0.085 (0.306)	0.098 (0.401)	−0.217 (0.379)
Farm ownership	−0.177 (0.424)	1.047 (0.280)****	0.289 (0.472)	−0.312 (0.326)
Natural logarithm total income	0.285 (0.115)**	0.221 (0.074)***	−0.290 (0.096)***	0.260 (0.085)***
Land fertility	0.189 (0.164)	−0.059 (0.108)	−0.128 (0.141)	0.112 (0.130)
Market access				
Informal market integration	1.303 (0.277)****	0.264 (0.131)***	0.269 (0.195)	0.857 (0.153)****
Formal market integration	0.034 (0.182)	−0.217 (0.131)*	0.317 (0.158)**	−0.164 (0.169)
Natural logarithm of distance to market	0.229 (0.082)***	−0.032 (0.061)	−0.037 (0.078)	0.056 (0.078)
Institutional factors				
Extension	0.183 (0.180)	0.016 (0.122)	0.052 (0.166)	0.165 (0.145)
Access to credit	−0.228 (0.197)	−0.061 (0.125)	−0.178 (0.163)	−0.112 (0.149)
Group membership	−0.120 (0.211)	0.217 (0.124)*	0.055 (0.161)	0.148 (0.153)
Information on new agricultural technologies	0.198 (0.187)	−0.193 (0.121)	0.388 (0.172)**	−0.047 (0.144)
Information on health benefits of AIVs	0.152 (0.218)	−0.240 (0.141)*	−0.145 (0.191)	−0.164 (0.168)
Environmental constraints				
Crop pest	0.208 (0.257)	−0.002 (0.205)	−0.111 (0.261)	−0.380 (0.219)*
Crop disease	0.396 (0.346)	−0.135 (0.245)	0.235 (0.299)	0.486 (0.377)
Water shortage	−0.180 (0.332)	0.343 (0.206)*	−0.276 (0.290)	−0.406 (0.212)*
Unusual heavy rainfall	0.108 (0.235)	−0.111 (0.153)	0.332 (0.184)*	−0.008 (0.184)
Drought	0.062 (0.183)	−0.134 (0.112)	0.115 (0.152)	−0.150 (0.134)
Farm location				
Peri-urban	1.364 (0.235)****	−0.163 (0.132)	0.416 (0.181)**	−0.226 (0.149)
Constant	−6.377 (1.382)****	−2.85 (0.827)***	0.186 (1.197)	−2.287 (0.960)**
Regression diagnostics for MVP model				
Number of observations	685			
Log pseudo-likelihood	−950.073			
Wald Chi^2 (100)	269.80****			

****, ***, ** and * indicate significance at $p < 0.001$, 0.01, 0.05 and 0.1 respectively.

economic benefits than investing in labour intensive integrated soil fertilization.

Market integration had a strong influence on the adoption of SIPs. The 69% of farmers who sell AIVs to informal markets significantly adopted improved irrigation systems, use of organic manure and diversifying AIV production. Those selling AIVs through formal market outlets were also more likely to adopt integrated soil fertility management, but refrained from solely using manure. These findings suggest that integrating farmers with formal or informal AIV market outlets encourages the uptake of SIPs since the adoption may have economically rewarding effects for farmers.

The positive relationship between market participation and AIV diversification, however, contradicted the common assumption that market linkages contribute to the loss of agro-biodiversity. For instance, Ngugi et al. (2007) reveal that the AIV market demand in Nairobi and the surrounding areas is limited to a few species, and therefore negatively affects the opportunities for farmers to diversify in AIVs for sale. The inverse relationship between formal market integration and use of manure could be due the fact that market-integrated farm households use fertilizers because they are likely to have more money to purchase it. The significant ($p < 0.0004$) positive relationship between distance to the nearest market and adoption of improved irrigation systems was not expected. One possible reason for this could be the high demand for AIV throughout the year, particular during the dry season, and the possibility of selling it directly to the consumer or retailer a short distance away.

Access to farmers' groups and information on new agricultural technologies and innovations significantly determined adoption of organic manure and integrated soil fertility management. Ajayi et al. (2007) revealed similar findings that farmers organized in groups were more likely to apply organic manure in Cameroon. The positive influence of farmers' groups on the adoption of integrated soil fertility management was consistent with the common understanding of social networks facilitating access to information, knowledge and credit, thereby considerably reducing transaction costs. Group marketing leads to greater bargaining power, which in turn enhances the adoption of new technologies (Bandiera & Rasul, 2006). This finding suggests that social networks would be effective entry points for enhancing farmers' capacity to adopt SIPs, also recommended in the adoption of SI for climate change adaptation (Vignola et al., 2015).

Environmental constraints had a mixed effect on the adoption of SIPs. For example, it seemed that AIV farmers understood the positive effect of organic manure in conserving soil moisture content, as water shortage positively affected the adoption of organic manure. Similar results are reported by Gandure, Walker, and Botha (2013), with water shortage and evaporation losses being the main contributors to the adoption of mulching. Unusually heavy rainfall also had a positive impact on the adoption of integrated soil fertility management. Incidences of crop pest attacks and water shortages meanwhile negatively affected the adoption of AIV diversification. This result was in contrast to the general understanding that crop diversification is a strategy employed by farmers to reduce production risks associated with pest and disease attacks, and harsh weather (Teklewold et al., 2013). This could mean that farmers who face water shortages and pest attacks are likely to opt for other staple crops rather than cultivate more AIVs.

With regard to the level of farm location, the coefficient for AIV production in peri-urban areas was positive and significant ($p < 0.0006$) in the adoption of improved irrigation systems and integrated soil fertility management. Peri-urban areas are characterized by improved infrastructural development – transport and communications – ,which enables farmers to access farm inputs and technologies, lucrative urban market outlets and relevant information at reduced transaction costs than their counterparts in rural areas.

4. Conclusion

This study is one of the first to examine the level of and factors influencing the adoption of interrelated SIPs among rural and peri-urban smallholder farmers in Kenya producing AIVs. The findings revealed that use of organic manure and AIV diversification was widespread, both in rural and peri-urban vegetable production, and in general higher than other field crops such as maize. However, the adoption of improved irrigation systems and integrated soil fertility management was rather low and even significantly lower in rural areas compared to peri-urban settings. Similarly, the adoption intensity of multiple SIPs was less prevalent in rural areas than in peri-urban areas. This finding suggests that specific targeted approaches are needed to increase the adoption of improved irrigation systems and integrated soil fertility management in the two areas. Such promotion programmes should be emphasized more in rural areas through local institutions such as farmers' groups, as social capital is a major determinant of adoption of SIP. The study also revealed complementarities and substitutabilities between SIPs, implying that policy changes that affect adoption of a given SIP may also influence adoption of other SIPs. Therefore, when a set of SIPs complement one other, farmers should be encouraged to adopt such SI packages. Adopting a range of SIPs would contribute more effectively to the desired productivity and environmental protection compared to a single SIP that might only solve one issue, *e.g.* irrigation for dry season production. Household characteristics, household income, market integration, level of urbanization, environmental constraints and institutional factors influenced the decision to adopt SIPs in a heterogeneous way. These findings imply that the SI of AIVs could potentially be promoted through well-designed policies and programmes targeting the integration of farm households in effective and efficient vegetable markets, build household financial capital base, and improve land tenure security. Furthermore, social capital and farmers' groups play a crucial role in the choice of adoption. Farmers' institutions may be an efficient channel for promoting the adoption of SIPs, particularly those with low adoption levels, as wells as other agricultural technologies not yet included here. Future studies may be necessary to build up evidence on the relative economic and environmental advantages and complexity of SIPs in vegetable production in order to develop guidelines for SIPs in leafy vegetables and AIVs. It is also important to evaluate whether there is any gender difference with regard to adoption of SIPs in vegetable production in peri-urban and rural areas.

Notes

1. Markets with formalized transaction systems and also with clear market institutions such as supermarkets, retail groceries, institutions and hotels.
2. Informal market are either undesignated areas near farming communities or in peri-urban areas where door-to-door and roadside markets do exist and suppliers and buyers exists with very few or no transaction documents.

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References

Abdulla, A., Owes, V., & Baking, J. A. (2011). Adoption of safer irrigation technologies and cropping patterns: Evidence from Southern Ghana. *Ecological Economics*, *70*(7), 1415–1423. doi:10.1016/j.ecolecon.2011.03.004

Abukutsa-Onyango, M. K., Amoke, P., & Habwe, F. (2010). Iron and protein content of priority African indigenous vegetables in the Lake Victoria *Basin. Journal of Agricultural Science and Technology*, *4*(29), 67–68.

Ajayi, O. C., Akinnifesi, F. K., Sileshi, G., & Chakeredza, S. (2007). Adoption of renewable soil fertility replenishment technologies in the Southern African region: Lessons learnt and the way forward. *Natural Resources Forum*, *31*, 306–317.

Asfaw, S., McCarthy, N., Lipper, L., Arslan, A., Cattaneo, A., & Kachulu, M. (2014). *Climate variability, adaptation strategies and food security in Malawi*. ESA Working Paper No. 14-08. Rome: FAO.

Badgley, C., Mightier, J., Quintero, E., Zaeem, E., Chappell, M. J., Aviles-Vázquez, K., … Perfecto, I. (2007). Organic agriculture and the global food supply. *Agriculture and Food Systems*, *22*(2), 86–108. doi:10.1017/S1742170507001640

Bandiera, O., & Rasul, I. (2006). Social networks and technology adoption in Northern Mozambique. *The Economic Journal*, *116*, 869–902.

Chelang'a, P. K., Obare, G. A., & Kimenju, S. C. (2013). Analysis of urban consumers' willingness to pay a premium for African Leafy Vegetables (ALVs) in Kenya: A case of Eldoret Town. *Food Security*, *5*(4), 591–595.

Chivenge, P., Vanlauwe, B., & Six, J. (2011). Does the combined application of organic and mineral nutrient sources influence maize productivity? A meta-analysis. *Plant and Soil*, *342*, 1–30. doi:10.1007/s11104-010-0626-5

Croft, M. M., Marshall, M. I., & Hallett, G. S. (2016). Market barriers faced by formal and informal vendors of African Leafy Vegetables in Western Kenya. *Journal of Food Distribution Research*, *47*(3), 49–60.

Danson, G., Drechsel, P., Wiafe-Antwi, T., & Gyiele, L. (2002). Income of farming systems around Kumasi, Ghana. *Urban Agriculture Magazine*, *7*, 5–6.

Dile, Y. T., Karlberg, L., Temesgen, M., & Rockström, J. (2013). The role of water harvesting to achieve sustainable agricultural intensification and resilience against water related shocks in Sub-saharan Africa. *Agriculture, Ecosystems & Environment*, *181*, 69–79. doi:10.1016/j.agee.2013.09.014

Drechsel, P., Graefe, S., Sonou, M., & Cofie, O. (2006). *Informal irrigation in urban West Africa: An overview*. Colombo: International Water Management Institute. (IWMI Research Report 102)

Gandure, S., Walker, S., & Botha, J. J. (2013). Farmers' perceptions of adaptation to climate change and water stress in a South African rural community. *Environmental Development*, *5*, 39–53. doi:10.1016/j.envdev.2012.11.004

Gelgo, B., Mshenga, P., & Zemedu, L. (2016). Analysing the determinants of adoption of organic fertilizer by smallholder farmers in Shashemene District, Ethiopia. *Journal of Natural Sciences Research*, *6*(19), 35–44.

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, *114*(1), 23–34. doi:10.1016/j.fcr.2009.06.017

Godfray, J. C. (2015). The debate over sustainable intensification. *Food Security*, *7*, 199–208.

Gotor, E., & Irungu, C. (2010). The impact of biodiversity international's African leafy vegetable programme in Kenya. *Impact Assessment and Project Appraisal*, *28*(1), 41–55.

HCDA. (2014). *National horticulture validated report*. Kenya: Ministry of Agriculture, Department of Horticultural Crops Development Authority. Kenyan Government Printer. Retrieved from http://www.agricultureauthority.go.ke/wp-content/uploads/2016/05/Horticulture-Validated-Report-2014-Final-copy.pdf

Indeche, A., Mensah, A. O., & Annor-Frempong, F. (2017). Level of knowledge on quality standards of high value markets in Kenya among indigenous vegetable women farmers in Kakamega county. *International Journal of Contemporary Applied Sciences*, *4*(3), 26–34.

Kassie, M., Jaleta, M., Shiferaw, B., Mmbando, F., & Mekuria, M. (2013). Adoption of interrelated sustainable agricultural practices in smallholder systems: Evidence from rural Tanzania. *Technological Forecasting and Social Change*, *80*(3), 525–540. doi:10.1016/j.techfore.2012.08.007

Kassie, M., Teklewold, H., Jaleta, M., Marenya, P., & Erenstein, O. (2015). Understanding the adoption of a portfolio of sustainable intensification practices in eastern and Southern Africa. *Land Use Policy*, *42*, 400–411. doi:10.1016/j.landusepol.2014.08.016

Kassie, M., Zikhali, P., Pender, J., & Köhlin, G. (2010). The economics of sustainable land management practices in the Ethiopian highlands. *Journal of Agricultural Economics*, *61*(3), 605–627.

Kim, D., Thomas, D. A., Pelster, D., Rosenstock, S. T., & Sanz-Cobena, A. (2016). Greenhouse gas emissions from natural ecosystems and agricultural lands in Sub-Saharan Africa: Synthesis of available data and suggestions for further research. *Biogeosciences*, *13*, 4789–4809.

Kurgat, B. K., Stöber, S., Mwonga, S., Lotze-Campen, H., & Rosenstock, S. (2018). Livelihood and climate trade-offs in Kenyan peri-urban vegetable production. *Agricultural Systems*, *160*, 79–86.

Lee, D. R. (2005). Agricultural sustainability and technology adoption: Issues and policies for developing countries. *American Journal of Agricultural Economics*, *87*, 1325–1334.

Lin, C. J., Jensen, K. L., & Yen, S. T. (2005). Awareness of foodborne pathogens among US consumers. *Food Quality and Preference*, *16*(5), 401–412.

Marenya, P. P., & Barrett, C. B. (2007). Household-level determinants of adoption of improved natural resources management practices among smallholder farmers in western Kenya. *Food Policy*, *32*(4), 515–536. doi:10.1016/j.foodpol.2006.10.002

Mbaga-Semgalawe, Z., & Folmer, H. (2000). Household adoption behaviour of improved soil conservation: The case of the North Pare and West Usambara Mountains of Tanzania. *Land Use Policy*, *17*, 321–336.

The Montpellier Panel. (2013). *Sustainable intensification: A new paradigm for African agriculture*. London: Imperial College.

Muhanji, G., Roothaert, R. L., Webo, C., & Stanley, M. (2011). African indigenous vegetable enterprises and market access for small-scale farmers in East Africa. *International Journal of Agricultural Sustainability*, *9*(1), 194–202. doi:10.3763/ijas.2010.0561

Mulwa, C., Marenya, P., Rahut, D. B., & Kassie, M. (2017). Response to climate risks among smallholder farmers in Malawi: A multivariate probit assessment of the role of information, household demographics, and farm characteristics. *Climate Risk Management*, *16*, 208–221. doi:10.1016/j.crm.2017.01.002

Ndiritu, S. W., Kassie, M., & Shiferaw, B. (2014). Are there systematic gender differences in the adoption of sustainable agricultural intensification practices? Evidence from Kenya. *Food Policy*, *49*, 117–127. doi:10.1016/j.foodpol.2014.06.010

Ngugi, I. K., Gitau, R., & Nyoro, J. (2007). *Access to high value markets by smallholder farmers of African indigenous vegetables in Kenya: Re-governing markets innovative practice series*. London: International Institute for Environment and Development.

Okalebo, J. R., Othieno, C. O., Woomer, P. L., Karanja, N. K., Semoka, J. R. M., Bekunda, M. A., … Mukhwana, E. J. (2007). Available technologies to replenish soil fertility in East Africa. *Nutrient Cycling in Agroecosystems*, *76*(2–3), 153–170. doi:10.1007/s10705-005-7126-7

Onium, M., & Mwaninki, P. (2008). *Cataloguing and evaluation of available community/farmers-based seed enterprise on African indigenous vegetables for ECA countries*. Lagrotech Consultants.

Pender, J. L., & Kerr, J. M. (1998). Determinants of farmers' indigenous soil and water conservation investments in semi-arid India. *Agricultural Economics*, *19*, 113–125.

Pincus, L., Margenot, A., Six, J., & Scow, K. (2016). On-farm trial assessing combined organic and mineral fertilizer amendments on vegetable yields in central Uganda. *Agriculture, Ecosystems & Environment*, *225*, 62–71. doi:10.1016/j.agee.2016.03.033

Pretty, J., Toulmin, C., & Williams, S. (2011). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability*, *9*(1), 5–24. doi:10.3763/ijas.2010.0583

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York: Free Press.

Shackleton, M. C., Pasquini, M. W., & Dresher, W. A. (2009). *African indigenous vegetables in urban agriculture*. London: Earthscan.

Shiferaw, B. A., Okello, J., & Reddy, R. V. (2009). Adoption and adaptation of natural resource management innovations in smallholder agriculture: Reflections on key lessons and best practices. *Environment, Development and Sustainability*, *11*(3), 601–619. doi: 10.1007/s10668-007-9132-1

Stöber, S., Chepkoech, W., Neubert, S., Kurgat, B., Bett, H., & Lotze-Campen, H. (2017). *Adaptation Pathways for African Indigenous Vegetables' Value Chains*, 413–433. doi:10.1007/978-3-319-49520-0_25

Teklewold, H., Kassie, M., Shiferaw, B., & Köhlin, G. (2013). Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: Impacts on household income, agrochemical use and demand for labour. *Ecological Economics*, *93*, 85–93.

Tilman, D., & Clark, M. (2014). Global diets link environmental sustainability and human health. *Nature*, *515*(7528), 518–522.

Vanlauwe, B., Coyne, D., Gockowski, J., Hauser, S., Huising, J., Masso, C., … Van Asten, P. (2014). Sustainable intensification and the African smallholder farmer. *Current Opinion in Environmental Sustainability*, *8*, 15–22. doi:10.1016/j.cosust.2014.06.001

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R., & Six, J. (2011). Agronomic use efficiency of N fertilizer in maize-based systems in Sub-Saharan Africa within the context of integrated soil fertility management. *Plant and Soil*, *339*, 35–50.

Vanlauwe, B., Tittonell, P., & Mukalama, J. (2007). Within-farm soil fertility gradients affect response of maize to fertilizer application in western Kenya. *Nutrient Cycling in Agroecosystems*, *76*, 171–182.

Vignola, R., Harvey, C. A., Bautista-Solis, P., Avelino, J., Rapidel, B., Donatti, C., & Martinez, R. (2015). Ecosystem-based adaptation for smallholder farmers: Definitions, opportunities and constraints. *Agriculture, Ecosystems & Environment*, *211*, 126–132.

Waithaka, M. M., Thornton, P. K., Shepherd, K. D., & Ndiwa, N. N. (2007). Factors affecting the use of fertilizers and manure by smallholders: The case of Vihiga, western Kenya. *Nutrient Cycling in Agroecosystems*, *78*(3), 211–224. doi:10.1007/s10705-006-9087-x

Weinberger, K., & Pichop, G. N. (2009). Marketing African indigenous vegetable along urban and peri-urban supply chain in Sub-Sahara Africa. In M. C. Shackleton, M. W. Pasquini, & W. A. Dresher (Eds.), *African indigenous vegetables in urban agriculture* (pp. 225–244). London: Earthscan.