Agroecological practices increase farmers’ well-being in an agricultural growth corridor in Tanzania

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Abstract
Millions of people rely on nature-rich farming systems for their subsistence and income. The contributions of nature to these systems are varied and key to their sustainability in the long term. Yet, agricultural stakeholders are often unaware or undervalue the relevance of those contributions, which can affect decisions concerning land management. There is limited knowledge on how farming practices and especially those that build more strongly on nature, including agroecological practices, may shape farmers’ livelihoods and well-being. We aim to determine the effect that farmer perception of contributions from nature, socioeconomic conditions, and farming practices, have on outcomes related to food security and human well-being. We conducted 467 household surveys in an agricultural growth corridor in rural Tanzania, which is also essential for nature conservation due to its high biodiversity and its strategic location between several protected areas encompassing wetland, forest, and grassland habitats. Results show that implementing more agroecological practices at farm scale has a positive effect on farmer well-being in the study landscape. Results also indicate that higher awareness of benefits from nature, as well as engagement with agricultural extension services, are associated with higher number of agroecological practices applied in the farm. This research confirms the relevance of capacity-building initiatives to scale up the uptake of agroecological practices in the tropics. It also shows, using empirical evidence, that farming practices taking advantage of nature’s contributions to people can positively affect food security and human well-being, even when those practices complement conventional ones, such as the use of synthetic inputs. Understanding the impact of agroecological farming on the well-being of smallholder farmers in the tropics paves the way for policy and program development that ensures global food demands are met in a sustainable way without compromising the well-being of some of the world’s most vulnerable people.

Keywords  Agroecology • Sustainable agriculture • Land use management • Nature • People • Socioecological systems • East Africa
1 Introduction

One of the greatest challenges of our time is how to improve agricultural practices to meet increasing global food demand in a sustainable way (Van Ittersum et al. 2016; FAO 2017). Industrialized or conventional approaches to crop production are favored by current policy and market conditions. However, there are growing concerns about their long-term sustainability and pressure on planetary boundaries (Campbell et al. 2017; Kremen and Merenlender 2018). Agroecological practices, proposed as alternatives, can help accomplish a transition towards more sustainable food systems (Caron et al. 2014; HLPE 2019). Agroecological practices are defined as agricultural practices aiming to produce significant amounts of food, which integrate ecological processes and ecosystem services (Wezel et al. 2014). Its principles include nutrient recycling, enhancement of soil health, reduction of external inputs, and biodiversity conservation (Wezel et al. 2020). Both the principles and practices of agroecology are sometimes blurred with other concepts, such as ecological intensification (Wezel et al. 2015). Likewise, agroecological intensification is to “improve the performance of agriculture while minimizing environmental impacts and reducing dependency on external inputs through integration of ecological principles” (Wezel et al. 2015). Aligning with the same common principles, in this study we consider agroecological intensification as the application of multiple practices, namely, rainwater harvesting and storage, water retaining pits, fodder banks, cover cropping, mulching, crop rotation, reduced tillage, no tillage, intercropping, post-harvest use of residues, manuring, integrated soil management, fallow, use of natural predators, natural pesticides, and agroforestry (Wezel et al. 2015; HLPE 2019).

Natural elements, including biodiversity and ecological interactions, play a fundamental role in agroecological practices, as they underpin the trade-offs and synergies occurring between multiple ecosystem services (e.g., pollination) and disservices (e.g., crop pests) at farm or landscape scale (Zhang et al. 2007). Within agricultural landscapes in the tropics, agroecological practices can enhance food security, safety, and livelihood outcomes for smallholder farmers and increase the long-term sustainability and resilience of those systems, including retention of its biodiversity (Chappell and LaValle 2009; Duriaux Chavarria et al. 2018; Mdee et al. 2018; HLPE 2019). It has been shown that farming systems integrating agroecological practices have the potential to improve indicators of household well-being, including dietary diversity and nutrition, through subsistence and income-generating pathways, while significantly reducing the negative externalities of farming (Kremen and Miles 2012; Jones 2017; Mdee et al. 2018). For example, a long-term study focused on an agroforestry program in Kenya found positive effects of that intervention on household asset accumulation, particularly in female-led households, fuelwood access, and income generation (Hughes et al. 2020). Nevertheless, smallholder farmers and other relevant stakeholders may be unaware or undervalue the benefits they receive from working with nature (Kleijn et al. 2019). The cross-cutting feature of agroecological practice in the context of rural development creates potential to contribute to the achievement of multiple Sustainable Development Goals, including reducing poverty (SDG1), ensuring conservation, restoration and sustainable use of land (SDG15), improving water quality (SDG6), improving good health and well-being (SDG3), reducing inequalities (SDG10), responsible consumption and production (SDG12), and climate action (SDG13) (Mbow et al. 2014; HLPE 2019). This is particularly relevant when many of the world’s most vulnerable people are smallholder farmers in the tropics (Morton 2007).

Agricultural growth corridors have been established across Africa to promote agricultural development and the closure of yield gaps (Enns 2018). Initiatives so far predominantly used conventional approaches to agricultural intensification, including intensified application of synthetic inputs and conversion of natural habitats to cropland, which carry both environmental and social risks (Pretty and Bharucha 2014; Laurance et al. 2015). When those risks are taken into account in decision-making processes, the areas identified as most suitable to development can change (Laurance et al. 2015; Nijbroek and Andelman 2016). If initiatives fitted for the needs of large agribusinesses exacerbate imbalances in social equity and local access to land and markets, smallholders are unlikely to benefit, with benefits being captured instead by local elites (Sulle 2017). For agricultural development corridors to overcome inconsistencies in their win-win narratives, nuanced perspectives are required, supported by empirical data to help policymakers better address the social and environmental changes caused by corridor routes (Enns 2018). Moving corridor planning towards land management interventions that promote and take advantage of the benefits from agrobiodiversity, such as agroecological practices, allows achieving higher multifunctionality in landscapes that work both for people and nature (Kremen and Merenlender 2018).

Human well-being is vital for our physical, social, psychological, and spiritual fulfilment (MEA 2003). There are still significant knowledge gaps concerning the extent that land use management, including biodiversity conservation or sustainable farming practices, impact smallholder farmers’ livelihoods and well-being (Caron et al. 2014; Milner-Gulland et al. 2014). It is known that biodiversity is of central importance to human well-being and intrinsically linked to sustainable development (MEA 2003; Naeem et al. 2016; Soga and Gaston 2016). Furthermore, there is evidence suggesting that economic outputs at farm level are not sufficient to understand farmer well-being in rural communities (Rivera et al. 2018). As well as a growing recognition of the need to shift...
measurement of development away from simplistic economic metrics to human well-being (Stiglitz et al. 2009; Dasgupta 2021). That questions the rationale for agricultural growth corridors focused solely on conventional intensification. Recent advancements in the field have increased our ability to capture the multidimensional scope of well-being in an objective metric and use it to assess the outcomes of agricultural interventions in a more comprehensive way (Agarwala et al. 2014; Costanza et al. 2016; Rasmussen et al. 2018; Beauchamp et al. 2018; Loveridge et al. 2020).

In this study, we have the unique opportunity to use household data from a case study in Tanzania to investigate relationships between nature, food security, and human well-being. We use an empirical approach to explore how smallholder farmer perceptions of contributions from nature, socioeconomic conditions, and farming practices, interlink with agroecological intensity, food security, and human well-being, in the context of rural landscapes in the tropics (Fig. 1). More specifically, our research objectives are to determine whether (i) farmer socioeconomic conditions and their perceptions of the contributions from nature drive the uptake of agroecological practices; (ii) higher farm-level agroecological intensity has an impact on the perceived yield of staple crops; and (iii) higher farm-level agroecological intensity contributes to farmer well-being.

2 Methods

2.1 Study area

We conducted this study in the northern part of Kilombero District, Morogoro Region, Tanzania (Fig. 2). Smallholder farming, particularly maize, rice, and sugarcane, and a large commercial sugarcane farm are major land uses in that area. The District constitutes the Kilombero cluster of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT), a priority area for agricultural development (SAGCOT 2011). SAGCOT plans for that cluster include a 320-km road upgrade, 60-km power transmission lines, several thousand hectares of land converted to large commercial farming, and promotion of links between agribusiness and smallholder farmers via out-grower schemes (SAGCOT 2011). Kilombero District also constitutes part of a floodplain that was designated a Ramsar Site in 2002 and is one of the largest wetlands in Africa (Dinesen 2016). The area is important for wildlife mobility—including large mammals—and habitat connectivity, due to its strategic location between several different protected areas. Within the north of Kilombero District, we randomly selected seven villages with a total of 38,456 inhabitants (National Bureau of Statistics 2013) (Fig. 2).

2.2 Data collection

We conducted a survey of 467 randomly selected households in seven villages from four wards in northern Kilombero District (Fig. 2). Sampling effort was proportional to village population size (or sub-village when data was locally available). Data collection occurred between November and December 2019. We randomly selected households after consulting the respective village registries to ensure that our sample reflected local socio-economic variation. Only one individual was surveyed per household, since well-being is highly correlated between members of the same household (de Lange et al. 2016). To avoid gender bias, men and women were selected in rotation from one household to the next, whenever possible. Three locally hired enumerators with previous experience were trained and applied the surveys. A pilot study and focus group discussions were conducted in two of the sampled villages to guarantee the wording was adapted to the local context.
context. The questionnaire was developed in English and translated to Swahili using clear and simple language. For data entry, we used Open Data Kit (ODK) tools, specifically ODK Collect and Aggregate (Hartung et al. 2010). Free, prior, and informed consent was obtained before starting the questionnaire. The questionnaire aimed to gather information on farmers’ agricultural practices, their interaction with nature, and their well-being levels. It took approximately 60 min to complete and consisted of nine different sections: basic information, household characteristics, health and education, livelihood and labour, assets, perspectives on ecosystem services and disservices, perspectives on nature, quality of life, and farming practices. Its design integrated elements from previous works developed in Tanzania (CGIAR (Consultative Group on International Agricultural Research) 2015; EDI (Economic Development Initiatives) 2007; Loveridge et al. 2020; World Bank 2016). For the map in Fig. 2, the forest layer was developed by the European Space Agency using Sentinel-2A data (ESA, 2017). Dwelling areas were classified manually. Spatial data for the protected areas represented, including Kilombero Valley Floodplain Ramsar site and Nyerere National Park (previously Selous Game Reserve), was downloaded from the World Database on Protected Areas (UNEP-WCMC and IUCN, 2021).

### 2.3 Modelling approach

To investigate how smallholder farmers’ socioeconomic conditions, their perceptions, and farming practices relate with food security and human well-being, we used a three-tiered modelling approach. This followed our understanding of causal pathways starting at farmer perceptions, socioeconomic conditions, and farming practices and leading to (i) agroecological intensity, (ii) food security, and finally to (iii) well-being. The systems approach framework underlying relationships within the causal pathways was described in Milheiras et al. (2022). We analyzed pathways using three different models with agroecological intensity (model 1), estimated crop yield (model 2), and human well-being (model 3) as response variables. Considering that our focus are smallholder farmers in tropical countries, we worked under the assumption that crop yield is highly correlated with food security for this context (IFAD and UNEP 2013).

We also assumed that agroecological intensity, food security, and human well-being can be affected by the same socioeconomic factors. This builds on existing literature suggesting that perceptions of nature impact on uptake of sustainable farming practices (Piñeiro et al. 2020), food security (Akinnifesi et al. 2010), and well-being (Hartig et al. 2014), and so do socioeconomic conditions (Bashir and Schilizzi 2013; Kassie et al. 2013; Reyes-Garcia et al. 2016). There is less evidence on the effects that agroecology uptake has on food security (Altieri et al. 2012) or on well-being (Miller et al. 2020; Ojedokun et al. 2020). However, the association between food security and human well-being is well established (Frongillo et al. 2017).

The variables used in our three-tiered modelling approach were selected after checking for multicollinearity and missing values. We excluded as predictors variables already being used to generate the well-being composite indicator. The
description of all model covariates can be found in Table 1. The description of well-being indicators can be found in Table 2.

### 2.4 Well-being composite indicator

Following the approach developed by Loveridge et al. (2020), we used 20 indicators along five well-being dimensions to calculate a well-being composite indicator. The indicators used are described in Table 2. These indicators are representative of the five well-being domains put forward in the Millennium Ecosystems Assessment (MEA 2003), namely ‘basic material for a good life’, ‘health’, ‘social relations’, ‘security’, and ‘freedom of choice and action’. They were selected through the Well-being Indicator Selection Protocol (Loveridge et al. 2020), except diet diversity, which was added posteriorly for a more balanced representation of food security in the index. Prior to combining the variables, the data was checked for missing values and normalized. Missing cases were assumed to be missing at random and were deleted. Variables where higher values meant a more negative outcome were inverted. Normalization was achieved by dividing each variable by its respective maximum. To calculate the index, each variable was weighted in relation to the number of variables within the corresponding dimension, ensuring that all dimensions carried the same weight in the final composite index, irrespective of the number of constituting variables.

### 2.5 Data analysis

After excluding 47 respondents through quality control (survey categorized as poor quality by the interviewer; respondents lived in region for less than 1 year; respondents stated no participation in farming activities or decisions), analysis was conducted on the resulting 420 valid questionnaires. The sample had adequate gender balance (200 adult men and 220 adult women). We used linear mixed effects models fitted by maximum likelihood. The fixed effects in each model are described in Table 1. All three models include village as the random effect, as we expected values within each village to be more similar than values between villages (Harrison et al. 2018). Interviewer was added in all models as a control fixed effect, rather than a random effect, due to its small number of levels (n=3) (Bolker et al. 2009).

The response variables for model 1 (agroecological intensity) and model 2 (staple crop yield) were log transformed, due to their right-skewed distribution. The correlation coefficients between model covariates were low. We acknowledge the high correlation between well-being indicator ‘land area’ and model covariate ‘plot ownership’ (rho=0.82, p-

### Table 1 Description of the model covariates used in models 1, 2, and 3. The response variables were agroecological intensity (model 1), staple crop yield (model 2), and human well-being (model 3)

| Variable                     | Description | variable type | categories | Mean (SD) | Range |
|------------------------------|-------------|---------------|------------|-----------|-------|
| Age                          | Respondent’s age | Integer      |            | 49.96 (14.05) | 20–96 |
| Gender                       | Respondent’s gender | Binary      | ‘1’= woman, ‘0’= man | 0.52 (0.5) | 0–1   |
| Village responsibilities      | Has local role or responsibility for which respondent is publicly known | Binary | ‘1’= yes, ‘0’= no | 0.21 (0.41) | 0–1   |
| Group membership             | Number of local groups or associations the respondent is member of | Integer |            | 1.2 (1.34) | 0–7   |
| Food needs                   | Frequency of difficulties satisfying the food needs of the household | Integer |            | 2.6 (1.22) | 0–4   |
| Perceived crop damage        | Lost more than a ¼ crop production to pests and/or mammals in the last year | Binary | ‘1’= yes, ‘0’= no | 0.62 (0.49) | 0–1   |
| Perceived ecosystem services | Total number of ecosystem services listed as being provided by natural habitats in and around the farm | Integer |            | 5.2 (3.4) | 0–22  |
| Perceived nature impact on livelihood | Perceived overall impact of natural areas on and around the farm on the respondent’s livelihood | Ordinal | ‘5’= very good, ‘1’= very bad | 3.84 (1.21) | 1–5   |
| Perceived future conditions  | How respondent believes natural environmental will be in 5 years | Ordinal | ‘3’= better than now, ‘1’= worse than now | 2.03 (0.79) | 1–3   |
| Farming advice               | Farmer received farming advice in the last 3 years | Binary | ‘1’= yes, ‘0’= no | 0.3 (0.46) | 0–1   |
| Plot ownership               | If respondent’s household owns farm plots | Binary | ‘1’= yes, ‘0’= no | 0.69 (0.46) | 0–1   |
| Synthetic inputs             | Number of different synthetic inputs (inorganic fertilizer, pesticides, herbicides, fungicides) used at farm-scale | Integer |            | 1.69 (1.15) | 0–4   |
| Agroecological intensity     | Number of different agroecological practices used at farm-scale | Integer |            | 1.46 (1.8) | 0–12  |
| Staple crop yield            | Estimated productivity (kg/acre) of maize and rice in last year, both normalized on a 0-1 scale and added together | Interval |            | 0.13 (0.17) | 0–1.06 |
| Well-being                   | Composite indicator of human well-being calculated from 20 indicators | Interval |            | 0.55 (0.17) | 0.12–1 |


value<0.001). However, we decided to maintain ‘plot ownership’ as covariate in model 3 for consistency between the three models, due to the low correlation between ‘plot ownership’ and the response (well-being) in model 3 (rho= 0.15, p-value = 0.002), and the lack of significant differences based on a chi-square test between models with and without that covariate (chisq=2.00, p-value=0.157). Visual inspection of residual plots did not indicate deviations from homoscedasticity and normality, with the exception of model 2 where moderate deviations were observed.

Models were fitted with R package ‘lme4’. The Satterthwaite’s method was used to approximate degrees of freedom and calculate p-values (R package ‘lmerTest’; Kuznetsova et al. 2017). Both the marginal (representing variance explained by the fixed effects only) and conditional Pseudo-R-squared values (assessing the variance explained by the entire model with fixed and random effects) were calculated using ‘MuMln’ R package (Nakagawa et al. 2017). Confidence intervals were computed using likelihood ratio tests. We focus on full/global models as we are interested in

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### Table 2

Indicators used to calculate the well-being composite index. The indicators were selected based on the methodology developed by Loveridge et al. (2020). All variables were normalized prior to the calculation.

| Variable                  | Description                                    | variable type | categories | Mean (SD) | Range |
|---------------------------|------------------------------------------------|---------------|------------|-----------|-------|
| Material                  | Has financial savings | Binary | 1= yes, 0= no | 0.21 (0.41) | 0–1   |
| Household wall material   | Material used for household walls | Ordinal | 3= concrete bricks, 2= plastered mud bricks, 1= mud bricks, 0= mud and sticks | 1.27 (0.55) | 0–3   |
| Household assets          | Total of assets owned in a list of 13 household items | Integer |           | 4.33 (2.11) | 0–10  |
| Banking                   | Uses formal banking services | Binary | 1= yes, 0= no | 0.63 (0.48) | 0–1   |
| Water access              | Walking time (minutes) to reach drinking water supply | Ordinal | 2= [0-1], 1= [1-10], 0= [10-120] | 1.29 (0.67) | 0–2   |
| Land area                 | Total farm area owned (acres) | Ordinal | 4= >10, 3= [5, 10], 2= [2, 5], 1= [0,2], 0= none | 1.54 (1.37) | 0–4   |
| Livestock                 | Most valuable livestock owned | Ordinal | 3= cattle, 2= pigs, sheep, goat, 1= poultry, fish, rabbits, 0= none | 0.66 (0.64) | 0–3   |
| Health                    | Too unwell to work in the last year | Binary | 1= no, 0= yes | 0.39 (0.49) | 0–1   |
| Health insurance          | Has health insurance | Binary | 1= yes, 0= no | 0.17 (0.38) | 0–1   |
| Diet diversity            | Number of different food items eaten in last 7 days | Integer |           | 8.05 (2.21) | 2–12  |
| Social relations          | Borrowed money in last year including informal loans | Binary | 1= yes, 0= no | 0.4 (0.49) | 0–1   |
| Recognition in the village| Perception that voice is heard in important village decisions | Ordinal | 2= yes, 1= don’t know, 0= no | 1.4 (0.74) | 0–2   |
| Security                  | Confidence in providing for dependents | Ordinal | 4= very confident, 3= somewhat confident, 2= neutral/ don’t know, 1= somewhat uncertain, 0= very uncertain | 2.37 (1.38) | 0–4   |
| Provision for self in old age | Confidence in providing for oneself in old age | Ordinal | 4= very confident, 3= somewhat confident, 2= neutral/ don’t know, 1= somewhat uncertain, 0= very uncertain | 2.12 (1.3) | 0–4   |
| Number of livelihoods     | Total of different livelihood-generating activities | Integer |           | 4.22 (2.02) | 1–11  |
| Theft security            | Perception of security from theft | Ordinal | 4= very safe, 3= somewhat safe, 2= neutral/ don’t know, 1= somewhat unsafe, 0= very unsafe | 1.97 (1.31) | 0–4   |
| Freedom                   | Satisfaction with livelihood opportunities | Ordinal | 4= very satisfied, 3= somewhat satisfied, 2= neutral/ don’t know, 1= somewhat dissatisfied, 0= very dissatisfied | 1.22 (1.2) | 0–4   |
| Nature access             | Agreement with sentence “I have access to enough natural land to meet all the needs of my household” | Ordinal | 4= completely agree, 3= somewhat agree, 2= neutral/ don’t know, 1= somewhat disagree, 0= completely disagree | 0.46 (1.01) | 0–4   |
| Education                 | Highest education level completed | Ordinal | 6= university, 5= college, 4= secondary (form 1-6), 3= primary (standard 5-7), 2= primary (standard 1-4), 1= no formal education but can read and write, 0= no formal education | 2.6 (1.21) | 0–5   |
| Overall quality of life   | Level of life satisfaction | Ordinal | 0= not at all satisfied to 10= completely satisfied | 4.11 (2.86) | 0–10  

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Models were fitted with R package ‘lme4’. The Satterthwaite’s method was used to approximate degrees of freedom and calculate p-values (R package ‘lmerTest’; Kuznetsova et al. 2017). Both the marginal (representing variance explained by the fixed effects only) and conditional Pseudo-R-squared values (assessing the variance explained by the entire model with fixed and random effects) were calculated using ‘MuMln’ R package (Nakagawa et al. 2017). Confidence intervals were computed using likelihood ratio tests. We focus on full/global models as we are interested in
the relationships between all covariates. The use of full models has been advocated in the literature as a valid alternative to the shortcomings of stepwise deletion and best fit models (Whittingham et al. 2006; Harrison et al. 2018; Smith 2018). Furthermore, our full models are not over-parameterized using the rule of thumb of a minimum of 10 observations for each parameter (Harrison et al. 2018). Non-parametric \( W \) and chi-squared statistics were calculated with Wilcoxon rank sum and Kruskal-Wallis tests, respectively, to assess significant differences in the distribution of two or more than two samples. Tukey’s ‘Honest Significant Difference’ (HSD) post hoc test complemented the Kruskal-Wallis tests by calculating pairwise comparisons of the mean between multiple groups. We used R package ‘ggplot2’ to create plots (Wickham 2016) and QGIS to create the map in Fig. 2.

3 Results

We start by reporting on the variables described in Tables 1 and 2 and their associations, followed by the results of our three-tiered modelling approach. Overall, respondents reported an average well-being index of 0.546 (standard deviation= 0.165). The composite indicator had a normal distribution. Mean village well-being ranged from 0.420 (SD= 0.167) to 0.625 (SD= 0.185). Of the five dimensions that contribute to the well-being metric (Table 2), average values were lowest for the freedom dimension and highest for social relations.

Most farmers applied at least one agroecological practice in their farms (61.9%). The most common agroecological practices were mulching (\( n=123 \)), intercropping (\( n=103 \)), and post-harvest use of residues (\( n=71 \)). Farmers that applied at least one agroecological practice on average owned more land (5.11 vs 4.00 acres; \( W=17858, p\text{-value}=0.013 \)) and listed a higher number of activities contributing to their household livelihood (\( W=14250, p\text{-value}<0.001 \)). Education levels were similar regardless of applying agroecological practices or not (\( W=19837, p\text{-value}=0.356 \)). Of the individual well-being indicators, those more highly correlated with agroecological intensity were number of livelihood-generating activities pursued (rho= 0.35, \( p\text{-value}<0.001 \)), perception of access to nature (rho= 0.26, \( p\text{-value}<0.001 \)), and most valuable livestock owned (rho= 0.26, \( p\text{-value}<0.001 \)) (Table 2). Results suggest that the use of agroecological practices contributes to farmer well-being along multiple dimensions, with significant improvements for the material (\( W=18272, p\text{-value}=0.036 \)) and security (\( W=17628, p\text{-value}=0.009 \)) dimensions.

Women with higher food needs had lower mean well-being (chisq= 46.87, \( p\text{-value}=0.001 \)), although not significantly different from men with high food needs (Fig. 3). In fact, 50.5% of respondents have been food insecure at least sometimes over the previous year. Female respondents reported similarly sized farms and levels of plot ownership, but on average owned a lower number of plots than men (1.66 vs 2.18; \( W=11884, p\text{-value}=0.029 \)). They were less likely to have received farming advice in the last 3 years (\( W=24410, p\text{-value}=0.014 \)) and to have used different categories of synthetic inputs (\( W=25682, p\text{-value}=0.002 \)). Women also had a lower share of their land dedicated to cash crops than men (\( W=24141, p\text{-value}=0.015 \)) and were less likely to agree that natural areas are good for their livelihoods (\( W=25476, p\text{-value}=0.003 \)) and that environmental conditions would improve over the next 5 years (\( W=24546, p\text{-value}=0.030 \)).

Unsurprisingly, landowners were much more likely to consider that they have access to enough fertile land to meet all the needs of their household (\( W=8593.5, p\text{-value}<0.001 \)). They also had more trees planted in their farms (\( W=12694, p\text{-value}<0.001 \)) and more tree richness with a mean of 1.76 in-farm tree species for landowners versus 0.97 tree species for other tenure arrangements (\( W=13196, p\text{-value}=0.001 \)). In fact, not being the landowner was the second main reason (\( n=133 \) respondents) given for not planting more trees, after small farm size (\( n=151 \)), and before concerns that tree shade reduces crop yield (\( n=128 \)).

Loss of crop production to animals, both invertebrate and vertebrate, is a considerable issue in the study area, with 61.9% of respondents stating that they lost more than a 1/4 of their production to animals. Levels of invertebrate crop damage are significantly higher in farms that use pesticides (\( W=15280, p\text{-value}<0.001 \)) but similar between farms that use none versus at least one agroecological practice. Perceived crop damage caused by invertebrates is on average higher than the damage caused by vertebrates. However, the 95 respondents that indicated elephants as the main cause of vertebrate damage stated a considerably higher perceived damage when compared with farmers experiencing damage mainly from other vertebrates (2.28 vs 0.90, \( W=128045, p\text{-value}<0.001 \)). Farmers experiencing elephant crop damage also had a significantly more negative perception of the impact nature has on their livelihood, regardless of the level of damage due to invertebrates (chisq= 15.68, \( p\text{-value}=0.001 \)).

Slightly less than a third of respondents (29.8%) reported receiving agricultural advice in the last 3 years. Main sources of advice were the extension service (\( n=68 \)), nongovernmental organizations (\( n=22 \)), and cooperatives (\( n=16 \)). Farmers that received training were more likely to take measures to protect their crops against wildlife (\( W=16022, p\text{-value}=0.009 \)), for example. Training was also positively correlated with the use of different synthetic inputs (rho= 0.190, \( p\text{-value}<0.001 \)), the use of pesticide specifically (rho= 0.157, \( p\text{-value}=0.001 \)), and with agroecological intensity (rho= 0.198, \( p\text{-value}<0.001 \)). The association between farming advice and the number of trees planted in-farm was relatively weaker (rho= 0.102, \( p\text{-value}=0.036 \)). Trained farmers were not more likely to have planted at least one tree in the previous year, nor more likely to be landowners. There
was an association between farming training and perception of the number of ecosystem services being provided by nature (\(\rho = 0.2090\), \(p\)-value < 0.001). That perception was strongly correlated with the number of trees in-farm (\(\rho = 0.440\), \(p\)-value < 0.001) (Fig. 4). The correlation between number of in-farm trees and agroecological intensity was also positive (\(\rho = 0.264\), \(p\)-value < 0.001).

Advancing to the results of our modelling approach (Table 3), models 1 and 3 show that agroecological intensity and human well-being are influenced by different variables in our study area. Model 2, with staple crop yield as response, only had one significant covariate (agroecological intensity) and was poorly fitted (conditional \(R^2 = 0.122\)). Women farmers were more likely to use more agroecological practices in their farms. A higher awareness of ecosystem service provision also had a positive effect on agroecological intensity, as well as having received farming training, using more synthetic inputs, and being landowner. In model 3, variables representing socioeconomic conditions, perceptions, and farming practices all were found to have an impact on the multidimensional human well-being composite indicator. Gender and age were significant variables, with younger and male farmers showing higher well-being levels. Group membership and local-level social responsibilities were also positively linked with well-

**Fig. 3** Boxplot comparing the distribution of the well-being indicator for four different groups: food insecure men (orange, dashed line), food-secure men (blue, dashed line), food-insecure women (orange, solid line), and food-secure women (blue, solid line). Food security is defined using the ‘Food needs’ variable described in Table 1. Respondents that always or often had problems satisfying the food needs of the household were considered food insecure. The middle line shows the median, the box defines the interquartile range, and the whiskers extend to 1.5 times the interquartile range. Outliers are pictured as crosses. The letters above the boxplots refer to the results of Tukey’s HSD post hoc test.

**Fig. 4** Boxplot relating the total number of ecosystem services perceived by the respondent as being provided by natural habitats in and around the farm and the number of trees planted in their farm. The middle line shows the median, the box defines the interquartile range, and the whiskers extend to 1.5 times the interquartile range. Outliers are pictured as crosses. The letters above the boxplots refer to the results of Tukey’s HSD post hoc test.
Agroecological practices increase farmers’ well-being in an agricultural growth corridor in Tanzania

4 Discussion

Understanding interlinkages between agroecology, food security, and human well-being in tropical rural Africa is crucial to improve the effectiveness of agricultural development policies and programs. Our results identify multiple factors, namely indicators of socioeconomic conditions, perceptions of benefits from nature, and farming practices, with an impact on agroecological intensity at farm-level. Our findings also show that higher agroecological intensity at farm-level can contribute positively to the food security and well-being of smallholder farmers. There is limited empirical evidence in the literature for the relationship between agroecological intensity and smallholder farmer well-being in rural landscapes in the tropics (Miller et al. 2020). Still, our results align with previous studies indicating that, despite high variability, the overall impact of sustainable agricultural practices on livelihoods and well-being in the tropics tends to be positive (Reed et al. 2017; Mdee et al. 2018; Leakey 2020; Castle et al. 2021).

Our analysis suggests that the use of agroecological practices improves farmer well-being along multiple dimensions, with significant improvements for the material and security dimensions. Younger or male farmers, farmers with a more positive perception of how nature impacts their livelihood, farmers that had village responsibilities or were involved in local groups and had lower food needs, and farmers applying more different types of synthetic inputs were all more likely to have higher well-being. The observed relationships suggest that greater access to social, produced, and natural capital within a community constitutes an advantage that is reflected on the well-being of individuals (Isham 2002; Jeckoniah et al. 2020; Dasgupta 2021). Interestingly, women were more likely to have higher agroecological intensity in their farms, in contrast to previous findings (Miller et al. 2017), but that does not seem to improve their well-being. Mean well-being of women with a civil status other than married was similar to those of men in the same situation. But, for married respondents, well-being seems to improve their well-being. When adjusted by the other covariates, land ownership and perceived damage to crops were not significant drivers of well-being in our study area. Finally, higher number of different synthetic inputs and higher in-farm agroecological intensity both also contributed to well-being.

Table 3 Modeling coefficients (Coefs), 95% confidence intervals (CI), and p-values. Response variables are agroecological intensity for model 1, staple crop yield for model 2, and human well-being for model 3. Significant p-values are in bold.
(Masamha et al. 2018). Exploring the social dynamics that might be behind this result is beyond the scope of this study.

Reassuringly, in light of recent discussions on sustainable intensification of agriculture, our results suggest that higher agroecological intensification increases yield of staple crops. This association is highly variable in the literature. For example, a recent review failed to find significant effect of agroforestry interventions on yields, although it found a neutral to positive impact on nutrition and food security (Castle et al. 2021). Food security for smallholder farmers in the tropics is highly linked to staple crop yield (IFAD and UNEP 2013). Agroforestry can work as a safety net for food-insecure households (Ndoli et al. 2021). Still, the low goodness of fit of model 2 indicates that most of the variation is not being captured by the model covariates, so it is likely that important drivers of staple crop yield are missing. These might include further socioeconomic factors, external drivers, such as market or regulatory factors, or environmental variables, such as soil fertility or distance to water resources (Milheiras et al. 2022).

The use of agroecological practices, such as mulching, was relatively common in our sample, which indicates that at least some of those practices are relatively accessible and carry low short-term investment risks (Jerneck and Olsson 2014). Being female, having a higher awareness of ecosystem service provision, having received farming advice in the previous 3 years, being the landowner and applying different synthetic inputs were variables that significantly contributed to a higher uptake of agroecological practices. Land ownership has previously been identified as a driver of sustainable agricultural practices (Kassie et al. 2013; Teklewold et al. 2013; Miller et al. 2017). Women might be applying more agroecological practices in our sample as a consequence of their choices on crop type, with a stronger preference for planting staple crops than men, or as result of more limited access to productive resources (Masamha et al. 2018; Mason et al. 2015). But further research is needed to investigate the causal mechanism in this relationship. Our results also suggest that farmers that are more aware of ecosystem service provision adopt their practices accordingly in favor of practices that protect future benefits, which is in line with previous research (Meijer et al. 2015; Piñeiro et al. 2020). Positive perceptions on nature can be reinforced and negative ones mitigated to favor nature conservation outcomes (Sanou et al. 2019). It has been shown, and our study provides additional evidence, that providing extension services and training to farmers are effective ways of promoting sustainable agricultural practices, especially when also acknowledging farmer perceptions of future benefits and predicted trade-offs between economic, environmental, and social outcomes (Meijer et al. 2015; Sanou et al. 2019; Piñeiro et al. 2020). There is strong evidence that measures that increase plant diversity in agroecosystems can increase crop and forage yield, wood production, yield stability, pollinators, weed suppression, and pest suppression (Isbell et al. 2017). This information needs to be translated into clear, straightforward, locally adjusted messages targeted at smallholder farmers and other stakeholders.

It is interesting to note that the amount of crop damage perceived by farmers was not a significant driver of agroecological intensification, nor well-being. This suggests that current levels of damage are expected, localized, and/or not intense enough to have a direct influence on well-being. Still, elephant damage seems to sharply change farmer perceptions on how beneficial nature is to their livelihood, and this will indirectly affect well-being. Elephant damage might also considerably reduce local support for conservation interventions (Matejcek and Verne 2021). And we know that the uptake of sustainable agricultural practices is reduced if those practices are perceived to attract or shelter species considered to be problematic (Pfund et al. 2011). If ongoing conversion rates of natural habitat to cropland continue (Munishi and Jewitt 2019), these conflicts, and local animosity towards wildlife, are likely to be aggravated.

The use of more types of synthetic input is associated with higher agroecological intensity in our data, which suggests smallholder farmers are combining practices to achieve complementary farming goals, namely, higher farm resilience and farm productivity. In a way, this reflects the regulatory context in the country, where the policy that frames agricultural development (Agricultural Sector Development Program, phase II) prioritizes both sustainable land use management (component 1) and enhanced productivity and profitability (component 2). Also in SAGCOT plans for the region, despite their focus on large-scale commercial farms, there is a strategy for sustainable intensification targeted at smallholder farmers (EcoAgriculture Partners 2012). While ecological intensification is presented in that strategy as part of the solution, too little detail is provided on how farmers should navigate any eventual trade-offs between industrial and ecological intensification practices. It is relevant to understand how both approaches affect well-being, inclusively when both are being simultaneously implemented at farm or landscape scale. For now, we have an incomplete picture of the impacts of sustainable agricultural practices on food production and well-being over a wide range of farming systems (Reed et al. 2017; Castle et al. 2021). Policymakers should not assume that industrial farming intensification will inevitably result in higher human well-being, if that intensification is done at the expense of natural areas (Rasmussen et al. 2018) and/or human health (de Bon et al. 2014). Future research should focus on detailing trade-offs and synergies adjusted to local contexts, including on outcomes (e.g., profitability, food security) that are most relevant to smallholder farmers and specifically on how vulnerable groups are affected (Below et al. 2012; Kleijn et al. 2019; Castle et al. 2021). Moving forward from our observational study, we recommend measuring the impact on well-being of specific interventions linked to sustainable agricultural practices using quasi-experimental approaches (Miller et al. 2020).
Our analysis should be interpreted in the context of our case study and we advise against generalizations to broader spatial scales or dissimilar socioecological systems. Furthermore, our approach comes with at least three possible limitations. First, we have not included direct metrics of wealth and education levels as model covariates, due to those variables being part of the well-being index, although they have been associated with both agroecological intensity and well-being (Miller et al. 2020). However, it can be argued that other covariates indirectly capture the wealth of individual respondents (for example the food needs variable) and the respondents’ education level is strongly correlated with age ($\rho = -0.33$, $p$-value $< 0.001$) and village responsibilities ($\rho = 0.31$, $p$-value $< 0.001$). Second, while intra-household decision-making dynamics can result in household members not necessarily sharing the same views, the use of individual-based variables to analyze farming practices requires caution, as most farming decisions will be done in the context of a household, a family, and a local community (Anderson et al. 2017). Third, we could not include total area of land owned as a model covariate, since it is one of the indicators used to calculate well-being, but exploratory analysis suggests that using it instead of the binary of plot ownership variable would not change results substantially if it had substituted the binary plot ownership variable used.

5 Conclusions

This study presents new empirical evidence in support of the well-being benefits to smallholder farmers of the implementation of agroecological practices. We show that practices taking advantage of nature’s contributions to people within agricultural systems can contribute positively to food security and human well-being of smallholder farmers in rural landscapes of the tropics. In addition to the positive relationship between agroecological practices and farmer well-being, other conclusions are noted. First, our research finds that farmers applying agroecological practices continue to use conventional practices too, and both are contributing to higher well-being in our study area. This suggests that a transition to more ecological farming can have impact on human well-being, even if that transition complements rather than fully replaces conventional farming. Second, our results corroborate previous studies on how fundamental technical training and capacity building of smallholder farmers is for the uptake of sustainable agricultural practices. That uptake will be more successful if institutions promoting it are able to show how farmers will benefit, via extension services or demonstration farms, for example. Finally, our study confirms that well-being metrics are a valuable tool for measuring, in a comprehensive way, the impacts of farming practices and policy interventions at local scales. Understanding which factors increase individual well-being will allow more effective policies across sectors. The challenge in our study area, and in similar landscapes, is to find the incentives and interventions that maximize the benefits from agriculture to human well-being by integrating, rather than opposing, food production and nature conservation goals. More research is needed to understand which combination of agricultural practices best contribute to well-being under specific environmental, social, and economic conditions. This study informs the design of nature-positive interventions, in the context of agricultural development and land use management, aiming to improve the well-being of rural communities in sub-Saharan Africa.

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Data availability The datasets generated and analyzed during the current study are available in the Newcastle University data repository at https://doi.org/10.25405/data.ncl.17192867.

Code availability The code used for data analysis is available upon request to the corresponding author.

Declarations

Conflict of interest The authors declare no competing interests.

Ethics approval The household survey was reviewed and approved by the University of Leeds Business, Environment and Social Sciences joint Faculty Research Ethics Committee under reference AREA 19-017.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication The authors affirm that human research participants provided informed consent for this publication.
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