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RESEARCH

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Adoption of a sustainable land management practice for invasive *Prosopis juliflora* in East Africa

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Abstract

Background Woody invasive alien species are among the world's worst invaders, significantly affecting ecosystem services, increasing the cost of farming and reducing access to land. *Prosopis juliflora* ("prosopis"), a spiny shrub or tree, was introduced from its native Latin America into Eastern Africa to reduce dust and sandstorms and provide wood and fodder for livestock, but it has spread from the original areas of introduction and invaded large areas of land, thereby replacing grazing and arable land with impenetrable thickets. Stakeholders in two invaded regions of Kenya and Tanzania selected and tested, through an inclusive and participatory process guided by the Woody Weeds project, one sustainable land management (SLM) practice to manage prosopis through uprooting and subsequent use of the cleared land for continuous crop and fodder production. The practice was successful and was adopted by stakeholders in the communities where it was tested.

Methods We assessed reasons why people adopted the practice or not, as well as whether there was an effect of the Woody Weeds project on the adoption, through in-person interviews with 154 household heads in Baringo, Kenya, and 148 in Kahe, Tanzania.

Results About 75% of the respondents implemented the practice, 76 didn't implement the practice and ten respondents no longer implemented the practice. We found that the likelihood of people adopting was higher for male than female respondents and was positively related to farm size. Results of a choice experiment revealed that almost all respondents prefer the SLM over a situation where their land is invaded by prosopis, even if the investment is high, which confirms that people prefer farming over prosopis, and that their perception of the SLM became more positive over time. Altogether, our results illustrate the beneficial effects of the SLM practice, despite high initial investment and risk of injury while uprooting prosopis. The results further indicate the value of communal meetings for dissemination, as many people learn about new practices through observation of their neighbours' activities and during public barazas and village meetings.

Conclusions We recommend awareness raising about these SLM practices and their benefits and upscaling of the practices to other areas infested by prosopis.

Keywords Sustainable management, Neltuma, Invasive alien plant species, Adoption, Baringo, Kenya, Tanzania

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Introduction

Land degradation as a result of encroachment by invasive alien plant species is a key driver of reduced availability of land for agricultural activities such as crop production and livestock grazing (Pyšek and Richardson 2010). Invasion by such species may hinder animal access to and reduce the quality of grazing land, and reduces crop productivity while at the same time increasing weeding costs. For example, a recent study of the cost of invasive alien species to the African economy estimated that the cost of weeding alone amounts to USD 36.34Bn annually (Eschen et al. 2021). The worst affected areas often are the rangelands and other fragile landscapes. Thus, there is an urgent need to manage invasive alien plants in ways that sustainably reduce their abundance in and increase crop productivity on agricultural land.

One of the worst invaders that affects large areas in East Africa is *Prosopis juliflora* ("prosopis"), an evergreen, spiny shrub or tree that is native to Latin America (Kaur et al. 2012). The species was introduced in different parts of the region in the 1980s through donor funded projects and government initiatives with the aim of reducing land degradation and provide benefits, such as wood for fuel and timber, as well as fodder (Choge et al. 2022). Since its introduction it has spread to hundreds of millions of hectares in, amongst other countries, Ethiopia, Kenya and Tanzania (Mbaabu et al. 2019; Shiferaw et al. 2019), severely degrading grassland quality and access, water availability, as well as agricultural land (Dzikiti et al. 2013; Shiferaw et al. 2019), thus profoundly changing people's income sources and livelihoods (Linders et al. 2019; Bekele et al. 2018; Linders et al. 2020).

Common practices to manage trees include "control through utilisation", the cutting of aboveground parts to make charcoal that was promoted especially by the Kenyan Government (Choge et al. 2022), but that has proven ineffective in reducing the spread or abundance of prosopis (Mbaabu et al. 2019) because this method does not kill the tree, which coppices profusely and can produce seeds within months of resprouting (MSM, unpublished). Chemical herbicides to manage prosopis are unavailable in Kenya and one product that has been shown to be effective is, while available on the market in Tanzania, not yet in use (Eschen et al. 2023). Thus, although many land users manage prosopis, current management practices are often ineffective or unsustainable as they neither reduce the spread (Mbaabu et al. 2019), nor do they often lead to lasting removal of prosopis (Adoyo et al. 2022; Adoyo et al. 2022).

Sustainable Land Management (SLM) technology, can be defined as a practice or a combination of practices and measures aimed at the integrated management of land, water and environmental resources to improve productivity and that of ecosystem service provision, in a manner that ensures the long-term integrity of these resources (Dallimer et al. 2018). SLM can be an alternative to conventional management practices that provide significant ecological and livelihood benefits. Giger et al. (2018) analysed the case studies of SLM technologies included in the World Overview of Conservation Approaches and Technologies (WOCAT) technology database and found that agronomic measures (improvement of soil cover, enhancement of soil fertility, soil surface and subsurface treatments) were largely perceived as positive, while vegetative measures were largely seen as negative in the short term (1–3 years) although perceptions on the long term were more positive, possibly because of the time for reseeded grassland or planted trees to establish and provide benefits.

Little research has been conducted to identify sustainable practices for prosopis management. Kamiri et al. (2024) recently reviewed 53 papers about prosopis management in the east African region, because the effectiveness and large-scale application of management measures remains poor. A small fraction of studies in that review that applied eradication (complete removal of isolated plants) or control by mechanical methods (clearing or pruning of young trees), while the majority of studies of prosopis management focus on utilisation of prosopis as a resource, which usually does not kill trees or reduce the spread (Mbaabu et al. 2019). Eschen et al. (2023) recently tested different practices to remove prosopis, as well as interventions to restore grassland on the cleared land. The results of this work showed that uprooting and targeted herbicide applications, either applied on freshly cut stumps or on the lower bark of prosopis trees, were highly effective. However, no evidence of adoption, or the perceived or realised benefits of prosopis management practices were recorded, and it is unclear if and why local actors adopt these or similar SLM practices against prosopis. While a few studies have assessed and quantified stakeholder willingness to manage prosopis (Bekele et al. 2018; Tilahun et al. 2017; Al-Assaf et al. 2020), these studies did not reveal whether this willingness translated into action.

An SLM practice to control prosopis in agricultural land was tested in the Woody Weeds project (www.woodyweeds.org). Woody Weeds was a transnational, transdisciplinary research and development project (2015–2021) that co-developed knowledge about the ecology and socio-environmental impacts of prosopis, as well as SLM practices to control the species in Ethiopia, Kenya and Tanzania. The tested SLM practice for prosopis control consisted of lasting removal of prosopis through cutting of aboveground parts of the trees and uprooting down to at least 50 cm belowground to prevent coppicing, followed by continuous use of the land for agriculture. In Kahe, Tanzania, the SLM practice was co-developed and selected for testing by a diverse group of stakeholders and it was then tested by six farmers. In Baringo, Kenya, the practice was tested on ten farms as part of a study to assess cost and benefits of the practice in comparison with the common practice of "control through utilisation". After the Woody Weeds project ended officially, and follow-up projects started, we learned that some people surrounding the sites where we tested have adopted the practice, while others did not.

The impacts or adoption of management practices tested in many donor-funded research-for-development projects are usually not expected before the end of those projects, and the sustained adoption of interventions that were tried or promoted during such projects should be studied after projects have ended. The overall aim of this study was to assess reasons for (non-)adoption for implementing the SLM, as well as to assess the impact of the Woody Weeds project on adoption of the SLM practice. We hypothesised that adoption is associated with higher household income and capital because of the high initial implementation cost. We also expected that the likelihood of adoption is higher in Kenya than in Tanzania, because prosopis has been a bigger, and more longstanding issue in Baringo County of Kenya. Respondents also prefer the SLM practice over the status quo, irrespective of country. Furthermore, income from crops is the most influential attribute influencing respondents' choices as the practice aims at increasing agricultural output.

Methods

Study areas

Baringo, Kenya

Kenya's Baringo County (35°57'–36°12'E, 0°02'–0°44'N) has a hot and dry climate, with maximum and minimum mean daily temperatures of 30–35 °C and 16–18 °C. Rainfall is highly variable, with average annual rainfall 650 mm and weak bimodal peaks from March-May and June-August. The economy relies largely on (agro-) pastoralism and the main livestock are cattle (*Bos taurus* L.), sheep (*Ovis aries* L.) and goats (*Capra aegagrus hircus* L.). *Prosopis juliflora* was first introduced on an extensive scale in 1983 through the Fuelwood Afforestation Extension Project that promoted tree planting for mitigating problems such as lack of firewood and control spread of desertification (Kariuki 1993). Prosopis was planted in an area of over 250 ha and in 2016 the prosopis invasion covered an area of more than 18,000 ha (Mbaabu et al. 2019), replacing grazing areas and agricultural land. Prosopis currently dominates the Njeps flats between Lake Baringo and Lake Bogoria (Mbaabu et al. 2019).

Kahe, Tanzania

In Tanzania, the study was conducted in Kahe Ward in Moshi District (37°20'–37°30' E, 3°25'–3°35' S). The area experiences mean daily temperature from 14 °C to 35 °C, with January being the hottest month. Average annual rainfall of 365 mm, with most rain occurring between March and May (de Bont et al. 2019). The main economic activities are crop cultivation (maize (*Zea mays* L.), bean (*Phaseolus vulgaris* L.) and tomatoes (*Solanum lycopersicum* L.)) which rely mostly on irrigation from existing canals, rivers and wells, and livestock keeping dominated by cattle, sheep and goats. *Prosopis juliflora* arrived accidentally in the area around 1990, mainly through livestock movements and floods which carry substantial amount of seeds from invaded areas in the north eastern side bordering Kenya (Kilawe 2017) and has replaced most of the natural vegetation and it is now the dominant tree species in the area. Prosopis has invaded agricultural fields under fallow, making crop production laborious and more expensive, and replaced grasslands, thus preventing livestock grazing.

The sustainable land management practice

The selected SLM practice can be best described as removal of prosopis through manual uprooting, followed by continuous cultivation. Crops may include various food crops as well as grass for fodder, seeds and thatching. The removed prosopis was used for making charcoal and firewood, which covered part of the cost of removing the trees and the rootstock. In Kahe, the selection of the SLM was done by a diverse group of stakeholders, using a deliberative decision-making process (Schwilch et al. 2009) accompanied by scientists of the Woody Weeds project that involved identification, documenting and ranking of known weed management practices and technologies, based on three groups of sustainability criteria: economic, ecological, and socio-cultural variables. The decision-making process and the economic costs and benefits of the SLM practice was described by Malila et al. (2023) and Kaaya et al. (in prep.). The SLM practice was test-implemented in 2019–2020 by six farmers on land that was heavily infested by prosopis. Woody Weeds provided each farmer with ~USD25 (TZS50,000) as facilitation at the start of the implementation (2019) and the project paid for the installation of a solar-powered water pump for irrigation of the six farms in Kahe, but no further financial support was provided. The crops grown in the first two seasons were maize, beans and tomatoes, but no information about subsequent crops is available and the participating farmers may have decided to grow other crops. In Baringo, the SLM practice was implemented in 2020–2021 on ten heavily invaded farms in two villages as part of a PhD student's study that compared economic costs and benefits of the SLM practice with the common practice of "management through utilisation" that involved removal of aboveground biomass to make charcoal and leaving the stumps to regrow for future harvest of wood (MSM, unpublished). Each farmer was given KSH7,000 (~USD 70) to lease the land at the start of the experiment (2020), and a single cash incentive of, on average USD67 (+/- 0.84) per farm, was provided to cover the cost of cutting and uprooting of prosopis, charcoal making, fencing, cultivation and sowing of crops in one 20×20 m plot per farm. The crops grown in the first two seasons in Baringo were green gram, followed by grass, but no information about subsequent crops is available and the participating farmers may have decided to grow other crops.

Data collection

Data was collected through ca. 150 interviews each in Kenya and Tanzania, carried out by trained enumerators with knowledge of the local conditions and language, in October 2022. The interviews consisted of a questionnaire survey (Supplementary Information 1) and a choice experiment and respondents were household heads that were selected because they participated in Woody Weeds activities, adopted the SLM practice, or were aware of the SLM practice that was tested by Woody Weeds.

Description of the interview tool

An interview instrument was designed that covered broadly four themes: (1) About the respondent and their household, which included age, gender, farming experience, household demographics, income sources and assets; (2) About the farm, which included size of land owned or managed, crops grown and yields; (3) About the history of prosopis, including knowledge and perceptions of introduction and impacts; and (4) about the SLM practice, which included knowledge and perception of the SLM, history of implementation, perceived benefits and disadvantages (Supplementary Information 1). The questions aimed at collecting information that was used to explain adoption of the SLM practice and included main sources of information about agricultural practices and weed management. Although all participants had to indicate that they were aware of the SLM practice to be interviewed, one of the questions asked whether the respondent had implemented the practice. The response to the latter question was used as response variable in the analyses to assess factors associated with (non-) adoption of the SLM practice (see below). If people indicated that they didn't implement the SLM practice, the subsequent questions about their knowledge and realised and perceived costs and benefits were skipped and the interview continued immediately with the choice experiment.

Choice experiment

A choice experiment to assess respondents' marginal willingness to pay (WTP) for implementing the SLM practice was conducted. Time to implement the SLM on one acre of prosopis invaded land was the payment vehicle (in weeks), while benefits were represented by four attributes that reflect well known impacts of prosopis or expected benefits of removing prosopis and growing crops: (1) expected income from crop sales, (2) reduced human health care costs, (3) the percent increase in useful grasses, and (4) the distance to a watering point (in meters). Respondents were presented one card at the time, with each card representing two alternatives differing in attribute levels, plus a status quo option that represented the current situation of prosopis invaded land without implementation of the SLM practice.

Five sets of four choice cards were generated using the optFederov() function of package Support.CEs (Aizaki 2021)in R (R Core Team 2022), representing twenty unique combinations of attribute levels. The attributes were implementation time (one week or two weeks), expected income from crops (local currency equivalent of USD 1000 or 5000), increased human health care cost (local currency equivalent of USD 50 or 100), increase in useful grasses (10% or 50%) and distance to watering point (100–500 m). The attribute levels were verified during the training and pre-testing of the interview instrument. Any monetary values on the cards were presented in local currency. Each of the attributes was represented by a simple pictogram on each choice card (Fig. 1). In Kenya the choice cards were presented in English and in Tanzania cards were translated into Swahili because the enumerators deemed it easier to understand for respondents in Kahe if the presented text was translated. Each enumerator had a copy of all sets and changed the presented set for each new respondent in order to increase the fraction of possible attribute level combinations assessed in the experiment. Each respondent made four choices.

Training of enumerators; interviews; selection of respondents

Data were collected using Open Data Kit (https://www.getodk.org/) installed on handheld tablets by six enumerators in each country. Prior to starting the interviews, the enumerators in each country spent two days familiarising themselves with the interview instrument and ODK. Then, each enumerator conducted an interview with one respondent in the study area and the data as well as any

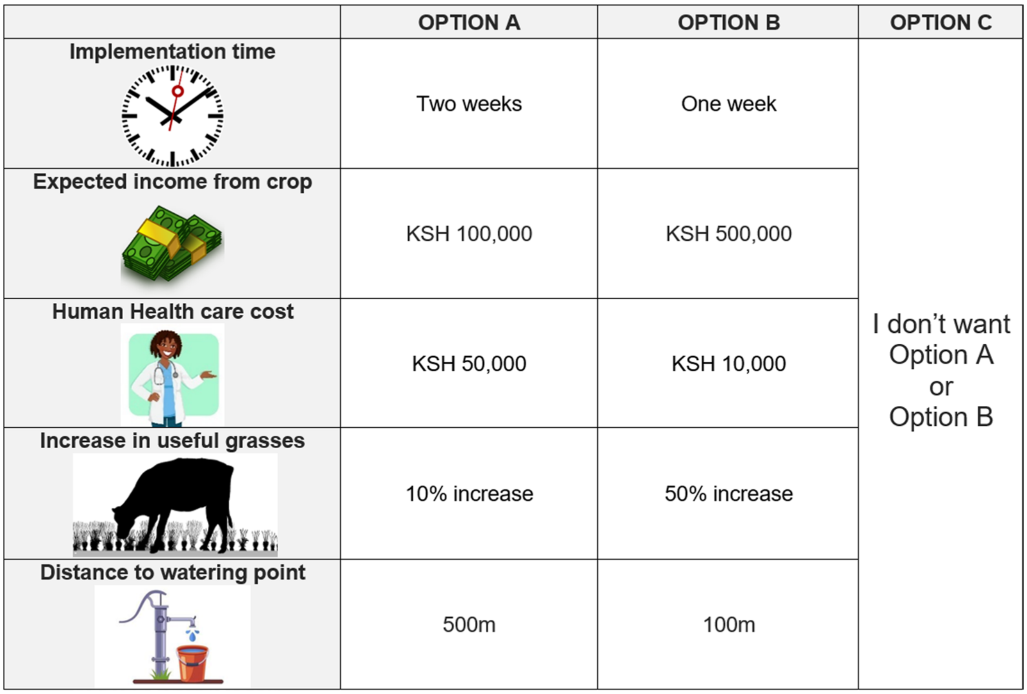

Fig. 1 Example of a choice card used in the choice experiment for Kenyan respondents. Each card represented two alternatives differing in attribute levels (Options **A** and **B**), plus a status quo option (**C**) that represented the current situation of prosopis invaded land without implementation of the SLM practice. Five sets of four choice cards were generated, representing twenty unique combinations of attribute levels. Each respondent was shown, one-by-one, the four of one set of cards and asked to choose their preferred option. In Tanzania, the cards were translated into Swahili and the monetary values converted to TSH

issues were then discussed as a group to ensure the collected data were useful and appropriate and all enumerators understood the questions well. Only then were the interviews conducted for data collection.

One of the enumerators in each country contacted potential respondents, ensuring their awareness of the SLM, and made appointments for the interviews. The interviews lasted for about half an hour each. In Tanzania, respondents suggested subsequent interviewees to the enumerators. Data were downloaded and inspected every evening to ensure data quality and consistency. At the end of the interview period, data were downloaded and anonymised as described below.

Statistical analyses

The characteristics of the respondents, their farms and knowledge about prosopis and the SLM practice were summarised using descriptive statistics, separated by country where appropriate.

To identify factors that influence if people adopt the SLM or not, we analysed the interview results using a generalised linear model with whether respondents said that they implement the SLM or not as binary response variable, and other interview responses as explanatory variables. Because of the large number of potential explanatory variables collected through the interviews, we decided to focus on key variables to analyse their effect on the likelihood of adoption of the SLM practice, specifically those for which we had hypotheses. Where multiple responses could be selected for a single question, such as "main sources of information concerning farming practices", we tested multiple responses and only retained those that were significant. We realised that some of the explanatory variables included in the model may be affected by a household's decision to implement the SLM practice. For example, growing crops instead of living with the prosopis invasion is likely to yield more income. Thus, we interpreted the results cautiously and didn't always assume causal relationships between the chosen explanatory variables and the likelihood of adoption. Estimated marginal means for factors and interactions were calculated using the emmeans() function of the emmeans package in R (Lenth 2023).

We analysed the combined results of the choice experiment from Kenya and Tanzania using a conditional logit model, with the set of choice cards presented to a respondent as blocking factor. While it has been argued that mixed models are more appropriate for the analysis of data collected through Discrete Choice Experiments (Hess 2014; Hess and Train 2011), this is based on the assumption of individual taste preference and the respondent is then included in the analysis as a random factor. The individual coefficients obtained using mixed models are commonly used to generate groups of respondents using multivariate analyses, with the aim of developing product options to target potential customers (e.g. Hess 2014; Revelt and Train 1999). By contrast, we aimed to test hypotheses about how characteristics of respondents affect their preferences (Revelt 1999). Therefore, we opted for a conditional logit model, where respondents are not random and selected characteristics were included as explanatory factors to assess their effect on the attributes (Ryan et al. 2012). We acknowledge that potentially only a small fraction of the variation in the data will be explained by the selected respondents' characteristics (Hess 2014). We included interactions of the attributes with whether people adopted, to assess whether experience with the SLM affects peoples' choices. We also included interactions between interactions of the attributes with country, to assess whether the country affected the choices made by respondents during the choice experiment and thus whether the results may be of more general applicability. The analysis of the choice experiment was done using the clogit() function of the Support.CEs package (Aizaki 2021).

Results

Household characteristics

A total of 302 household heads were interviewed, 154 in Kenya (85 men and 69 women) and 148 in Tanzania (81 men and 67 women). The respondents were on average 45 years old (42.6 +/- 1.3 and 47.7 +/- 1.2 (mean +/- SE) in Kenya and Tanzania) and had on average 16.7 years of farming experience (14.4 +/- 0.9 and 19.2 +/- 1.2 in Kenya and Tanzania). There was substantial variation in age and farming experience, and age and farming experience were positively correlated (Pearson correlation coefficient 0.74, $t_{300} = 19.09$, $P < 0.001$).

On average, households had 5.6 members (6.6 +/- 0.2 and 4.5 +/- 0.2 in Kenya and Tanzania), with very few people of 65 or older (0.32 +/- 0.05 and 0.25 +/- 0.05 in Kenya and Tanzania) and the other persons fairly equally divided between children (< 15 years: 3.08 +/- 0.17 and 1.63 +/- 0.13 in Kenya and Tanzania) and adults (15–64 years: 3.25 +/- 0.16 and 2.62 +/- 0.12 in Kenya and Tanzania). Two-thirds of the respondents had primary school as highest education, one sixth secondary education, while ca. 12% had no formal education and a small number had finished middle school, vocational training or a tertiary education.

As a measure of character or likelihood to invest in novel technologies, we asked about respondents' self-perception with regards to risk taking, i.e. whether someone is fully prepared to take risks or rather risk averse, on a scale from 0 to 10. While the average score was 5.44 (5.30 +/- 0.24 and 5.58 +/- 0.19 in Kenya and Tanzania), there was a lot of variation, with respondents self-assessing their risk acceptance or avoidance covering the entire spectrum.

Farm characteristics

The responses were very informative about the farms in both study areas. What follows is a summary and a fuller description can be found in Supplementary Information 2. Most people in the two regions indicated that they own their land (with or without a title deed), while a few people indicate that their land is communal. Ca 12% of the households indicated that they rent their land. In Kenya households farmed, on average, more land than in Tanzania (3.38 +/- 0.28 vs. 1.71 +/- 0.17 acres) and in Tanzania the area rented was larger than in Kenya (0.32 +/- 0.07 vs. 0.65 +/- 0.08 acres).

Annual household income in Kenya was double that in Tanzania (USD1,618 +/- 239 vs. USD811 +/- 101). The main income sources and their ranks were roughly comparable in both countries (crops, livestock, non-agricultural activities, trading and charcoal). Charcoal was a more important source of income in Kenya than in Tanzania (14.0 vs. 5.9% of total income, respectively).

The primary sources of information about farming practices mentioned by respondents included traditional media, neighbours and friends, agri-input dealers and extension agents. Kenyan respondents indicated a larger number of information sources than Tanzanian respondents (4.6 +/- 0.2 vs. 2.4 +/- 0.1).

About prosopis

Respondents indicated the year prosopis arrived in the area, with Kenyans indicating that it arrived on average longer ago than Tanzanians: 35% of respondents in Tanzania indicated that the species arrived 16–20 years ago, and 44% of respondents in Kenya indicated that it arrived more than 25 years ago. There was significant variation in the responses, which may be due to the ongoing expansion or multiple introductions of prosopis in both regions and the spatial distribution of the respondent's households in the region.

There were large differences between the two countries with respect to who planted prosopis. In Kenya, the majority of respondents indicated that it was planted by NGOs and locals, while in Tanzania most respondents indicated that the species was introduced through livestock (seeds being dropped in faeces).

In Kenya, prosopis abundance on farms was higher than in Tanzania. In Kenya, 45% reported prosopis cover

Table 1 Ranking of negative impacts and benefits of prosopis, as cited by a total of 302 respondents. Numbers in cells indicate the number of times a category was mentioned

Negative impacts	1st	2nd	3rd	Benefits	1st	2nd	3rd
Thorns/injury	111	52	44	Charcoal	166	78	31
Animal health (tooth decay)	39	36	30	Fuelwood	60	80	42
Impacts farming	36	55	26	Fencing	15	28	28
Charcoal burning (pollution)	27	14	13	Nothing	14	29	78
Death of livestock	20	15	8	Shade	10	31	44
Obstruction	13	11	24	Soil fertility	9	4	8
Nothing	11	41	74	Beautiful environment	3	2	1
Water availability	10	16	15	Less desertification	2	11	7
Reduces pasture	10	4	8	Fodder	2	9	19
Reduces biodiversity	6	14	20	Building material	1	21	18
Other	7	16	20	Medicine	1	0	0
				Other	76	144	229

on their farm in the range of 26–75%, while over 55% of respondents in Tanzania reported that prosopis cover is between 1 and 10% and only 12.8% of respondents reporting prosopis cover on their farm in the range of 26–75%.

Respondents across the two countries listed many benefits and drawbacks, when asked to list the top three of each (Table 1). The most frequently cited benefits were related to the use of prosopis for charcoal making or as fuelwood, followed by fencing and shade. Negative impacts were primarily related to the human health impacts of the thorns, followed by animal health (mainly tooth decay) and death, impact on farming through increased farming cost, yield loss and lower soil fertility, and air pollution because of charcoal burning.

About the SLM practice

Out of the 302 respondents, 76 said they don't implement the SLM practice: 36 in Kenya and 40 in Tanzania. Moreover, ten respondents no longer implemented the SLM practice (3 in Kenya and 7 in Tanzania). Two thirds of respondents indicate that there was a similar or the same management practice prior to testing of the SLM practice by Woody Weeds (no clear difference between the countries).

Over 80% of respondents in both countries had a positive perception of the SLM, with only nine people saying it is "Not so good". There was no clear difference in perception of people who learnt of it through Woody Weeds and those who didn't. After having implemented the SLM practice, people had a more positive impression of the SLM. People who had an unfavourable impression of the SLM ("Not so good") saw less improvement than people who had a more positive perception. Yet only two of the ten people with a bad perception no longer implement the SLM. The other eight that no longer implement had a positive perception.

By far most respondents would recommend the SLM practice (94% and 85% of Kenyan and Tanzanian respondents), with only 24 saying they would not recommend the practice. Over a quarter of those who recommended the practice (27.7%) did so to increase the area available for farming, 21.3% if prosopis was abundant or spreading and 16.8% because they expected the SLM to be a good investment to increase income. Most cited reasons for not recommending were that the SLM practice was perceived as ineffective (33.3%), or because most people already implement the SLM (20.8%). Half of the respondents indicated that they have recommended the SLM to 1–5 people (50%), although one third of the respondents in Tanzania indicate that they didn't recommend the SLM to anyone (33%). The frequency of responses for the different ranges of recommendations and adopters appear to correlate very well, which suggests that many of the people who were informed also adopted.

Most people adopted the SLM practice because they want to improve the value of the land, because they prefer farming over prosopis, or because they find farming more sustainable. The top reasons for non-adoption were that it is too expensive to hire labour to remove prosopis, the investment is too high (initial or continuous) or that it is too dangerous to remove prosopis (human health risk) (Fig. 2).

Factors influencing implementation of the SLM practice

Analysis of the selected explanatory variables on the likelihood that a respondent implemented the SLM practice revealed that men are more likely to adopt than women (probability of 0.997 +/- 0.87 and 0.994

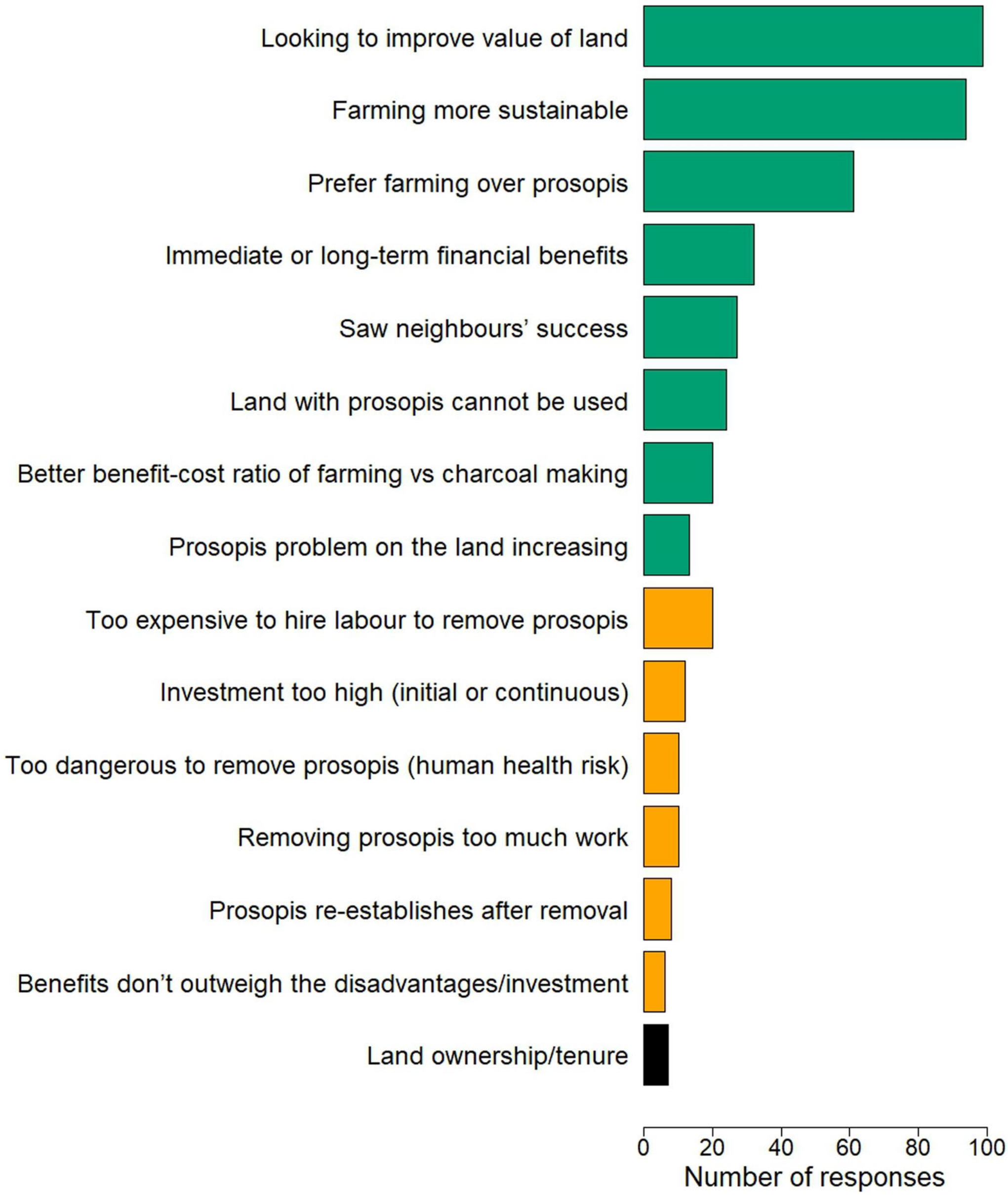

Fig. 2 Reasons for adoption and non-adoption of the SLM practice mentioned by respondents. Green, orange and black bars indicate reasons for adoption, for non-adoption and neutral responses, respectively

+/- 1.57 respectively (estimated marginal means +/- SE); Table 2; Supplementary Information 3). Respondents who indicated that one of their main information sources about agricultural practices is public barazas and village meetings were more likely to adopt than those who did not mention barazas and village meetings as a main source of information (probability of 1.000 +/- 0.03 and 0.707 +/- 0.06 respectively). Respondents in Kenya were less likely to adopt than people in Tanzania (probability of 0.777 +/- 0.08 and 1.000 +/- 0.04 respectively). Overall, size of the farms (owned + rented land combined) was positively associated with the likelihood to adopt. Respondents who adopted the SLM practice had more income from crop production, from wages and salaries for non-agricultural employment/business (e.g. civil service, masonry, carpentry etc.) and from business than those who didn't implement the practice. Other sources of income didn't differ between implementers and non-implementers. Prosopis abundance on the farm and the years of farming experience of the respondent did not significantly affect the likelihood to adopt.

Table 2. ANOVA-style table showing results of a generalised linear model to analyse the effect of various explanatory variables on the likelihood of implementation of the SLM practice

	Df	SSq	MSq	F	P
Gender	1	2.18	2.183	13.18	<0.001
log10(Experience + 1)	1	0.02	0.017	0.10	0.748
Risk acceptance	1	0.17	0.172	1.04	0.309
log10(Farm size)	1	1.94	1.941	11.71	<0.001
log10(Total income USD + 1)	1	0.97	0.965	5.83	0.016
Prosopis abundance	5	1.21	0.242	1.46	0.203
Info Barazas	1	1.30	1.299	7.84	0.005
Country	1	1.39	1.387	8.37	0.004
Gender * Country	1	0.01	0.015	0.09	0.767
log10(Experience + 1) * Country	1	0.27	0.274	1.65	0.200
Risk acceptance * Country	1	0.13	0.135	0.81	0.368
log10(Farm size) * Country	1	0.36	0.363	2.19	0.140
log10(Total income USD + 1) * Country	1	0.40	0.403	2.43	0.120
Prosopis abundance * Country	4	0.19	0.047	0.283	0.889
Info Barazas * Country	1	0.10	0.096	0.576	0.448
Residuals	279	46.23	0.166		

Barazas only happen in Kenya and in Tanzania these are called village meetings; the word barazas indicates both

Willingness To Pay and preference for attributes in choice experiment

The overall model fit was good (McFadden's $R^2 = 0.26$). The significant constant indicates that, overall, respondents prefer to adopt the SLM practice over the status quo situation with prosopis (Alternative Specific Constant: $P < 0.005$; Table 3. The status quo option was chosen in just 3.6% of the choices. Implementation time was significant and the coefficient positive, indicating a preference for options that require larger time investment. The coefficient for implementation time was, although very small (coefficient: 0.151, SE: 0.007), the largest coefficients of all attributes. None of the other attributes was significant. The significant interaction between financial return and adoption indicates that financial return was a less important attribute for respondents who adopted than for those who don't adopt, although the coefficient was very small, indicating a minor difference. No differences in importance of attributes between the two countries were found.

Effect of Woody Weeds activities

Many people started implementing the SLM practice prior to testing implementation of the practice by Woody Weeds, but the largest increases in the number of implementers in Baringo were in years when Woody Weeds started implementing uprooting: 2017 (Kilawe 2017) and 2020 (17; Fig. 3). Across both countries, there was an increased rate in new implementers after 2016, with the stronger annual increases recorded in 2017, 2019 and 2020, the years when Woody Weeds started activities in Baringo and Kahe.

The average annual increase in the number of adopting respondents from 1990 to 2016 was 3.4 +/- 0.9 (mean +/- SE), whereas from 2017 to 2022, when Woody Weeds started testing SLMs it was 22.8 +/- 4.8. Even in the six years prior to 2017 the average increase was only about one third of the increase since Woody Weeds started testing the SLM 7.8 +/- 2.5. So, although it is impossible to ascertain to what extent the increased adoption of the SLM was the direct result of the Woody Weeds project, the strong increase in the annual new implementers

Table 3. Results of a conditional logit model to analyse the results of the choice experiment

	coef	exp(coef)	se(coef)	z	P
Alternative Specific Constant	2.1230	8.3550	0.2395	8.862	<0.001
Implementation time	0.0151	1.0150	0.0075	2.009	0.045
Human health care cost	-0.0027	0.9973	0.0078	-0.351	0.725
Increase in useful grasses	-0.0009	0.9991	0.0074	-0.121	0.904
Distance to watering point	0.0007	1.0010	0.0008	0.976	0.329
Financial return	0.0010	1.0010	0.0007	1.366	0.172
Implementation time : Adopted	0.0040	1.0040	0.0046	0.879	0.379
Human health Care cost : Adopted	0.0046	1.0050	0.0049	0.944	0.345
Increase in useful grasses : Adopted	0.0021	1.0020	0.0046	0.450	0.653
Distance to watering point : Adopted	0.0000	1.0000	0.0005	0.080	0.936
Financial return : Adopted	-0.0010	0.9990	0.0005	-2.138	0.033
Implementation time : Country	-0.0063	0.9938	0.0040	-1.555	0.120
Human health care cost : Country	0.0011	1.0010	0.0044	0.250	0.802
Increase in useful grasses : Country	0.0008	1.0010	0.0040	0.203	0.839
Distance to watering point : Country	-0.0006	0.9994	0.0004	-1.503	0.133
Financial return : Country	-0.0003	0.9997	0.0004	-0.775	0.438

Rho-squared = 0.2629704

Adjusted rho-squared = 0.2509143

Akaike information criterion (AIC) = 1988.259

Bayesian information criterion (BIC) = 2069.806

Number of coefficients = 16

Log likelihood at start = -1327.124

Log likelihood at convergence = -978.1294

suggests that the Woody Weeds activities inspired people to adopt the practice.

About one fifth of respondents has heard of the practice through Woody Weeds, 63% observed neighbours doing it, about half (54%) was unknowingly already implementing and just 6% heard about it through extension workers. It was possible to select multiple responses for this question. "Others" include four times neighbours and once "project supported by mzungu", which we interpret to mean Woody Weeds. Although the numbers were consistently somewhat lower in Tanzania, this is likely due to the smaller number of respondents and the patterns were virtually identical in both countries.

Discussion

The results of the present study reveal a high rate of adoption of the tested SLM practice in Baringo and Kahe, several years after the end of the project that introduced or promoted them. Respondents were well aware of the

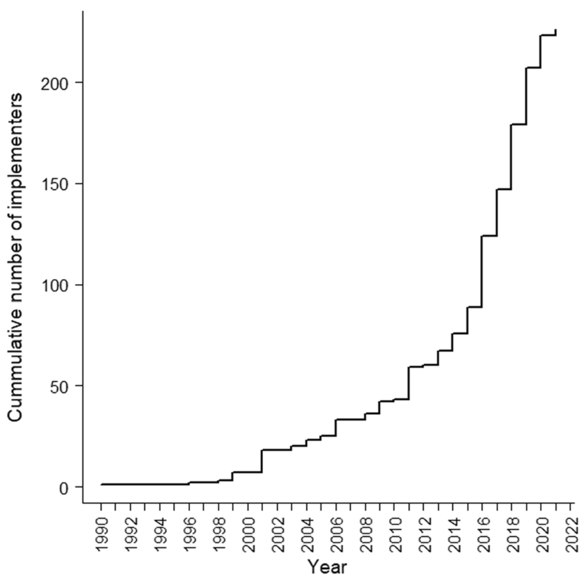

Fig. 3 Cumulative number of respondents implementing the SLM practice, indicated by the year they started implementing

SLM practice and its costs and benefits. They had a very positive perception of the practice, which improved after implementation, perhaps as a consequence of the high returns of crop production that outweigh the cost of removing prosopis.

Willingness to adopt the SLM

Part of our study relied on a choice experiment, in which respondents were asked to choose between two alternative scenarios of benefits as a result of implementing the SLM or continuation of the current situation with prosopis. Every respondent in the choice experiment preferred prosopis management over the status quo and in the rare cases where the status quo was preferred this was only one of the four choices by each respondent. This is different from the results of a recent study of people's willingness to implement the SLM in Kahe (Malila et al. 2023), where a smaller proportion of respondents indicated that they would be willing to adopt than the respondents in our study. One reason for the difference between the two studies may be that perceptions about and practices for the management of prosopis have changed when compared to the period when Malila et al. (2023) collected their data as a result of awareness creation by the Woody Weeds project. Contrary to the past, prosopis is now known as a non-native, bad tree and farmers can cut the tree without the need of a permit from the Forest Department. Hence, implementation of the SLM may have become easier and willingness to adopt, as well as actual adoption, likely have increased. Other studies from Kenya and Ethiopa found a similar widespread willingness to pay for management of prosopis as the study by Malila et al. (2023), (Bekele et al. 2018; Tilahun et al. 2017; Al-Assaf et al. 2020), either as in-kind labour or as a financial contribution, over the status quo.

The results of the choice experiment suggest that respondents are willing to invest in implementing the practice irrespective of the benefits in the scenarios, and the results further suggest that financial return was more important for people who didn't adopt the practice than for people who did. However, the results reveal little about the attributes that respondents considered most important. This is surprising, as the attributes were selected on prior knowledge from literature and interactions with stakeholders in both study areas, which reveal that prosopis affects water availability (Shiferaw et al. 2021), human health (Muller et al. 2017), crop yield and fodder availability (Linders et al. 2020). People in areas invaded by prosopis are well aware of the impacts of the species on their environment and are willing to invest in management of the species, and the attributes in this study reflect those in the study by Bekele et al. (2018). One explanation for the lack of significant effects of most attributes is that, despite the pre-trials, the scenarios provided in the choice experiment were very low costs in comparison to the perceived benefits of removing prosopis and the wealth of the households. Alternatively, the almost consistent rejection of the status quo and the absence of significant coefficients reflect the extent of the prosopis problem and how respondents perceive prosopis—people are willing to invest in removing the trees because they don't want them in their farms, irrespective of the detail in the benefits in the proposed scenarios.

What motivates people to implement/what people implement the SLM practice?

The interviews revealed that households with more land, but not those with more income, were more likely to implement the SLM practice. The implementation of the SLM practice is resource-intensive and the results indicate that households with more capital, are more likely to implement the practice. Residents of Baringo are aware of the need to obtain title deeds for their land, as this will enable access to bank loans which would facilitate investment in management (RE, pers. obs.), which is similar to findings of a study on farmers' motivation to invest in SLM in Burundi where farmers acknowledged the need to have a property title in order to access credit (Ndagijimana et al. 2019). Household income may partially be a result of implementing the practice, as indicated by the higher income from several sources reported by households that implemented the practice than those that didn't. However, it appears unlikely that farm size will have changed significantly as a result of the implementation of the practice and we found a weak but significant positive correlation between farm size and household income. This is a somewhat different result to that of Malila et al. (2023), who found that household income was positively correlated with the willingness to implement the SLM in Kahe, and those of Al-Assaf et al. (2020) who found the wealthier households in Jordan were more likely to support prosopis management. Based on those and our studies, it appears that wealthier households are more likely to implement practices to remove prosopis.

We found that respondents were not more likely to implement the SLM if the prosopis abundance was high. Previous studies of people's willingness to implement prosopis management have yielded mixed results and the results may be context dependent. For example, Malila et al. (2023) interviewed 120 people from four villages in Kahe Ward with varying levels of prosopis abundance and found a negative relationship between prosopis abundance and willingness to adopt the SLM. By contrast, no relationship with prosopis impact was found in a study of willingness to manage prosopis in Jordan (Al-Assaf et al. 2020). The result of our study appears to be consistent with the choice experiment, which revealed an overall high willingness to adopt the SLM practice irrespective of the selected benefits and a willingness to accept high labour investment, similar to results of a study of willingness to pay for prosopis management in the Afar Region of Ethiopia (Tilahun et al. 2017), which indicates that people prefer alternative land uses and economic activities over prosopis invaded land.

Many respondents indicated that they would recommend the SLM to open land for agriculture or because they think it is a good investment, which is similar to results of an analysis of the WOCAT database of SLM practices that found that three quarters of the practices described in the database were perceived as having a positive cost:benefit ratio (Giger et al. 2018). This confirms that even though many people in heavily invaded areas derive benefits from prosopis, they believe that removal of prosopis for agriculture is preferable to living with the tree that was perceived negatively by most respondents and appears supported by our finding that respondents' perception of the practice was better if the respondents had adopted the practice. This is similar to results of a study in Jordan, where people would prefer seeing the trees removed from the landscape, or if it is to be maintained because of the livelihood benefits certain people derive, removed from areas where the disadvantages are most felt (Al-Assaf et al. 2020).

What was the effect of Woody Weeds on implementation of the SLM practice?

Woody Weeds was not the first to identify and implement the SLM practice in Baringo (Choge et al. 2022; Kamiri et al. 2024) and Kahe, as indicated by the fairly large number of respondents who indicated that they started implementing the SLM practice prior to the start of Woody Weeds (ca. half of the respondents; Fig. 3). For example, close to Kahe, in Mabogini, there is a cooperative irrigation scheme, called the Mtakuja Development Organization, that practices intensive farming on 200 ha of land that has been cleared of prosopis before 2015 and in Baringo an agricultural scheme has been developed in Eldume sublocation, where a local group has cleared prosopis and practiced continuous, irrigated crop and commercial seed production on ca. 80 ha. The latter scheme was initiated in 2017, around the same time and close to the locality as Woody Weeds initiated a study to test prosopis control methods, and although the initiators of the scheme practiced the SLM prior to the Woody Weeds study, they said that the knowledge and awareness about the SLM increased as a result of Woody Weeds (WN, pers. obs.). Similarly, awareness creation done by the Woody Weeds project changed public perceptions about prosopis in and around Kahe, which enabled management of prosopis trees without the need for permission from the authorities to cut large prosopis trees, likely establishing the conditions needed for adoption of the SLM (CJK, pers. obs.). Thus, although it is impossible to ascertain that the increasing number of implementers among the respondents after 2016 is the direct result of Woody Weeds, we found two indications that the project increased adoption of the SLM.

Almost one fifth of the respondents indicated that they learned about the SLM practice through Woody Weeds, and the largest annual increases in the number of implementers coincides with the two years when Woody Weeds implemented the SLM (or closely resembling practices) in experimental settings. In 2017, three experimental plots were established to assess differences in cost and effectiveness of three prosopis control methods, as well as restoration of grassland (Eschen et al. 2023). These methods included one option that was removal of prosopis through uprooting. In 2019, the SLM practice was first tested by members of a stakeholder group established by the project to identify acceptable SLM practices for prosopis management in Kahe. The group involved about 25 people and so the awareness of local stakeholders about the SLM was more widespread than just the four (of total six) farmers who tested the SLM practice with initial support of Woody Weeds. A similar process with a similar number of stakeholders was conducted in Baringo, where the same SLM was selected, and in 2020, a study was set up in Baringo to test whether the SLM is effective and assess costs and benefits of its implementation (MSM, unpublished). Ten farmers in two villages participated in this study, adding to the visibility of the SLM and awareness of people from the area.

Conclusions

Our study showed that the SLM, which was selected by people constituting Local Implementation Groups in the two regions as part of the Woody Weeds project, are adopted well beyond the people directly involved in the project. Despite the studies on willingness to adopt prosopis management from Ethiopia and Jordan (Bekele et al. 2018; Tilahun et al. 2017; Al-Assaf et al. 2020), we believe this is the first study that assesses adoption of prosopis management, and the factors that explain the rate of adoption, rather than the intention to adopt. Co-development, selection and implementation of the SLM practice with a group of stakeholders, even if the practice was known especially in Baringo (Choge et al. 2022; Adoyo et al. 2022; Kamiri et al. 2024), likely helped adoption. That the project was actively engaging with, and reaching out to a wide range of stakeholders about sustainable practices and strategies for management of prosopis, contributed to more informed decision making about the most appropriate SLM practice.

Although it is impossible to attribute adoption to individual interventions or local circumstances, the participatory decision-making process is likely to have contributed to the high adoption rate of the practice in both regions, as has information about the practices being shared during village meetings (barazas). It also appears that project activities, including demonstration of the practices as part of research done on effectiveness of prosopis control in both regions, were important for adoption as indicated by the higher rate of adoption during the years where the project implemented practical activities. The ability to see the practice being implemented and discuss practical aspects and the favourable benefit:cost ratio of the practice with those who were involved in implementation, either land users or project staff, may have convinced other people of the benefits of crop production over prosopis.

Given the positive opinion of people who have adopted the practice in the two regions, and that the overwhelming majority of interviewees prefer the practice over not managing prosopis, we propose upscaling of the practice to other areas infested by prosopis. Promoting the practice in new areas through implementation by stakeholders at demonstration sites as well as through community meetings may increase the rate of adoption. These results also highlight the need for further projects aiming at engaging residents of other regions, in East Africa and elsewhere in the world where prosopis is invasive, in sustainably managing prosopis infested lands.

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

Supplementary Material 3.

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Author contributions

R.E. and W.N. designed the study, W.N. and O.E.K. supervised data collection, R.E. conducted the data analysis and R.E. and W.N. wrote the manuscript with input of all authors. All authors read and approved the final manuscript.

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Availability of data and materials

The dataset supporting the conclusions of this article is available from https://doi.org/10.34857/0075917.

Declarations

Ethics approval and consent to participate

All respondents were informed about the purpose of the study and the intended use of the data. It was made clear to them that participation was voluntary and unpaid, that they could refuse to answer questions, terminate the interview at any time and that they could revoke their participation in the study at any time until a summary of the data had been published. It was explained that their personal data would not be visible to the researchers analysing the data because any data that can be used to identify respondents would be separated from the interview data once these were downloaded from ODK and stored separately from their responses; personal data were replaced in the dataset with a numerical identifier for each respondent. Respondents were assured their identities would never be revealed in presentations of the results. Prior to the start of the interview, respondents were asked for written consent to the use of their data, and a printed copy of the consent form was given to each respondent. This research was done with CABI Ethical Review Board Approval No. ERB0122-04, and under NACOSTI (Kenya) research permit No. NACOSTI/P/23/23364, and under COSTECH (Tanzania) research permits No. 2022-931-NA-2022-151, 2022-932-NA-2022-151, 2022-933-NA-2022-151, 2022-934-NA-2022-151, and 2022-935-NA-2022-151

Consent for publication

No personal data are included in the manuscript.

Competing interests

The authors declare that they have no competing interests.

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