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Who uses sustainable land management practices and what are the costs and benefits? Insights from Kenya

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Abstract

Suboptimal land management practices are degrading soils and undermining food production. Sustainable land management (SLM) practices can improve soil and enhance yields. This study identifies variations in SLM uptake, characterising farmers most likely to use SLM practices, identifying when it makes economic sense for farmers to implement particular SLM practices and how long it takes before benefits exceed costs. Using questionnaire data from farmers in western Kenya, we undertake a cost–benefit analysis and analyse determinants of SLM practice use. SLM implementation varied between counties and SLM practice(s), with household and farm characteristics, and access to assets and advice, playing a key role. SLM practices with high upfront and maintenance costs (e.g., terraces and agroforestry) offer low benefit-to-cost ratios for individual farmers who must also wait many years to break even on their investments. Nevertheless, over the policy-relevant time horizon considered (to 2030), Net present value can be positive. Simple SLM practices (manuring and intercropping) have low input costs and offer high benefit to cost ratios, providing a positive net present value up to 2030. Findings suggest that simple practices should be prioritised within policy to improve soil and increase yields. These should be supported by subsidies or other economic measures, facilitating uptake of practices such as agroforestry, which can provide wider societal benefits (e.g., improved water retention and carbon sequestration). Economic mechanisms could be augmented with support for agricultural innovation systems, improved monitoring of land management and yield relationships, and investment in climate and soil information services.

KEYWORDS

Africa, ecosystem services, food security, land degradation, sustainable agriculture

1 | INTRODUCTION

Land degradation takes a variety of forms (Adeel, Safriel, Niemeijer, & White, 2005) and is driven by several processes that operate over multiple temporal and spatial scales (Stringer, Reed, Fleskens, Thomas, & Lala-Pritchard, 2017). Outcomes of land degradation are ecologically, economically, and socially negative. Degradation disrupts ecosystem functions, processes, integrity, and services; diminishes food, livelihood, and income security; and undermines capacities to adapt to climate variability and other shocks and stresses. The rural poor often

disproportionately bear the burden of these negative impacts (Nkonya et al., 2008; Warren, 2002), particularly where they depend on the natural resource base to survive. Identifying ways to improve land productivity and sustainability for smallholder farmers who are often most negatively affected by land degradation is a central challenge in reversing declining per capita food availability (Mutoko, Ritho, Benhin, & Mbatia, 2015).

Many actions can be taken to reverse the degradation trend. Sustainable land management (SLM) offers one set of solutions and is defined as follows: "the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions" (World Overview of Conservation Approaches and Technologies [WOCAT], 2016). Such actions are not just important for food security and improving local livelihoods but can also help progress towards the Sustainable Development Goals, in particular target 15.3: "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world" (UN General Assembly, 2015).

SLM is grounded in improving water productivity and use efficiency; enhancing soil fertility; managing vegetation; and attending to microclimatic conditions (Liniger, Mekdaschi Studer, Hauert, & Gurtner, 2011). SLM practices reduce water losses (from runoff and evaporation) through water harvesting, infiltration and storage, improving irrigation, and managing surplus water. They increase soil fertility by improving surface cover using, for example, crop rotation, fallowing, intercropping, applying animal/green manure, and composting (ideally as part of an integrated crop-tree-livestock system). SLM practices can trap sediments and nutrients through use of vegetative and structural barriers, helping to reduce erosion. Microclimatic conditions can be managed through the use of windbreaks, shelterbelts, and trees for shade (via agroforestry and multi-storey cropping; Liniger et al., 2011). Not all SLM practices target each of the above, and they can be employed individually or in combination. Each SLM practice also has a unique set of costs and benefits (perceived and actual; Giger, Liniger, Sauter, & Schwilch, 2015). The literature provides an increasing body of evidence that SLM can be effectively employed to improve soil quality and increase crop production (Kassie, Zikhali, Pender, & Kohlin, 2010; Tesfaye, Brouwer, & van der Zaag, 2016). However, for land users, to adopt SLM practices requires them to gain a higher net return on their investments than from non-SLM practices, lower their risks, or both (Liniger et al., 2011). Although the literature on the economics of SLM is still accruing (Economics of Land Degradation [ELD], 2015), little work has been done to assess perceived costs and benefits from a farmer uptake perspective (e.g., Mazvimavi & Twomlow, 2009; McCarthy, Lipper, & Zilberman, 2018; Pannell, Llewellyn, & Corbeels, 2014).

Different beneficiaries need to balance costs and benefits over different temporal and spatial scales. Most land management decisions take place at individual farm scale (Dallimer et al., 2009). Decisions are therefore likely to be based on farmer knowledge and understandings of how land management affects yields and profits (Giger et al., 2015), regardless of the accuracy of farmer perceptions (Iiyama et al., 2012). However, the uptake of agricultural practices, and their continued use, does not solely rely on economic considerations. Overall, uptake is influenced by a combination of factors. Research to date has focused largely on household

socio-economic and farm attributes, but farmers are also influenced by different social, political, cultural, and institutional contexts that shape their experiences. For instance, resource gaps, such as a lack of tools, knowledge, and capacity, can inhibit SLM (Kwayu, Sallu, & Paavola, 2014; Shepherd & Soule, 1998). Further, Rogers (2003) emphasises the importance of social interaction and exchange in the widespread use of, and exposure to, particular practices (Stringer et al., 2017). Such social interactions and exposure to new knowledge is shaped by not only an individual's characteristics including their socio-economic status but also the wider context in which they are operating. Indeed, recent studies found that over 20 characteristics are required to develop a predictive model of the uptake of new agricultural practices (Kuehne et al., 2017). It is therefore essential to focus on the individual farmer scale if we are to understand how variations in the farming systems and perceptions of soil fertility influence uptake of particular SLM practices.

Individual land users are likely to prioritise yields and profitability (perceived or actual) of their own farming enterprise above wider societal benefits relating to the use of particular land management practices (Giger et al., 2015; Lutz, Pagiola, & Reiche, 1994; Shiferaw & Holden, 2001). At the same time, cumulative impacts of local land management decisions at larger, for example, catchment scales (Kwayu et al., 2014; Mulatu, van der Veen, & van Oel, 2014) ultimately determine whether a region is on an improving or declining soil quality trajectory. Interventions at national level, through relevant policies, laws, and economic and financial instruments, can shape local decisions to prevent, reduce, and reverse degradation. Actions and mechanisms can be identified from empirical data that incentivise SLM and reduce degradation at, and across, multiple scales, informing development of evidence-based policy and institutional frameworks.

Here, we examine who uses SLM practices and to identify the costs and benefits of doing so (cf. Tanui, Groeneveld, Klomp, Mowo, & van Ierland, 2013). We first identify barriers to, and enablers of, SLM use based on secondary questionnaire survey data and, second, undertake a cost–benefit analysis (CBA; e.g., Iiyama et al., 2012; Tesfaye et al., 2016) to assess when it makes economic sense to use particular SLM practices. Finally, we identify ways to reduce or remove barriers to their use, providing important insights for policy.

We focus on a region of high agricultural potential in western Kenya. In this region, as is the case globally, there are a large number of smallholder farmers managing a substantial area of land, which gives them a central role in food production (Samberg, Gerber, Ramankutty, Herrero, & West, 2016). This means that it is essential to understand their role in SLM implementation, not least because issues around declining crop yields for smallholder farmers through mitigating soil fertility loss remain a persistent policy challenge. Kenya's soils are suffering from degradation in the form of nutrient depletion, acidification, and erosion, all of which negatively affect agricultural production. These problems are largely driven by land management practices, such as elimination of fallows, removal and burning of crop residues, and shifts to more demanding crops (Vlek, Le, & Tamene, 2010). The Government's Kenya Vision 2030 and associated national-level policy developments on soils, recognises the need to increase agricultural productivity if food security is to be maintained and enhanced to meet demands from a rapidly increasing population. However, ongoing yield declines put achievement of this vision at risk.

For more than a decade, the country has experienced a downward production trend with land degradation, and soil fertility loses key contributors (Gicheru, 2012; Vlek et al., 2010).

Within Kenya's western counties of Siaya, Kakamega, and Bungoma, yields of the major cereal (maize; *Zea mays*) are low and declining, averaging 1 t/ha compared with 8 t/ha under optimal conditions (Muasya & Diallo, 2001). These declines are particularly significant as cereals provide approximately 50% of daily calorie intake in Africa (Food and Agriculture Organization, undated). Low productivity is attributed to suboptimal land management practices (Institut Français des Relations Internationales, 2009; Pimentel & Burges, 2013; Wiebe, 2003), driven in part by rapid human population growth, which has led to intense land fragmentation (Ovuka, 2000). The region has high population density (up to 522 people/km^2; Kenya National Bureau of Statistics, 2010), and average farm sizes are 0.5–2.0 ha (Tittonell, Vanlauwe, de Ridder, & Giller, 2007). Although general statistics provide broad-scale information, across the three counties, altitude, soils, and suitability for certain crops and farming systems (and therefore yields) vary, as do farm household characteristics and access to expertise regarding farming techniques and whether land is actively farmed by its owners or via relatives or rental arrangements. Each of these factors will influence SLM practice uptake and the costs and benefits of implementation (Kassie et al., 2007; Mwakubo, Maritim, & Yabann, 2004; Tittonell, Valauwe, Leffelaar, Rowe, & Giller, 2005). Use of SLM practices is therefore likely to vary widely. Understanding the reasons for this is an important first step in improving SLM uptake.

2 | METHODOLOGY

2.1 | Determinants of SLM practice use

To identify the determinants of current levels of SLM practice implementation, we used an existing secondary dataset collected in 2014 ("Farming Systems Analysis" or FSA dataset). It comprised surveys of the agricultural activities of 320 farming households. Farms were selected to cover the full range of agricultural conditions and farming systems in the three counties. The final participant list was based on households already known to local representatives of the survey funders due to their participation in previous initiatives (Schuh, 2015). Although it is not, therefore, a random subset of all farms in the region, the FSA nevertheless provides the most comprehensive data on farming systems and household characteristics for the region.

From over 40 questions centred on the socio-economics of farming, the FSA included questions directly relevant to soil degradation and SLM practices, namely, closed questions on whether the farmer implemented the following: (a) any SLM practice; (b) intercropping; and (c) manuring. It also included an open question about other SLM practices that had been followed in the previous 3 years. We used these questions as response variables, namely, 'Any SLM Practice Use,' 'Intercropping Use,' and 'Manuring Use,' respectively (Table S1).

As explanatory variables, we took those questions that were directly relevant to SLM practice uptake and determinants of uptake. We based our variable selection on questions that characterised farm and household access to assets and advise (Rogers, 2003). We determined which were associated with SLM practices by carrying out a logistic regression

(with response variables taking the value one if the respondent implemented the SLM practice and zero if they did not). We used the "best subset regression" approach implemented in the R package "glmulti." Best subset regression is a model selection technique, which assesses all possible regression models (from the full model with all explanatory variables to the null model including all possible subsets of explanatory variables in between these two extremes) and selects the best fitting one. Having removed colinear variables, we included 21 explanatory variables, which could broadly be categorised as those relating to the farm, the farming household, and access to assets (see Table S1 for explanatory variables).

2.2 | Cost–benefit analysis

Costs and benefits of SLM practices vary according to the (a) biophysical properties of a farm; (b) underlying sociodemographic factors of the farming household; and (c) characteristics of the farm business (Kassie et al., 2007; Tesfaye et al., 2016; Tittonell et al., 2005). To bound our study, we therefore concentrated on the most widespread growing conditions present in the region (the 'lower midland' agroecological zone; Ministry of Agriculture, 2009). Farm sampling followed a two-stage approach to capture as much of the remaining variation as was feasible. Initially, in a geographical information system, wards (the smallest and therefore most spatially resolved administrative unit in the region within which agricultural services and support are administered) were selected if they were (a) not urban and (b) at least half their area fell within the 'lower midland' zone. From this list, we used stratified random sampling to select wards in each county on the basis of ward and county area. The sample of wards was therefore broadly proportional to the area of each county covered by the "lower midland" zone. This resulted in 10 wards (four each in Siaya and Kakamega and two in Bungoma). Within each ward, six farms were chosen in consultation with the agricultural extension officers working in each ward. Criteria for farm selection included that they cultivated at least one of the region's eight major crops (maize *Zea mays*; beans *Fabaceae* spp.; sugar cane *Saccharum officinarum*; vegetables, millet, and sorghum *Eragrostideae* tribe spp.; groundnuts *Arachis hypogaea*; bananas *Musa* spp.), were active farmers (i.e., farming themselves, rather than renting their land to others to manage), and could be considered as smallholder farmers (which we defined managing 1.2–2 ha and predominantly subsistence in character; a definition in line with regional farm typologies; Koge, Birnholz, & Birthe, 2016). Farms were not known to the extension officers solely because of their use of SLM practices, because they had received advice from the office or due to their involvement in programmes intended to improve uptake. Due to this, exact farm size and the particular mixture of crops grown were unknown prior to data collection. We nevertheless recognise that our sample was not representative and was still likely to have been subject to biases. Conclusions drawn from our data therefore cannot be taken as representative of the county as a whole.

The questionnaire survey was designed following scoping visits to three farmer communities in December 2015. Piloting allowed questions that were unclear to be refined or removed. The final version investigated cropped land management practices to provide data for the CBA and included questions about household and farmer characteristics, farm and land attributes, and inputs (e.g., labour, materials, and machinery) and

outputs (e.g., crop yield, crop residues, and fodder) from the main cultivation activity undertaken on the farm (defined as that occupying the largest area of the farm). In March 2016, 60 farmers who had not been involved in the FSA survey answered the questionnaire survey.

We ascertained costs for SLM implementation via questions focussed on the most recently completed growing season (the "long rain season" in 2015) for which farmers had finished harvesting and knew their yields. Respondents were also asked if any SLM practices were implemented and the additional inputs (labour, materials, and machinery) used in doing so compared with cultivation of that crop without the SLM practices. If an SLM practice required construction/establishment (e.g., of a terrace), farmers reported inputs for construction and annual maintenance separately. If an SLM measure took up land area, farmers stated the physical dimensions of that land. Given that many smallholder farms are managed, at least in part, for subsistence purposes, using personal and family labour, we made several assumptions in order to estimate the total monetary value of inputs (including labour) and outputs associated with crop farming (Methods S1).

Assessing the benefits of implementing an SLM practice over the longer term requires longitudinal data covering pre- and post-implementation. However, farmers in western Kenya do not keep written records of past practices or yields. From the pilot study, it was apparent that farmer decisions regarding SLM implementation were based on individual perceptions of changes to inputs and outputs (cf. Giger et al., 2015), even though the accuracy of perceptions may be questionable (Iiyama et al., 2012). To quantify the benefits to farmers of implementing SLM practices, participants stated their perceptions of how the SLM practice altered labour and yield compared with a similar field where the SLM practice was not in place.

In line with the principles of SLM and the types of degradation occurring, we assumed that the main benefit of SLM to individual farmers would be increased yields through reduced soil erosion and improved fertility. However, the pilot survey highlighted that SLM practices alter labour requirements for cultivation, the production of crop residues, fodder, and timber, all of which vary according to the SLM intervention and biophysical characteristics of the farm. We therefore also asked farmers how implementing the SLM practice had changed the labour requirements for the cultivation of the main crop, residue, fodder, and timber production (for details, see Methods S1). All questions were asked using the local unit of land (acres; 1 acre = 0.4 ha) and currency (Kenya Shilling; 100 Ksh = 1 US$). Calculations were performed in these units and subsequently converted to US$ and hectares.

Because the costs incurred and benefits obtained happen over time, we took into account the time-value of money by (a) setting a timeframe over which to perform the analysis to match policy needs and (b) discounting future costs and benefits. This allowed calculation of the net present value (NPV) of investments in SLM practices. Where the NPV is positive, it makes (economic) sense for a farmer to implement an SLM practice. Other related measures are the benefits–cost ratio (BCR): the benefits divided by costs over the timeframe of analysis. A BCR > 1 indicates that benefits are greater than costs and the SLM practice should be implemented. To understand how long a farmer might have to wait before benefits exceed costs, we also calculated a return on investment (RoI) period: The length of time (years) after an SLM practice is initiated when total benefits exceed total costs.

CBA was based on SLM practices implemented in 2015, assuming their continued operation until 2030. This time period was used to parallel Kenya's *Vision 2030*, which seeks to enhance agricultural yields at the national level. To investigate the sensitivity of the CBA to discounting, we included discount rates (*r*) of 5% (Republic of Kenya, 2010) and 10% (Mogaka, Simons, Turpie, Emerton, & Karanja, 2001) from previous Kenyan studies and a lower rate of 3.5% (HM Treasury, 2013) to represent a typical figure used by national and international donors and policymakers. These rates were deemed suitable by stakeholders too, especially given the unknown and largely unknowable personal discount rates of individual smallholders. Both the time horizon and discount rates applied were set together with policymakers and decision makers in Kenya and considered most relevant and useful for their consultations as part of the *Vision 2030* policy agenda.

Data were used to calculate costs and benefits of cultivation with and without SLM implementation. However, farmer estimates of costs and benefits of a given practice varied according to individual circumstances and farm characteristics. Consequently, the total cost of implementing an SLM practice also varied. We accounted for this by using Monte Carlo simulations assuming uniform distribution of the costs/benefits of each activity, bounded by minimum/maximum reported values (see Methods S1 for details). Final CBA metrics were computed by Monte Carlo simulation whereby 1,000 sets of random samples were drawn for all variables, with these variables used to calculating the NPV, BCRs, and RoI period (and associated measures of uncertainty calculated as the 95% confidence intervals of the outputs of the simulations).

3 | RESULTS

3.1 | Determinants of SLM practice use

FSA survey respondents (*n* = 320) were well distributed between the three counties (Bungoma 33%, Kakamega 29%, and Siaya 38%). Respondents were household heads and, therefore, mostly male (82%, *n* = 261). Maize was the most commonly grown crop (62% of farms). An average farm grew 2.9 crops and had 3.6 cattle. Mean farm size was 3.9 ha, and the mean area cultivated for maize was 1.2 ha (Table S1). About 83% of the total farm area was owned by those farming it. Annual income from farming was 900–12,120 US$, constituting 75% of household income. Maize yields ranged from 846 to 5712 kg/ha. Farm income and yield data were only available for a subset of the sample so were not included in subsequent analyses.

Nearly three quarters (72%; *n* = 229) of respondents had experienced land degradation during 2012–2015, and 63% employed at least one SLM practice (Table S1). Best subset regression analysis indicated that across all three counties, household and farm characteristics and access to assets and advice variables (Table S2) predicted farmer use of an SLM practice with moderate accuracy (McFadden r^2 = 0.250; prediction error rate = 0.309). Uptake was more likely if a farmer had more recent contact with a crop adviser (β = 0.211; *p* < .05). No other variables were significant (Table S2; Figures 1 and 2).

When farmers were asked specifically about manuring and intercropping, 251 (78%) and 171 (53%) followed these practices,
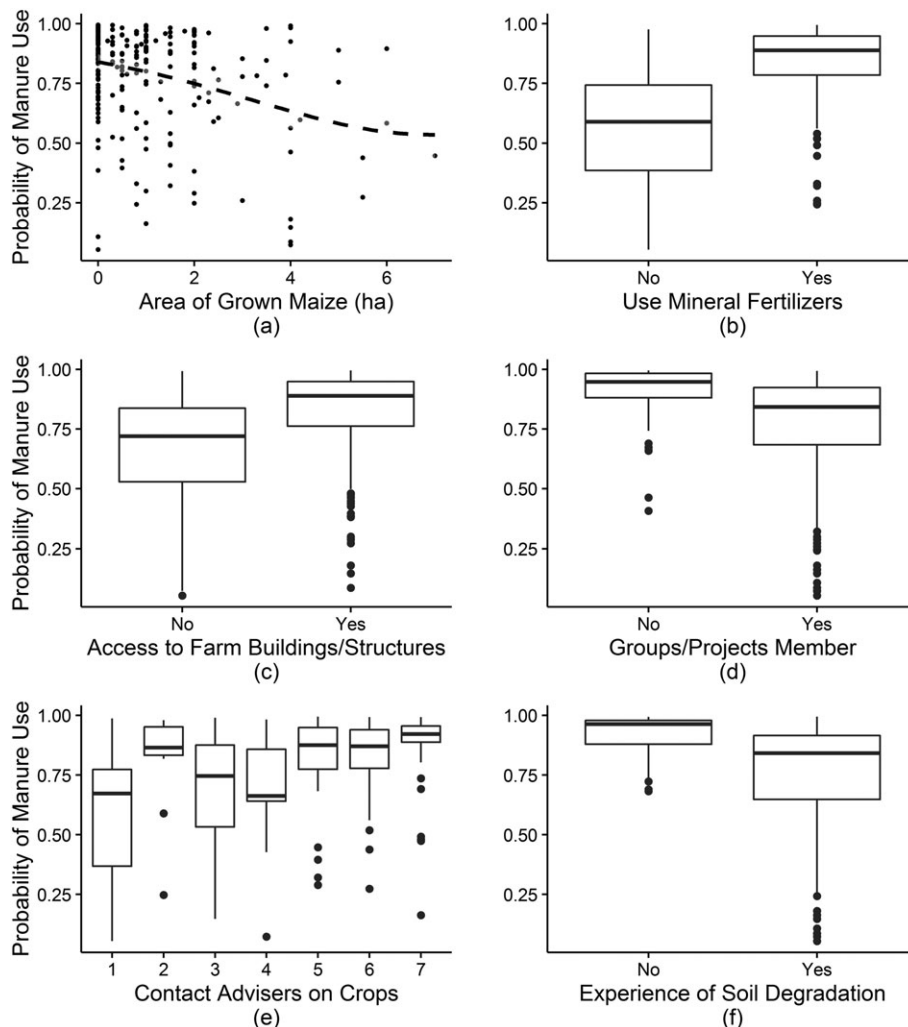
FIGURE 1 Significant relationships between estimated probability of manuring use and (a) area of grown maize, (b) use mineral fertilizers, (c) access to farm buildings/structures, (d) member of agriculture groups, (e) contact advisers on crops, and (f) experience of soil degradation (in the last 3 years) for farmers within all three counties

respectively. Across all three counties, household characteristics were unimportant in predicting manure use, but intercropping was more likely if the head of the household was female ($\beta = 0.823$; $p < .05$). Both manuring and intercropping were less likely with greater areas of maize grown ($\beta = -0.274$, $p < .01$; $\beta = -0.39$, $p < .01$, respectively; Table S2, Figures 1 and 2). Access to assets/advice was particularly important in understanding manure use. Membership of an agricultural group or project was negatively associated with manuring ($\beta = -1.921$, $p < .01$). In contrast, manuring was more likely with more recent contact with crop advisors ($\beta = 0.334$, $p < .01$). Experiencing soil degradation in the 3 years prior to data collection was associated with reduced likelihood of manure use ($\beta = -1.330$, $p < .05$) but increased likelihood of intercropping ($\beta = 0.813$, $p < .05$).

Different predictor variables were significant at the individual county level, with none for Bungoma, where the overall model was not significant. For Siaya and Kakamega, farmers were more likely to implement SLM if they were members of an agricultural group or project ($\beta = 4.674$, $p < .01$; $\beta = 1.226$, $p < .05$, respectively), but there were no other common predictor variables. In Kakamega, farms with more cattle ($\beta = 0.989$; $p < .05$) were more likely to implement an SLM practice, whereas those growing a greater range of crops ($\beta = -1.861$,

$p < .05$) were less likely to do so. In Siaya, farms where a greater proportion of the land was owned ($\beta = 1.400$, $p < .05$) or the total labour was from family members ($\beta = 2.681$, $p < .05$) were more likely to implement an SLM practice (Table S2; Figures 3 and 4). Models for manuring and intercropping were not developed within each county as, at this scale, almost all farmers use these practices.

3.2 | Cost–benefit analysis

Among farmers sampled in the CBA, nearly all employed at least one SLM practice (59 from 60); notably higher than in the FSA dataset (63%). This indicates that farm selection for the CBA was concentrated on farmers using practices, despite efforts to ensure that this was not the case. This might have happened either because maize farming in the lower midland zone is characterised by the use of SLM practices or due to the approach taken to identify farmers through agricultural extension officers. Maize was the main crop for 51/60 farms (85%). Subsequent analyses were restricted to these farms. Twenty-one households (35%) generated all their income from farming, whereas 48 participants stated that their farm produced "enough food" for their household in 2015. Yields, labour use, gross
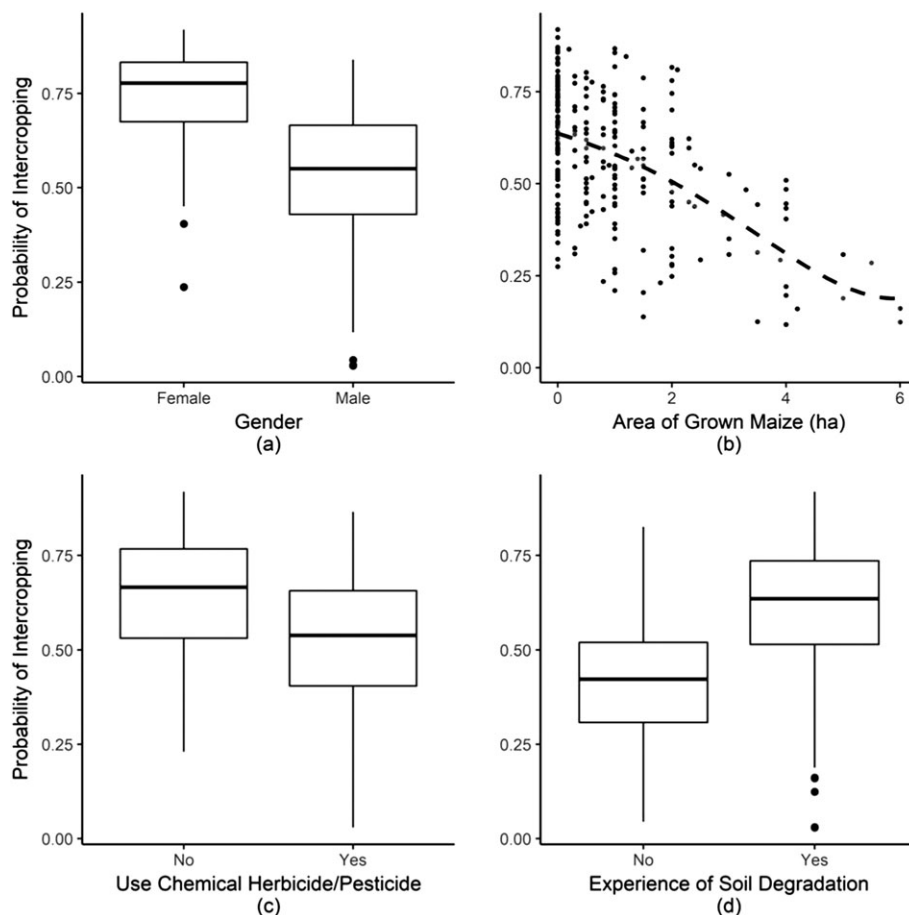
FIGURE 2 Significant relationships between estimated probability of intercropping use and (a) gender, (b) area of grown maize, (c) use chemical herbicide/pesticide, and (d) experienced soil degradation (in the last 3 years) for farmers within all three counties

margins, and net profit associated with cultivating maize varied substantially (Table 1). Seven SLM practices were used by over 20 farmers (Table S3). The CBA focused on four of the most common practices: two that took land out of cultivation and required a construction phase as well as annual maintenance (physical terraces and agroforestry); and two that were carried out annually but did not take space away from cultivation (manuring and intercropping; the most frequently employed practices). Agroforestry in this context only covered farming systems with trees either within the cultivated field or planted around the edges (WOCAT, 2016).

Farmers stated perceived benefits from SLM as proportional changes from an equivalent field where no SLM practices were followed. We converted these to farm-specific yield, labour hours, and gross profits in addition to those reported for the cultivation activity without SLM (Table 1). SLM practices varied in their perceived impacts on labour requirements, yield, and profit (Table 2). For instance, the perceived benefit of agroforestry in Siaya was 14 US$·ha^{-1}·year^{-1} compared with 121 US$·ha^{-1}·year^{-1} in Bungoma. Conversely, farmers in Siaya perceived an average benefit of 293 US$·ha^{-1}·year^{-1} for intercropping compared with 178 US$·ha^{-1}·year^{-1} in Kakamega. Differences in perceived monetary benefits were due to variations in perceived changes in labour and yield, as well as variation in actual wage-rates and crop-sale prices.

Benefits of manuring over the time horizon of *Kenya's Vision 2030* outweighed the costs (mean NPV [95% confidence interval from

Monte Carlo simulations] 3,375 [3,525–4,025] US$/ha; Table 3; Figure 5), regardless of the discount rate. Although substantial variation existed between counties, for instance, BCR for r = 3.5% was 1.46 (1.42–1.50) in Bungoma, but 3.67 (3.42–3.91) in Kakamega, benefits accruing to individual farmers were universally positive and RoI periods were all less than 3 years. Aggregating data across counties, NPVs of intercropping were always positive, regardless of discount rate. However, between county, variation was high, and (for r = 10%) NPV for intercropping in Kakamega was slightly negative at −5.8 (−147–140) US$/ha (Figure 6). This variation was likely due to differing perceptions of the impact of intercropping on yields and labour required for the main crop. Averaged across all three counties, farmers would see an RoI from physical terraces between 6.40 (6.02–6.80) and 8.42 (7.78–9.18) years, depending on the discount rate (Table 3; Figure 5). Whether physical terraces resulted in a positive NPV varied between counties and with discount rates; NPV was −252.5 (−214 to −292.5) US$/ha in Siaya but 727.5 (655–800) in Kakamega. Agroforestry gave the lowest NPV, BCR, and RoI from the individual farmer perspective (Table 3; Figure 5). Despite additional income from wood, NPV across all counties ranged from −277.5 (−249 to −307.5) US$/ha to −460 (−437.5 to −482.5) for r = 3.5% and r = 10%, respectively. Losses varied among counties. The most negative NPV was calculated for Siaya −465 (−442 to −487.5) US$/ha. In contrast, calculations for Kakamega indicated that agroforestry could offer positive returns (NPV = 16 [−13–44] US$/ha).
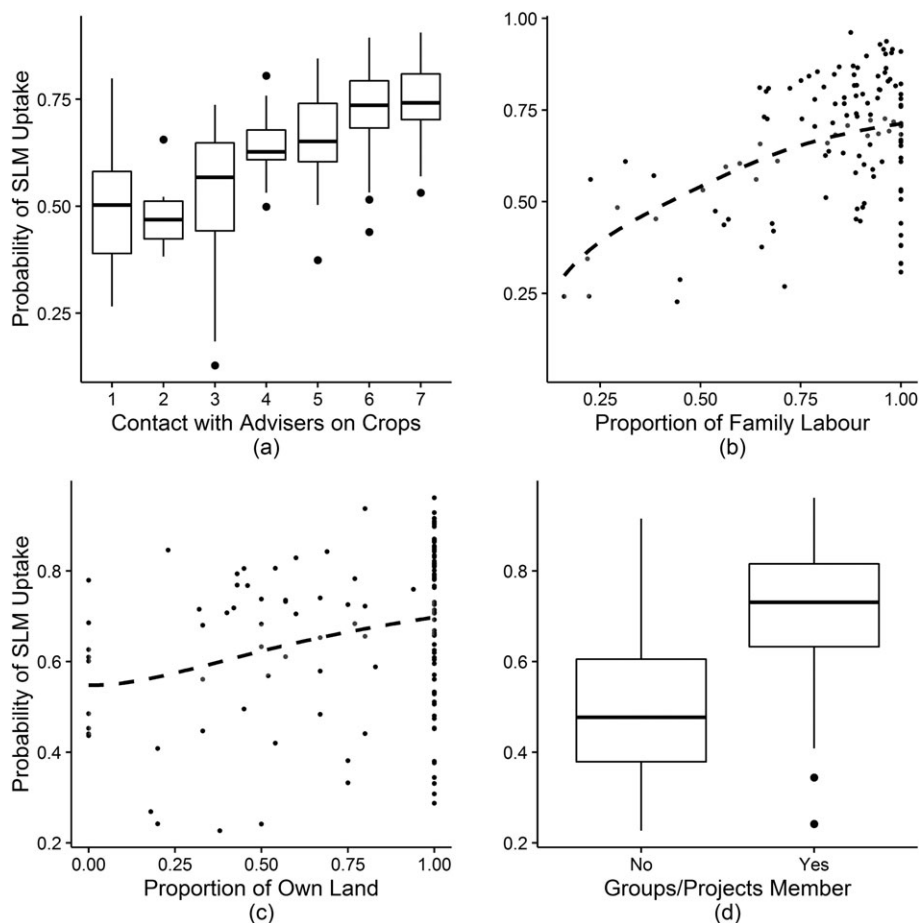
FIGURE 3 Relationship between estimated probability of SLM uptake and (a) access to crop advisers across all three counties, where access to advice was assessed on a 1 to 7 scale (7 = *advice received a week ago*; 6 = *a month ago*; 5 = *3 months ago*; 4 = *6 months ago*; 3 = *a year ago*; 2 = *longer than a year ago*; 1 = *no contact*); (b) proportion of family labour, (c) proportion of land, which is owned, and (d) membership of agricultural groups or projects for farmers within the county of Siaya. SLM = sustainable land management

4 | DISCUSSION

Global and regional assessments of the financial and societal benefits of implementing SLM practices universally indicate that benefits outweigh costs. For instance, preventing top soil loss to increase crop productivity across Africa could have benefits in the region of 1 trillion US$ over the next 15 years (ELD, 2015). Indeed, our study showed that farmers perceived yield benefits from the use of particular SLM practices. Despite this, at subnational scales, SLM use rates can still be moderate and vary both spatially and among different farm types (e.g., Mwakubo et al., 2004; Kwayu et al., 2014). Subnational analyses often highlight resource gaps that can act as barriers to SLM, particularly for smallholder farmers who were the focus of our analyses. Such gaps include, for example, lack of tools and inputs, labour, awareness, knowledge, and capacity (Shepherd & Soule, 1998; Kwayu et al., 2014). They can also highlight RoI periods where bridging mechanisms might be needed (Shiferaw & Holden, 2001). Our findings show that in western Kenya, SLM use varies, as do the determinants of use, emphasising the need for policy to be better targeted to local contexts and small-holder farmer needs (cf. Kassie et al., 2007). A one-size-fits-all policy would not suffice. Although based on a non-representative sample, our CBA findings emphasise the yield and financial benefits that can accrue to individual farmers by implementing simple, low-cost SLM

practices such as manuring and intercropping. This contrasts with the long RoI periods and negative NPVs for terraces and agroforestry, which require substantial upfront time and resource investments from individual farmers. Further research is needed in both comparable and different contexts within Kenya in order to better elucidate the conditions under which these practices can deliver positive NPVs and to inform better targeted policy.

The use of an SLM practice is a product of complex interactions between individual farmers, practice characteristics, farm conditions, and the surrounding social, political, and economic context (Dougill et al., 2017). Although the secondary FSA dataset that we analysed was not a randomly selected subsample of all farmers in the region, it nevertheless allowed us to draw some conclusions regarding uptake. In western Kenya, no universally applicable relationships between farm and household characteristics and SLM use were elucidated, paralleling work suggesting that causes of variability in use of soil fertility management in the same region are heterogeneous but include biophysical, institutional, and socio-economic drivers (Tittonell et al., 2005). This is to be expected given the devolved nature of policy implementation in Kenya, variation in biophysical characteristics across the western Kenya region, and the widespread failure of general policy initiatives (Kassie et al., 2007). In Bungoma, our analyses revealed that no farm or household characteristics were significant
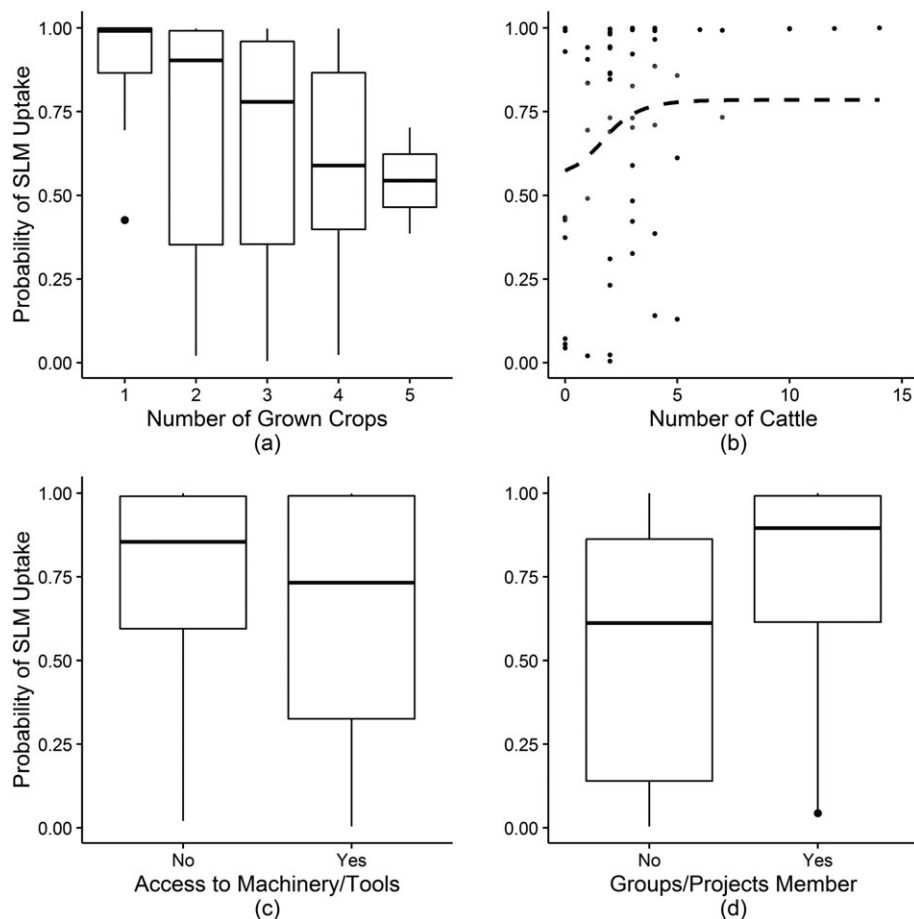
FIGURE 4 Significant relationships between estimated probability of SLM uptake and (a) number of crops grown, (b) number of cattle, (c) access to machinery and tools, and (d) membership of agricultural groups or projects for farmers within the county of Kakamega. SLM = sustainable land management

TABLE 1 Mean (standard deviation) yield, profit, labour use, and SLM practice costs (for all practices implemented on a farm combined) associated with maize cultivation during the "long rain" growing season within 51 farms in the three counties in western Kenya

	Bungoma	Kakamega	Siaya	Three counties
Number of farms growing maize	8	23	20	51
Area (ha)	0.38 (0.20)	0.58 (0.39)	0.58 (0.42)	0.55 (0.38)
Years farmed	29 (15)	20 (11)	12 (9)	18 (12)
Maize yield (kg/ha)	3,628 (1,098)	2,888 (1,460)	1,795 (1,507)	2,575 (1,560)
Proportion sold	0.35 (0.34)	0.29 (0.27)	0.27 (0.30)	0.29 (0.29)
Gross profit (US$/ha)	1,127 (340)	851 (460)	530 (503)	769 (502)
Maize cultivation labour use (hr/ha)	1,498 (688)	1,210 (608)	1,035 (528)	1,185 (600)
Maize cultivation labour cost (US$/ha)	741 (304)	561 (320)	562 (385)	590 (345)
Net profit (US$/ha)	386 (492)	290 (498)	−32 (627)	179 (568)
SLM practice implementation labour use (hr/ha)	438 (340)	308 (233)	255 (235)	308 (255)
SLM practice implementation cost (US$/ha)	234 (174)	166 (115)	151 (161)	171 (144)
Intercropped beans yield (kg/ha)	350 (280)	153 (135)	150 (175)	183 (190)
Intercropped beans gross profit (US$/ha)	245 (246)	97 (92)	137 (164)	136 (158)
Fertiliser use (proportion of farmers)	1.00	0.91	0.75	0.86
Pesticide use (proportion of farmers)	0.13	0.17	0.05	0.12
Herbicide use (proportion of farmers)	0.13	0.04	0.05	0.06

Note. SLM = sustainable land management.

determinants of SLM use. However, elsewhere in the region, participation in agricultural projects, project membership and receiving advice on crops were all associated with SLM use. These findings suggest

that receiving advice or project membership is important in enhancing SLM use for some practices (noting, for instance, that project membership was associated with a lower chance of using manure, perhaps

TABLE 2 Perceived benefits of implementing an SLM practice on a hectare of maize for (a) manuring, (b) intercropping, (c) physical terraces, and (d) agroforestry within each individual county and for the data from the three counties combined. The approach used to calculate the additional benefits from fodder and wood production from agroforestry is described in Methods S1. SLM = sustainable land management.

SLM practice		Bungoma	Kakamega	Siaya	Three counties
Manuring	Time lag between implementation and accrual of benefits assumed for this study	Full benefits accrued in Year 3 and each year subsequently, 25% in Year 1, 75% in Year 2			
	Cost of construction (labour US$/ha)	—	—	—	—
	Annual cost of implementing the SLM (labour US$/ha)	99	41	69	61
	Perceived benefit (increase in yield kg/ha)	2,195	1,560	1,213	1,565
	Perceived benefit (decrease in labour hr/ha required to cultivate maize)[a]	88	129	19	73
	Gross profit from second crop (US$/ha)	—	—	—	—
	Perceived benefit (US$/ha)[b]	747	533	359	516
Intercropping	Time lag between implementation and accrual of benefits assumed for this study	Full benefits accrued in Year 2 and each year subsequently. Additional gross profit from the intercrop of beans is accrued immediately.			
	Cost of construction (labour US$/ha)	—	—	—	—
	Annual cost of implementing the SLM (labour US$/ha)	40	58	56	54
	Perceived benefit (increase in yield kg/ha)	−213	168	218	115
	Perceived benefit (decrease in labour hr/ha required to cultivate maize)[a]	128	−7.25	1.5	22
	Gross profit from second crop (US$/ha)	245	124	171	165
	Perceived benefit (US$/ha)[b]	226	178	293	231
Physical terraces	Time lag between implementation and accrual of benefits assumed for this study	Full benefits accrued after 5 years; 75% in Year 4; 50% Year 3; 25% Year 2; 10% Year 1			
	Cost of construction (labour US$/ha)	113	50	60	56
	Annual cost of implementing the SLM (labour US$/ha)	19	27	33	29
	Perceived benefit (increase in yield kg/ha)	2,700	783	230	623
	Perceived benefit (decrease in labour hr/ha required to cultivate maize)[a]	77	55	55	56
	Gross profit from second crop (US$/ha)	—	—	—	—
	Perceived benefit (US$/ha)[b]	1,035	305	98	246
Agroforestry	Time lag between implementation and accrual of benefits assumed for this study	Full benefits accrued after 10 years; 75% Years 8 and 9; 50% Years 6 and 7; 25% Years 4 and 5; 10% Years 2 and 3			
	Cost of construction (labour US$/ha)	13	20	20	19
	Annual cost of implementing the SLM (labour US$/ha)	4	7	0	4
	Perceived benefit (increase in yield kg/ha)	405	125	50	153
	Perceived benefit (decrease in labour hr/ha required to cultivate maize)[a]	0.0	213	−125	67
	Gross profit from intercropped beans (US$/ha)	—	—	—	—
	Perceived benefit (US$/ha)[b]	121	38	14	45

[a]Positive values indicate a decrease in labour, and negative values indicate an increase (i.e., the benefit is negative and is therefore an additional cost).

[b]Perceived benefits are the net result of labour costs/savings and additional yields.

because manure was not discussed in the group or project, or because mineral fertiliser was positively associated with manure use, suggesting that farmers used whatever measures they could do to increase yields without necessarily considering whether they are sustainable). Projects and extension advice variables encapsulate key aspects of theories on the use of agricultural innovations (Rogers, 2003) emphasising the importance of social interactions and knowledge/experience exchange (e.g., through farmer field schools) in the out-scaling of particular practices (Stringer et al., 2017). A knowledge gap nevertheless remains in terms of identifying which mechanisms work best for whom in the context of western Kenya.

Rogers (2003) notes that farmer decision-making regarding SLM use plays out iteratively over time, starting with exposure to

knowledge about an SLM practice. Exposure itself is shaped by an individual's characteristics, their socio-economic status, and their communication behaviour. Once exposed to particular SLM practices, farmers form their attitude towards that practice, evaluating its attributes and weighing up its advantages and disadvantages. At this stage, if farmers interact with others through projects or are in contact with advisers, it can influence whether uptake happens or not. Indeed, we found in Siaya and Kakamega that farmers were more likely to implement SLM if they were members of an agricultural group or project. This is because access to social settings can help dispel or reinforce farmer concerns about the practice in question or support or change their positive evaluation. Rogers (2003) states that adoption of an SLM practice happens when the decision is made to use it. Even then,

TABLE 3 NPV, BCR, and RoI period (in brackets 95% confidence intervals from Monte Carlo simulations) stated over the lifetime of the project (2015 to 2030) for three discount rates (r) for implementing four SLM practices (manuring, intercropping, physical terraces, and agroforestry) in western Kenya

SLM practice	Scale	Measure	r = 3.5%	r = 5%	r = 10%
Manuring	Three counties	NPV (US$/ha)	3,775 (3,525 to 4,025)	3,375 (3,175 to 3,600)	2,448 (2,283 to 2,600)
		BCR	2.70 (2.50 to 2.90)	2.68 (2.48 to 2.88)	2.60 (2.40 to 2.79)
		RoI Period (years)	1.23 (1.16 to 1.31)	1.23 (1.16 to 1.31)	1.23 (1.16 to 1.32)
	Siaya	NPV (US$/ha)	1,593 (1,460 to 1,728)	1,425 (1,303 to 1,545)	1,013 (923 to 1,103)
		BCR	2.10 (1.97 to 2.23)	2.08 (1.95 to 2.21)	2.02 (1.90 to 2.15)
		RoI Period (years)	1.50 (1.43 to 1.57)	1.50 (1.44 to 1.58)	1.51 (1.45 to 1.59)
	Kakamega	NPV (US$/ha)	4,450 (4,250 to 4,675)	4,025 (3,825 to 4,200)	2,925 (2,775 to 3,075)
		BCR	3.67 (3.42 to 3.91)	3.64 (3.39 to 3.88)	3.53 (3.30 to 3.76)
		RoI Period (years)	0	0	0
	Bungoma	NPV (US$/ha)	2,088 (1,943 to 2,235)	1,860 (1,725 to 1,993)	1,300 (1,203 to 1,398)
		BCR	1.46 (1.42 to 1.50)	1.45 (1.41 to 1.49)	1.41 (1.37 to 1.44)
		RoI Period (years)	2.00 (1.95 to 2.13)	2.00 (1.96 to 2.15)	2.08 (2.05 to 2.23)
Intercropping	Three counties	NPV (US$/ha)	154,000 (142,000 to 165,000)	138,000 (127,000 to 148,000)	98,400 (90,700 to 106,000)
		BCR	2.67 (2.53 to 2.81)	2.64 (2.51 to 2.78)	2.56 (2.43 to 2.69)
		RoI Period (years)	0	0	0
	Siaya	NPV (US$/ha)	3,850 (3,550 to 4,125)	3,450 (3,175 to 3,700)	2,460 (2,268 to 2,650)
		BCR	2.33 (2.25 to 2.41)	2.31 (2.23 to 2.39)	2.24 (2.16 to 2.32)
		RoI Period (years)	0	0	0
	Kakamega	NPV (US$/ha)	103 (−114 to 320)	72 (−124 to 268)	−5.8 (−147 to 140)
		BCR	1.15 (1.06 to 1.25)	1.14 (1.05 to 1.24)	1.11 (1.02 to 1.20)
		RoI Period (years)	4.41 (3.53 to 6.33)	4.52 (3.59 to 6.61)	6.41 (4.55 to 11.41)
	Bungoma	NPV (US$/ha)	1,918 (1,703 to 2,135)	1,713 (1,518 to 1,905)	1,208 (1,065 to 1,350)
		BCR	2.07 (1.95 to 2.18)	2.05 (1.94 to 2.16)	1.99 (1.88 to 2.10)
		RoI Period (years)	0	0	0
Physical terraces	Three counties	NPV (US$/ha)	595 (518 to 670)	475 (405 to 543)	180 (129 to 232)
		BCR	1.08 (1.05 to 1.11)	1.03 (1.00 to 1.06)	0.87 (0.84 to 0.89)
		RoI Period (years)	6.40 (6.02 to 6.80)	7.37 (6.97 to 7.98)	8.42 (7.78 to 9.18)
	Siaya	NPV (US$/ha)	−78 (−21 to −135)	−129 (−77 to −180)	−252 (−214 to −293)
		BCR	0.82 (0.80 to 0.85)	0.78 (0.76 to 0.81)	0.66 (0.64 to 0.68)
		RoI Period (years)	—	—	—
	Kakamega	NPV (US$/ha)	728 (655 to 800)	595 (528 to 663)	273 (222 to 323)
		BCR	1.12 (1.09 to 1.15)	1.06 (1.04 to 1.09)	0.90 (0.87 to 0.90)
		RoI Period (years)	6.24 (5.92 to 6.61)	6.52 (6.16 to 6.89)	7.68 (7.17 to 8.27)
	Bungoma	NPV (US$/ha)	470 (405 to 535)	365 (305 to 423)	107 (63 to 151)
		BCR	1.09 (1.06 to 1.13)	1.04 (1.01 to 1.07)	0.87 (0.84 to 0.89)
		RoI Period (years)	6.61 (6.24 to 7.01)	6.90 (6.51 to 7.39)	8.29 (7.68 to 9.01)
Agroforestry	Three counties	NPV (US$/ha)	−278 (−249 to −308)	−333 (−305 to −360)	−460 (−438 to −483)
		BCR	0.86 (0.83 to 0.89)	0.77 (0.75 to 0.80)	0.51 (0.50 to 0.53)
		RoI Period (years)	—	—	—
	Siaya	NPV (US$/ha)	−465 (−443 to −488)	−498 (−475 to −520)	−570 (−548 to −588)
		BCR	0.66 (0.64 to 0.68)	0.59 (0.57 to 0.61)	0.39 (0.37 to 0.40)
		RoI Period (years)	—	—	—
	Kakamega	NPV (US$/ha)	16 (−13 to 44)	−75 (−49 to −102)	−290 (−268 to −313)
		BCR	1.14 (1.10 to 1.18)	1.02 (0.99 to 1.06)	0.67 (0.65 to 0.70)
		RoI Period (years)	13.15 (12.56 to 13.56)	15.05 (14.05 to 15.57)	—
	Bungoma	NPV (US$/ha)	−358 (−333 to −380)	−393 (−370 to −415)	−478 (−458 to −498)
		BCR	0.72 (0.69 to 0.75)	0.64 (0.61 to 0.66)	0.42 (0.40 to 0.43)
		RoI Period (years)	—	—	—

Note. All estimates given to three significant figures. BCR = benefits–cost ratio; NPV = net present value; RoI = return on investment; SLM = sustainable land management.

however, it needs to be implemented. Social interactions between farmers were important in shaping use in our study and may also be vital in reducing dis-adoption of SLM (Chinseu et al., under review). Indeed, when farmers are involved in the design and implementation of programmes from an early stage, they are more likely to implement sustainable practices (De Vente, Reed, Stringer, Valente, & Newig, 2016; Orchard & Stringer, 2016; Reed, Stringer, Fazey, Evely, & Kruijsen, 2014). Recent experiences can also shape farmer decisions to use SLM practices, with stresses such as droughts altering farmer willingness to adopt new practices that can build resilience and/or reduce risk (Holden & Quiggin, 2017). Nevertheless, timing of periods of increased farmer openness to innovations does not always coincide with availability of or accessibility to resources that can enable technology adoption. This too requires further investigation.

SLM practices with low material requirements and implementation costs (e.g., manuring and intercropping) offered high BCR and a positive NPV to smallholder farmers over the time horizon of our analyses. This finding mirrors others in East Africa, where traditional and low input practices are often preferable in terms of both soil conservation/fertility and individual farmer benefits (e.g., when comparing minimum tillage to the use of commercial fertilisers in Kassie et al., 2010). Despite this, not all smallholder farmers are using them. This suggests that policy should prioritise simple and/or traditional practices that are known to work, not least because upfront implementation costs are a barrier to uptake of SLM practices that require construction (Giger et al., 2015; Kwayu et al., 2014), and the loss of land can lead to negative impacts on yields (Lutz et al., 1994). SLM practices with high upfront costs and high maintenance costs, such as physical terraces
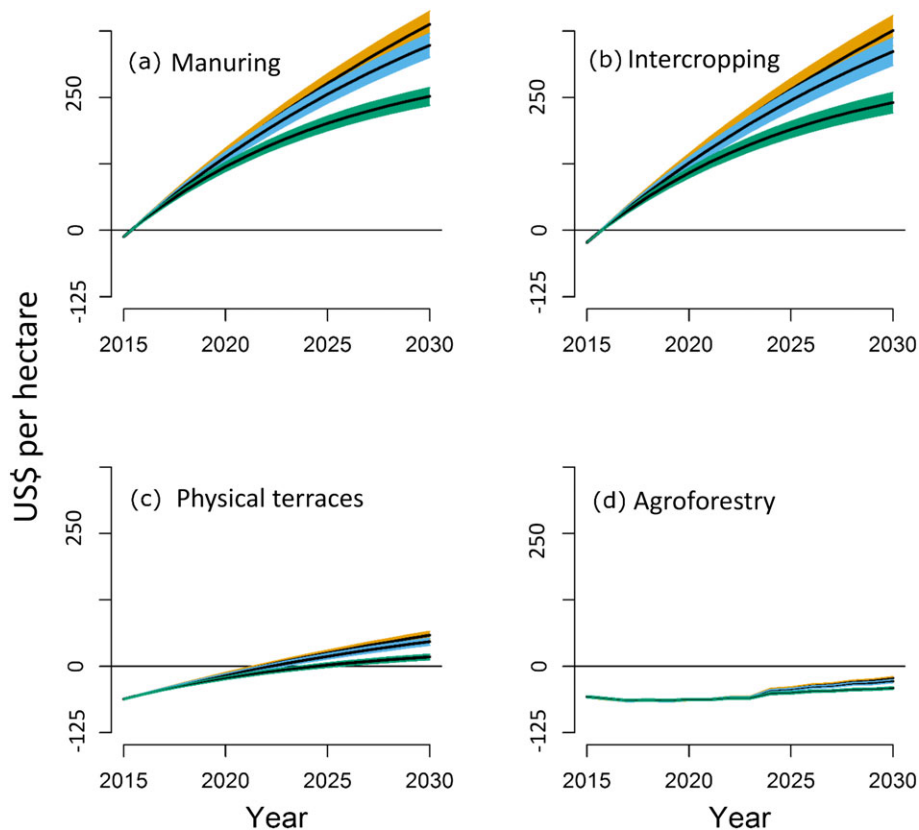
FIGURE 5 Cumulative NPV (US$) for implementing four SLM practices in Year 1 (2015) until Year 16 (2030), for a typical hectare of maize within the three counties. The four SLM practices are as follows: (a) manuring; (b) intercropping; (c) physical terraces; and (d) agroforestry. Three discount rates were applied (r = 3.5% [orange]; 5% [blue]; 10% [green]), with the shading indicating 95% confidence interval around the mean NPV based on 1,000 Monte Carlo simulations. For (a) manuring, farmers rapidly see their initial expenditure outlay covered by increased incomes (all three lines become positive after Y1), but for (d) agroforestry, despite the additional income from timber, the cumulative NPV never becomes positive, indicating that farmers would not see a return on their investment within the time horizon (2015 to 2030) that we examined. NPV = net present value; SLM = sustainable land management [Colour figure can be viewed at wileyonlinelibrary.com]

and agroforestry, offered lower BCRs for individual smallholder farmers and have a long RoI period, even though over the time horizon considered their NPV can be positive. Indeed, the possible negative effects on smallholder farmer productivity of SLM practices that take land out of production and require maintenance have been previously noted (Lutz et al., 1994), indicating that these practices are unlikely to be widespread unless farmers receive some form of support or subsidy for their use. This is reinforced by farm simulation models for the region, which indicate that low levels of land and capital resources constrain farmer adoption of SLM practices, despite benefits that can be accrued at individual and wider scales (Shepherd & Soule, 1998).

CBAs in this research were based on smallholder farmers' actual costs and perceived benefits for their main crop only. Had our research looked at wider scale societal values and ecosystem services beyond maize crop yields, different output data are likely. Benefits such as improved water retention, reduced siltation of rivers and dams, lower downstream flood risk, and enhanced carbon sequestration (United Nations Convention to Combat Desertification, undated) would need to be included in a CBA of societal values, as benefits are accrued by society as a whole. This highlights the importance of the scale of analysis, and the values that different stakeholders are likely to hold for environmental goods and services (e.g., Favretto et al., 2016), and is especially critical for public and communal lands.

Despite this, some smallholder farmers engaged in agroforestry because they perceived benefits for the soil and for water retention, even though they considered it made little short-term difference to yields. This suggests that reducing financial and capacity/knowledge barriers to those SLM practices that deliver societal benefits could help increase their use (Giger et al., 2015).

4.1 | Policy implications

A central finding in our analysis is that SLM use, and determinants of use, vary and that the same SLM practices will not result in the same perceived benefits spatially or across all farm and household types. Such findings are likely robust to the non-representative nature of our sampling and the method of relying on perceived benefits, both of which might have skewed conclusions further in favour of SLM use. Indeed, maize cultivation on some farms took place at or below financial profitability. In these cases, economic activities outside the farm and remittances from relatives help smallholder farmers to overcome short-term financial short-falls. When cultivation is not financially profitable, the additional costs of implementing SLM practices (e.g., labour and inputs) can exacerbate losses (cf. Pannell et al., 2014, who found that conservation agriculture can lead to increased or decreased profits depending on the context). This indicates that
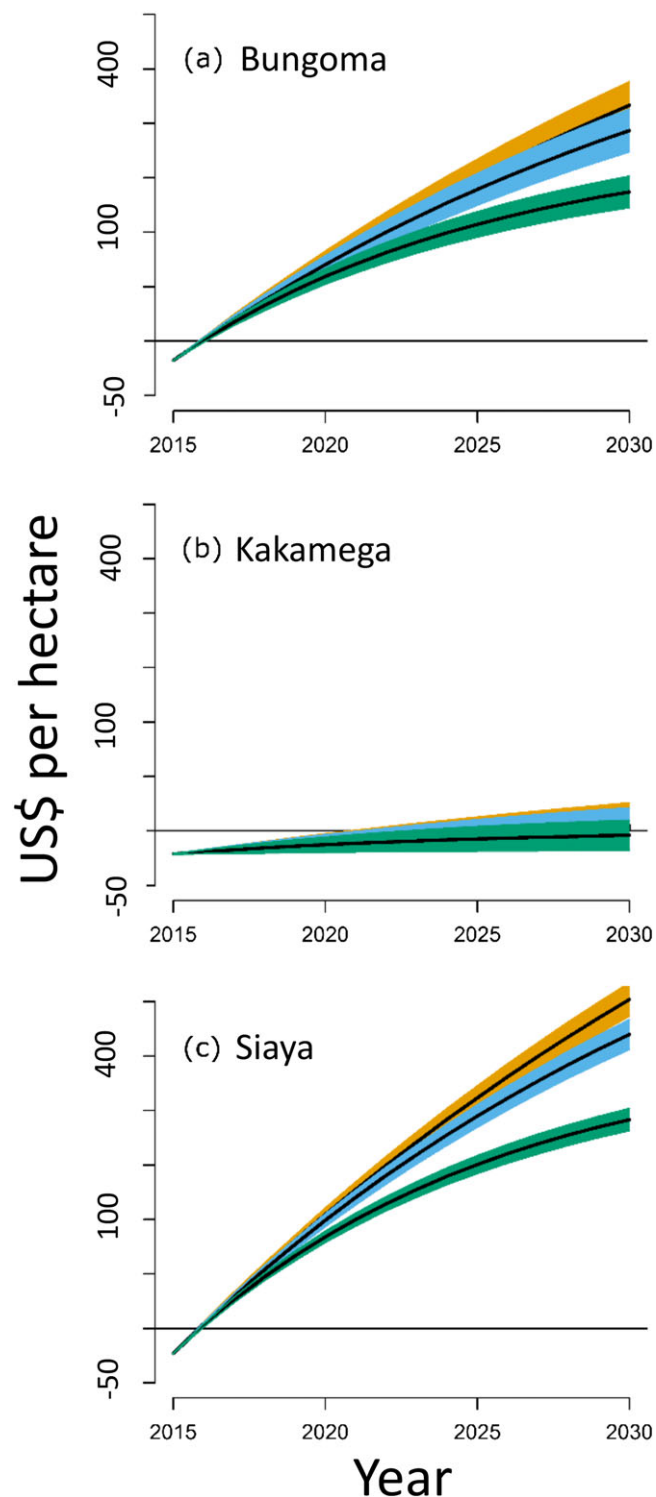
FIGURE 6 Cumulative NPV (US$) for implementing intercropping as an SLM practice in Year 1 (2015) until Year 16 (2030) for a typical hectare of maize within (a) Bungoma, (b) Kakamega, and (c) Siaya, illustrating the variability in the net benefits resulting from an SLM. Three discount rates were applied ($r = 3.5\%$ [orange]; 5% [blue]; 10% [green]), with the shading indicating 95% confidence interval around the mean NPV based on 1,000 Monte Carlo simulations. NPV = net present value; SLM = sustainable land management [Colour figure can be viewed at wileyonlinelibrary.com]

policy should provide targeted support for SLM, so it reaches those who need it the most (e.g., benefitting individual farmers whose land is severely degraded) and where potential is greatest for positive NPVs (benefiting national food security and agricultural production). In practice, however, achieving both these objectives simultaneously might not be possible. Policy approaches that explicitly consider social and institutional measures could usefully be considered, especially because national-level polices are unlikely to be implemented uniformly under the devolved system of governance, which operates in Kenya (Mulinge et al., 2016). One way to incorporate social and institutional factors would be to strengthen and reinforce agricultural innovation systems (AIS) to tackle soil degradation through SLM. Aerni et al. (2015, p. 834) define an AIS as "a network of organizations, enterprises and individuals that focused on bringing new products, new processes and new forms of organization into economic use, together with the institutions and policies that affect their behaviour and performance." Explicit inclusion of AIS in policy could help provide support where it is most needed for farmers to use particular SLM practices (building on CBA findings). It could integrate approaches anchored in existing networks and platforms including participation in projects and interaction with extension advisors, supporting farmer-to-farmer learning and knowledge exchange (Stringer et al., 2017) and reducing disadoption of SLM practices (Chinseu et al., under review).

Reducing SLM input (and implementation) costs to individuals, for example, through subsidy schemes could increase attractiveness of SLM practices to smallholder farmers (TerrAfrica, 2009) and enhance uptake. The Kenya Government already subsidises tractors and fertilisers. This could be extended to support SLM; for instance, if farmers pay for manure, transport costs could be subsidised. Lowering seed costs for crops such as beans, which can be intercropped with maize, is likely to improve uptake too. Subsidies would also be useful in supporting agroforestry and terraces, where BCRs and NPVs for individual farmers were more diverse, especially given that some long-term trials of these methods indicate that they are not always profitable (Nkonya et al., 2008), in line with our findings. Support for implementing and maintaining physical structures and agroforestry systems would provide wider societal benefits (e.g., Mulatu et al., 2014). To improve the use of these SLM practices requires that individual farmers do not solely bear the costs. Given that individual farmers in other parts of Africa are willing to accept compensation for implementing more costly SLM practices as part of a proposed watershed-based payment scheme (Mulatu et al., 2014), the appropriateness of publically funded payment for ecosystem services schemes could be investigated for the Kenya context and would allow policy to target SLM practices for which longer-term benefits for wider society are likely to be apparent.

5 | CONCLUSION

We have identified variations in SLM practice use and characterised those farmers most likely to use SLM practices. Our CBA suggests that policy should target support towards simple practices, many of which smallholder farmers are already using. Increasing uptake of practices that are demonstrated to deliver high returns at low cost should be prioritised to improve soil and increase yields at a wider scale. A combination of economic and financial instruments, institutional and capacity building actions, and changes to the legal, political, social,

and technical context in which land users operate need to be considered by policymakers. These could include, for example, legal changes to better secure property rights to support longer-term investments in land quality or investments in AIS and extension services to enhance the social and technical context. Overall, it is likely that a portfolio of measures will be needed to help to reverse the current trend in yield declines and deliver important positive impacts for both the environment and farmers' livelihoods.

Scale is important because many of the costs of SLM accrue to individual farms, whereas the majority of benefits (e.g., improved water-related ecosystem services, increased carbon sequestration, and enhanced national food security) are experienced at larger scales. We focused on the individual smallholder farm; however, given the number of smallholder farmers, the areal extent of the land that they manage, and their central role in food production (\Samberg et al., 2016), prioritising societal benefits without taking into account farm-scale costs, benefits and decision-making will inevitably result in lower uptake rates than society as a whole would find desirable. If the twin goals of reducing land degradation and improving food security are to be addressed, it will be vital for smallholder farmers to be adequately and appropriately compensated and supported for undertaking environmentally sustainable practices.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.