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Does dairy intensification threaten livelihood diversity in East Africa?

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ABSTRACT

Intensifying smallholder dairy farming can reduce global greenhouse gas emissions and increase food production on existing croplands. Much public policy therefore assumes that dairy intensification reduces emissions per unit of production, while simultaneously improving both rural incomes and food security. Whether the hypothesized social co-benefits of intensification manifest in practice has not however been fully empirically validated. Because intensification is labor and capital intensive, resource diversions may occur that could make rural livelihoods more specialized. This in turn could threaten dietary diversity and smallholder resilience to shocks. In this article, we accordingly examine the relationship between dairy intensification, livelihood diversity, nutrition diversity, and wellbeing, drawing on primary research conducted in two developing countries, Kenya and Tanzania, with vibrant smallholder dairy sectors. We find that dairy intensification by and large enhances livelihood diversity, nutritional diversity, and wealth. These findings suggest that for dairy, intensification and diversification may be complementary livelihood strategies.

1. Introduction

The global development community increasingly prioritizes the reduction of greenhouse gas (GHG) emission intensities from agriculture, with special attention to livestock production systems (Herrero et al., 2016; Uwizeye et al., 2020). At the same time, raising the productivity of smallholder farmers who continue to struggle to make a living and achieve food security through agriculture remains high on the policy agenda (Gomez y Paloma et al., 2020). Low emission development strategies (LEDS), generally understood as 'forward-looking national development plans or strategies that encompass low-emission and/or climate-resilient economic growth' (Clapp et al., 2010: 13), are viewed as a particularly promising avenue for reconciling these two priorities.

In East Africa, LEDS are increasingly being applied to dairy production for their potential to deliver win-win-win outcomes. By raising productivity through the dissemination of climate-smart production practices, national dairy output increases, emission intensities go down, and dairy farmers' incomes go up. Emission intensities are particularly high in the East African dairy sector because of poor animal feeding, manure management, herd management, and animal health practices and can be addressed by strengthening public extension and building a more dynamic service sector (Ericksen and Crane, 2018). Consequently, the sector has become a prime target for delivering on both national poverty reduction and climate change mitigation targets.

While there is evidence to suggest that emission intensities and productivity are typically inversely correlated (Havlík et al., 2014), whether LEDS-inspired intensification yields expected socio-economic gains is less clear. Intensifying dairy may, for example, require households to divert land, labor, and capital from other livelihood activities. This could threaten household food security and livelihood resilience when household ability to allocate assets to other critical sources of food and income is reduced (e.g. Megersa et al., 2014). East African dairy farmers generally produce dairy within diversified crop-livestock systems with a plethora of on- and off-farm activities contributing in unique and complementary ways to livelihoods (Acosta et al., 2021). Such systems allow households to spread risk and produce for both consumption and income (Waha et al., 2018). The socio-ecological merits of crop-livestock systems are well recognized by the development community. Recent attention paid to lowering GHG emissions may,

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however, disrupt the equilibrium of these systems (Tavenner et al., 2019). The political thrust toward dairy intensification, for example, may inadvertently reduce both the ability and imperative to continue managing diversified and integrated farming.

By exploring the interaction between dairy intensification, livelihood diversification, and household wellbeing, this article speaks to this dilemma. While intensification can be interpreted in many ways (Pretty, 2018; Rockström et al., 2017), for dairy it generally means producing more milk per year per cow. Intensification can lead to specialization (Ellis, 2000; Iiyama et al., 2008), specialization being: "… the process of concentrating resources (land, labor, and capital) on producing a limited variety of goods." (Abson, 2018: 301). Diversification strategies are typically motivated by risk reduction, utilization of idle resources, and social motivations (Hansson et al., 2013; Northcote and Alonso, 2011; Rider Smith et al., 2001). Because specialization can enhance farmer exposure to shocks, from a climate change adaptation perspective, diversification and mixed farming is typically stimulated (Andersson Djurfeldt et al., 2018; Mulwa and Visser, 2020; Macours et al., 2012). Some studies suggest that to reduce poverty, emphasis should be placed on increasing returns to existing baskets of livelihood activities rather than encouraging households to disproportionately invest in one (Iiyama et al., 2008; Dagunga et al., 2020). For dairy, encouraging households to produce more milk per cow may inadvertently divert resources from other activities. However, the debate about household specialization or diversification remains active and unanswered with supportive arguments for both – and combinations of strategies (de Roest et al., 2018).

In this article, we explore whether dairy intensification drives specialization and consequently threatens household wellbeing. We hypothesize that dairy intensification leads to livelihood specialization, which in turn reduces dietary diversity as less time and capital is invested in subsistence cropping. The ability to effectively accumulate assets may particularly become challenging in contexts of price fluctuations in input and output markets, environmental degradation of the natural environment and consequently increased vulnerability to cattle and crop diseases and failures. We contend that because dairy intensification is so labor- and capital-intensive, considerable household human and financial capital could get locked up by dairy, thereby necessitating specialization. As households become more reliant on purchased inputs and the household cost burden subsequently goes up, we fear that the household's ability to acquire other instrumental livelihood assets is undermined. Moreover, because on-farm feed production is also land-extensive, households may well need to produce fewer food crops, thereby threatening household dietary diversity.

To test our hypothesis about dairy intensification leading to livelihood specialization, which in turn reduces dietary diversity as less time and capital is invested in subsistence cropping, we conducted 2250 semi-structured interviews with dairy households across seven study sites in Kenya and Tanzania. In this article, we use the data from these surveys to model the relationship between intensification and diversification and household well-being. Specifically, through a multinomial treatment effect model, we estimate the effects of three levels of intensification on livelihood diversity, nutritional security, and wealth. We opted for a model that can control for endogeneity since we can reasonably assume that assignment to specific intensification regimes is non-random.

2. Literature review

Intensification is depicted as an endogenous response to rising population pressure, as originally posited by Boserup (1965). Decreasing land-to-population ratios can prompt farmers to adopt technologies that enhance land productivity to overcome relative factor price changes (e.g. Theory of Induced Innovation, Ruttan and Hayami, 1984, also see Baltenweck et al., 2003). Studies about determinants of and motivations for diversification (e.g. Alobo Loison, 2015; Ellis, 2000) and intensification (e.g. Pretty, 2018; Rudel, 2020) infer that concentrating productive resources on certain farm activities (e.g. specializing or intensifying) reduces the ability to diversify when productive resources up and cannot any longer be utilized for other activities. Some contend that diversification and intensification do not take place along distinct pathways, however. Rather, rural communities can be characterized by 'multiplex livelihoods' (Bryceson, 2002) and multifaceted livelihood pathways, which constitute "a complex *bricolage* or portfolio of activities" (Scoones, 2009: 172, italics in the original). This suggests that diversification and intensification are not necessarily conflicting strategies and can be mutually supportive - in contrast to early sustainable rural livelihoods literature depicting these as distinct livelihood strategies (Scoones, 1998). The literature below presents studies that explores the interplay between agricultural diversification and intensification strategies, which forms a niche in a broader debate about livelihood diversification and specialization (see e.g. de Roest et al., 2018).

Most empirical research on intensification and diversification study these as separate strategies, with distinctive motivations and determinants (e.g. Boncinelli et al., 2017; Andersson Djurfeldt et al., 2021; Klasen et al., 2016; Smith et al., 2019; Clay et al., 2020). A small number do explore their interplay. A study about ecosystem outcomes and intensification processes shows how highly diversified systems can still be highly intensive (Rasmussen et al., 2018). They also show that higher input use such as fertilizers, irrigation, seeds, and labor might even encourage diversification when there are opportunities for polyculture. This applies to, for example, integrated fish and rice farming (Berg et al., 2012), integrated rice and fruit production (such as mango) (Rahman et al., 2016), and vegetable diversification (Agoramoorthy et al., 2012; Seck et al., 2005). Research on the intensification-diversification relationship is sparse for non-polycultural systems, with evidence to support recent views on their complementary functions largely missing. Even though intensification features highly on many policy agendas and can, theoretically, be risky to smallholder livelihoods, the lack of attention to the intensification-diversification interplay is concerning for praxis too.

In a similar vein, how diversification and specialization strategies compare concerning their poverty alleviation potential is also unclear. A literature review of rural livelihood diversification strategies in Sub-Saharan Africa provides mixed results. For instance, Alobo Loison (2015) suggests that due to asset constraints, the large majority of smallholders have not (yet) meaningfully benefitted from diversification, but this depends on context. De Roest et al. (2018) show that diversified farms are often as or more profitable than specialized farms, with specialization strategies often weakening economic resilience due to excessive exposure to market volatility.

Research on the outcome of intensification paints a rosier picture, with agricultural intensification often shown to positively impact household income (Rasmussen et al., 2018). Research from Northern Ghana shows how food security can improve as a result (Yahaya et al., 2018), but the authors point to the unique conditions in this area. Research from Rwanda suggests nutritional diversity may still be observed as a result of intensification (Del Prete et al., 2019). For dairy specifically, results are more mixed, with dairy intensification in Africa shown to have both positive and negative effects on income (Ahmed et al., 2000; Hoddinott et al., 2015). In a study specific to East Africa, Kebebe (2017) does find a generally positive effect of dairy intensification on both household income and nutritional diversity but shows that benefits are not evenly distributed, with marginalized producers less likely to benefit from intensification.

3. Materials and methods

3.1. Study sites

This research was carried out in Kenya and Tanzania, where dairy is a leading agricultural sector and contributes to rural livelihoods. Across the two countries, over 80% of milk comes from smallholders, and more than half of rural households own cattle. Kenya's dairy subsector contributes 4% to the Gross Domestic Product (GDP), while Tanzania's dairy sector contributes 1.5% to GDP. In the region, Kenya has a high milk consumption at 110 L per person per year, while Tanzanians consume 45 L on average (Katjiuongua and Nelgen, 2014). Milk consumption is rising in both countries, and increased management practices can bridge supply gaps, especially among smallholders who often use low-input, low-output strategies.

Research activities were performed across seven sites capturing a wide array of agroecological, geographic, and market conditions, namely in three counties in Kenya and four districts in Tanzania (Fig. 1). In Kenya, the study sites include Nandi, Bomet, and Murang'a counties. Nandi and Bomet are both located within the former Rift Valley Province and are dominated by semi-intensive livestock systems. While milk is mostly sold informally, several large processors source from these counties The third county, Murang'a, is dominated by more intensive dairy systems. Located in the former Central Province, population pressure is comparatively high and markets are more formalized (Vernooij et al., 2023). Tea is an important cash crop in the counties, and maize, beans and potatoes are common food crops. Current dairy farming practices in the areas are shaped by combinations of the presence or absence of large milk markets, population pressure and subsequent land availability, and while this study focusses at household level, contextual factors are crucial as elaborated for these study sites in Vernooij et al. (2024).

In Tanzania, the study sites include the Mvomero district in the Morogoro region, Mufindi district in the Iringa region, Njombe district in the Njombe region, and Rungwe district in the Mbeya region. In Rungwe, smallholders produce dairy within intensive and semi-intensive systems, alongside crops such as bananas and maize, and dairy production is commercialized. The district's milk market is dominated by well-organised farmer cooperatives, which aggregate milk for a private milk factory and the area's many informal milk traders. There is a critical mass of milk producers, with frequent supply gluts during wet seasons that depress prices (Kihoro et al., 2021). Njombe's dairy sector is more intensified from over 30 years of dairy development interventions, which produced a well-established farmer cooperative and milk processing plant. The main cash crop is tea, and food crops include maize and potatoes. Mufindi has semi-intensive systems but lacks a dynamic milk market and is more crop oriented. With fewer milk producers, most of the milk in sold to neighbours and through informal channels. Mvomero has a wider range of dairy systems, with pastoralists keeping cows within extensive systems and mixed crop farmers keeping cattle under intensive or semi-intensive systems. Milk availability fluctuates significantly throughout the seasons: there is excess supply during the wet season, with shortage but higher prices prevailing in the dry season. Additionally, the composition of milk buyers varies seasonally, with local traders dominating during the dry season and milk processors purchasing higher volumes during the wet season.

3.2. Surveying activities

Data were collected from 2250 households using a structured questionnaire. Households were sampled using a two-staged approach. First, a spatial cluster analysis was performed on each administrative unit to capture internal agroecological variabilities shaping dairy practices. Using spatially explicit rainfall, temperature, and elevation data, each unit was clustered into three zones representing different levels of agroecological suitability. 36 locations were randomly selected across the three clusters in every administrative unit, with several locations per cluster proportionate to the relative size of each cluster. Villages closest to each location were selected for inclusion in our surveying activities. Households were then randomly sampled in each village, based on sample frames constructed in collaboration with local authorities and leaders, with the number of farmers sampled per village informed by the relative size of each sample frame.

The administered questionnaire was loosely based on the Rural Household Multi-Indicator Survey (Hammond et al., 2017). Topics covered in the questionnaire relate to, amongst others: (1) household demographics; (2) household assets; (3) livelihood activities; (4) dairy and crop management practices; (5) milk marketing; (6) production output, revenues and costs; and (7) household psycho-social attributes. Following data cleaning, 2069 households were retained for our analysis (978 in Kenya and 1091 in Tanzania). More information about the (spatial) sampling strategy and survey instrument can be found in Kihoro et al. (2021). In addition to the surveying activities, the authors also conducted validation workshops and extensive qualitative research in the study sites that support the interpretation of results (see Kihoro

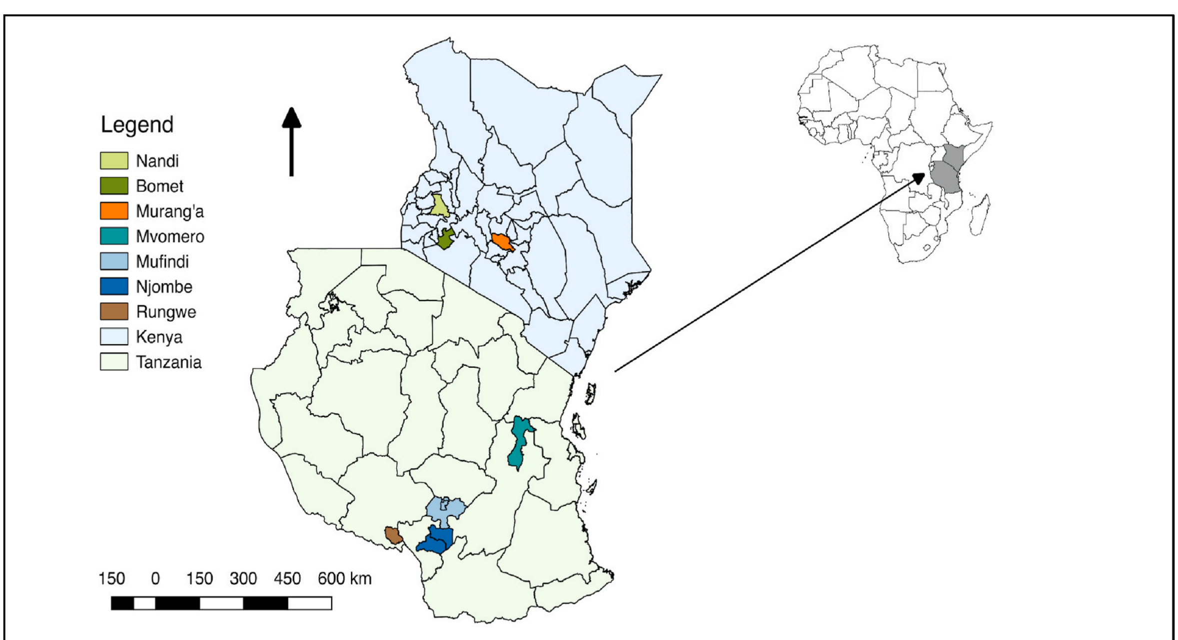

Fig. 1. Study sites.

et al., 2021; Vernooij et al., 2024).

3.3. Analytical framework

We explored the relationship between household diversification and dairy intensification and related household welfare outcomes; specifically, wealth and dietary diversity. We do that by specifying a multinomial treatment effect model using the user-written *mtreatreg* package in STATA 15 that is estimated by maximum simulated likelihood. The two-stage model estimates the effect of endogenous multinomial treatments on continuous, count, and binary outcome variables. Such a model is considered appropriate for capturing multiple intensification levels while correcting for endogeneity problems. We assume that our multinomial treatment variable (intensification) is endogenous since allocation to a specific intensification regime is expected to be non-random.

In our model, the first stage consists of a multinomial selection equation that models household allocation to one of three intensification regimes, namely intensive, semi-intensive, or extensive. Regime allocation is determined by the adoption of two critical production practices: zero-grazing and keeping of improved dairy cows (see Table 1). These practices are widely considered reliable predictors of overall dairy production intensity (Herrero et al., 2016).

In the first stage, ui_{ij} represents the indirect utility function of household i for j^{th} intensification regime ($j = 0,1,2$) and

$$ui_{ij} = x_i\alpha_j + \delta_j l_{ij} + \mu_{ij} \qquad \text{Equation 1}$$

where x_i denotes exogenous co-variates with associated parameters α_j and μ_{ij}, the independent and identically distributed error terms. l_{ij} is the latent factor that incorporates unobserved characteristics for household i treatment choice and is assumed to be independent of μ_{ij}. Let p_j represent the observable variables for the intensification regimes, then the probability of treatment can be expressed as:

$$Pr\left(p_j|x_i l_i\right) = g\left(x_i'\alpha_1 + \delta_1 l_{i1}, x_i'\alpha_2 + \delta_2 l_{i2}, \ldots, x_i'\alpha_j + \delta_j l_{ij}\right) \qquad \text{Equation 2}$$

where the vector g is assumed to follow a multinomial probability distribution with a mixed multinomial logit structure (Deb and Trivedi, 2006).

The second stage estimates the outcome equations for wealth, dietary diversity, and livelihood diversification. These equations can be expressed as:

$$e(y_i|\, p_i x_i l_i) = x_i'\beta + \sum_{j=1}^{j}\gamma_j p_{ij} + \sum_{j=1}^{j}\lambda_j l_{ij} \qquad \text{Equation 3}$$

where y_i denotes the welfare outcome for household i and x_i a vector of exogenous co-variates with an associated vector of parameters β, while γ_j captures the treatment effect relative to the control group (extensive dairy farmers) and λ_j the factor-loading parameter associated with the latent factors.

A total of 500 simulations were performed to estimate the model. This follows Deb and Trivedi (2006) who note that models with endogenous regressors require 10 times more draws than the commonly recommended square root of n ($\sqrt{2069} = 46$).

Table 1
Intensification regimes.

Category	Zero grazing	Improved cows	Number of observations	Proportion (%)
Intensive	1	1	885	42.77
Semi-intensive	0	1	794	38.38
Extensive	0	0	390	18.85

3.4. Variables

Outcomes were estimated using indices that proxy for livelihood diversification, nutritional diversity, and wealth. Livelihood diversification is captured by the commonly used Herfindahl–Hirschman Index (HHI) (Herfindahl, 1955), a measure of income concentration. To represent diversification, we calculated an inversed HHI (*InvHHI*) as follows:

$$InvHHI_i = 1 - \sum\nolimits_{j=1}^{n} s_{ij}^2 \qquad \text{Equation 4}$$

where s_{ij} captures the share of total net income household i derives from income source j. Net income is derived from survey data and grouped into food crops, cash crops, livestock, dairy, forestry, formal employment, informal employment, commerce, and remittances. *InvHHI* ranges from 0 to 1, with a higher value representing greater livelihood diversification.

To capture nutritional diversity, we calculated Household Dietary Diversity Scores (HDDS) following the Food and Agriculture Organization of the United Nations (FAO, 2013). HDDS is a food consumption measure reflecting the diversity of foods households have access to and the nutritional quality of a household's diet. HDDS is derived from 12 standardized questions about the types of foods consumed by the household over the last 24 h. This includes starchy staples, dark green leafy vegetables, other vitamin-rich fruits and vegetables, other fruits and vegetables, organ meat, meat and fish, eggs, legumes nuts and seeds, and milk and milk products. Values range from 0 to 12, with higher values indicating more diverse diets.

Finally, wealth was captured using an asset index, a non-income wealth indicator. An asset index is often preferred over household income and consumption expenditure because monetary wealth indicators tend to fluctuate over time and capture only one asset from which households derive well-being (Kakwani and Silber, 2008; Laderchi et al., 2003). Asset ownership is less affected by seasonal variations and better represents long-term well-being (Rakodi, 1999). We used the approach developed by Filmer and Pritchett (2001) to calculate an asset index for each household. This involved performing a Multiple Correspondence Analysis (MCA) on binary asset variables that, based on exploratory research activities were found to be locally relevant indicators of wealth. This includes ownership of an electric iron, refrigerator, mobile phone, mattress, sewing machine, stove, motorized vehicle, bicycle, DVD player, TV, radio, sofa, computer, chaffcutter, house, improved roofing material, brick or concrete wall, toilet, use of electricity, and use of modern cooking fuels. Following Filmer and Pritchett (2001), the factor scores of the first component, which captures the maximum variation between households, were subsequently used as weights to construct the wealth index as forth:

$$w = f_1\left(\frac{a_1 - \overline{a}_1}{s_1}\right) + f_2\left(\frac{a_2 - \overline{a}_2}{s_2}\right) + \ldots f_p\left(\frac{a_p - \overline{a}_p}{s_p}\right) \qquad \text{Equation 5}$$

where $f = (f_1, f_2 \ldots f_p)$ is the vector of coefficients obtained from the MCA, and $\overline{a}$ and s are the mean and standard deviation across all households for asset a_k. The wealth score for household i is then $w_i = f'x_i$, where x_i is a vector of standardized variables $(a_k - \overline{a}_k / s_k)$. Scores were then normalized (0–1), with higher values representing greater household wealth.

To correct for endogeneity, we employed two binary instrumental variables (IV) that are assumed to be uncorrelated with the error term: use of radio, and discipline or innovativeness of the household head. The latter indicator was derived from psycho-social questions in the survey where household heads could characterize themselves across eight dimensions, ranking in the top three. Only those households where heads foremost characterized themselves as being either innovative or self-disciplined were assigned a positive value of 1.

Based on extensive qualitative research, we are confident that these instruments best meet the IV relevance assumption (e.g. the IV is correlated with intensification). In all the study areas, radio is a source of technical information on dairy management, with innovativeness and discipline typically required to invest or direct additional labor and capital in (new) practices. These IVs are expected to only affect outcomes indirectly (e.g. through intensification). Adherence to the IV monotonicity assumption is also assumed. Radio use will only have a unidirectional effect on intensification since radio broadcasts on dairy, given public policy, only promote intensification and are therefore unlikely to deter intensification. Information from radio could however be correlated to the provision of nutrition information, and the instrument was hence not used for the HDDS model. Additionally, while radio was used in developing the wealth index, its contribution to the overall asset index was insignificant as the majority (86%) of the households had a radio. In the absence of more profitable income-generating opportunities that provide the level of prestige and co-benefits (e.g., manure for crops) in the study areas, disciplined and innovative people are unlikely to purposefully avoid dairy intensification.

Descriptive statistics for the dependent and independent variables, disaggregated by treatment group, which were used to estimate our model are provided in Table 2.

4. Results

4.1. Determinants of intensification

The results of the stage one selection equation are presented in Table 3. Results are generally consistent across the three models and demonstrate that the probability that households intensify dairy production is strongly shaped by household composition and lifecycle. Intensified households are generally older and smaller and have relatively few dependents. Such households tend to have more disposable income to invest in fixed and variable inputs and hired labor, while less burdened by childcare obligations. The effects of household composition and lifecycle are less pronounced for semi-intensifying, though lower dependency ratios do appear to enable a transition away from extensive production practices.

Table 2
Descriptive statistics.

Regime	Intensive	Semi-Intensive	Extensive	Total
Variable	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Dependent				
Diversification	0.43 (0.22)	0.39 (0.22)	0.33 (0.47	0.39 (0.23)
Dietary diversity	7.53 (1.52)	7.14 (1.30)	6.54 (1.60)	7.19 (1.50)
Wealth	0.59 (0.13)	0.51 (0.15)	0.46 (0.15)	0.53 (0.15
Independent				
Age of Household head	53.64 (12.83)	52.40 (14.09)	49.98 (13.35)	52.47 (13.48)
Male household head	0.83 (0.38)	0.83 (0.38)	0.91 (0.29)	0.84 (0.36)
Household members	5.05 (2.04)	5.71 (2.21)	6.23 (2.72)	5.52 (2.29)
Dependency ratio	0.44 (0.24)	0.45 (0.23)	0.49 (0.22)	0.45 (0.24)
Indigenous to the area	0.80 (0.40)	0.84 (0.37)	0.87 (0.34)	0.83 (0.39)
Land size (in acres)	6.87 (11.06)	6.94 (10.99)	9.51 (11.32)	7.39 (11.12)
Group membership	0.57 (0.10)	0.54 (0.50)	0.20 (0.40)	0.49 (0.50)
Instruments				
Information from radio	0.11 (0.32)	0.12 (0.32)	0.04 (0.21)	0.102 (0.30)
Discipline or innovativeness	0.41 (0.52)	0.25 (0.46)	0.36 (0.51)	0.34 (0.50)

Household origin impacts the adoption of both intensive and semi-intensive practices, with migrant (e.g. non-indigenous) households more inclined to intensify dairy production. Less constrained by 'traditional' livestock management norms and with weaker access to common pool resources such as pasturelands, such households experience a greater desire and imperative to intensify. Group membership also positively influences (semi-)intensification. Because farmer groups often collectively buy inputs and sell milk, as well as facilitate horizontal learning, farmers generally gain greater confidence to adopt new practices.

Interestingly, land size positively predicts semi-intensification, but not intensification. Arguably, households with more land where cows can freely graze are less compelled to invest in zero-grazing structures, while households with less land that are necessarily reliant on feed and concentrate markets can benefit more from fully intensifying.

Finally, results also point to geographic determinants. For example, farmers in Murang'a (Kenya), Njombe, and Rungwe (Tanzania) are more inclined to fully intensify dairy production, compared to the base administrative unit (Mvomero, Tanzania). Those districts/countries have especially well-developed milk markets, which helps reduce marketing risks and ensures surplus can be absorbed. Under such conditions, intensification risks can be more effectively ameliorated. As can be observed, farmers in Mufindi are least inclined to intensify, largely because milk markets are underdeveloped, and household milk production largely serves subsistence purposes. Furthermore, in the Kenyan counties of Bomet and Nandi, semi-intensification is seemingly preferred. With readily available land and pastoral commons, few farmers in these counties are incentivized to invest in zero-grazing structures.

Both IVs are statistically significant, though discipline/innovativeness only at a 10% confidence interval.

4.2. Effects of dairy intensification

The second stage of our model estimates the effect of participation in different intensification levels on the three outcome variables (Table 4). The results largely show significant positive effects of dairy intensification across all three outcomes, especially for intensified households. Thereby discrediting much of our hypothesis, our results show that households that intensify dairy become more diversified and achieve greater dietary diversity and wealth. While households in the semi-intensification category also achieve greater dietary diversity and wealth, albeit not to the same extent as intensified households, their livelihoods do appear to become more specialized. As can be observed, across the three models, effects are positively moderated by the household head being male (as opposed to female) and the amount of land owned, but negatively by dependency ratios (e.g. fewer dependents contribute positively to our outcomes).

For the intensifiying households, the factor loadings for the latent factors *(λ intensive)* are statistically significant and negative in all three models. As proxies for unobserved covariates, this implies that unobserved factors that increase the likelihood of dairy intensification reduce the outcome effect compared to random selection. In other words, the treatment and outcome are negatively correlated through unobservables, with households with below-average wealth and livelihood and nutritional diversity more likely to intensify. Because we consequently observe negative selection, without correcting for the non-random nature of intensification decisions, our results would have been downward-biased. In the case of semi-intensified households *(λ semi-intensive)*, negative selection is also observed about nutritional diversity though not statistically significant, and a positive correlation with income diversity, though no correlation can be established between wealth and the treatment. In contrast, the significant positive effect of the factor loading on diversification points to positive selection and risk of upward-bias results for semi-intensified households without correction.

To better illustrate effect size, we calculate the predicted value by the

Table 3
Intensification determinants.

Variables	InvHHI		HDDS		Wealth index	
	Intensifying	Semi- intensifying	Intensifying	Semi- intensifying	Intensifying	Semi- intensifying
Age of household head	**0.079***	0.007	**0.086****	0.011	**0.094****	0.011
	(0.043)	(0.048)	(0.043)	(0.046)	(0.043)	(0.047)
Age squared	−0.001	0.000	**−0.001***	0.000	**−0.001***	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Male household head	−0.238	−0.284	−0.181	−0.219	−0.223	−0.263
	(0.278)	(0.285)	(0.269)	(0.280)	(0.284)	(0.283)
Household members	**−0.075***	−0.019	**−0.079****	−0.006	**−0.071***	−0.007
	(0.039)	(0.043)	(0.039)	(0.040)	(0.040)	(0.041)
Dependency ratio	**−0.010****	**−0.014*****	**−0.013*****	**−0.017*****	**−0.011****	**−0.016*****
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Indigenous to the area	**−1.420*****	**−1.623*****	**−1.498*****	**−1.662*****	**−1.428*****	**−1.623*****
	(0.296)	(0.298)	(0.287)	(0.293)	(0.291)	(0.300)
Land size	0.001	**0.028*****	0.003	**0.029*****	0.001	**0.029*****
	(0.008)	(0.007)	(0.009)	(0.008)	(0.009)	(0.008)
Group membership	**1.607*****	**1.250*****	**1.622*****	**1.220*****	**1.526*****	**1.204*****
	(0.203)	(0.212)	(0.200)	(0.214)	(0.205)	(0.212)
Information from radio	**1.705*****	**0.798****	**−1.066*****	0.351	**2.193*****	**0.866***
	(0.374)	(0.377)	(0.305)	(0.317)	(0.384)	(0.484)
Discipline/innovativeness	**0.325***	**0.267***	**2.892*****	**1.815*****	**0.331***	**0.372***
	(0.177)	(0.187)	(0.311)	(0.371)	(0.176)	(0.198)
Mufindi	**−1.276*****	0.284	**2.411*****	0.323	**−1.144*****	0.311
	(0.321)	(0.329)	(0.293)	(0.407)	(0.315)	(0.321)
Rungwe	**2.925*****	**1.886*****	0.008	**5.427*****	**2.958*****	**1.882*****
	(0.314)	(0.366)	(0.492)	(0.403)	(0.309)	(0.374)
Njombe	**2.465*****	0.341	**−0.962***	**4.980*****	**2.622*****	0.398
	(0.297)	(0.396)	(0.558)	(0.397)	(0.296)	(0.402)
Bomet	0.027	**5.515*****	**3.294*****	**1.023****	0.102	**5.540*****
	(0.485)	(0.405)	(0.361)	(0.462)	(0.498)	(0.412)
Nandi	**−1.032***	**4.996*****	−1.311	−0.724	**−1.013***	**5.019*****
	(0.547)	(0.397)	(1.143)	(1.302)	(0.563)	(0.410)
Murang'a	**3.259*****	**1.196*****	**0.086****	0.011	**3.311*****	**1.128****
	(0.374)	(0.461)	(0.043)	(0.046)	(0.369)	(0.469)
Constant	−1.544	−0.763	**−0.001***	0.000	**−2.012***	−0.991
	(1.160)	(1.366)	(0.000)	(0.000)	(1.167)	(1.321)

The base category is the extensive producers. * = $p < 0.10$, ** = $p < 0.05$, *** = $p < 0.01$.

country for each model at means (e.g., co-variates are held constant), see Fig. 2. This shows that a transition from extensive dairy production to intensive dairy production increases dietary diversity by slightly over 1 food group, and wealth and livelihood diversity by 16% and 21%, respectively. Differences in effect size between the two countries are nominal.

The likelihood-ratio test for exogeneity of treatment is positive and significant across the income diversity and wealth models. This implies that the null hypothesis of exogeneity is rejected at a 1% level of significance for the diversification and wealth models but was not significant for the dietary diversity model. This confirms the presence of selection bias and the necessity of correcting for this in the income and wealth models through instrumental variables while the same was not necessary for the HDDs model, thereby justifying the used instruments.

5. Discussion

This study explored the link between dairy intensification, livelihood diversification, and household well-being in East Africa. It was hypothesized that intensification might lead to reduced diversification, impacting nutrition and wealth. However, our findings challenge this, showing that more intensive dairy systems lead to increased diversification, improved dietary diversity, and greater wealth compared to extensive systems. These results support the 'win-win-win' discourse in research and policy (Herrero et al., 2016; Uwizeye et al., 2020), emphasizing the potential for reduced emissions, agrobiodiversity preservation, and rural livelihood resilience through intensification. Additionally, our results suggest that, contrary to early sustainable livelihoods literature (Scoones, 1998), intensification and diversification are not distinct livelihood strategies but in certain contexts may well be complementary and mutually reinforcing strategies.

While acknowledging that intensification can drive specialization, we recognize that dairy intensification mostly strengthens on-farm diversity within mixed systems due to the cyclical nature of resources. For instance, crop residues are utilized as feed, manure is employed to fertilize crops, and bulls are utilized for traction. Extensive qualitative research and validation workshops with respondents unveiled a key motivation for more intensive dairy farmers: the interplay between crop cultivation and livestock rearing. This synergy was seen in the use of maize stovers as feed and dung as manure, enhancing nutrient recycling within households, corroborating findings by Acosta et al. (2021). Furthermore, intensive dairy farmers actively pursue diversification to bolster their income sources, especially during times of volatile milk prices, cattle losses, or surging input costs due to supply shortages. The inherently high-risk nature of dairy farming drives many households to seek alternative income streams and reinvest their dairy proceeds into different activities. However, semi-intensive farmers tend to be less diversified compared to their extensive and intensive counterparts initially. This is likely due to the temporary reallocation of resources away from other livelihood activities as they intensify dairy production. Acquiring and maintaining improved cattle requires substantial human and financial investments, including cattle feeding, manure management, and saving for zero-grazing structures. As farmers practice intensification, there are opportunities to effectively reinvest surpluses in a variety of income-generating ventures.

However, this reasoning likely applies to a sub-sample since in some of our study areas where land is relatively abundant, many semi-intensive dairy farmers have no ambition to further intensify. This is despite semi-intensive households having the least diverse livelihood portfolios, and thereby can be considered the most specialized in dairy,

Table 4
Intensification impacts.

Variables	InvHHI	HDDS	Wealth index
Intensive	**0.158***** (0.022)	**1.083***** (0.154)	**0.231***** (0.01)
Semi-intensive	**−0.074***** (0.022)	**0.711***** (0.217)	**0.045***** (0.02)
Age of household head	0.001 (0.003)	0.015 (0.016)	**0.003**** (0.001)
Age squared	−0.000 (0.000)	−0.000 (0.000)	**−0.000**** (0.000)
Male household head	**0.032*** (0.017)	**0.179**** (0.083)	**0.031***** (0.009)
Household members	0.003 (0.003)	0.007 (0.015)	**0.005***** (0.002)
Dependency ratio	**−0.000*** (0.000)	**−0.003*** (0.001)	**−0.001***** (0.000)
Indigenous to the area	0.015 (0.016)	**−0.236***** (0.090)	**−0.029***** (0.009)
Land size	**0.002***** (0.000)	**0.013***** (0.004)	**0.002***** (0.000)
Group membership	**0.037***** (0.011)	−0.043 (0.067)	0.003 (0.006)
Mufindi	**0.072**** (0.033)	**1.007***** (0.154)	**0.125***** (0.014)
Rungwe	−0.023 (0.022)	**0.531***** (0.164)	**−0.035**** (0.015)
Njombe	−0.001 (0.024)	**0.598***** (0.160)	0.018 (0.016)
Bomet	**0.095***** (0.026)	**0.615***** (0.209)	0.027 (0.028)
Nandi	**0.129***** (0.031)	**0.632***** (0.207)	**0.065**** (0.028)
Murang'a	**−0.070**** (0.028)	**0.839***** (0.166)	**0.062***** (0.017)
Constant	**0.217***** (0.075)	**5.596***** (0.474)	**0.276***** (0.042)
lnsigma	**−3.052***** (0.665)	**0.336***** (0.033)	**−2.441***** (0.172)
λ intensive	**−0.065***** (0.015)	**−0.190*** (0.115)	**−0.098***** (0.018)
λ semi-intensive	**0.215***** (0.013)	−0.190 (0.191)	−0.018 (0.024)
Sigma	0.01 (-0.01)		0.04 (-0.01)
LR test Chi^2 (2)	**43.09*****	6.12	**13.26*****
N	2048	2069	2069

Note LR = test of independence of equation. The base category is the extensive producers. * = p < 0.10, ** = p < 0.05, *** = p < 0.01.

implying that dairy plays a central role in their livelihoods. Not wishing to further intensify can be because they have more land and can allow their cattle to graze, which is considered financially more interesting than having to invest in buying feed. Relatedly, where land is available at a relatively low cost compared to labor, it might not make sense for semi-intensive households to zero-graze, which is more labor intensive, when grazing is available. Supporting this suggestion, Baltenweck et al. (2003) show that the ratio of the value of land to the value of labor is a key determinant in livestock intensification. Other factors such as proximity to markets also influence dairy intensification strategies (van der Lee et al., 2020). This also warrants against assuming that households always wish to intensify in their given context, or that intensification is a binary: to intensify or not to intensify. Qualitative research disclosed that some households temporarily employ practices associated with dairy intensification in certain periods of the year (Vernooij et al., 2024, forthcoming). Understanding processes of combinations of livelihood strategies such as intensification and diversification over time and connected to the relevant contextual factors, is essential for further sense-making of our findings.

Findings show that households with dairy-intensive systems have greater household dietary diversity and wealth, giving reason to assume that diversification somehow contributed to this. Qualitative research revealed that more regular (almost daily) income associated with intensification-induced productivity gains allows households to plan their finances, asset investments, and food purchases better. This explains why dairy intensification, *ceteris paribus*, directly improves household well-being. But, indirectly, being able to manage manure more effectively because of zero grazing contributes to greater productivity and reduced input acquisition costs for cropping activities. Similarly, having a more regular income allows households to reinvest more income in a timelier manner into other activities, which in turn increases net economic surplus. In other words, dairy intensification contributes both directly and indirectly to household welfare. Our modeling approach is not equipped to measure the magnitude of the indirect (e.g., diversification-induced) effect, however. This, as well as the precise mechanics, could be an interesting area of future inquiry.

In addition to not being able to capture the magnitude of indirect effects, our study also does not speak to the effects of intensification on intra-household cost - and benefit distribution patterns. Even though intensified households on aggregate have more diverse diets and can accumulate more wealth, that does not mean that, for example, women in the household are necessarily better off. Keeping improved cattle is labor-intensive (Lenjiso, 2020). In our research areas, women play an important role in milking, cleaning, feeding, and marketing, which could imply that the female labor burden might also have increased disproportionately (Tavenner et al., 2019). Similarly, our modeling approach captures only aggregate effects and not distribution patterns within groups. As the findings from Kihoro et al. (2021) and Vernooij et al. (2024) illustrate, not all (intensive) producers are the same, meaning that undoubtedly some benefit more than others from intensification. With our findings suggesting that farmers with more land (who are probably also more affluent) achieve better outcomes, intensification could produce inclusivity challenges.

Furthermore, our HDDS measure has limitations: nutritional diversity does not mean households are necessarily food secure throughout the year or necessarily meet their calorific and nutritional requirements. While the correlation between HDDS and other measures of food security is generally considered strong (Leroy et al., 2015), we do urge future research to consider other dimensions and indicators of food security. As such, while our research shows that intensification has the potential to produce win-win-win outcomes, limitations do suggest that some caution is warranted. Further research into intra-household effects and impact heterogeneity issues, including those related to conditions under which households make decisions, is needed to arrive at more definitive conclusions.

5.1. Policy implications

For policy targeting and LEDS design purposes, we do urge that policies should address the immediate constraints confronting farmers within their chosen production systems rather than attempting to alter their choices. For instance, in semi-intensive systems, addressing issues such as animal health and improving pastures could be more effective in enhancing productivity and sustainability. This can for example be done by targeting systems where crops whose residues can function as (sufficiently nutritious) animal feed and where soils stand to particularly benefit from organic amendments, or by helping farmers that aspire to intensify dairy to fully exploit synergistic potentials. This requires geographically grounded approaches that account specifically for the pluriactive nature of rural livelihoods in low and middle-income countries.

We expect our results to be relevant to low and middle-income countries, where rural dairy-producing communities are typically accustomed to crop-livestock integration. However, in countries where commercial dairy markets are less developed, increasing milk production without having the markets needed to absorb more milk may instead produce greater milk losses and reduce farmers' ability to recover incurred costs. In such contexts, sector commercialization

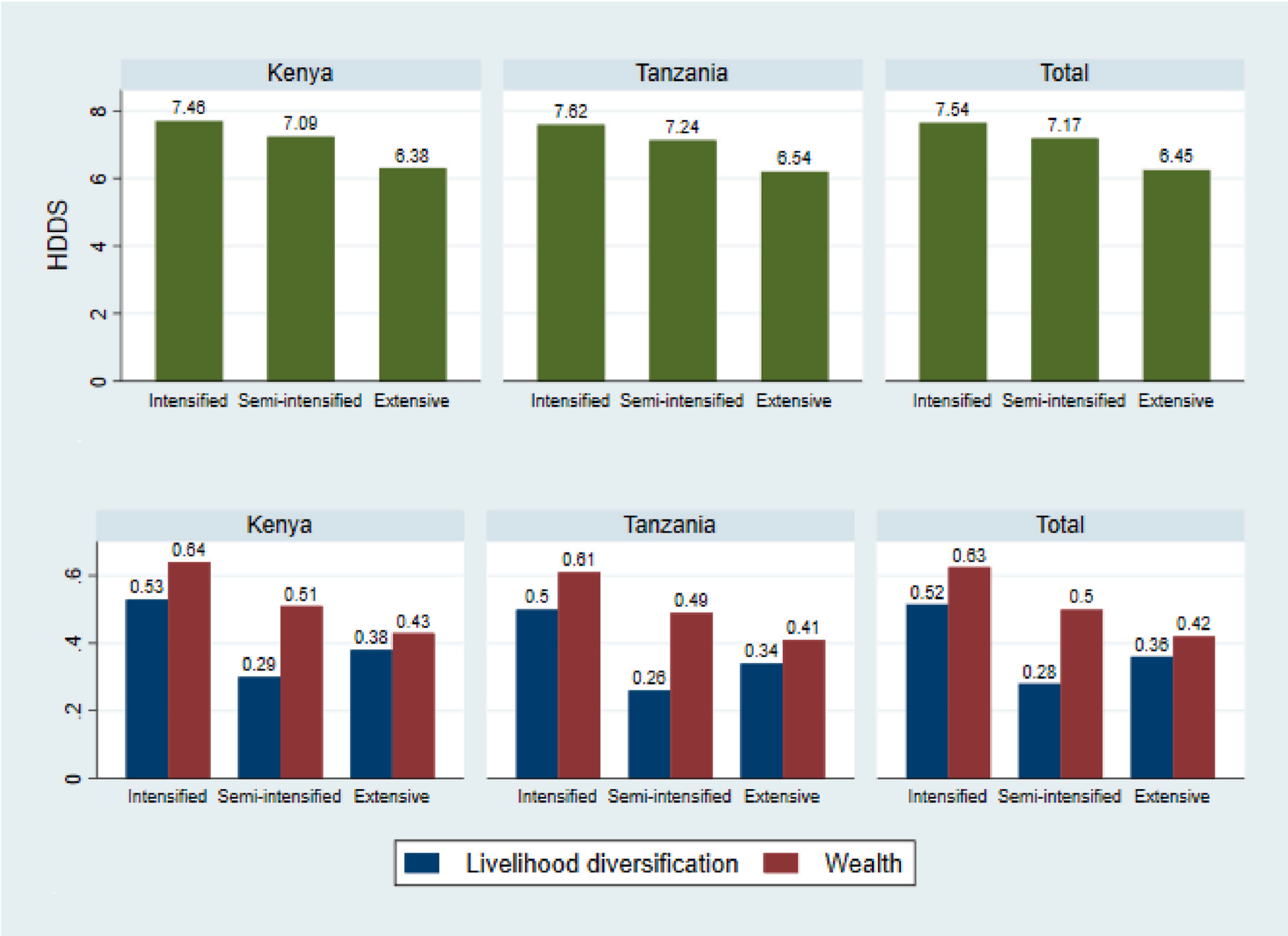

Fig. 2. Average predicted values per country and production system.

objectives need to feature explicitly in intensification strategies and associated policies. However, although some of the semi-intensive households have the resources to intensify, it might not make financial sense, or they prefer to prioritize other livelihood activities.

With intensification also featuring in climate - and poverty alleviation policy discourse for a wide diversity of agricultural activities, whether a virtuous relationship between intensification and diversification can be observed outside dairy (and how that can be maximized) is supremely relevant to increasing food production within planetary boundaries, while also safeguarding the environmental services generated through diversified (agroecological) smallholder production systems.

6. Conclusion

Development policies increasingly emphasize sustainable agricultural intensification, particularly for livestock, including dairy in East Africa, due to their relatively high, reducible GHG emissions. This article examined whether intensification is pro-poor, as policymakers claim, and as LEDS assume, via exploring potential adverse impacts of dairy intensification on household well-being due to resource diversion. Contrary to our concerns, the results reveal that households with intensive dairy production are more diversified, better able to accumulate livelihood assets, and have more diversified diets, supporting recent policy initiatives focused on dairy intensification. Albeit with caveats, these results partly legitimize recent enviro-centric policy and LEDS innovations focused on intensifying dairy and suggest that a ‘win-win’ can under certain conditions for certain households be achieved. We do however find that semi-intensive households are less diversified than extensive and intensive farmers. The findings from our study are relevant to dairy production systems in low- and middle-income countries where most farmers practice semi-intensive or intensive production within crop-livestock systems. Our sampling method carefully considered agroecological, market, and socio-economic diversities across the study sites. Therefore, these findings can serve as valuable insights for decision-making in similar agroecological geographies, involving comparable livestock breeds, socio-economic contexts, and development initiatives. In addition to the policy relevance, the study addresses a gap in agricultural development literature, emphasizing the intricate and potentially additive relationship between intensification and livelihood diversity in dairy and other sectors.

Ethics approval

This research was approved by the Institutional Research Ethics Committee (IREC) of the International Livestock Research Institute (ILRI) in 2017. All participants of the survey and key informant interviews provided written consent; all other participants of the research provided oral consent.

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CRediT authorship contribution statement

E. Kihoro: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **V. Vernooij:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **G. Schoneveld:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. **T. Crane:** Conceptualization, Funding acquisition, Supervision. **S. Vellema:** Conceptualization, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors have no declaration of competing interests to declare.

Data availability

Data will be made available on request.

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