Research

Indirect contributions of forests to dietary diversity in Southern Ethiopia

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ABSTRACT. We assess whether forests contribute indirectly to the dietary diversity of rural households by supporting diverse agricultural production systems. We applied our study in a landscape mosaic in Southern Ethiopia that was divided into three zones of increasing distance to Munesa Forest—"near," "intermediate," and "distant." A variety of research tools and methods, including remote sensing, participatory methods, farm survey, and yield assessment, were employed. Diets of households were more diverse in the near zone than in the other two zones (6.58 ± 1.21, 5.38 ± 1.02, and 4.41 ± 0.77 food groups consumed daily in the near, intermediate, and distant zones, respectively). This difference was not explained by food items collected from Munesa Forest but by biomass flows from the forest to farmlands. Munesa Forest contributed an average of 6.13 ± 2.90 tons of biomass per farm and per year to the farms in the near zone, in the form of feed and fuelwood. Feed from the forest allowed for larger livestock herds in the near zone compared with the other two zones, and fuelwood from the forest reduced the need to use cattle dung as fuel in the near zone compared with the two other zones. These two biomass flows contributed to the availability of more manure to farmers closer to the forest (908 ± 853 kg farm^{-1}, 771 ± 717 kg farm^{-1}, and 261 ± 487 kg farm^{-1} in the near, intermediate, and distant zones, respectively). In turn, increased manure enabled a larger percentage of farms to cultivate a diversified homegarden (87, 64, and 39% of farms in the near, intermediate, and distant zones, respectively). Homegardens and livestock products provided the greater contribution to household dietary diversity closer to the forest.

Key Words: *fuelwood; homegarden; landscape mosaic; livestock; nontimber forest products; nutrition; nutrition-sensitive agriculture*

INTRODUCTION

Since the Green Revolution, the global number of undernourished people—i.e., those not consuming sufficient calories—has declined (Gómez et al. 2013). Although there are still an estimated 800 million people suffering from caloric under-nutrition, many more people today suffer from "hidden hunger" or a lack of vitamins and minerals (IFPRI 2014). As such, an estimated two billion people are currently affected by micronutrient deficiencies (Muthayya et al. 2013, IFPRI 2014). Micronutrient adequacy is strongly associated with dietary diversity (Foote et al. 2004, Steyn et al. 2006). The contribution of agriculture to the dietary diversity of rural people, through food production pathways (Jones et al. 2014) and income pathways (Sibhatu et al. 2015), is relatively well understood. Several recent case studies from around the world have also found a positive association between proximity to forests and dietary diversity (Dounias and Froment 2006, Powell et al. 2011, Johnson et al. 2013, Ickowitz et al. 2014). For example, using data from 21 African countries on children's diets (from USAID's Demographic Health Surveys) and tree cover (from MODIS data), Ickowitz et al. (2014) found that children in Africa who lived in areas with more tree cover had more diverse and nutritious diets.

With forests disappearing at an alarming rate in the tropics (Gibbs et al. 2010), better understanding of their overall contribution to the dietary diversity of rural people living in their vicinity is increasingly important. However, research on the relationship between forest cover and dietary diversity remains somewhat limited. Forests contribute directly to diets of people through the provisioning of a diversity of wild forest-sourced foods, such as mushrooms, berries, bushmeat, and fruits—Pathway 1 (Hladik et al. 1990, Fa et al. 2003, Vinceti et al. 2008, Nasi et al. 2011, Termote et al. 2011). In addition, access to fuelwood can facilitate the

cooking process of a range of food items, such as legumes, which, on average, require a long cooking time—Pathway 2 (Remans et al. 2011). The collection and sale of nontimber forest products (i.e., any wild biological resource—animal or plant—harvested from forested lands by rural households for domestic consumption or small-scale trade, with no, or limited, capital investment) (Shackleton et al. 2007) also contribute to people's income—Pathway 3 (Williams 1998, Beck and Nesmith 2001, Kaschula et al. 2005, Pfund et al. 2011)—which, in turn, may contribute to better economic access to a diversity of food items that are available in markets. Access to nontimber forest products is critical for poverty alleviation and mitigation because it allows the poorest and most vulnerable rural households to use these free resources to meet their daily needs for energy, shelter, food, and medicine, and to save their scarce cash resources to meet other needs or accumulate assets for more secure livelihoods (Shackleton and Shackleton 2004, Shackleton et al. 2007). Nontimber forest products also provide rural households with a safety net—Pathway 4—in times of crises; e.g., drought, illness, or other external shocks (Shackleton and Shackleton 2004, Shackleton et al. 2007, Arnold et al. 2011). Forest may be the most profitable land use for degraded land, complementing income from crop and livestock production on more favorable parts of the landscape (Jagger and Pender 2003).

Forests may also contribute to dietary diversity of rural people through a fifth pathway, by supporting diverse agricultural production. In African smallholder farming systems characterized by low fertilizer use, trees are important to maintain soil fertility, which supports the productivity of food crops (Sanchez et al. 1997, Foli et al. 2014). Biodiversity-rich forests also supply numerous ecosystem services, including pollination and pest control (Pimentel et al. 1997, Reed et al. 2017). Using the case study of a landscape of Southern Ethiopia that is characterized by a gradient of increasing distance from a natural forest (Munesa Forest) and

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Fig. 1. Map of the study area.
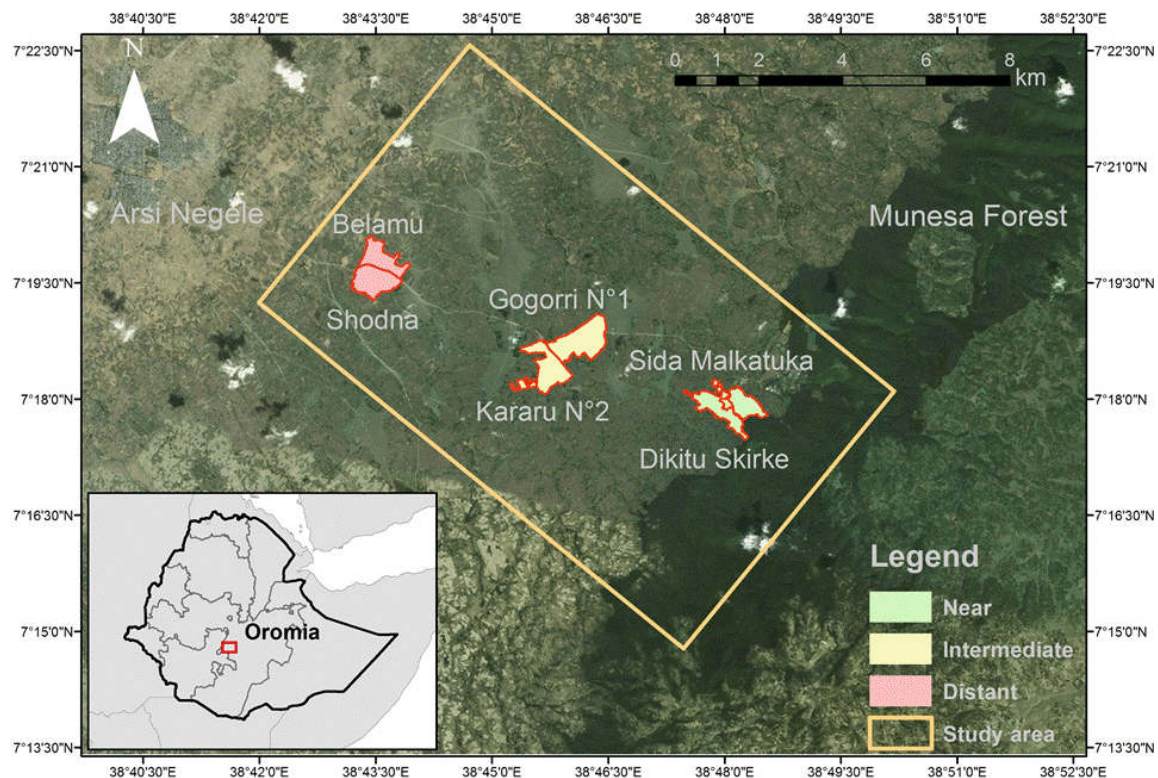
decreasing distance from a main road and market (town of Arsi Negele), we tested the existence of this fifth pathway. This area was selected because forest food was seldom consumed, and the sale of nontimber forest products is rare (the sale of forest fuelwood, for example, is prohibited); i.e., forests did not make a significant contribution to dietary diversity through the four other pathways described.

METHODS

Study area

The study was conducted in the Woreda (district) of Arsi-Negele, located in the Oromia region of Ethiopia. The study area (Fig. 1) covers approximately 100 km^2 between 38°42.14' and 38°49.92' East and 7°15.05' and 7°22.57' North; it also borders the state forest of Munesa, and encompasses parts of three kebeles (subdistricts): Ashooka, Bombaso Regi, and Gambelto, in which a total of six villages were studied (Duriaux and Baudron 2016). The study area is located between 2050 and 2214 m above sea level. Its climate is subhumid and is characterized by a mean annual rainfall of 1075 mm per year (18 years average) and a mean annual temperature of 15°C (16 years average). Three seasons are clearly defined: a short rainy season from March to May, a long rainy season from July to September, and a dry season from October to February (winter). The natural vegetation is classified as dry Afromontane forest (Tesfaye 2007). Inhabitants belong to

the Oromo ethnic group and are almost exclusively of Islamic faith. Until the land reform that took place during the first years of the Marxist-Leninist regime (from 1974 to 1991), the landscape was largely forested and people were mainly pastoralists. The land was owned by nonresident landlords who seldom used the land itself. Resident tenants were only allowed to cultivate very small fields. Today, the study area outside Munesa Forest has been largely deforested. Mixed crop-livestock farming is the main economic activity. Wheat (*Triticum* sp. L.), maize (*Zea mays* L.), and potato (*Solanum tuberosum* L.) are the main crops, followed by enset (*Ensete ventricosum* (Welw.) Cheesman) and faba bean (*Vicia faba* L.). Most farmers keep livestock, such as cattle, sheep, goats, horses, donkeys, and chickens.

The Sida Malkatuka village and Dikitu Shirke village (in Ashooka kebele) border the state forest of Munesa (Fig. 1), and their residents have access to it for grazing and collection of fuelwood (Duriaux and Baudron 2016). These villages form a zone that we refer to as "near." Gogorri Lako Toko village (in Ashooka kebele) and Kararu Lakobsa Lama village (in Bombaso Regi kebele) are located about 3 km away from Munesa Forest (Fig. 1) and do not have access to it. They do have access to a large communal grazing area for livestock grazing and fuelwood collection (Duriaux and Baudron 2016). These villages form a zone that we refer to as "intermediate." Shodna village and Belamu village (in Gambelto kebele) are located about 7 km away from Munesa Forest (Fig.

Fig. 2. (a) Food security (number of months for which households reported to have adequate food provisioning), (b) household diet diversity score (mean number of food groups [0–11] consumed daily during a week of recall), and (c) scores (number of days during a week a household consumes a particular food group) for 11 food groups in the three zones of the study area (near, intermediate, and distant to Munesa Forest). Bars represent standard deviations. χ^2 and P values are given for Kruskal–Wallis tests (comparison of medians). For a given food group, the presence of a star indicates statistically significant differences in the medians of the three zones. (HDDS: household diet diversity score; Cereals: cereals, grains, and cereal products; Roots: roots and tubers; Animal prod: meat and animal products; Milk prod: milk and milk products; Sugar prod: sugar, sugar products, and honey; Spices: spices and condiments; Snack: snack and processed foods).
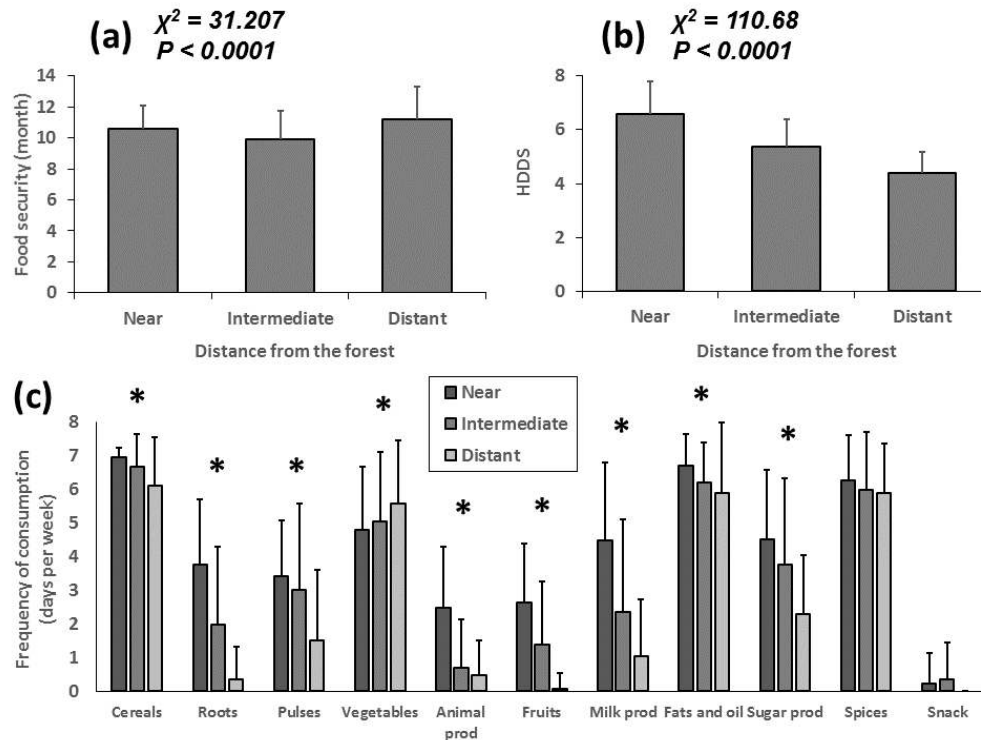
1). They do not have access to the forest or to any other common land for livestock grazing and fuelwood collection (Duriaux and Baudron 2016). These villages form a zone that we refer to as "distant." The near, intermediate, and distant zones are located about 16, 11.5, and 6.5 km away from the main market of Arsi Negele town, respectively (Fig. 1).

Data sources and sampling
Between December 2014 and February 2015, the head of each household in the study area—266 households in total (88 in the near zone, 97 in the intermediate zone, and 81 in the distant zone)—was interviewed using a standardized questionnaire that addressed household composition, dietary diversity, food security, crop and livestock management, and forest use. Questionnaires were administered only when consent was granted verbally. To asses dietary diversity, the Food and Agriculture Organization of the United Nations' household diet diversity tool (Kennedy et al. 2010) was adapted to capture the frequency of consumption of 11 food groups (Fig. 2c) in the household during the seven days that preceded the survey. Food security was determined based on the number of months for which households

reported to have adequate food provisioning (Bilinsky and Swindale 2007). The location (including elevation) of each interviewed household was recorded using a handheld global positioning system (GPS) Garmin Etrek 10.

Between May and September 2015, tree cover in the three zones was estimated by counting and measuring the diameter at breast height ([DBH] 135 cm from ground level) of all trees with a DBH > 10 cm that were located within a radius of 50 m from 24 sampling points per zone. Sampling points were selected by overlaying 150-m grids on the map of the zone and randomly selecting 24 points.

To describe farm heterogeneity, a self-categorization exercise was conducted in each zone, each with a group of 50–60 community members who were representative of the diversity of community members in the kebele (in terms of gender, age, and wealth). Based on the criteria from these self-categorization exercises, three farm types were identified: crop-oriented farms (more than 1 ha of farmland and less than four adult cattle per hectare of farmland), livestock-oriented farms (at least four adult cattle per hectare of farmland), and resource-poor farms (1 ha of farmland or less,

Table 1. Summary of the main variables assessed, their units, the methods of assessment, and the size of the samples (*N*).

Variables	Unit	Method	*N*
Sex of the head of the household	Male/Female	Survey	266
Age of the head of the household	No.	Survey	266
Family size	No.	Survey	266
Head of the household schooled	0/1	Survey	266
Tertiary education	0/1	Survey	266
Remittances	0/1	Survey	266
Paid work	0/1	Survey	266
Year the land was cleared	No.	Survey	266
Year the household started farming	No.	Survey	266
Food security	No. months	Survey	266
Score per food group	No. days per week	Survey	266
Presence of a homegarden	0/1	Survey	266
Diversity in homegarden	No. crop species	Survey	266
Presence of enset in homegarden	0/1	Survey	266
Oxen and bulls	No.	Survey	266
Cows	No.	Survey	266
Steers and heifers	No.	Survey	266
Calves	No.	Survey	266
Donkeys	No.	Survey	266
Beehives	No.	Survey	266
Elevation of each farming household	Meters above sea level	GPS measurement	266
Diameter at breast height of all trees within 50-m radius	m^2 ha^{-1}	Tree survey	96
Area of each field	ha	GPS measurement	27
Production per crop	kg	Detailed characterization	27
Seasonal milk production	L day^{-1}	Detailed characterization	27
Fuelwood from the forest and other common lands	% total fuel	Detailed characterization	27
Fuelwood from the farm	% total fuel	Detailed characterization	27
Dung used as fuel	% total fuel	Detailed characterization	27
Crop residues used as fuel	% total fuel	Detailed characterization	27
Purchased fuelwood	% total fuel	Detailed characterization	27
Feed from the forest and other common lands	% total feed	Detailed characterization	27
Feed from the farm (crop residue and "weeds")	% total feed	Detailed characterization	27
Purchased feed	% total feed	Detailed characterization	27
Manure applied	kg $year^{-1}$	Detailed characterization	27
Seasonal milk production	L day^{-1}	Empirical measurement	9
Seasonal fuel consumption	kg dry matter day^{-1}	Empirical measurement	9
Distance to nearest forest patch > 0.5 ha	m	Remote sensing	266
Distance to nearest forest patch > 0.25 ha	m	Remote sensing	266
Distance to nearest grassland patch > 0.5 ha	m	Remote sensing	266
Distance to nearest grassland patch > 0.25 ha	m	Remote sensing	266
Distance to nearest road	m	Remote sensing	266

and less than four adult cattle per hectare of farmland). A stratified subsample of nine farms was selected in each zone (27 farms in total) for detailed characterization. For each selected farm, the detailed characterization produced three main outputs: a resource flow map, resource use calendars, and a timeline (Geifus 2008, Giller et al. 2011). In addition, the area of each field was measured using a handheld GPS Garmin Etrek 10.

Empirical measurements were collected in nine of the 27 farms (one farm per type and per zone, selected randomly): daily fuel consumption (once in March 2015 and once in August 2015), and milk production over a period of seven days (once in March 2015 and once in September 2015).

Current land use was calculated from classified RapidEye imagery. Four tiles of RapidEye 3A imagery (5-m resolution) taken in January 2015 were used to classify the landscape into croplands and bare soil, enset homegardens, grassland, natural

forest and tree cover, tree plantations, and woodlots. A combination of object-based and maximum likelihood supervised classification was performed to distinguish between these classes. Training sites were verified using a combination of high-resolution imagery from Google Earth and ground verification via onsite fieldwork. Furthermore, enset homegarden patches were digitized using high-resolution imagery from Google Earth. The minimum mapping unit was set at the size of the smallest spatial resolution (5 m x 5 m). Distances between each farming household and Munesa Forest, the nearest forest patch of at least 0.5 ha, the nearest forest patch of at least 0.25 ha, the nearest grassland patch of at least 0.5 ha, the nearest grassland patch of at least 0.25 ha, and the nearest road were then calculated. For this, the nearest Euclidean distance to these features—selected via query—was calculated and extracted for each farming household point. Table 1 summarizes the main variables assessed and the methods of assessment.

Calculations and data analysis

For each household, the household diet diversity score was calculated as the mean number of food groups [0–11] consumed daily during a week of recall (Kennedy et al. 2010). Food security was calculated as the number of months for which households reported to have adequate food provisioning (Bilinsky and Swindale 2007). Tree cover was estimated for each tree count point by the basal area, calculated by dividing the sum of the section area of all trees (at breast height) by the total surface area. Yields were calculated by dividing the quantity of grain, tuber, or fresh product harvested (as recalled by farmers during the household interview) by the area of the corresponding field (as measured using a GPS) and multiplying it by the estimated dry matter content of the product harvested, using standard values from Feedipedia and USDA web databases (http://www.feedipedia. org/; https://ndb.nal.usda.gov/ndb/search). To compare livestock density in the different zones and farms, the livestock numbers reported in the survey were converted into tropical livestock units (TLU), using a value of 250 kg live weight for one TLU (Houérou and Hoste 1977). Following the method of Gryseels (1988), oxen and bulls were assumed to be equivalent to 1.1 TLU, cows to 0.8 TLU, steers and heifers to 0.5 TLU, calves to 0.2 TLU, sheep and goats to 0.09 TLU, horses to 0.7 TLU, and donkeys to 0.36 TLU. Milk production was estimated from farmer recall, and was compared with empirical measurements. Meat production was estimated from recalled annual animal sales and animal slaughtering (for self-consumption). For crop and livestock products, conversion to energy content was undertaken using standard values from Feedipedia and USDA web databases (http://www.feedipedia.org/; https://ndb.nal.usda.gov/ndb/search).

Statistical analysis

Quantitative data were tested for normal distribution using Shapiro-Wilk normality tests. When testing for differences between zones, Fisher tests were used to compare means of quantitative data, and Kruskal–Wallis (nonparametric) tests were used for medians. For the qualitative data, proportions were compared using Chi-square tests. Correlations between quantitative variables were tested using Kendall's tau coefficient, and logit models were used to test correlations between quantitative and qualitative variables.

Generalized linear models were used to assess the source of variability in food security, dietary diversity, frequency of consumption of the 11 food groups, presence of a homegarden in the farm, and crop diversity in homegardens (for the subset of farms that owned a homegarden). A logit distribution was used when presence of a homegarden in the farm was used as a response variable, and a Gamma distribution was used when all other variables were used as response variables. Model 1 aimed at testing the effect of farm location (e.g., zone), when controlling for demographic variables (e.g., family size) and structural variables (e.g., farm area). Model 2 aimed at testing the effect of functional variables (e.g., livestock ownership) when controlling for demographic variables and structural variables. Models were constructed as follows:

(Model 1)

$$Y_{ijklmn} = \alpha + \beta ZN_i + \gamma EL + \delta DF0.5 + \epsilon DF0.25 + \zeta DG0.5 \\ + \eta DG0.25 + \theta DR + \iota SX_j + \kappa AG + \lambda FS \\ + \mu ED_k + \nu TE_l + \xi RE_m + o PW_n + \pi YC \\ + \rho YS + \varsigma FA + R \quad (1)$$

(Model 2)

$$Y_{ijklmnopqrstuvw} = \alpha + \beta HG_i + \gamma CA + \delta SG + \epsilon EQ + \zeta BH \\ + \eta CH + \theta SX_j + \iota AG + \kappa FS + \lambda ED_k \\ + \mu TE_l + \nu RE_m + \xi PW_n + o YC + \pi YS \\ + R \quad (2)$$

where Y_{ijklmn} represents food security, dietary diversity, frequency of consumption of food groups, presence or absence of homegarden, or crop diversity of homegarden; ZN_i is the ith zone (near, intermediate, or distant); EL is the elevation; DF0.5 is the distance to the nearest patch of forest of at least 0.5 ha; DF0.25 is the distance to the nearest patch of forest of at least 0.25 ha; DG0.5 is the distance to the nearest patch of grassland of at least 0.5 ha; DG0.25 is the distance to the nearest patch of grassland of at least 0.25 ha; DR is the distance to the nearest road; SX_j is the jth sex of the head of the household, AG is the age of the head of the household; FS is the family size of the household; ED_k is the kth level of education of the head of the household (presence or absence); TE_l is the lth level of tertiary education of the head of the household (presence or absence); RE_m is the mth level of remittances received by the household (presence or absence); PW_n is the nth level of paid work of the head of the household (presence or absence); YC is the year the land was cleared; YS is the year farming started; FA is the farm area; HG_i is the ith level of homegarden presence on the farm (presence or absence); CA is cattle ownership (in TLU); SG is sheep and goats ownership (in TLU); EQ is equine ownership (in TLU); BH is the number of beehives owned; CH is the number of chicken owned; and R is the residual; α, β, γ, θ, ι, λ, μ, ξ, o, π, ρ, and ς represent fixed effects values. A probability of 0.05 was used to test the significance of each factor. In each model, factors that had a t value less than 0.1 were removed. Two-way interactions between the factor "zone" and other factors on which "zone" had a significant influence were added in Model 1. Similarly, two-way interactions between the factor "homegarden" and other factors on which "homegarden" had a significant influence were added in Model 2. All analyses were conducted using R software (version 2.14.1, Foundation for Statistical Computing, 2011).

RESULTS

General characterization of the gradient

Tree cover—as assessed by the mean basal area—decreased with increasing distance from Munesa Forest: 5.11 ± 4.21, 2.13 ± 1.69, and 0.63 ± 0.87 m^2 ha^{-1} in the near, intermediate, and distant zones, respectively (χ^2 = 34.535, P < 0.0001). Farm elevation—as measured by handheld GPS—decreased with increasing distance from Munesa Forest (Table 2). From the remote sensing analysis, distance to a patch of forest (excluding Munesa Forest), whether small (minimum area of 0.25 ha) or large (minimum size of 0.5 ha), increased with increasing distance from Munesa Forest (Table 2). Farms in the intermediary zone were closer to small (minimum area of 0.25 ha) and large (minimum size of 0.5 ha) patches of grassland compared with farms in the two other zones (Table 2). Conversely, farms in the near zone were closer to a road than farms in the two other zones (Table 2).

The analysis of the demographic data collected through household survey revealed that the age of the head of the household, the year the household started farming, the percentage of female-headed households, the percentage of households with

$Y \qquad = \alpha + \beta HG + \gamma CA + \delta SG + \epsilon EQ + \zeta BH$

Table 2. Comparison of locational, demographic, and farming system characteristics of the farming households in the three zones of the study area (near, intermediate, and distant to Munesa Forest). Units are given in parentheses. Standard errors are given after the "±" signs. χ^2 and *P* values are given for Kruskal–Wallis tests that compared medians between the three zones (TLU: tropical livestock unit).

Farm/household characteristics	Near	Intermediate	Distant	χ^2	*P*
Elevation (meters above sea level)	2176.4 ± 14.5	2102.6 ± 9.0	2070.3 ± 7.2	231.59	< 0.0001
Distance to Munesa Forest (m)	91.7 ± 129.8	2715.6 ± 296.4	6766.5 ± 276.5	231.5	< 0.0001
Distance to nearest forest patch > 0.5 ha (m)	8.8 ± 12.4	21.1 ± 29.6	269.9 ± 175.5	163.87	< 0.0001
Distance to nearest forest patch > 0.25 ha (m)	8.8 ± 12.4	17.4 ± 23.7	167.0 ± 123.4	140.74	< 0.0001
Distance to nearest grassland patch > 0.5 ha (m)	137.0 ± 120.0	47.5 ± 72.6	143.3 ± 81.2	60.019	< 0.0001
Distance to nearest grassland patch > 0.25 ha (m)	61.6 ± 62.5	17.0 ± 25.4	49.1 ± 53.3	39.309	< 0.0001
Distance to nearest road (m)	641.2 ± 809.7	740.4 ± 768.4	538.9 ± 745.8	7.0494	< 0.05
Age of the head of the household	43.2 ± 13.5	41.0 ± 13.3	42.0 ± 13.8	1.439	n.s.
Family size	8.5 ± 4.8	6.2 ± 3.6	5.3 ± 2.5	22.347	< 0.0001
Year land was cleared	1964 ± 12	1965 ± 13	1960 ± 14	10.315	< 0.01
Year the household started farming	1999 ± 13	2000 ± 12	1999 ± 14	0.84818	n.s.
Farm area (ha)	1.98 ± 7.99	0.98 ± 0.68	0.86 ± 0.57	10.667	< 0.005
All livestock (TLU)	3.49 ± 3.02	2.23 ± 1.98	1.86 ± 2.39	19.999	< 0.0001
Cattle (TLU)	2.94 ± 2.69	1.88 ± 1.80	1.68 ± 2.27	15.235	< 0.0005
Sheep and goats (TLU)	0.25 ± 0.33	0.10 ± 0.18	0.03 ± 0.12	43.129	< 0.0001
Equines (TLU)	0.27 ± 0.40	0.21 ± 0.33	0.13 ± 0.22	5.8336	< 0.1
Beehives (number)	0.62 ± 1.94	0.47 ± 1.83	0.05 ± 0.45	7.5423	< 0.05
Chicken (number)	2.98 ± 3.52	4.09 ± 5.02	2.14 ± 3.85	11.573	< 0.005
Diversity in homegarden (number of species)	2.88 ± 1.59	2.10 ± 2.04	0.88 ± 1.31	49.845	< 0.0001
Female-headed households (% farms)	23.3	25.0	25.0	1.3278	n.s.
Homestead with a metal roof (% farms)	52.3	53.1	36.3	5.9226	< 0.1
Head of the household schooled (% farms)	76.7	74.0	58.8	8.7184	< 0.05
Tertiary education (% farms)	27.9	27.1	7.5	7.4487	< 0.05
Remittances (% farms)	7.0	11.5	0.0	11.826	< 0.005
Paid work (% farms)	16.3	17.7	19.0	0.45221	n.s.
Homegarden (% farms)	85.5	62.4	38.5	38.13	< 0.0001
Presence of enset (% farms with homegarden)	100.0	98.3	43.3	16.407	< 0.0005

a metal roof (proxy of wealth), and the proportion of households involved in paid work did not differ significantly between the three zones (Table 2). Conversely, family size tended to decrease with increasing distance from Munesa Forest, while the percentage of household heads having received education (any form of education, or tertiary education) and the percentage of households receiving remittances were lower in the distant zone compared with the two other zones (Table 2).

Characteristics of farms and farming systems that were collected through the household survey revealed that farms in the distant zone tended to have been cleared a few years earlier than farms in the other two zones (Table 2). Farm area and livestock ownership tended to decrease significantly with increasing distance from Munesa Forest (Table 2). The same trend was observed for all livestock types except chicken: i.e., cattle, sheep and goats, equines, and beehives. Chicken ownership in the intermediate zone was significantly higher than in the two other zones. The percentage of farms with a homegarden decreased significantly with increasing distance from Munesa Forest, as did the crop diversity in these homegardens and the percentage of these homegardens that contained enset (Table 2).

Dietary diversity and food security along the gradient
Food security, in terms of months of adequate household food provisioning, was lower in the intermediate zone compared with the two other zones, although the difference was less than 1 month (10.6 ± 1.5, 9.9 ± 1.8, and 11.2 ± 2.1 months year^{-1} in the near, intermediate, and distant zones, respectively) (Fig. 2a). Households in the near zone had more diverse diets than households in the distant zone (Fig. 2b). Households in the intermediate zone ranked between households in the two other zones (Fig. 2b). Differences in household dietary diversity scores between the three zones were much larger than differences in food security. The difference in household diet diversity scores was explained by the more frequent consumption in the near zone of every food group except "vegetables"; the frequency of consumption of "spices and condiments" did not differ between the three zones (Fig. 2c). Follow-up interviews revealed that these food groups were predominantly sourced from the market, while households sourced the other food groups predominantly from their own agricultural production. Consumption of wild foods from the forest was seldom reported in the dietary recall, and follow-up interviews confirmed that this happened only very rarely in this setting, and involved mainly young herders guarding livestock in the forest and occasionally picking wild fruits.

Table 3. Summary of the results of Model 1 for explaining the variability in food security (months of adequate food provisioning) and dietary diversity (household dietary diversity score). Significant effects (*P* < 0.05) are shown in bold.

Model variables	Food security		Dietary diversity	
	t value	*P* value	*t* value	*P* value
Intercept	0.272	0.7850	-1.116	0.2470
Zone	-0.068	0.9460	2.422	**0.0162**
Elevation	1.275	0.2020	2.505	**0.0129**
Distance to nearest forest patch > 0.5 ha			1.178	0.2400
Distance to nearest forest patch > 0.25 ha	-0.930	0.3520	-1.566	0.1188
Distance to nearest grassland patch > 0.5 ha			-0.496	0.6204
Distance to nearest grassland patch > 0.25 ha	-0.577	0.5640	1.163	0.2461
Distance to nearest road			1.196	0.2328
Sex of the head of the household	0.258	0.7960	0.221	0.8255
Age of the head of the household	0.467	0.6400	-1.077	0.2827
Family size			-1.003	0.3171
Head of the household schooled	0.220	0.8260	1.086	0.2787
Tertiary education	0.671	0.5020	-3.480	**0.0006**
Remittances	-0.733	0.4630	-0.509	0.6112
Paid work	-0.419	0.6750		
Year land was cleared	-0.824	0.4100	0.474	0.6359
Year the household started farming	0.525	0.6000	-1.062	0.2895
Farm area	0.758	0.4490	0.926	0.3555
Zone × Elevation	-0.478	0.6330	-2.904	**0.0040**
Zone × Distance to nearest forest patch > 0.5 ha			-1.229	0.2203
Zone × Distance to nearest forest patch > 0.25 ha	0.996	0.3190	1.549	0.1226
Zone × Distance to nearest grassland patch > 0.5 ha			-0.149	0.8816
Zone × Distance to nearest grassland patch > 0.25 ha			-0.707	0.4803
Zone × Family size	-0.952	0.3410	1.041	0.2988
Zone × Head of the household schooled	0.565	0.5720	-2.097	**0.0370**
Zone × Tertiary education	-0.681	0.4960	2.752	**0.0064**
Zone × Remittances			0.793	0.4288
Zone × Paid work				
Zone × Year land was cleared	0.473	0.6360	-0.371	0.7110
Zone × Farm area	-0.838	0.4020	-0.951	0.3427

When testing for the effect of farm location in Model 1 (while controlling for demographic and structural variables), the zone in which a particular farm was located had no effect on food security but had a statistically significant effect on dietary diversity (Table 3). The effects of zone on dietary diversity appeared to be nonlinear because the two-way interactions between zone and elevation and between zone and education of the head of the household were significant in Model 1. None of the variables that described the farm location and which were tested in Model 1 had a significant effect on food security. The factor zone and/or the interaction between zone and elevation were also significant when using frequency of consumption as a response variable in Model 1 for the following food groups: roots and tubers; pulses; meat and animal products; fruits; milk and milk products; sugar, sugar products, and honey; and snack and processed foods (Appendixes 1 and 3). The effect of proximity to the forest was positive for all these food groups except sugar, sugar products, and honey, and snack and processed foods, for which it was negative.

When testing for the effect of functional variables in Model 2 (while controlling for demographic and structural variables), the presence/absence of a homegarden and livestock ownership (in particular, ownership of sheep and goats and beehives) had a significant effect on dietary diversity but no effect on food security (Table 4). The two-way interaction between the presence/absence

of a homegarden and the number of beehives was also significant in Model 2. None of the variables tested in Model 2 had a significant effect on food security. The factor homegarden and/ or the interaction between homegarden and any livestock category except chicken (cattle, sheep and goats, or equines) were also significant and positive in Model 2 when using frequency of consumption as a response variable for the following food groups: roots and tubers; pulses; vegetables; meat and animal products; fruits; milk and milk products; sugar, sugar products, and honey; and snack and processed foods (Appendices 2 and 4).

Functioning of the farms along the gradient: homegarden, biomass use, and crop and livestock productivity
When testing for the effect of farm location (Model 1), the interaction between zone and family size had a significant effect on the presence/absence of a homegarden in the farm (Annexe 5, Fig. 3a). Other significant variables were family size and farm area. When using the crop diversity in the homegarden as a response variable, the interaction between zone and distance to the nearest grassland patch of at least 0.25 ha was significant in Model 1 (Appendix 5). Other significant variables were distance to the nearest grassland patch of at least 0.5 ha, farm area, and the interaction between zone and farm area. When testing for the effect of functional variables (Model 2), livestock ownership (in particular, ownership of sheep and goats) had a significant effect on the presence/absence of a homegarden in the farm (Appendix

Table 4. Summary of the results of Model 2 for explaining the variability in food security (months of adequate food provisioning) and dietary diversity (household dietary diversity score). Significant effects ($P < 0.05$) are shown in bold (Homegarden: presence of absence of a homegarden; TLU: tropical livestock unit).

Model variables	Food security		Dietary diversity	
	t value	P value	t value	P value
Intercept	0.817	0.4140	1.761	0.0795
Homegarden			-4.223	**0.0000**
Cattle (TLU)	1.027	0.3040	-0.382	0.7026
Sheep and goat (TLU)	1.017	0.3090	-2.579	**0.0105**
Equines (TLU)	-1.299	0.1940		
Beehives	-0.631	0.5280	-2.139	**0.0335**
Chicken	0.370	0.7120	-0.764	0.4454
Family size	-1.155	0.2480	-1.772	0.0776
Head of the household schooled	1.338	0.1810	-1.516	0.1308
Tertiary education	-0.292	0.7700	-2.702	**0.0074**
Remittances	-0.956	0.3390	-1.275	0.2035
Paid work	-0.464	0.6420	0.904	0.3669
Year land was cleared	-1.238	0.2160	-0.866	0.3872
Year farming started	0.851	0.3950	-0.969	0.3335
Homegarden × Cattle (TLU)	-0.600	0.5480	0.140	0.8888
Homegarden × Sheep and goat (TLU)	-0.740	0.4590	1.934	0.5440
Homegarden × Equines (TLU)	1.365	0.1720		
Homegarden × Beehives	0.695	0.4870	2.184	**0.0299**
Homegarden × Chicken				

Fig. 3. Percentage of farming households with a small family (0–5 people [pp]) or a large family (more than 5 people) and a homegarden in the three zones of the study area (near, intermediate, and distant to Munesa Forest), and (b) percentage of farming households with small livestock ownership (less than 1 tropical livestock unit [TLU]), medium livestock ownership (1–3 TLU), and large livestock ownership (more than 3 TLU), and a homegarden.
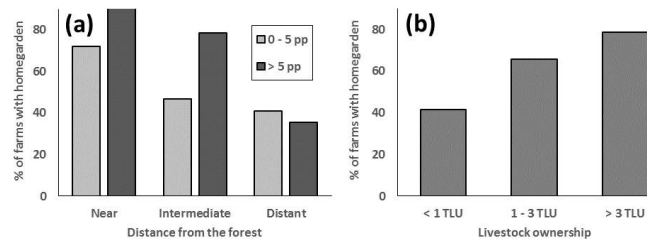

6, Fig. 3b). Other significant variables were family size and year that farming started. When using the crop diversity in the homegarden as a response variable, the presence/absence of enset was found to be overruling in Model 2. No other variable was significant. Livestock ownership had a statistically significant effect on the presence or absence of enset in the homegarden ($Z = 3.548$, $P < 0.0005$).

The quantity of biomass used as household fuel tended to decrease with increasing distance from Munesa Forest, but the differences were not statistically significant (Table 5). In addition, group interviews revealed that these differences had no effect on the food items households were or were not able to cook and consume. However, the composition of the household fuel changed with increasing distance from the forest. Closer to the forest, households used significantly more fuelwood from the forest (and other commons), while farther away from the forest, households used significantly more cattle dung as fuel (Table 5). Farmers in the distant zone also purchased fuelwood, while farmers closer to the forest were able to access free fuelwood, mostly from the farms in the intermediate zone, and mostly from Munesa Forest in the near zone (Fig. 4a).

Fig. 4. (a) Harvesting of firewood, (b) cattle grazing in Munesa Forest, and (c) section of Munesa Forest showing signs of degradation.
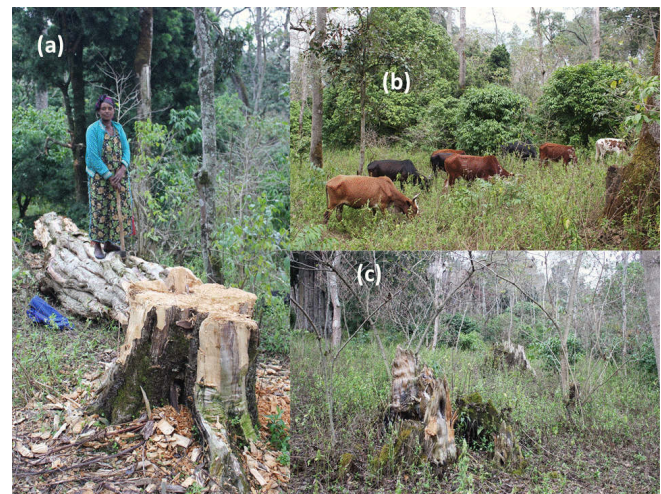
Similarly, the quantity of biomass used as livestock feed tended to be lower in the distant zone compared with the two other zones, but the differences were not statistically significant (Table 6).

Table 5. Comparison of the mean quantity of biomass in kg household^{-1} year^{-1} from different sources used as household fuel in the three zones of the study area (near, intermediate, and distant to Munesa Forest). Standard errors are given after the "±" signs. χ^2 and P values are given for Kruskal–Wallis tests that compared medians between the three zones.

Biomass used as fuel	Near	Intermediate	Distant	$\chi2$	P
Forest and common lands	3257 ± 1461	407 ± 978	353 ± 530	16.911	< 0.0001
Crop residues and farm trees	1055 ± 1534	2833 ± 1032	668 ± 667	10.444	< 0.01
Dung	0 ± 0	72 ± 144	428 ± 330	13.695	< 0.005
Crop residues	794 ± 414	760 ± 305	876 ± 472	0.20174	n.s.
Purchased	0 ± 0	0 ± 0	510 ± 524	11.669	< 0.005
Total	5106 ± 1678	4073 ± 1443	2835 ± 954	5.6257	n.s.

However, the sources of feed for livestock differed significantly across the three zones. The quantity of biomass from the forest (and other commons) that was used as feed decreased significantly with increasing distance from Munesa Forest (Table 6), which is intensively used as a grazing area by farmers from the near zone (Fig. 4b). The quantity of biomass from the farm that was used as feed followed a similar trend, but the statistical significance of the differences was weak. The overall quantity of feed purchased in the three zones did not differ significantly. Total livestock ownership was significantly correlated to the quantity of biomass from the forest and other commons that was used as feed (Z = 4.3191, P < 0.0001).

Summing the biomass flows from fuelwood and feed, Munesa Forest contributed an average of 6.13 ± 2.90 tons of biomass per farm and per year to farms in the near zone. The input of biomass from commons to farms in the other two zones was less than half that value (2.72 ± 1.05 and 2.20 ± 2.47 tons per year in the intermediate and distant zones, respectively).

There was no difference between the three zones in the application rate of the two types of mineral fertilizer used in the area: diammonium phosphate (F = 0.454, n.s.) and urea (F = 0.761, n. s.). However, farmers in the distant zone applied significantly less manure on their farms than did farmers in the two other zones (908 ± 853 kg farm^{-1}, 771 ± 717 kg farm^{-1}, and 261 ± 487 kg farm^{-1} in the near, intermediate, and distant zone, respectively; χ^2 = 55.31, P < 0.0001). Farms that did not use dung as fuel tended to apply more manure than did farms that used dung as fuel, although the statistical significance of the difference was moderate (χ^2 = 3.2056, P < 0.1). The total crop productivity (calculated as the sum of all calories produced from crops within a year and divided by the total farm area) did not differ in the three zones (34.2 ± 9.7 GJ ha^{-1}, 31.8 ± 19.2 GJ ha^{-1}, and 37.7 ± 14.5 GJ ha^{-1} in the near, intermediate, and distant zones, respectively) (Fig. 5a). However, the total livestock productivity (calculated as the sum of calories produced from livestock within a year and divided by the total farm area) was significantly higher in the near zone compared with the two other zones (2.62 ± 1.60 GJ ha^{-1}, 0.97 ± 0.73 GJ ha^{-1}, and 0.95 ± 0.97 GJ ha^{-1} in the near, intermediate, and distant zones, respectively) (Fig. 5b).

DISCUSSION

This study illustrates indirect contributions, through flows of biomass, from Munesa Forest to the dietary diversity of surrounding farming households, and plays a pioneering role in unraveling such pathways (Fig. 6).

Fig. 5. (a) Mean crop productivity, and (b) mean livestock productivity of farms in the three zones of the study area (near, intermediate, and distant to Munesa Forest). Bars represent standard deviations. F and P values are given for the Fischer test (comparison of means), and χ^2 and P values are given for the Kruskal–Wallis tests (comparison of medians).
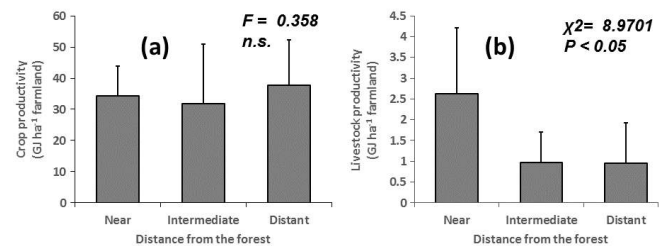

Fig. 6. Schematic representation of the effect of forest (and other commons) on the quantity and quality of crop and livestock products. The "+" signs show positive relationships; the "-" signs show negative relationships.
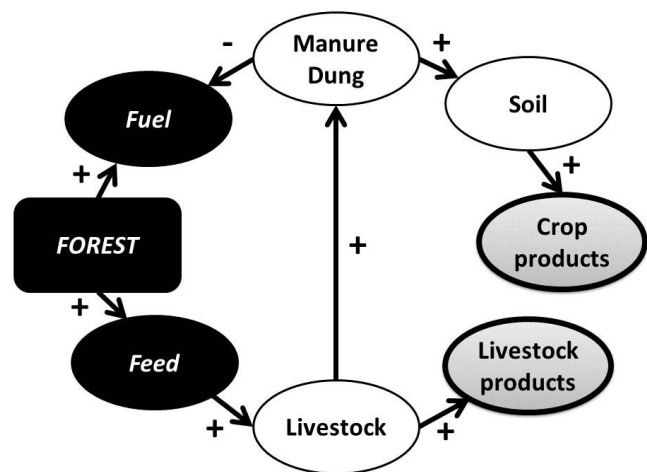
Table 6. Comparison of the mean quantity of biomass in kg farm^{-1} year^{-1} from different sources used as livestock feed in the three zones of the study area (near, intermediate, and distant to Munesa Forest). Standard errors are given after the "±" signs. χ^2 and *P* values are given for Kruskal–Wallis tests that compared medians between the three zones.

Biomass used as feed	Near	Intermediate	Distant	χ^2	*P*
Forest and common lands	2876 ± 2860	1935 ± 859	306 ± 471	11.912	< 0.005
Crop residue and weeds	5184 ± 3646	4640 ± 3074	2301 ± 3630	4.9749	< 0.1
Purchased	143 ± 311	348 ± 545	113 ± 318	1.6406	n.s.
Total	8203 ± 4641	8016 ± 4686	5787 ± 10051	4.0498	n.s.

Impact of forest proximity on food security, dietary diversity, and agricultural productivity

The proximity to Munesa Forest had no effect on household food security per se (Table 3, Fig. 2a), probably because of a lack of difference in the production of staples, but it had a significantly positive effect on dietary diversity (Table 3, Fig. 2b). Higher dietary diversity closer to the forest was explained by a higher prevalence of homegardens and higher livestock ownership (Table 4). More farms closer to the forest had homegardens because they tended to have larger livestock herds (Fig. 3), which produced more manure that was preferentially applied on homegardens, as revealed by group interviews and observations. The availability of manure for farms closer to the forest was also higher because they tended to use forest wood instead of livestock dung as fuel.

Thus, higher livestock ownership in farms closer to the forest compared with farms farther away was central in explaining the increase in dietary diversity with increasing proximity to the forest. Larger livestock herds of all species (except chicken) in farms that were closer to the forest compared with farms that were farther away was permitted by the use of a larger quantity of biomass from the forest (and other commons) as feed (Table 6). Larger livestock herds also contributed to the higher dietary diversity of households that were closer to the forest, directly through the production of milk and milk products and meat and animal products (as demonstrated by the much higher livestock productivity in the near zone compared with the two other zones) (Fig. 5b), and more indirectly through the production of manure, which facilitated the existence of homegardens—true hot spots of nutrient-dense food items. The proximity to the forest may also explain the higher number of beehives (Table 2) and the higher consumption of the food group sugar, sugar products, and honey (Fig. 2c) in the near and intermediate zones compared with the distant zone, due to the greater availability of pollen and nectar provided by trees.

Homegardens were key in explaining the higher consumption of almost all food groups, including roots and tubers (through enset and potato), pulses (through faba bean), meat and animal products (through eggs), fruits, milk and milk products (through fodder produced in homegardens; e.g., enset leaves) and sugar, sugar products, and honey (through honey). In addition, crop diversity in homegardens increased with increasing proximity to Munesa Forest (Table 2). This appears to be due to the higher prevalence of enset, which is known to modify local biophysical conditions in ways that may be favorable to other crops by capturing rainwater with its fan-shaped leaves and fibrous pseudostem and by modifying the microclimate under its canopy

(i.e., they are described as "spacemakers") (Kanshie 2002). The presence of enset may be conditioned by the amount of manure applied (higher closer to the forest), as this crop is known to require high soil fertility (Kanshie 2002).

Although farmers in the distant zone were closer to the main market of Arsi Negele and had transformed their landscape for crop production more than had farmers in the two other zones, their crop productivity was not notably higher (Fig. 5a). This questions the validity of the paradigm of the modern conventional approach to agricultural intensification based on landscape simplification and high dependence on external inputs. Conversely, although farmers in the near zone applied equal rates of mineral fertilizers and more manure than did farmers in the two other zones, it had no influence on overall crop productivity (Fig. 5a). This is likely because manure was not spread evenly in the farmland but instead was concentrated in homegardens, which influenced the quality of crop production but not its quantity.

These findings support more integrated landscape approaches to agriculture and food production, which represent a paradigm shift from the modern conventional approach to agricultural productivity (Tscharntke et al. 2005, Sayer et al. 2013). Landscape approaches are based on the interconnections between land uses, including transfer of nutrients from natural and seminatural areas to farmland, as found in this study. Although not investigated here, natural and seminatural areas may also subsidize farmland with beneficial organisms that provide several regulating services, including pollination and pest control (Bianchi et al. 2006, Garibaldi et al. 2013). Through these multiple interactions, landscape approaches may be used to design farming systems that are more sustainable, self-organized (i.e., maintained through energy cycling instead of regular input of energy in the form of mechanical operations and agrochemicals), and often more productive (Tittonell 2014). As illustrated by the findings of this study, landscape approaches could also be one of the foundations of nutrition-sensitive agriculture.

Forest sustaining agriculture: flows of biomass from forest to farms

Munesa Forest subsidized farms in the near zone with an annual flow of biomass that is estimated to be greater than 6 tons per farm, which provided positive effects on the diversity of crop and livestock products in these farms. Livestock played a key role in the transfer of nutrients from Munesa Forest (and other commons) to farms by providing manure. In addition, fuelwood from Munesa Forest (and other commons) allowed for more manure to be available as organic amendment instead of being burned as fuel in the absence of wood energy (Table 5).

The fact that farms from the near zone relied mostly on Munesa Forest for fuel and feed, and not from the zone itself, may explain greater tree cover in this zone compared with the other zones. Similarly, farms from the intermediate zone used a large communal grazing area—located outside the zone—for fuel and feed, which may explain the greater tree cover in this zone compared with the distant zone. Group and individual interviews revealed that most deforestation in the area occurred between 1974 and 1982, when the imperial regime was replaced by a Marxist-Leninist regime that gave "land to the tillers" in Ethiopia. The area was said to be largely forested before that. It appears that deforestation was less intense in the most remote part of the study area (away from the main market of Arsi Negele) where more common resources (e.g., Munesa Forest, large communal grazing areas) were found in the vicinity. The retention of more trees closer to Munesa Forest may also contribute to the productivity and sustainability of farming, through erosion control (Young 1989), nutrient cycling (Chikowo et al. 2003), and regulation of the local climate (Ong et al. 2000). Trees may also provide habitats for beneficiary species, such as natural enemies that prey on yield-reducing pests (Dix et al. 1995). Finally, some tree species may fix atmospheric nitrogen (Danso et al. 1992), or mobilize phosphorus through root exudation or mycorrhiza (Watt and Evans 1999, Smith and Read 2008).

Are the observed transfers of nutrients from Munesa Forest to neighboring farmlands sustainable, or is the forest being mined at an unsustainable rate, thus threatening current farming systems and local diets? Based on the estimated mean quantity of biomass used as fuel and feed by the different farm types in the near zone, the number of farms from each farm type, and the estimated area of forest accessible to farms from the near zone (102 ha), the quantity of biomass harvested from the forest was estimated to be 2.89 tons fuelwood ha^{-1} forest and 1.34 tons feed ha^{-1} forest. Based on the study of Tesfaye (2007), conducted in a dry tropical Afromontane forest near the study area, this could represent a sustainable harvest: he estimated the stem diameter increment to be 6.3–11.6 t ha^{-1} (i.e., more than double the quantity of fuelwood harvested from Munesa Forest estimated in this study) and the herbaceous biomass to be 5.5–6.6 t ha^{-1} (i.e., more than four times the quantity of biomass grazed from Munesa Forest estimated in this study). However, large sections of Munesa Forest showed signs of degradation (Fig. 4c). Thus, the sustainability of the current use of Munesa Forest should be rigorously assessed.

Implications for the design of nutrition-sensitive farms and landscapes

In common with the findings of Ickowitz et al. (2014), but contrary to the thesis of Sibhatu et al. (2015), dietary diversity decreased when market access increased in this study. In remote settings such as the study area, encouraging production diversity will remain a major strategy to increase dietary diversity (Remans et al. 2015).

This study demonstrates that—under certain circumstances—landscape approaches that consider the transfer of nutrients from forests to farmlands may be used as a basis for the design of nutrition-sensitive agriculture. Forests and pastures tend to be areas of accretion of nutrients because they are dominated by perennial plants—trees and perennial grasses—which are characterized by long residence time and deep and dense root

systems, and thus by the ability to capture and recycle more carbon and nutrients than can annual crops (Sanchez et al. 1997). In this study, as in many others conducted in other farming systems around the world (Powell et al. 2004), livestock played the role of vector of nutrients from forests and pastures to croplands where food crops were produced. Thus, although livestock is increasingly portrayed as a growing global environmental threat (see e.g., Steinfeld et al. 2006), it plays an important role in the sustainability of many food production systems, and it contributes to the nutrition of millions of rural people directly, for example, through milk and milk products that are rich in high-quality proteins and micronutrients such as zinc (Young and Pellett 1994, Murphy and Allen 2003), and indirectly through the nutrients they vector to fields and gardens (as demonstrated in this study). However, the use of livestock dung as organic amendment may be prevented if it is used as fuel instead. This study, similar to other studies conducted in Ethiopia (e.g., Duguma et al. 2014, Baudron et al. 2015), demonstrates the link between fuelwood availability and the quantity of manure applied annually.

CONCLUSIONS

In this study, the forest did not serve as a direct source of food products for rural people (aside from the anecdotic wild fruits occasionally eaten by young herders). Nevertheless, the forest was crucial in ensuring a high dietary diversity of rural households living near it by contributing large quantities of feed and fuelwood, which sustained agriculture and in particular ensured regular flows of nutrients to homegardens that locally served as production hot spots of nutrient-dense food items. Forests may also sustain agriculture in other ways, including through pollination, pest control, water regulation, and climate regulation (Foli et al. 2014, Reed et al. 2017).

These interactions have been largely ignored by the land-sparing and land-sharing approaches, which—since the seminal paper of Green et al. (2005)—constitute the main conceptual framework used by policy-makers when looking at the relations between agriculture and nature (Bennett 2017). It may be that positive interactions between forest and agriculture are not taken into account by the framework (which focuses largely on trade-offs) because it has been developed (and is being used) chiefly by conservation ecologists but not by agronomists. The contribution of agronomists to the framework is urgently needed for synergies not to be missed in the design of landscape mosaics that contribute to both biodiversity conservation and human well-being (Reed et al. 2016). In particular, agronomists may contribute to a better selection of proxies of "agricultural yield" when plotting yield-density functions classically used to identify—in a particular context—species that are better suited to land sparing or land sharing. To the best of our knowledge, all the studies using such yield-density functions (e.g., Green et al. 2005, Kleijn et al. 2009, Clough et al. 2011, Phalan et al. 2011, Gabriel et al. 2013) have used crop productivity as the proxy of farming intensity/human well-being and have found strong trade-offs between maintaining biodiversity and increasing agricultural production/human well-being. From the results of this study, very different results would probably be obtained if livestock productivity, fuel availability, or dietary diversity were used as proxies of farming intensity/human well-being instead of crop productivity (synergies instead of trade-offs).

The case of rural households living at the periphery of Munesa Forest is probably not isolated, and forests no doubt contribute in a similar way to the diet of millions of rural households living at the periphery of forests in developing countries. For these forests, which are often managed as common pool resources, to continue to play their key role of supporting rural livelihoods in areas that are often sustaining rapid land use changes, policy and institutions will have to be crafted to ensure they are managed sustainably (e.g., through self-governance) (Ostrom et al. 1992) and do not fall victims to the "tragedy of the commons" (Hardin 1968).

We conclude that nutrition-sensitive agriculture in remote rural settings that are dominated by mixed crop–livestock systems may be achieved through a combination of landscape management (and in particular the retention of patches of forest and pastures), livestock management (to transfer nutrients from forest and pastures to farmlands), and household energy management (i.e., guaranteeing alternative fuel sources to livestock dung).

Responses to this article can be read online at:
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APPENDIX 1. Summary of the results of Model 1 (see text) for explaining the variability in the frequency of consumption (number of days per week) of cereals, grains and grain products, roots and tubers, pulses, vegetables, meat and animal products, and fruits. Significant effects (P < 0.05) are shown in bold.

Model variables	Cereals, grains and grain products		Roots and tubers		Pulses		Vegetables		Meat and animal products		Fruits	
	t value	*P value*	t value	*P value*	t value	*P value*	t value	*P value*	t value	*P value*	t value	*P value*
Intercept	0.637	*0.5240*	1.862	*0.0626*	-0.642	*0.5209*	1.007	*0.3138*	-0.166	*0.8682*	2.626	***0.0086***
Zone	-0.769	*0.4418*	-2.308	***0.0210***	-1.397	*0.1625*	-1.812	*0.0699*	1.940	***0.0524***	-2.664	***0.0077***
Elevation	-0.485	*0.6277*	-3.163	***0.0016***	-2.001	***0.0454***	-0.059	*0.9530*	1.386	*0.1657*	-5.353	***< 0.0001***
Distance to nearest forest patch > 0.5 ha	-0.890	*0.3736*	1.204	*0.2284*	-0.197	*0.8440*	-1.847	*0.0647*				
Distance to nearest forest patch > 0.25 ha	0.773	*0.4394*	-0.470	*0.6381*	1.464	*0.1432*	1.592	*0.1115*				
Distance to nearest grassland patch > 0.5 ha	-0.170	*0.8653*	4.040	***0.0001***	2.479	***0.0132***	1.212	*0.2253*			-2.968	***0.0030***
Distance to nearest grassland patch > 0.25 ha	-0.365	*0.7148*	-2.892	***0.0038***	0.210	*0.8334*	-1.788	*0.0738*	-1.172	*0.2411*	1.921	*0.0548*
Distance to nearest road	0.168	*0.8664*	0.175	*0.8612*	-2.397	***0.0165***	-0.341	*0.7331*	0.420	*0.6748*	0.027	*0.9782*
Sex of the head of the household			1.735	*0.0828*	-0.835	*0.4039*	-0.706	*0.4800*	0.767	*0.4432*	-0.496	*0.6200*
Age of the head of the household	0.820	*0.4121*	2.051	***0.0403***	0.918	*0.3585*	0.353	*0.7242*	-0.498	*0.6185*	-2.844	***0.0044***
Family size	-0.258	*0.7967*	0.922	*0.3566*	0.580	*0.5620*	0.187	*0.8517*	0.617	*0.5372*	1.304	*0.1921*
Head of the household schooled	0.284	*0.7766*	1.757	*0.0790*	-2.521	***0.0117***	1.222	*0.2219*	-1.692	*0.0906*	-1.825	*0.0680*
Tertiary education			0.326	*0.7441*	2.481	***0.0131***	1.049	*0.2942*	2.922	***0.0035***	0.705	*0.4811*
Remittances	-0.143	*0.8866*	0.700	*0.4836*	1.936	*0.0528*	1.141	*0.2538*	-0.516	*0.6057*	0.692	*0.4887*
Paid work	-0.799	*0.4243*	1.640	*0.1010*			0.594	*0.5523*	-0.171	*0.8643*	0.114	*0.9090*
Year land was cleared	-0.547	*0.5843*	0.109	*0.9132*	1.493	*0.1354*	-1.040	*0.2982*	0.393	*0.6946*	0.136	*0.8919*
Year farming started	0.491	*0.6235*	-0.111	*0.9117*	1.232	*0.2179*	-0.229	*0.8192*	-2.081	***0.0374***	1.629	*0.1034*
Farm area	1.633	*0.1024*	-1.481	*0.1385*	0.928	*0.3533*	2.029	***0.0424***	-2.056	***0.0398***	-4.059	***< 0.0001***
Zone × Elevation			3.513	***0.0004***	3.126	***0.0018***	1.292	*0.1964*	-2.244	***0.0249***	3.289	***0.0010***
Zone × Distance to nearest forest patch > 0.5 ha	0.898	*0.3694*	-1.101	*0.2709*	0.079	*0.9373*	1.856	*0.0635*				
Zone × Distance to nearest forest patch > 0.25 ha	-0.816	*0.4147*	0.723	*0.4696*	-1.455	*0.1458*	-1.575	*0.1153*				
Zone × Distance to nearest grassland patch > 0.5 ha	0.256	*0.7976*	-4.283	***< 0.0001***	-1.008	*0.3133*	-0.986	*0.3239*			3.577	***0.0003***

(con'd)

Zone × Distance to nearest grassland patch > 0.25 ha	0.543	*0.5872*	3.197	***0.0014***	-0.896	*0.3700*	1.281	*0.2002*	1.342	*0.1796*	-2.333	***0.0196***
Zone × Family size	0.149	*0.8813*	-0.797	*0.4252*	-1.065	*0.2868*	-0.039	*0.9687*	-0.294	*0.7688*	-0.788	*0.4307*
Zone × Head of the household schooled	-0.130	*0.8966*	-2.206	***0.0274***	3.322	***0.0009***	-0.202	*0.8398*	2.315	***0.0206***	1.488	*0.1367*
Zone × Tertiary education			0.889	*0.3739*	-2.690	***0.0071***	-1.139	*0.2545*	-1.870	*0.0615*	-0.084	*0.9333*
Zone × Remittances	0.129	*0.8971*	-0.661	*0.5086*	-2.392	***0.0168***	-1.147	*0.2515*	1.292	*0.1964*	-0.636	*0.5250*
Zone × Paid work												
Zone × Year land was cleared	0.758	*0.4487*	-0.335	*0.7377*	-1.218	*0.2232*	1.335	*0.1818*	-0.727	*0.4670*	0.466	*0.6412*
Zone × Farm area	-1.666	*0.0956*	1.515	*0.1298*	-0.975	*0.3294*	-2.104	***0.0354***	2.084	***0.0372***	3.978	***0.0001***

APPENDIX 2. Summary of the results of Model 2 (see text) for explaining the variability in the frequency of consumption (number of days per week) of cereals, grains and grain products, roots and tubers, pulses, vegetables, meat and animal products, and fruits. Significant effects (P < 0.05) are shown in bold (Homegarden: presence of absence of a homegarden, TLU: Tropical Livestock Unit).

Model variables	Cereals, grains and grain products		Roots and tubers		Pulses		Vegetables		Meat and animal products		Fruits	
	t value	*P value*	t value	*P value*	t value	*P value*	t value	*P value*	t value	*P value*	t value	*P value*
Intercept	-0.554	*0.5800*	-0.351	*0.7254*	-2.134	***0.0328***	-0.202	*0.8400*	0.676	*0.4990*	-3.004	***0.0027***
Homegarden	0.479	*0.6320*	6.357	***< 0.0001***	2.175	***0.0296***			1.153	*0.2488*	3.679	***0.0002***
Cattle (TLU)	-0.762	*0.4460*	1.030	*0.3032*	-2.005	***0.0449***	-0.111	*0.9115*	0.127	*0.8988*		
Sheep and goats (TLU)	0.405	*0.6850*	3.166	***0.0015***	2.161	***0.0307***	-0.331	*0.7404*	1.867	*0.0619*	4.686	***< 0.0001***
Equines (TLU)	0.691	*0.4900*	-2.155	***0.0312***	2.508	***0.0122***	1.856	*0.0634*	-2.173	***0.0298***	-0.473	*0.6363*
Beehives			4.246	***< 0.0001***	0.314	*0.7532*	0.485	*0.6277*	2.625	***0.0087***	1.411	*0.1583*
Chicken	0.330	*0.7410*	1.170	*0.2421*	1.100	*0.2713*	-0.700	*0.4837*	-0.601	*0.5479*	0.706	*0.4799*
Sex of the head of the household												
Age of the head of the household												
Family size	-0.505	*0.6140*	3.214	***0.0013***	0.695	*0.4869*			2.904	***0.0037***	3.164	***0.0016***
Head of the household schooled			-1.126	*0.2600*	1.782	*0.0747*	3.543	***0.0004***	1.772	*0.0765*	0.657	*0.5109*
Tertiary education	0.676	*0.4990*	3.638	***0.0003***	0.286	*0.7750*	-0.501	*0.6166*	3.082	***0.0021***	2.942	***0.0033***
Remittances	0.339	*0.7350*	3.424	***0.0006***	0.628	*0.5302*	-0.826	*0.4087*	2.690	***0.0071***	1.775	*0.0758*
Paid work	-1.023	*0.3060*	0.362	*0.7172*	-0.515	*0.6065*	0.760	*0.4470*	-0.638	*0.5232*	-0.567	*0.5704*
Year land was cleared	0.780	*0.4350*	0.165	*0.8690*	1.623	*0.1046*	0.458	*0.6472*	0.846	*0.3975*	1.924	*0.0544*
Year farming started	0.441	*0.6600*	0.245	*0.8061*	1.387	*0.1655*	0.151	*0.8801*	-1.791	*0.0732*	2.202	***0.0277***
Homegarden × Cattle (TLU)	0.784	*0.4330*	-0.884	*0.3767*	1.000	*0.3175*	-0.525	*0.5994*	0.187	*0.8516*		
Homegarden × Sheep and goats (TLU)	-0.162	*0.8710*	-1.917	*0.0552*	-1.480	*0.1389*	-0.198	*0.8428*	-1.264	*0.2059*	-3.729	***0.0002***
Homegarden × Equines (TLU)	-0.620	*0.5350*	1.945	*0.0517*	-1.873	*0.0610*	-2.004	***0.0451***	2.476	***0.0133***	0.688	*0.4911*
Homegarden × Beehives			-4.084	***< 0.0001***	-0.530	*0.5963*	-0.723	*0.4695*	-2.940	***0.0033***	-1.422	*0.1550*
Homegarden × Chicken	-0.273	*0.7850*	-2.403	***0.0163***	-0.554	*0.5795*	1.223	*0.2214*	0.470	*0.6380*	0.937	*0.3486*

APPENDIX 3. Summary of the results of Model 1 (see text) for explaining the variability in the frequency of consumption (number of days per week) of milk and milk products, fats and oil, spices and condiments, sugar, sugar products and honey, and snack and processed foods. Significant effects (P < 0.05) are shown in bold.

Model variables	Milk and milk products		Fats and oil		Spices and condiments		Sugar, sugar products and honey		Snack and processed foods	
	t value	*P value*	t value	*P value*	t value	*P value*	t value	*P value*	t value	*P value*
Intercept	0.241	*0.8092*	0.678	*0.4980*	-0.917	*0.3590*	1.666	*0.09-57*	4.735	*< 0.0001*
Zone			-1.027	*0.3040*	0.855	*0.3920*	-3.157	***0.00-16***	-4.345	*< 0.0001*
Elevation	-1.321	*0.1865*	-0.636	*0.5250*	0.730	*0.4650*	-4.195	***< 0.00-01***	-4.057	*< 0.0001*
Distance to nearest forest patch > 0.5 ha	0.675	*0.4995*	-0.522	*0.6020*			4.056	***< 0.00-01***		
Distance to nearest forest patch > 0.25 ha			0.449	*0.6530*	0.178	*0.8590*	0.377	*0.70-58*		
Distance to nearest grassland patch > 0.5 ha	-0.899	*0.3687*	-0.123	*0.9020*	0.238	*0.8120*	-1.067	*0.28-61*	-0.216	*0.8293*
Distance to nearest grassland patch > 0.25 ha	0.495	*0.6209*	-0.475	*0.6350*	-0.421	*0.6730*	-0.777	*0.43-71*	1.573	*0.1158*
Distance to nearest road	1.152	*0.2494*	-0.321	*0.7490*	-0.611	*0.5410*	-1.482	*0.13-83*	0.079	*0.9368*
Sex of the head of the household	0.380	*0.7041*	-0.155	*0.8770*			-0.590	*0.55-49*	-0.566	*0.5711*
Age of the head of the household	1.982	***0.0475***	-0.284	*0.7760*			0.874	*0.38-23*	-2.575	***0.0100***
Family size	0.471	*0.6376*			-0.335	*0.7370*	0.906	*0.36-50*	3.439	***0.0006***
Head of the household schooled	-0.875	*0.3818*	-0.534	*0.5930*	-0.225	*0.8220*	0.470	*0.63-86*	-2.197	***0.0280***
Tertiary education	2.924	***0.0035***	0.228	*0.8190*	-0.153	*0.8780*	1.742	*0.08-15*	3.571	***0.0004***
Remittances	0.741	*0.4589*	-0.805	*0.4210*	-1.175	*0.2400*	0.589	*0.55-62*		
Paid work	-2.010	***0.0445***	-0.104	*0.9170*			1.008	*0.31-36*	-0.514	*0.6074*
Year land was cleared	0.798	*0.4252*	-0.622	*0.5340*			0.270	*0.78-69*	-2.743	*0.0061*
Year farming started	0.119	*0.9049*	0.766	*0.4430*	1.010	*0.3120*	0.803	*0.42-18*	-1.354	*0.1759*
Farm area	-3.297	***0.0010***	1.149	*0.2510*	0.211	*0.8330*	-4.866	***< 0.00-01***	-1.348	*0.1778*
Zone × Elevation	1.922	*0.0546*					5.082	***< 0.00-01***	4.362	*< 0.0001*
Zone × Distance to nearest forest patch > 0.5 ha	-1.186	*0.2356*	0.559	*0.5760*						
Zone × Distance to nearest forest patch > 0.25 ha	1.401	*0.1612*	-0.449	*0.6540*	-0.128	*0.8980*	-0.252	*0.80-10*		

(con'd)

	Estimate	p	Estimate	p	Estimate	p	Estimate	p	Estimate	p
Zone × Distance to nearest grassland patch > 0.5 ha	0.718	*0.4728*	0.178	*0.8580*	-0.315	*0.7530*	2.197	***0.0280***	-0.015	*0.9877*
Zone × Distance to nearest grassland patch > 0.25 ha	0.816	*0.4147*	0.413	*0.6800*	0.560	*0.5750*	-0.618	*0.5364*	-1.949	*0.0513*
Zone × Family size	-0.359	*0.7199*	0.183	*0.8550*	0.186	*0.8520*	-1.357	*0.1747*	-3.041	***0.0024***
Zone × Head of the household schooled	1.539	*0.1237*	0.463	*0.6430*	0.307	*0.7590*	0.117	*0.9068*	1.759	*0.0786*
Zone × Tertiary education	-2.618	***0.0089***	-0.614	*0.5390*	0.334	*0.7380*	-0.745	*0.4563*	-3.220	***0.0013***
Zone × Remittances	-1.309	*0.1906*	0.583	*0.5600*	0.990	*0.3220*	-0.881	*0.3783*		
Zone × Paid work										
Zone × Year land was cleared	-2.056	***0.0398***	0.990	*0.3220*	-0.860	*0.3900*	-0.683	*0.4946*		
Zone × Farm area	3.439	***0.0006***	-1.175	*0.2400*	-0.180	*0.8570*	4.910	***< 0.0001***	1.387	*0.1654*

APPENDIX 4. Summary of the results of Model 2 (see text) for explaining the variability in the frequency of consumption (number of days per week) of milk and milk products, fats and oil, spices and condiments, sugar, sugar products and honey, and snack and processed foods. Significant effects (P < 0.05) are shown in bold (Homegarden: presence of absence of a homegarden, TLU: Tropical Livestock Unit).

Model variables	Milk and milk products		Fats and oil		Spices and condiments		Sugar, sugar products and honey		Snack and process foods	
	t value	*P value*	t value	*P value*	t value	*P value*	t value	*P value*	t value	*P value*
Intercept	-0.486	*0.6272*	-0.775	*0.4390*	0.357	*0.7210*	-0.059	*0.9533*	3.481	***0.0005***
Homegarden	6.139	***< 0.0001***	0.581	*0.5610*			3.153	***0.0016***	1.907	*0.0565*
Cattle (TLU)	4.784	***< 0.0001***	-0.832	*0.4050*	0.486	*0.6270*	2.035	***0.0418***	-1.744	*0.0812*
Sheep and goats (TLU)	2.689	***0.0072***	0.427	*0.6700*	0.277	*0.7820*	2.477	***0.0133***		
Equines (TLU)	-2.131	***0.0331***	0.626	*0.5310*	0.193	*0.8470*	-2.040	***0.0414***	3.005	***0.0027***
Beehives	3.800	***0.0001***	0.195	*0.8450*	0.264	*0.7920*	1.746	*0.0808*		
Chicken	0.281	*0.7787*	0.909	*0.3630*	-0.597	*0.5510*	1.130	*0.2587*	-2.172	***0.0299***
Sex of the head of the household										
Age of the head of the household										
Family size	1.650	*0.0990*	-0.497	*0.6190*	-0.410	*0.6820*	1.340	*0.1801*	-1.852	*0.0641*
&;Head of the household schooled	-0.295	*0.7679*			0.521	*0.6020*	0.478	*0.6323*	1.387	*0.1656*
Tertiary education	2.038	***0.0416***	-0.722	*0.4700*	0.591	*0.5550*	2.547	***0.0109***	3.267	***0.0011***
Remittances	0.674	*0.5004*	-0.351	*0.7260*	-1.056	*0.2910*	1.331	*0.1831*	2.217	***0.0266***
Paid work	-3.431	***0.0006***	-0.425	*0.6710*	0.454	*0.6500*	0.424	*0.6716*	-1.938	*0.0527*
Year land was cleared	0.456	*0.6481*	0.855	*0.3930*	-0.724	*0.4690*	-0.653	*0.5140*	-2.573	***0.0101***
Year farming started			0.629	*0.5290*	0.653	*0.5140*	0.833	*0.4046*	-1.987	***0.0469***
Homegarden × Cattle (TLU)	-3.086	***0.0020***	1.172	*0.2410*	-0.309	*0.7580*	-1.557	*0.1195*	1.639	*0.1012*
Homegarden × Sheep and goats (TLU)	-2.112	***0.0347***	-0.455	*0.6490*			-2.179	***0.0293***		
Homegarden × Equines (TLU)	2.048	***0.0406***	-0.384	*0.7010*	-0.142	*0.8870*	1.693	*0.0905*	-2.460	***0.0139***
Homegarden × Beehives	-3.612	***0.0003***	-0.194	*0.8460*	-0.235	*0.8140*	-1.713	*0.0868*		
Homegarden × Chicken	0.595	*0.5518*	-1.033	*0.3020*	0.288	*0.7730*	0.230	*0.8179*		

APPENDIX 5. Summary of the results of Model 1 (see text) for explaining the variability presence/absence of a homegarden and crop diversity in homegarden. Significant effects (P < 0.05) are shown in bold.

Model variables	Presence/Absence of a homegarden		Crop diversity in homegarden	
	t value	*P value*	t value	*P value*
Intercept	0.263	*0.7923*	1.745	*0.0833*
Zone	-1.338	*0.1810*		
Elevation	1.135	*0.2565*	0.404	*0.6871*
Distance to nearest forest patch > 0.5 ha			0.631	*0.5290*
Distance to nearest forest patch > 0.25 ha	-0.481	*0.6305*	-0.972	*0.3330*
Distance to nearest grassland patch > 0.5 ha	-1.375	*0.1692*	1.964	***0.0516***
Distance to nearest grassland patch > 0.25 ha	1.069	*0.2849*		
Distance to nearest road	0.155	*0.8768*	0.947	*0.3455*
Sex of the head of the household	-0.327	*0.7438*	-0.167	*0.8676*
Age of the head of the household	-0.278	*0.7811*	0.980	*0.3289*
Family size	2.494	***0.0126***	0.114	*0.9091*
Head of the household schooled	-1.467	*0.1425*	-0.556	*0.5789*
Tertiary education	0.318	*0.7502*	1.374	*0.1718*
Remittances	-0.343	*0.7317*	1.090	*0.2776*
Paid work	0.254	*0.7994*	0.660	*0.5103*
Year land was cleared	-1.324	*0.1855*	-1.684	*0.0946*
Year farming started	1.494	*0.1351*	-0.296	*0.7680*
Farm area	2.134	***0.0328***	2.565	***0.0114***
Zone × Elevation	0.770	*0.4411*	-1.736	*0.0849*
Zone × Distance to nearest forest patch > 0.5 ha			-0.691	*0.4906*
Zone × Distance to nearest forest patch > 0.25 ha	0.298	*0.7654*		
Zone × Distance to nearest grassland patch > 0.5 ha				
Zone × Distance to nearest grassland patch > 0.25 ha	-0.446	*0.6558*	3.320	***0.0012***
Zone × Family size	-2.083	***0.0372***	-0.128	*0.8981*
Zone × Head of the household schooled	1.717	*0.0860*	0.494	*0.6223*
Zone × Tertiary education	-0.350	*0.7265*	-1.502	*0.1355*
Zone × Remittances	0.241	*0.8093*	-0.866	*0.3881*
Zone × Paid work				
Zone × Year land was cleared	1.104	*0.2695*	1.773	*0.0786*
Zone × Farm area	-1.549	*0.1213*	-2.607	***0.0102***

APPENDIX 6. Summary of the results of Model 2 (see text) for explaining the variability presence/absence of a homegarden and crop diversity in homegarden. Significant effects (P < 0.05) are shown in bold (Enset: presence of absence of enset in the homegarden, TLU: Tropical Livestock Unit).

Model variables	Presence/Absence of a homegarden		Crop diversity in homegarden	
	t value	*P value*	t value	*P value*
Intercept	-1.821	*0.0686*	0.541	*0.5897*
Enset			-4.949	***< 0.0001***
Cattle (TLU)			-0.795	*0.4280*
Sheep and goats (TLU)	2.448	***0.0143***	-0.667	*0.5061*
Equines (TLU)			-1.636	*0.1042*
Beehives			-1.751	*0.0821*
Chicken	0.789	*0.4300*	0.434	*0.6650*
Sex of the head of the household				
Age of the head of the household				
Family size	4.898	***< 0.0001***	-1.010	*0.3142*
Head of the household schooled	0.707	*0.4795*	-1.187	*0.2371*
Tertiary education			0.836	*0.4044*
Remittances			1.082	*0.2810*
Paid work	0.098	*0.9217*	0.306	*0.7603*
Year land was cleared	0.154	*0.8773*	0.216	*0.8290*
Year farming started	2.058	***0.0396***	-0.493	*0.6231*
Enset × Cattle (TLU)			1.212	*0.2274*
Enset × Sheep and goats (TLU)			0.657	*0.5123*
Enset × Equines (TLU)			1.329	*0.1861*
Enset × Beehives				
Enset × Chicken			-0.431	*0.6674*