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LETTER

Trees on farms improve dietary quality in rural Malawi

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Abstract

Trees on farms not only provide agricultural and environmental benefits but can also contribute to food security. We use panel data covering a 10-year period from the World Bank's Living Standards Measurement Study (LSMS) to examine the effects of trees on farms on people's dietary quality in rural Malawi. We found that having on-farm trees leads to higher and more diverse fruit and vegetable consumption. Specifically, households who had trees on their farm (or who acquired trees during the 10-year period) exhibited a 3% increase in vegetable consumption compared to households without trees. Moreover, for every additional tree species owned or acquired by a household during the study period, fruit consumption increased by 5%. These results demonstrate that trees on farms may play a role in meeting nutrition, conservation, and climate change mitigation goals, with important implications for sustainable development strategies in low- and middle-income countries.

KEYWORDS
agroforestry, biodiversity conservation, dietary quality, nutrition, poverty alleviation, trees on farms

1 | INTRODUCTION

Trees on farms are often studied in the context of agroforestry systems[1] and have been shown to be beneficial for biodiversity conservation (Udawatta et al., 2021), carbon sequestration (Nair et al., 2010), and agricultural production (Awazi & Tchamba, 2019). On-farm "fertilizer" trees have been found to improve crop yields (particularly staple cereal crops) (Musa et al., 2018), leading to indirect improvements in food security given that staple crops provide the majority of calories globally (Pingali, 2015). Yet, this perpetuates the narrative of food security being equated with having adequate dietary energy (calories) to meet requirements. Such a narrow empirical focus overlooks wider dietary quality issues such as low dietary diversity and inadequate intake of essential micronutrients. Indeed, comparatively few studies have examined how on-farm trees affect people's dietary quality (Vansant et al., 2022).

[1] The Center for International Forestry Research and World Agroforestry (CIFOR-ICRAF) defines agroforestry as "the interaction of agriculture and trees, including the agricultural use of trees." While the term "trees on farms" encompasses these types of farming systems, it is also used as a broader term to include woodlots, fruit trees planted next to homesteads, riparian buffers, and trees scattered in the wider agricultural landscape.

Trees on farms can improve dietary quality via four key pathways (Gergel et al., 2020; Vansant et al., 2022): (1) the direct consumption pathway, whereby trees provide nutritious foods (mainly fruits, green leaves, nuts, and seeds) for household consumption; (2) the income pathway, whereby tree products can be sold to generate income and thus used to purchase nutritious foods from markets; (3) the agroecological pathway, whereby trees provide ecosystem services such as water retention, soil nutrient cycling, and pollination (Jose, 2009), which can improve crop production on farms, leading to better diets; and (4) the energy pathway, whereby trees provide biomass which can facilitate the cooking of nutritious foods that would otherwise be inedible. Trees are also more drought tolerant than annual crops given their deep and extensive roots, meaning that they can provide food at times of the year when other crops may fail (Kehlenbeck et al., 2013). The potential for trees to support people's diets is likely to become more important as climate change increases the frequency and severity of drought conditions, particularly in sub-Saharan Africa (SSA) (Haile et al., 2020).

Given that trees in agricultural landscapes have shown to be beneficial for biodiversity conservation, carbon sequestration, and food security, the promotion of on-farm trees may therefore play a role in meeting multiple policy objectives. Yet, research is lacking on the extent to which trees can improve dietary quality. Here, we examine this relationship in Malawi, which is an appropriate case study country given that around 18% of the population is undernourished (FAO et al., 2023), micronutrient deficiencies are widespread (National Statistical Office, Community Health Sciences Unit, Centers for Disease Control & Prevention & Emory University, 2017), and over 75% of the population is engaged in smallholder agriculture (Tuni et al., 2022), signifying the potential of agricultural interventions for improving people's diets.

This study advances existing knowledge in two main ways. First, we use a 10-year panel dataset (four waves) to assess the relationship between trees on farms and people's dietary quality. Most studies examining this relationship have relied on cross-sectional data, with only one study to date using longitudinal data (Miller et al., 2020). Panel data are beneficial for estimating the effects of trees on diets over a long timeframe as there may be a time lag between planting or acquiring trees and improvements in dietary quality. Second, we look specifically at fruit and vegetable intake given the need to increase consumption of these food groups (particularly in SSA), as they tend to be rich in various micronutrients and offer multiple other health benefits (i.e., reduced risk of chronic diseases and overall mortality) (Angelino et al., 2019). Similarly, the majority of existing studies on tree–diet linkages use proxies for dietary quality, such as dietary diversity scores (Desalegn & Jagiso, 2020), or anthropometrics as proxies for nutritional status (Miller et al., 2020). While useful, these indicators are limited in their inference about the ways in which trees on farms can actually affect people's diets. By looking at the consumption of specific foods, we can better understand how trees on farms can contribute to overall dietary quality.

This study finds that on-farm trees have a positive effect on people's fruit and vegetable consumption in rural Malawi, highlighting the potential role of trees in agricultural landscapes for contributing to multiple policy goals.

2 | METHODS

2.1 | Measures of dietary quality

In this study, data on food consumption, housing, education, and agricultural activities (including trees on farms) came from a series of four National Panel Surveys (NPS) from the World Bank's Living Standards Measurement Study (LSMS) for Malawi. The four panel surveys were carried out in 2010/2011 (Wave 1), 2013/2014 (Wave 2), 2016/2017 (Wave 3), and 2019/2020 (Wave 4). We included households that matched across the four waves, giving a total sample of 936 households from 72 clusters (Figure S1). In each wave, households recalled their total food consumption over the past 7 days from a predetermined list of 132 food and drink items. We used these data to estimate the quantity of fruits and vegetables consumed per capita (using adult male equivalents [AME]; see Supporting Information) and the diversity of fruit and vegetable consumption. We also assessed household dietary diversity (using a modified version of the Minimum Dietary Diversity Score for Women [MDD-W]; see Supporting Information) as it is a good proxy for overall dietary quality given that diverse diets tend to have more adequate nutrient intakes and result in improved health outcomes (Verger et al., 2021).

2.2 | Trees on farms

Households were asked whether they owned any trees, and if so, how many and what species. The presence of trees on farms was our key predictor variable and was included as a binary variable (i.e., whether or not the household owned any trees), a count variable (total number of trees owned), and a species count (how many species the household owned). Only food trees were included, and any commercial trees (i.e., tea and coffee) or fuelwood/fodder trees were removed, as we were specifically interested in whether fruit trees directly contributed to dietary quality. Bananas were included as fruit trees in the LSMS, and while bananas are not ecological analogs to botanical trees, they function similarly to trees in household economies and farming systems (Miller et al., 2020). The final 12 trees included in the analysis were thus mango, banana, papaya, mexican apple, guava, avocado, orange, custard apple, masau, lemon, tangerine, and peach (listed in order of the most commonly owned species [Table S1]).

2.3 | Covariates

We included crop species count and livestock species count as measures of agricultural production diversity. Crop species count was the total number of different crops cultivated by the household in the rainy and dry seasons. While few households cultivated crops in the dry season, we included both seasons to capture crop diversity over the entire year (Jones et al., 2014). Livestock count was the number of different livestock species reared by the household over the 12 months preceding the survey.

We also controlled for household characteristics that previous studies have shown to be predictors of dietary quality, including household size (Powell et al., 2017), age and sex of the household head (Mango et al., 2014), education level (Torheim et al., 2004), and wealth level (Ickowitz et al., 2014). To account for education and wealth level, we used the Multidimensional Poverty Index (MPI) (Alkire & Santos, 2014).

Forest cover was also included as a covariate given the large body of literature showing the positive impact of forests on people's diets (Ickowitz et al., 2014; Rasolofoson et al., 2018), particularly in Malawi (Hall et al., 2019). We measured forest cover in a 10-km-radius circle surrounding each LSMS cluster using the publicly available 30-m-resolution global tree cover dataset (Hansen et al., 2013).

Lastly, we controlled for seasonality by constructing a binary variable of whether or not households were surveyed in the rainy season, given distinct differences in food consumption patterns in the rainy and dry seasons in Malawi (Zimba et al., 2019). We note that market access is also assumed to influence people's dietary diversity (Nandi et al., 2021), but because there are no longitudinal data on changes in market access, we could not include it in our panel model.

A detailed description of how we compiled all variables is provided in the Supporting Information (Section 1).

2.4 | Analytical approach

We used two-way fixed-effects regression analysis, which takes the form:

$$Y_{it} = \alpha_i + \gamma_t + \theta F_{it} + \beta X_{it} + \varepsilon_{it},$$

where Y_{it} represents the dietary quality indicators of household i in time period t, and F_{it} indicates the presence of trees on farm, tree count, or tree species count. α_i and γ_t are the unit and time fixed effects, respectively. Two-way fixed-effects regression allows us to control for both time and entity (household) fixed effects - eliminating bias from unobserved variables that change over time but are constant across households (such as political changes affecting all households equally), or factors that differ across households but are time constant (such as ethnicity). However, unobserved factors that jointly affect both trees on farm and dietary quality are not controlled for. Thus, we are not able to infer causation from our models, only associations. Separate models were run for each of the outcome variables (i.e., consumption of fruits and vegetables in grams, fruit and vegetable diversity, and dietary diversity). For the Modified Dietary Diversity Score (MDDS) and fruit and vegetable diversity, we used panel generalized linear models (PGLM package in R) and specified a Poisson distribution given that the outcomes were count variables. For fruit and vegetable consumption in grams, the PLM package was used. Fruit and vegetable consumption in grams was log transformed to reduce skewness and approximate a normal distribution (as some households consumed very small quantities of fruits and vegetables). All models were first run using the trees on farm binary variable, then the total tree count variable, and lastly the tree species count variable. Robust clustered standard errors were calculated for all models.

3 | RESULTS

Our results show that having trees on farm (vs. having no trees) is positively associated with vegetable consumption and vegetable diversity but is not associated with fruit consumption. Specifically, households with trees on their farm (or who acquired trees during the 10-year period) saw a 3% increase in vegetable consumption compared to households without trees. Yet, having a greater number of tree species is positively associated with fruit consumption, fruit diversity, and vegetable diversity (Figure 1). That is, for every additional tree species owned or acquired by a household during the study period, fruit consumption increased by 5%.

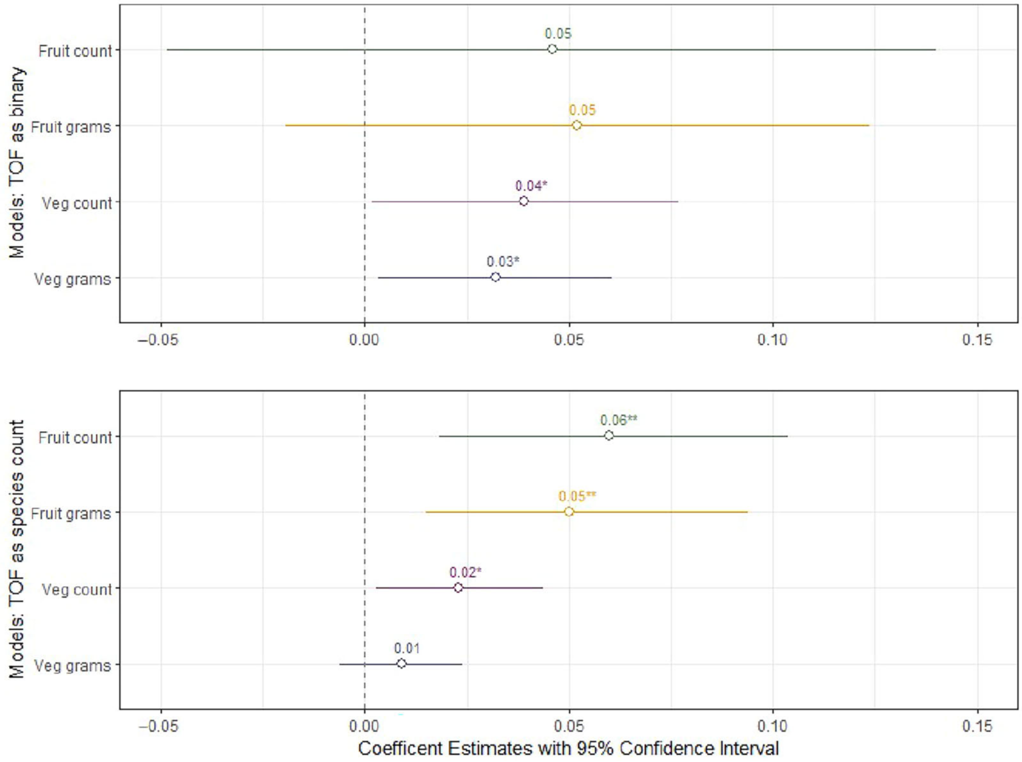

FIGURE 1 Coefficient plots summarizing the regression outputs for models run between trees on farm (binary and species count) and fruit and vegetable consumption (grams per adult male equivalent [AME] per day and diversity of consumption) over the study period (2010–2020) (†<0.1; *<0.05; **<0.01; ***<0.001). Abbreviations: TOF, Trees on Farm; Veg, vegetable.

These are small effect sizes, but the positive relationship demonstrates that having on-farm trees (and in particular, a diverse mix of species) may improve fruit and vegetable consumption to some extent for rural smallholders. This is particularly important given that average fruit consumption across the panel waves was very low at just 51 g/capita/day, which is well below the 200 g of fruit recommended by the World Health Organization (2005). Moreover, across the 10-year study period, fruit consumption and vegetable consumption declined by an average of 42% and 25%, respectively. Indeed, the average overall consumption of fruits and vegetables fell by over 100 g per person per day between Waves 1 and 3 (but then increased marginally between Waves 3 and 4 [Table 1]).

No relationship was found between the total number of trees people owned and any dietary variable. These results suggest that it is the presence of trees on farm (vs. having no trees) and the species diversity of those trees that matter for fruit and vegetable consumption, as opposed to the total number of trees people own. Interestingly, no relationship was found between any measure of trees on farm and dietary diversity score.

In addition to trees on farm, crop diversity, livestock diversity, and forest cover were all positively associated with one or more dietary variables (Tables 2 and 3). Crop count was positively associated with dietary diversity, fruit consumption, fruit count, and vegetable count. Livestock count was positively associated with all dietary variables. Forest cover was positively associated with fruit count, suggesting that people surrounded by a higher degree of forest cover consumed a wider range of fruits than households in less forested areas.

4 | DISCUSSION

4.1 | Having trees on farms improves fruit and vegetable consumption

Our results suggest that trees on farms are beneficial for people's fruit and vegetable consumption. Given that the presence of trees (vs. no trees) was beneficial for vegetable consumption, but a higher number of tree species was beneficial for both fruit and vegetable consumption, different pathways are likely driving these observed relationships. The first possibility is the direct consumption pathway whereby people were consuming fruits from their own trees. We investigated this further by examining the food source data in the LSMS, which specifies whether food was purchased, came from the household's own production, or

TABLE 1 Summary statistics for all variables in each wave of the panel data.

	Wave 1	Wave 2	Wave 3	Wave 4
Dietary diversity (MDDS)	6.58 (1.63)	6.81 (1.59)	6.33 (1.63)	6.76 (1.61)
Fruit and vegetable count	4.49 (2.06)	4.96 (2.15)	4.58 (1.97)	4.93 (2.16)
Fruit and vegetable consumption (g)	312.82 (303.49)	276.32 (256.96)	210.49 (216.16)	223.74 (203.31)
Fruit consumption (g)	65.15 (113.90)	61.87 (110.85)	38.24 (66.57)	38.03 (74.29)*
Vegetable consumption (g)	247.66 (254.39)	214.44 (208.87)	172.25 (197.78)	185.70 (171.34)**
Household size	5.03 (2.3)	5.53 (2.4)	5.50 (2.39)	5.27 (2.42)
Age	44.20 (16.6)	46.9 (16.1)	48.12 (16.66)	50.48 (15.1)
Sex (%)	73.7	72.0	67.8	66.45
MPI living standards	0.71 (0.18)	0.65 (0.17)	0.66 (0.18)	0.66 (0.18)
MPI education	0.33 (0.40)	0.27 (0.37)	0.25 (0.36)	0.26 (0.37)
Forest cover (ha)	2587.71 (3365.1)	2567.97 (3346.62)	2506.25 (3255.61)	2463.74 (3197.16)
Trees on farm (% households who owned trees)	28.3	42.1	38.7	32.2
Total tree count (of households who owned trees)	11.11 (20.10)	9.91 (20.43)	9.14 (17.89)	14.25 (33.19)
Tree species count (of households who owned trees)	1.62 (0.99)	1.78 (1.12)	1.36 (0.69)	1.55 (0.94)
Crop count	2.46 (1.40)	3.09 (1.84)	2.69 (1.53)	3.42 (1.74)
Livestock count	0.89 (0.94)	1.02 (1.01)	1.04 (1.03)	1.00 (1.02)
Season (% households surveyed in rainy season)	24.30	13.67	23.82	12.18

Note: All values are means with standard deviations in parentheses, with the exception of sex of the household head, trees on farm, and season, where we report proportions (%). Asterisks denote whether the changes in fruit and vegetable consumption between Waves 1 and 4 were statistically significant (†<0.1; *<0.05; **<0.01; ***<0.001). N = 936 households.

Abbreviations: MDDS, Modified Dietary Diversity Score; MPI, Multidimensional Poverty Index.

TABLE 2 Results from the two-way fixed-effects regression models with trees on farm (binary) as the key predictor variable.

	Dietary diversity score	Fruit consumption (g)	Vegetable consumption (g)	Fruit count	Vegetable count
Household size	0.005 (0.003)†	NS	−0.046 (0.005)***	0.028 (0.015)†	0.009 (0.004)*
Sex of HH head	NS	0.096 (0.058)†	NS	NS	NS
Age of HH head	NS	−0.006 (0.002)*	NS	−0.010 (0.003)***	NS
Living standards (MPI)	NS	NS	NS	NS	NS
Education level (MPI)	−0.043 (0.015)**	−0.129 (0.062)*	NS	−0.179 (0.083)*	NS
Forest cover	NS	NS	NS	0.0003 (0.0001)***	NS
Crop count	0.019 (0.003)***	0.027 (0.012)*	NS	0.052 (0.014)***	0.032 (0.005)***
Livestock count	0.029 (0.006)***	0.083 (0.022)***	0.021 (0.009)*	0.052 (0.026)*	0.038 (0.009)***
Season (rainy)	NS	0.201 (0.053)***	0.056 (0.027)*	0.181 (0.066)**	NS
Farm size	NS	NS	NS	NS	−0.011 (0.005)*
Trees on farm (binary)	NS	NS	0.032 (0.015)*	NS	0.039 (0.019)*

Note: Values are model coefficients with test statistics in parentheses. "NS" denotes not significant (†<0.1; *<0.05; **<0.01; ***<0.001). N = 936 households.
Abbreviations: HH, household; MPI, Multidimensional Poverty Index.

TABLE 3 Results from the two-way fixed-effects regression models with tree species count as the key predictor variable.

	Dietary diversity score	Fruit consumption (g)	Vegetable consumption (g)	Fruit count	Vegetable count
Household size	0.005 (0.003)†	NS	−0.046 (0.005)***	0.028 (0.015)†	0.009 (0.004)*
Sex of HH head	NS	0.096 (0.058)†	NS	NS	NS
Age of HH head	NS	−0.006 (0.002)*	NS	−0.010 (0.003)***	NS
Living standards (MPI)	NS	NS	NS	NS	NS
Education level (MPI)	−0.043 (0.015)**	−0.128 (0.062)*	NS	−0.177 (0.083)*	NS
Forest cover	NS	NS	NS	0.0003 (0.0001)***	NS
Crop count	0.018 (0.003)***	0.025 (0.012)*	NS	0.048 (0.014)***	0.032 (0.005)***
Livestock count	0.029 (0.006)***	0.082 (0.022)***	0.021 (0.009)*	0.049 (0.026)†	0.038 (0.009)***
Season (rainy)	NS	0.204 (0.053)***	0.057 (0.027)*	0.186 (0.066)**	NS
Farm size	NS	NS	NS	NS	−0.011 (0.005)*
Tree species count	NS	0.054 (0.020)**	NS	0.061 (0.022)**	0.023 (0.010)*

Note: Values are model coefficients with test statistics in parentheses. "NS" denotes not significant (†<0.1; *<0.05; **<0.01; ***<0.001). N = 936 households.
Abbreviations: HH, household; MPI, Multidimensional Poverty Index.

was a gift or obtained from another source. The analysis was, however, complicated by the fact that most households were surveyed in the dry season when fewer tree species were fruiting (Table S2). Thus, fruit consumption was likely lower than if the food consumption surveys had been conducted in the rainy season (indeed, we found that households surveyed in the rainy season had significantly higher fruit consumption [Tables 2 and 3]). Consequently, we found that only a third of households with trees on their farm actually consumed fruits that aligned with the tree species they owned (Table S3). That said, of the households who did report consuming fruits that aligned with the tree species they owned, an average of 75% came from the household's own production. This suggests that some households were consuming fruits from their own trees, but it is likely that the proportion would have been much higher had the food consumption surveys been conducted in the rainy season.

Another potential pathway is that households were selling their tree products and using the income to purchase more and/or a wider variety of fruits and vegetables at markets (the income pathway). For vegetables, there was very little difference in the proportion purchased by households with and without on-farm trees (an average of 63% and 67%, respectively [Table S4]). While the difference is small, these figures suggest that households with on-farm trees purchased less vegetables than households with no trees, which is contrary to the income pathway theory. In terms of fruits, households with on-farm trees purchased a much smaller proportion (34% on average) compared to households with no trees (49% on average). In line with this, households with on-farm trees reported 43% of fruits coming from their own production, as opposed to just 18% in households without trees. Thus, we find no evidence of the income pathway in our study. These findings are consistent with a study from western Kenya, which found that most of the income generated from selling fruits from on-farm trees was used to purchase starchy staples, not fruits and vegetables (Keding et al., 2017).

Another possibility is the agroecological pathway, whereby having on-farm trees supports increased/more diverse agricultural production via ecosystem services, which can lead to increased fruit and vegetable consumption. We tested this by running our models with crop count as an outcome variable and found that both trees on farm (binary) and tree species count were significant predictors of higher crop count (Tables S5 and S6). Given that crop count is positively associated with fruit consumption, fruit diversity, and vegetable diversity, this suggests that trees on farms may be indirectly affecting diets via the agroecological pathway. It should be noted that the LSMS data do not allow us to test the presence of the energy pathway, but we acknowledge that this could also be playing a role.

4.2 | Agricultural diversity and forest cover also improve dietary quality

While we find evidence that trees on farms may increase fruit and vegetable consumption, the effect sizes are small, and there are other factors influencing people's diets. For example, both crop and livestock count were positively associated with dietary diversity and fruit and vegetable consumption. This is consistent with findings from other studies in Malawi (Jones et al., 2014), where a large proportion of consumed food comes from people's own production (particularly vegetables that are often cultivated in small home gardens known as "dimbas") (Madsen et al., 2021). We also found that people in more forested areas consumed a wider range of fruits, which is consistent with the large body of literature demonstrating the benefits of forests for people's dietary quality (Hall et al., 2019; Ickowitz et al., 2014; Rasolofoson et al., 2018).

Despite a number of variables having a positive effect on fruit and vegetable consumption, it is important to note the significant decline in average consumption over the panel study. This aligns with findings by IFPRI (Gilbert et al., 2019) and could be occurring due to the impact of climate change on crops (Adhikari et al., 2015), a reduction in available wild fruits and vegetables due to deforestation (Hall et al., 2022), changing dietary preferences in line with a nutrition transition (Bosu, 2015), and price increases of fruits and vegetables relative to nonperishables, such as staple grains (Aberman et al., 2018). Such a steep decline in consumption highlights the importance of context-specific and culturally appropriate interventions (agricultural, nutritional, and socioeconomic) to improve consumption of these food groups.

4.3 | Policy implications

Our findings support the conservation and restoration of fruit trees in agricultural landscapes for improved diets in Malawi. However, there are several barriers to on-farm tree adoption and retention that will need to be taken into account to ensure that policies, campaigns, and incentives are contextually appropriate. Such barriers include the cutting of trees for fuelwood, the labor and monetary costs associated with tree planting and maintenance, land scarcity, and land tenure issues (Meijer et al., 2015). There is also evidence that the benefits of on-farm trees may be partly offset by the reduction in land devoted to crops (Benson & de Weerdt, 2023). Our results also highlight the importance of seasonality, given that in our study, some households who owned several fruit tree species did not consume any fruit from their own trees at the time of the survey, likely because the trees were not fruiting.

Landscape conservation and restoration initiatives can address such seasonal "micronutrient gaps" via promoting portfolios of tree species with staggered harvesting times (McMullin et al., 2019).

While our findings are specific to Malawi, they may have wider policy implications given that trees in agricultural landscapes can be a promising avenue for conservation initiatives trying to reconcile agricultural land use with biodiversity conservation. Indeed, current conservation initiatives often overlook opportunities for biodiversity conservation in agricultural landscapes, with a focus on natural landscapes such as intact forests. Yet, evidence suggests that agricultural landscapes can be synergistically managed for both biodiversity conservation and sustainable food production (Estrada-Carmona et al., 2022). Our study further supports this idea, yet further research is required to establish if this relationship holds across other countries and contexts.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data used in this study are freely available from the World Bank online database (Living Standards Measurement Study [worldbank.org]).

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SUPPORTING INFORMATION

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

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