Bio-economic evaluation and optimization of livestock intensification in the Central Highlands of Vietnam

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Bio-economic evaluation and optimization of livestock intensification in the Central Highlands of Vietnam

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Abstract

Beef cattle have high market demand in Vietnam and the Dak Lak local government encourages the development of beef value chains. Household surveys were carried out in Cu Jut and Ea Kar districts and farming systems and production specialization were found to differ in each district. Ea Kar farmers were more specialized in livestock production while Cu Jut farmers were more focused on cash crop production. The FarmDESIGN bio-economic model allowed us to study two representative farms, one from Ea Kar and one from Cu Jut district. The Ea Kar farm had a more integrated livestock production system, providing manure to the fields that produced feed for the livestock. Both farms had high farm-level nitrogen balances due to high feed and fertilizer imports. The soil organic matter (SOM) balance in Cu Jut was negative (-48 kg/ha) because of its manure management strategy. On both farms, the residues were removed from the fields, providing no input to SOM and were fed to livestock (Ea Kar) or burnt (Cu Jut). Livestock intensification scenarios that were implemented for the Ea Kar case study farm showed two possible pathways – forage-based and grain-based cattle fattening. Both strategies could lead to higher operating profits (+35% for forage-based cattle fattening and +59% for grain-based cattle fattening) and lower labor demands if they were skillfully implemented for the latter scenario. However, grain-based fattening negatively affected SOM balance, in contrast to forage-based fattening. The optimization of the current Ea Kar farm with FarmDESIGN indicated that there are options to change the farm setup in order to increase profitability and reduce family labor demands. However there are some trade-offs to consider. If reducing environmental impact is a priority, there are alternative farm configurations that will produce lower greenhouse gas emissions while increasing SOM and increasing overall farm profitability. These should be assessed along with the farmers' interests and priorities. Quantitative farm modeling of complex mixed farming systems can assess potential impact and support decision-making, targeting, prioritization and program design for sustainable intensification of livestock systems.

1. Introduction

The Central Highlands region of Vietnam, a series of undulating plateaus straddling the border of eastern Cambodia and southern Laos, was considered a "wild" region until the mid-1970s. The main ethnic minority groups (Ede, M'nong and Jarai) who practiced shifting cultivation and hunting and gathering from the still abundant forests of the region lived there (McElwee, 2001). After the end of the Vietnam War in 1975, Vietnamese government policy focused on moving people from densely populated areas to "New Economic Zones". Over half a million farmers of the majority Kinh ethnic group from the Red River Delta in northern Vietnam were settled in the Central Highlands (Dang et al., 2001; Cramb et al., 2004). In 1981, the Vietnamese central government banned slash-and-burn shifting cultivation, and following economic reforms (Doi Moi) initiated in 1986, farm households became independent, utilizing land allocated to them by the commune on a long-term basis (Salemink, 2003). More intensified and market-orientated forms of sedentary smallholder agriculture began to dominate. Coffee production, in particular, rapidly spread to become the agricultural mainstay of the region, increasing by about 20% per year between 1993 and 2000 (D'haeze et al., 2005). This coffee boom in turn drew more immigrants from other areas of Vietnam to the Central Highlands, especially into Dak Lak and Dak Nong provinces (which until recently this was one province); between 1990 and 2000, the population of these two provinces nearly doubled from about 1 million to just under 2 million (D'haeze et al., 2005). However, much of the coffee-growing area of the Central Highlands is dominated by acidic, light-textured and infertile soils (Tri, 1997; Tran, 1998; Thai and Nguyen, 2002). At the end of the 1990s, falling global coffee prices meant that smallholders who were growing coffee on land that was too acidic for good coffee productivity, where coffee yields were inherently low, had problems in making a profit (Bui, 2003; Long, 2007). As a consequence, many smallholder farmers began looking for alternatives to coffee production.

Seeking to ameliorate this situation, the International Center for Tropical Agriculture (CIAT), together with Tay Nguyen University (TNU), the Vietnamese National Institute of Animal Science (NIAS) and the Ea Kar Extension Office (DEO), initiated the Forages for Smallholders Project (FSP) in Ea Kar district of Dak Lak province in 2000. The FSP aimed to develop livestock husbandry systems that would allow smallholder farmers to better capitalize on their existing farm animals (Stür et al., 2006). Indeed, most smallholders in the Central Highlands raised several livestock species, including

pigs, poultry and cattle; about a third of all smallholders had at least one to three head of cattle (IFAD, 2011). However, traditionally, these animals were mainly kept as a quasi-cash reserve rather than as a productive asset to generate a regular income. Farmers bought cattle whenever cash was available and sold off animals at times when the household needed money (Stür et al., 2013). Such cattle were grazed on wild grasses, herbs and shrubs that grew along roadsides, in harvested fields or in nearby forests, and sometimes with freshly cut native grasses or rice straw or other crop residues. However, this resulted in light animals with a low meat yield at slaughter and poor reproductive performance, which could only be sold at local markets for local consumption. However, at time of the project launch, per-capita meat consumption in Vietnam was rapidly increasing, having risen by an average of 4% per person per year between 1980 and 2003 (Pica-Ciamarra and Otte, 2011), and in the case of beef, was predicted to double between 2001 and 2020 (Quirke et al., 2003). Additionally, there was a growing demand for higher quality beef in larger towns and cities in Vietnam (IFAD, 2011), which meant that those Ea Kar smallholder farmers that could commercialize their livestock production were given an opportunity to improve and diversify their livelihoods.

Yet many smallholders were caught in what Connell et al. (2010) term the "labor-productivity trap" i.e. more labor was needed to improve the feeding of animals but the low productivity of the animals did not justify the extra investment in time. Burgeoning human and animal populations in the Ea Kar district put more pressure on traditional, communal feed sources and made feeding animals appropriately an increasingly challenging task. As a solution, the FSP promoted the planting of highly productive, nutritious forages on small parcels of land on the farm. If forages were planted close to the homestead and animals were kept close by, this could decrease the labor required to collect feed, or tether and supervise grazing animals far away from the farm. Using this logic, the FSP worked with Ea Kar smallholders to develop new, forage-centered cattle feeding systems. The farm-grown forage cut-and-carry systems that emerged on many farms allowed farmers to keep their animals penned and with easy access to feed and, because the cattle were confined, farmers were gradually able to adopt more productive cattle breeds. Laisind cattle and the use of artificial insemination became more widespread (Stür et al., 2006). In turn, local traders became more interested and developed new markets for these higher quality animals. Ea Kar cattle husbandry moved gradually from traditional to more intensified and market-oriented production systems (Stür et al., 2013). By 2010, 3,100 smallholder households, or over one-third of all cattle producers in the Ea Kar district had started growing improved forages (Stür and Khanh, 2010). More than 500 households were fattening cattle for urban and city markets, and about 800 households produced crossbred and Laisind calves.

Beef cattle have high market demand in Vietnam, and the Dak Lak local government encourages the development of beef value chains. National demand is not yet met by domestic production, which is why beef intensification has become an attractive option to improve smallholder farmers' livelihoods. Pig production systems are run at several scales with different production systems and distinct value chains, including fattening of lean, exotic breeds and niche market production of local fatty pork production mainly for ceremonies (Lapar et al., 2015). Throughout the Central Highlands, a considerable variation in livestock production can be found. Many smallholders in the Ea Kar district of Dak Lak province gradually transitioned from grazing systems to cut-and-carry stall-fed systems as described above. This resulted in higher quantity and quality of beef production that enabled more market sales and higher incomes. The traditional grazing system relies on roadside grasses, semi-natural forests and crop residues. The low feed quantity and quality results in poor animal growth and low commercial value; collecting natural grasses is labor intensive. Farmers who transitioned to farm-grown fodders were mainly mixed livestock-crop systems that produced a wide variety of agricultural products for sale and self-consumption. Families usually had between one and three animals and used them as a financial buffer. Also, imported oil-seed-based feeds (e.g. soybean from Latin America) are becoming more popular. In Cu Jut district (Dak Nong province), livestock intensification has not taken off as it has in Ea Kar. Production systems are less productive in general, and based on crops rather than on livestock.

However, despite its various benefits, the livestock sector is one of the most significant contributors to a range of environmental problems, from local to global scales, including land degradation, air pollution, climate change and loss of biodiversity. First, livestock production is the largest anthropogenic land user, occupying one-third of the global ice-free surface for feed production and grazing. Further intensification of livestock production will increase land use for feed production, competition for natural resources and trade-offs between food, feed and energy production. Second, nutrient depletion is a major form of land degradation in mixed crop-livestock systems and nutrient balances are often negative. Areas of high population density and, therefore, diminishing farm sizes represent the most severe cases of ongoing deterioration of soil fertility, which is causing progressive impoverishment. In addition, around 20% of global rangelands and pastures are degraded through overgrazing, compaction and erosion. Third, livestock production is estimated to generate 18% of anthropogenic global greenhouse gases (GHG) – 9% of total anthropogenic CO_2 emissions, 37% of CH_4 and 65% of N_2O. The main contributors are land-use change due to conversion of forests and other natural vegetation to pasture and arable feed production (CO_2), enteric fermentation from ruminants (CH_4) and manure management (N_2O) (Steinfeld et al., 2006; Peters et al., 2013). Sustainable intensification of livestock systems is needed to increase agricultural production with more efficient use of all inputs – on a lasting basis – while reducing environmental damage. Ex-ante impact assessment and quantitative household modeling can assist in estimating potential impacts and, therefore, prioritize interventions that contribute to sustainable intensification. Integrated analyses and systematic explorations of trade-off frontiers are still rather rare (Groot et al., 2012; van Wijk et al., 2014).

This study aims to explore the diversity of smallholder farms in the Central Highlands of Vietnam, assess the potential bio-economic impacts of livestock intensification options and explore its optimization potential. Specifically, its objectives are to assess diversity in production specialization, intensification and livestock feeding; quantify bio-economic performance between contrasting farms; and explore management alternatives and trade-offs through optimization modeling.

2. Materials and methods

2.1 Study area

Two study sites (Ea Kar in Dak Lak province and Cu Jut in Dak Nong province) in the Central Highlands of Vietnam were selected due to their differences in terms of their agroecology, socioeconomic conditions and livelihood strategies. Most (95%) of the total area was covered with acidic soils (Thai and Nguyen, 2002). Historically, the Central Highlands were influenced by the arrival of nearly 1 million migrants of Kinh ethnicity that were resettled in the region for political reasons; thus both Ea Kar and Cu Jut have a mix of ethnicities. However, in the lower lying areas of Ea Kar, the Kinh are more prevalent while in the more remote upland areas of Ea Kar, the Ede (indigenous minority) are present. In Cu Jut district, there are more Ede than Kinh. The dominant farming system is mixed smallholder farms raising livestock (cattle, swine and poultry) for meat production. The main staple crop is rice and feed crops include maize, cassava and forages. Cash crops are coffee, pepper and cashew nuts. Dak Lak had the largest area under coffee cultivation in the 1990s and by the end of 2000, Vietnam was the second largest producer in the world. However, with the long-term collapse of coffee prices and the increase in demand for meat, livestock intensification has much potential to improve livelihoods in the Central Highlands.

In the study site in Ea Kar district, staff from CIAT and Tay Nguyen University have been involved in developing and integrating forage technologies with farmers since the early 2000s. Today, well over 3,000 cattle-raising smallholders or about 40% of all smallholders that raise cattle in Ea Kar district, now grow forages to feed their cattle on land set aside for this purpose. Over 600 smallholders in the district have transformed their cattle production from the traditional extensive grazing systems to highly specialized commercially oriented cattle systems. In the traditional system, cattle productivity is low, animals are only sold when the household needs cash and planted forages are used to complement other animal feeds. In the commercially orientated cattle systems, farmers permanently pen their crossbred cattle species, fattening them for the market on a mixture of cut-and-carried improved forage species and concentrates and giving them good veterinary care (Stür et al., 2013). The second study site is located in Cu Jut district, which has a lower population density and thus larger farms. CIAT has been working in this area for less than 5 years.

2.2 Household data collection

In total, 60 households from three villages in the two districts were selected to participate in the study – 30 from Cu Jut and 30 from Ea Kar district (Table 1, Figure 1). In Cu Jut district, all study farms in one village (Village 12) were sampled. A total of 15 farmers who were not growing forages were randomly selected and 15 farmers who were growing forages in the last 3–5 years were randomly selected. In Ea Kar district, two villages were sampled: Doan Ket village where selected farmers who started planting forages in the last 5 years and Chu Cuc village, where farmers have been planting forages for over 10 years. In both villages, a list of all households was compiled and split into two groups: those households that were growing forages and households that were not growing forages. Then 13 households in Doan Ket village and 17 in Chu Cuc village were randomly selected (Figure 2).

Surveys were conducted during the 2014/15 dry season (December–January). Individual interviews provided information on the socioeconomic attributes and livelihood strategies including the characteristics of the farm household head, family structure, land (e.g. land size, plots and tenure), crop production (e.g. crops, yields, utilization of crop products and residues, income from sales, labor activities, and inputs), livestock production (e.g. herd composition, production, income from sales, labor activities, feeding, management and inputs) and off-farm activities (income). The households surveyed were identified and mapped using GPS. Biophysical information on the farms included soil samples from different land uses. One composite sample was collected per field sampled and analyzed for bulk density, pH, C, N, P and K content. Soil texture was also determined from the same sample. Another sample was collected in the same field to measure soil bulk density. A total of 276 soil samples were collected and analyzed at the soil science laboratory at Tay Nguyen University. The households surveyed were mapped using GPS (Figure 1). Soil property thresholds for Vietnam were used to compare results against the baseline and different field scenarios (Table 2).

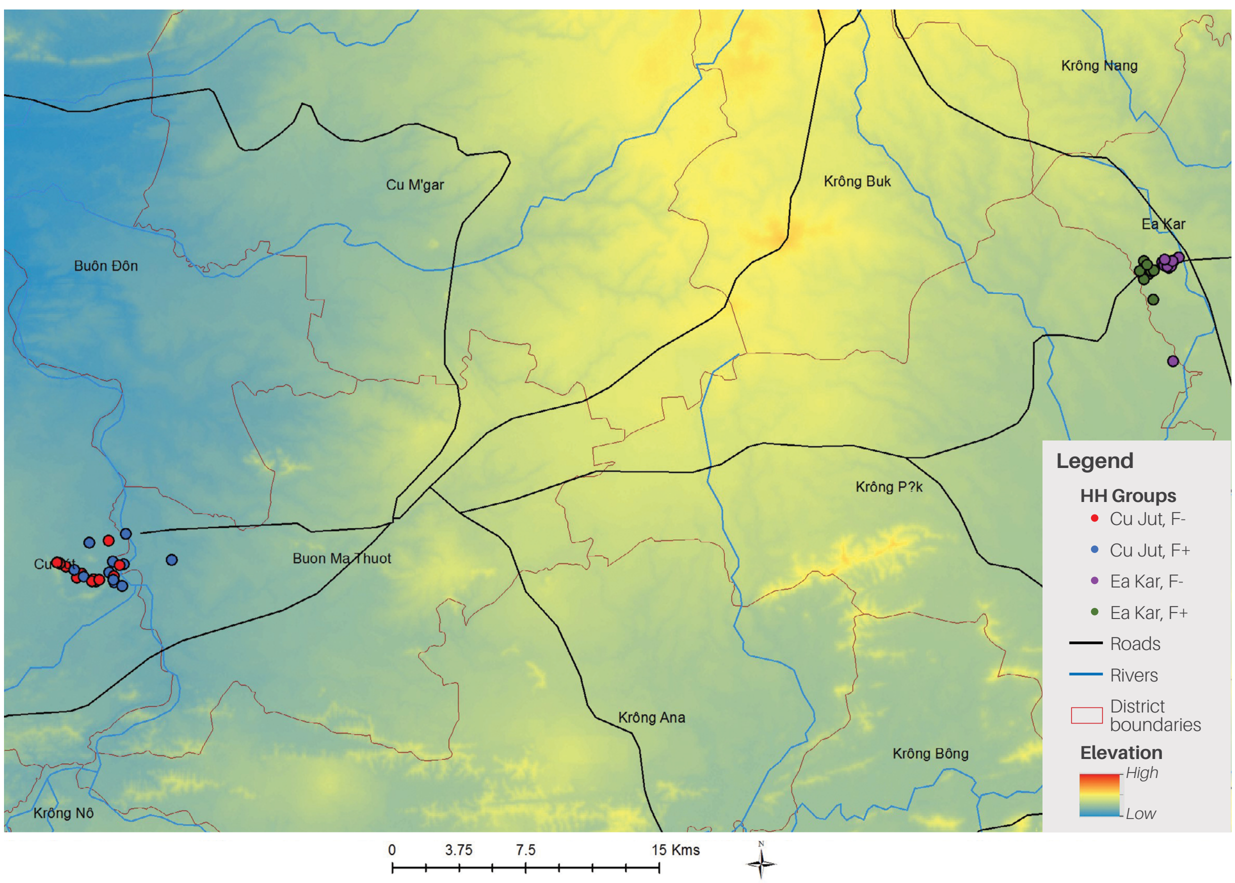

Figure 1: Study sites and HH locations in the Central Highlands of Vietnam.

Table 1: Study groups.

Province	District	Village	Years of forage adoption	Group name
Dak Nong	Cu Jut	Village 12	No forages 1–3	Cu Jut F0 Cu Jut F3
Dak Lak	Ea Kar	Doan Ket Chu Cuc	1–5 5–10	Ea Kar F5 Ea Kar F10

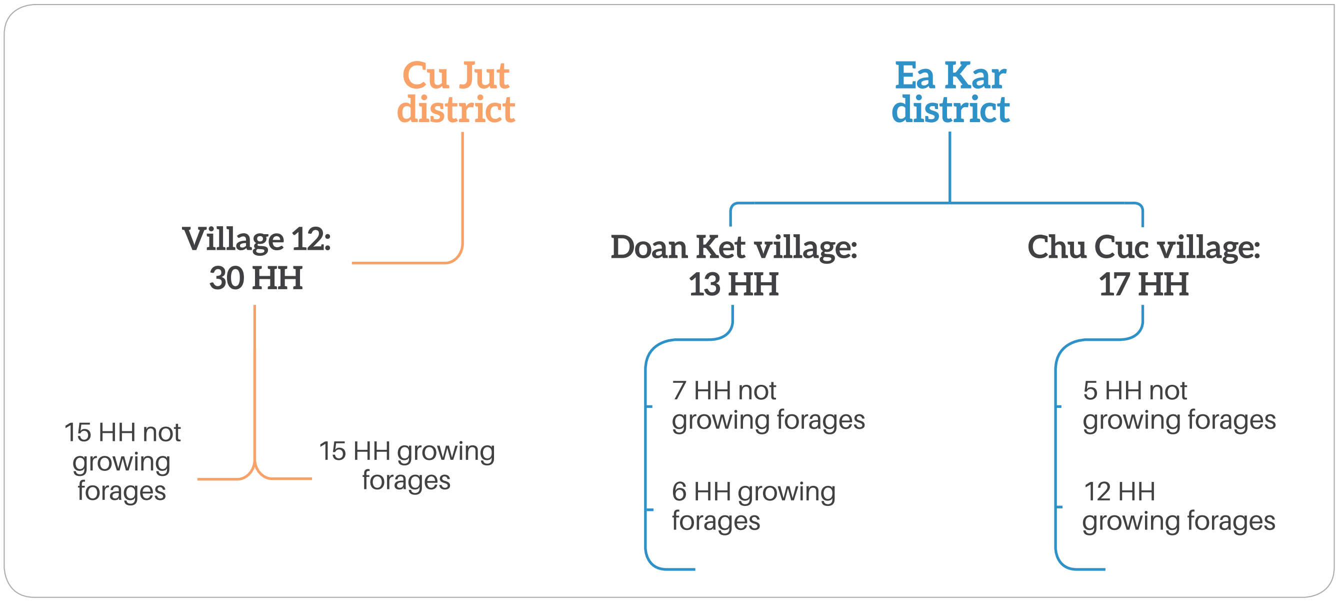

Figure 2: Sampling scheme of households (HH) for surveys.

2.3 Data analysis and household modeling

Using the whole farm population data set, the survey data was analyzed in terms of: soil quality; crop and livestock specialization; level of forage cultivation (% land under forages); and socioeconomic characteristics. Data was analyzed using Microsoft Excel and statistical analyses were carried out with R, Version 3.3.1 (R Core Team 2016, Vienna Austria). The diversity index was calculated as an average of the number of the following activities practiced on the farm (Range 1–12): (1) annual crop – rice; (2) annual crop – maize; (3) annual crop – cassava; (4) annual crop – other; (5) tree crop – coffee; (6) tree crop – pepper; (7) tree crop – cashew; (8) tree crop – other; (9) livestock – large ruminants; (10) livestock – poultry (e.g. chickens, ducks, geese); and (11) livestock – other. The significance of the effects of the sampling groups was quantified using one-way analysis of variance (ANOVA) and post hoc multiple comparisons for observed means (Tukey). For all analyses, a P-value of 0.05 or smaller was considered significant. Means were presented with standard errors to indicate the variation in each group.

From the list of 60 households, two farms were selected at random from Cu Jut F0 and Ea Kar F5 in order to compare contrasting farm types in terms of land, cropping and livestock activities and the use of forage technology: a non-forage growing farm from Cu Jut (Cu Jut farm) and a forage growing farm from Ea Kar for 5 years (Ea Kar farm).

Cu Jut farm case: The Cu Jut farm case study had five household members, and three of them provided on-farm labor. The farm was 2.7 ha in area and most of it was under cultivation. The crops grown were: cashew trees (0.7 ha), rice (0.25 ha), soybean (1.05 ha) and pepper (0.5 ha). Pepper is currently not productive and was thus not included in the modeling. Catfish was produced in fishponds (0.15 ha) all-year round and most catfish produced was sold. The rice and soybean fields were left fallow during the second season. Cashew nuts and soybeans were the main cash crops and all of them were sold. Rice was produced for household consumption and the surplus was sold. Different fertilizers, manure and insecticides were purchased and applied to the different crops (142 kg DAP/ha, 57 kg potash/ha, 214 kg N fertilizer/ha for cashew, 300 kg DAP/ha/season for rice and 143 kg/ha lime for soybean). All crop residues were burned in the field. Poultry (70 chickens) was kept providing eggs (on average 200 eggs/week) and meat (250 kg/year). The farmers were carrying out feeder-finisher swine production. Piglets were bought at a young age and kept until they reached market weight over a six-month period; most farmers sold 60 pigs per year on average. The poultry and pigs were exclusively fed on purchased concentrates (mixed bran). Manure produced on the farm was not used as fertilizer but was used to generate biogas. Self-employment and other activities contributed to off-farm income.

Ea Kar farm case: The Ea Kar farm is located in Doan Ket village. There were four adults in the household but only the head of the household provided labor for farming. He owns 1.7 ha of land, most of which is cultivated; there are four plots: Napier grass (0.3 ha) for the past 5 years, coffee (0.5 ha), maize (0.7 ha) and rice (0.2 ha). Maize and rice are grown twice a year. Coffee is a perennial crop and is harvested once a year in December and all of it is sold. Napier grass and maize are grown for livestock feed, while rice is produced for household consumption. In terms of inputs, different fertilizers were applied to each crop: NPK was applied at a rate of 200 kg/ha for maize, 300 kg/ha for rice, 400 kg/ha for Napier grass and 1,100 kg/ha for coffee. In addition, herbicide and/or insecticide were applied to rice, coffee and Napier grass crops.

Just 30% of farm-produced manure was used for fertilizing the soil while the rest was sold. A total of 200 chickens and improved cattle breeds for fattening were kept. The farmer had four adult female cows for reproduction, two (to six) steers and two calves. The young steers were usually bought at approximately US$440 and sold for double that amount after some months. He fed them rice bran, Napier grass, maize (whole) and maize bran, which were all provided by the farm. His chickens, which were fed purchased concentrates, produced 600 eggs per week on average, which were mostly sold. Apart from a pension, there was no other known off-farm income.

The FarmDESIGN whole farm model was used to describe and explain the impacts of the current configuration of selected farms on an annual basis and to explore alternative farm configurations of agricultural production systems by adjusting farm components (e.g. crops, animals, manures) and inputs (Groot et al., 2012). It is a tool that supports evaluation and redesign of mixed farming systems. The farm is described by the components of the farming system and their biological and economic characteristics.

The inputs required for the model can be grouped into: biophysical environment (e.g. soil and climate); socioeconomics (e.g. costs, labor demand and prices); crops (e.g. diversity, production, nutrient composition, labor demand and costs); crop products (e.g. diversity, demand, costs, and nutrient composition; external feed sources); animals and herd composition (e.g. diversity, management, productivity, and nutrient requirements); animal products (e.g. diversity, destination, prices, and composition); manure types and degradation (e.g. production, management and use efficiency); external sources of mineral nutrients (e.g. diversity, amounts, composition, costs, and use efficiency), and physical assets (e.g. buildings and machinery). Farm performance is evaluated in terms of feed balance, SOM balance, profitability, labor, greenhouse gases and nutrient cycles, among others (Groot et al., 2012). The dry matter, energy and protein supplied and required from the various feeds, as well as the type and size of the herd determined the herd feed balance.

The deviation between demand and supply of energy and protein should be within narrow ranges to allow the production levels to be defined by animal numbers and corresponding productivity. Moreover, the DM supply to the animals could not exceed the intake capacity (Cortez-Arriola et al., 2016). SOM balance is defined by inputs to the fields (e.g. roots and stubble, green manure, crop residues, on-farm and/or imported organic manures) and by the outputs (mainly degradation of manures and organic matter influenced by environmental conditions).

Farm productivity is derived from the return (gross margins) and costs. Further details of the profit module can be found in the model manual 6.12 (Groot and Oomen, 2012). The GHG emissions are calculated using the IPCC Tier 1 methodology. The sources of emissions considered were: emissions from livestock (methane from enteric fermentation and both methane and nitrous oxides from manure production and storage), from soil (nitrous oxide from crop residues, inorganic and organic fertilizers including manure and direct deposits from grazing and methane from rice production) and from burning of crop residues. Nutrient cycles at farm level such as the nitrogen cycle are comprised of flows entering the farm boundaries (inputs) such as imported fertilizers or animal feed, flows exiting the farm boundaries (outputs) such as crop and livestock products sold and soil losses and flows circulating within the farm boundaries, such as crops feed to livestock or crop and livestock products consumed by the household members and manure produced on farm used for fertilization. The extensive list of the flows can also be found in the user manual under Section 6.6 (Groot and Oomen, 2012). As a first step, baseline performance for Cu Jut farm and Ea Kar farm were modeled and compared.

The impact of two livestock intensification scenarios was then modeled and compared to the baseline performance of the Ea Kar farm only – forage-based and grain-based cattle fattening. Changes made to the allocation of crops (field sizes) for these scenarios are summarized in Table 2.

Forage-based cattle fattening scenario: In this scenario, the livestock system is a pure steer fattening system where there is no longer cow-calf production, but steers are bought and sold throughout the year. The number of animals that can be fattened can thus double to 12 animals per year. All maize fields are converted into Napier grass (a total of 0.93 ha). Some supplements are bought to complete the diet. After the Napier grass field was fertilized, 25% of the produced manure can be sold.

Grain-based cattle fattening scenario: This scenario is similar to the previous one as it is specialized in fattening steers, where 12 animals per year can be produced. However, they are no longer fed Napier grass as the main feed. Instead, the Napier grass field was replaced with a maize crop for feed. In addition, high energy and protein feed was purchased to supplement the livestock diet.

Table 2: Field allocation in baseline and scenarios (ha) of the Ea Kar farms.

Fields	Baseline	Forage-based cattle fattening	Grain-based cattle fattening
Total	1.7	1.7	1.7
Maize	**0.7**	**0**	**0.7**
Rice	0.2	0.2	0.2
Coffee	0.5	0.5	0.5
Napier	**0.3**	**0.1**	**0**

The optimization function of the model was used for the Ea Kar farm only. It uses an evolutionary algorithm to generate alternative configurations by adjusting the farm components (e.g. crop, animals, manures) and inputs and to evaluate the consequence from productive, economic and environmental outcomes (Groot et al., 2012). An overview of the decision variables used and the allowed ranges used for these variables during optimization can be found in Table 3. These variables focus on the herd composition (e.g. number and type of animals), feed items (e.g. share of residues for feed, quantity of concentrates) and land allocation, which are variables relevant to exploring farm alternatives based on livestock intensification.

Model constraints for the optimization scenarios were set as farm area and herd feed balances (Table 4).

Four optimization objectives were set:

1. Maximizing farm profitability (expressed in US$ per year);
2. Decreasing the amount of labor required (expressed in hours of family labor per year);
3. Minimizing greenhouse gas emissions (expressed in kg of CO_2e per hectare per year);
4. Maximizing organic matter input into the soil (expressed as kg per hectare per year).

Table 3: Decision variables given in their current value in the farm, and as possible minima and maxima for the multi-objective optimization of Ea Kar farm case study.

Description	Current farm value (Baseline)	Modeling parameters	
		Minimum	Maximum
1. Land adjustment options			
Area of farm planted to maize	0.7 ha	No maize	Entire farm maize only
Area of farm planted to napier grass	0.3 ha	No Napier	Entire farm Napier only
Area of farm planted to coffee	0.5 ha	No coffee	Entire farm coffee only
Area of farm planted to rice	0.2 ha	No rice	Entire farm rice only
2. Options for the number of cattle and poultry			
Steers for fattening	6 steers	0 head	20 heads
Cows for reproduction	4 cows	0 head	4 heads
Calves	2 calves	0 head	4 heads
Chickens	200 chickens	0 birds	200 birds
3. Cattle feeding options			
Percent of maize grain fed to cattle	100%	0%	100%
Percent of maize residue fed to cattle	100%	0%	100%
Percent of rice straw fed to cattle	90%	0%	100%
Imported cattle feed used	None	None	10 t
Percent of rice bran fed to cattle	100%	0%	100%
Percent of farm-grown Napier grass fed to cattle	100%	0%	100%
Daily average weight gain of steers	0.2 kg/day	0.15 kg/day	0.25 kg/day
4. Manure and residue use options			
Percent of farm yard manure applied to field	31%	0%	100%
Percent of maize residues applied as mulch	0%	0%	100%
Percent of rice residue straw used for bedding	10%	0%	100%

Table 4: Modeling constraints for the Ea Kar farm case study.

Variables	Current farm value	Possible minimum	Possible maximum
Farm area (ha)	1.7	0.1	1.7
Metabolisable energy balance all year (%)	0.6	-6	5
Crude protein balance all-year (%)	5.3	-10	17
Intake balance all-year (%)	-12.2	-20	0

3. Results and discussion

3.1 Farming systems characterization

Average farm sizes were larger in Cu Jut than in Ea Kar. Furthermore, the farms in the Cu Jut groups were more cash crop oriented as a higher percentage of fields was allocated to cash crops. Yet Ea Kar farms had in general a higher TLU, indicating more livestock activities on these farms (Table 5). There was no significant difference in terms of the composition of the herd (e.g. percentage of TLU and in numbers) from buffaloes, pigs, goats, chickens, ducks and geese across the four groups. However there was a significant difference in the mean number of cattle. There were significantly more cattle in the forage growing groups Cu Jut F3, Ea Kar F5 and Ea Kar F10 than in the Cu Jut F0 group. Furthermore, the share of cattle in the total herd was significantly higher in Cu Jut F3 and Ea Kar F5. It was on average 82% of the herd in Cu Jut F3. Napier hybrid was the most frequent crop in the three forage growing crops, emphasizing the importance of feed crops. Detailed information on crop frequencies can be viewed in the Appendix.

Area under feed crops was significantly higher in the two groups of Ea Kar compared to the two groups in Cu Ju. In Ea Kar, fodder production occupied over 60% of the field area and close to 20% in the group Cu Jut F3. Feed crops consisted mainly of maize and cassava as well as forage grasses. In actual acreage, farmers in Ea Kar F5 were planting mostly forages, followed by farmers in Cu Jut F3 and finally the Ea Kar F10 group (Table 6). Furthermore, Napier grass was the most frequent crop among the three groups cultivating forages (see Appendix). In the Cu Jut F3 group, the second most frequent crop was guinea grass (another forage crop). Indeed, the area under forage crops was significantly highest in Ea Kar F5 compared to the two Cu Jut groups.

In terms of livelihood indicators, such as household size, farm income (distinguishing income from crop and from livestock activities) and off-farm income, expenditures in inputs for crops and in livestock inputs, we found that there was no significant difference among the four groups (see Appendix).

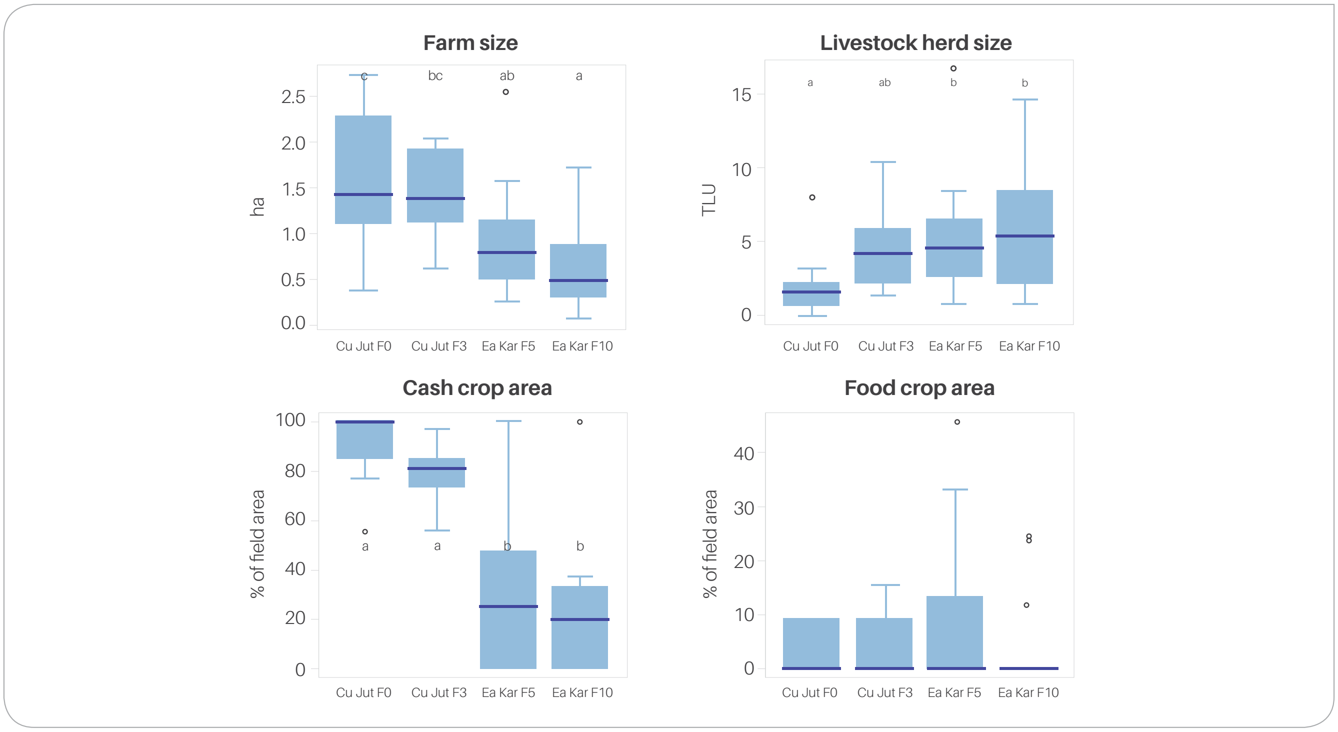

Figure 3: Farm area, livestock, cash crop area and food crop area (means and standard deviations). Letters indicate significant differences (P<0.05) between groups.
Levels of significance: *<0.05, **0.01, ***<0.001, ns, not significant. Farm Size ANOVA P< 4.83e-05 ***; TLU ANOVA P< 0.00758 **; Cash crop area ANOVA P< 5.45e-10 ***; Food area ANOVA P<0.59 ns.

Table 5: Herd composition per group. (TLU, % of TLU per species category, number of animals per category; mean and std. dev.).

Group	TLU	Cattle (% TLU)	Pigs (% TLU)	Poultry (% TLU)	Goats (% TLU)
Cu Jut F0	2.1 (2.1)a	0.31 (0.4)a	0.2 (0.4)	0.3 (0.4)	0.01 (0.03)
Cu Jut F3	4.5 (2.8)ab	0.82 (0.2)b	0.04 (0.1)	0.1 (0.1)	0.03 (0.1)
Ea Kar F5	5.2 (3.7)b	0.58 (0.3)ab	0.1 (0.2)	0.3 (0.3)	0.02 (0.1)
Ea Kar F10	5.8 (3.8)b	0.46 (0.4)a	0.2 (0.3)	0.2 (0.2)	0.2 (0.3)
ANOVA	0.00758 **	0.000736 ***	0.254ns	0.115ns	0.0629ns

Group	Cattle (nb)	Buffalo (nb)	Pigs (nb)	Goats (nb)	Chickens (nb)	Ducks and geese (nb)	Improved cattle (nb)	Improved pigs (nb)
Cu Jut F0	0.6 (0.98)a	0.26 (0.7)	6.20 (14.61)	0.2 (0.8)	38.1 (26.9)	4.67(10.07)	1 (2)a	2.7 (5.5)
Cu Jut F3	5.7 (4.68)b	0.26 (0.7)	1.06 (4.13)	1.1 (2.9)	36 (22)	6.00 (9.10)	5.2 (6.7)b	0 (0)
Ea Kar F5	4.12 (2.73)b	0 (0)	7.87 (16.1)	1.2 (3.4)	122.5 (184.3)	3.43.4 (10.1)	4.1 (2.8)ab	7.9 (16.1)
Ea Kar F10	4.14 (3.70)b	0 (0)	10.78 (15.67)	2.6 (5.9)	103.9 (263)	22.9 (62.7)	4.7 (4.5)b	8 (12)
ANOVA	0.000768 ***	0.242ns	0.276ns	0.355ns	0.322ns	0.312ns	0.0117 *	0.111ns

*Values are means with standard error (n=60). Letters indicate significant differences (P<0.05) between groups. Levels of significance: *<0.05, **0.01, ***<0.001, ns, not significant.*

Table 6: Land allocated to forages (in m²; mean ± SE).

Group	Forage area (m²)
Cu Jut F0	0 a
Cu Jut F3	2,066 (1,887) ac
Ea Kar F5	4,219 (3,496) b
Ea Kar F10	1,621 (1,391) bc
ANOVA	5.39e-07 ***

*Values are means with standard error (n=60). Letters indicate significant differences (P<0.05) between groups. Levels of significance: *<0.05, **0.01, ***<0.001, ns, not significant.*

Soil analysis reveals that in terms of soil N and pH and in most cases for soil P, the mean levels per group were below the thresholds ranking as poor soils based on the thresholds defined by the Vietnam Soil Science Society (Table 7; Figure 4). In terms of organic matter, soils were ranked as moderate.

Table 7: Soil properties threshold.

		Poor	Moderate	Good
Organic matter	(%)	< 2.50	2.50 – 3.50	> 3.50
Nitrogen	(%)	< 0.12	0.12-0.25	> 0.25
Available phosphorus	(mg/100 g soil)	< 3.00	3.00 – 6.00	> 6.00
Available potassium	(mg/100 g soil)	< 10.00	10.00 – 25.00	> 25.00

Vietnam Soil (2000).

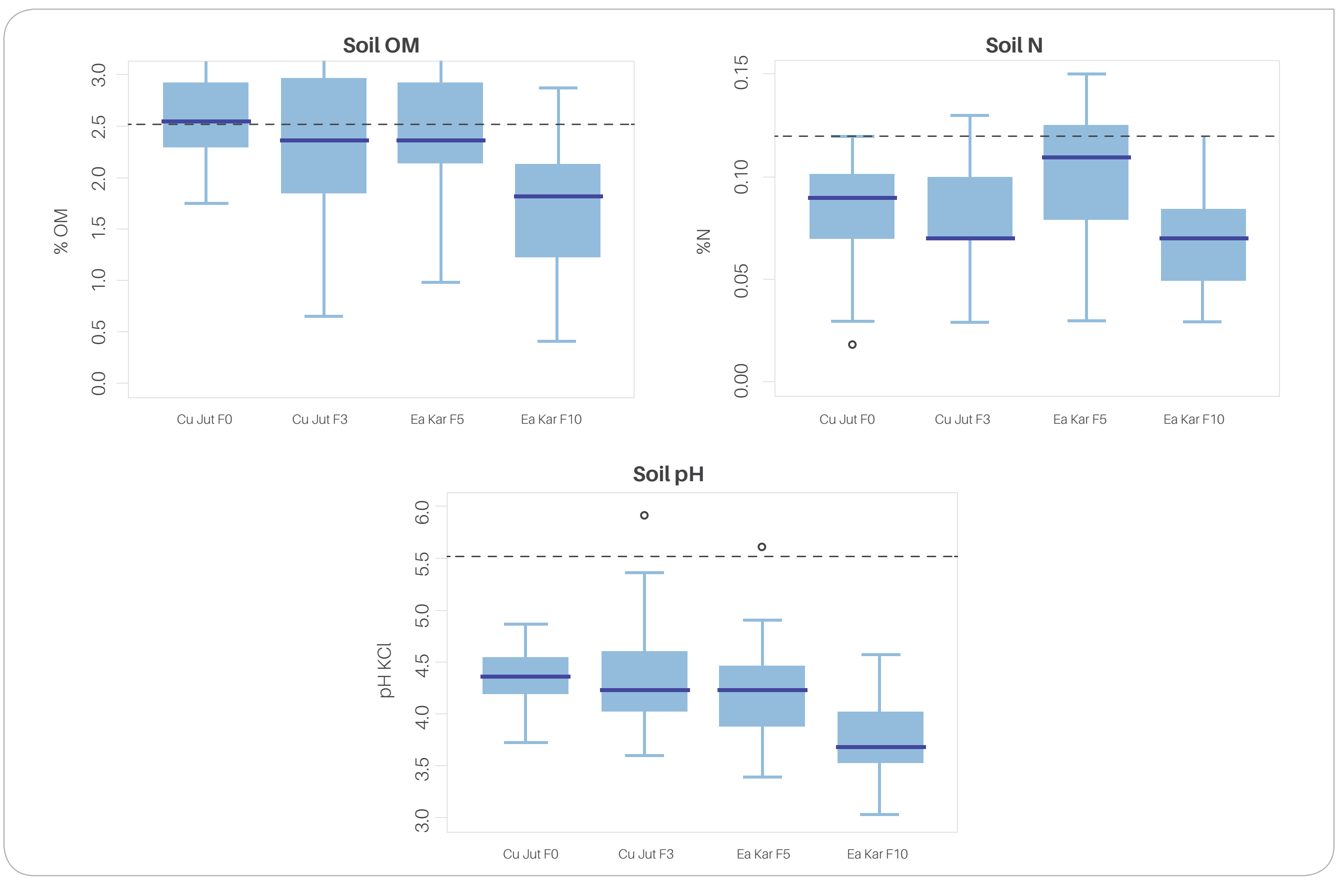

Figure 4: Soil C (%), N (%), pH and minimum threshold (dashed line) per group.

3.2 Bio-economic baseline performance of Ea Kar and Cu Jut farms

Comparing the baseline performance of the two contrasting mixed cash crop and livestock farms showed that sustainability depends on the level of integration of livestock to the system. Both farms produced cash crop trees: one cashew nuts and the other coffee. Such cash crop production is a long-term investment and is dependent on world market prices to determine profitability. Both crops are input demanding. Similarly both farms, similar to many sampled in the sites, will keep some poultry. Poultry production on these farms was not integrated as the feed was purchased and most livestock products were sold. As long as the inputs costs were lower than the returns, then this autonomous enterprise was profitable. The pig fattening production on the Cu Jut farm was similarly separate from the cropping system. Feed was purchased and the manure produced was not applied to the fields. It is sent to the biogas digester, although it is not known what happens to the digestate, we could assume some positive impact on SOM if it were to be applied.

Table 8 presents the margin, costs and profits in US$ of both farms. Agricultural production of Cu Jut farm was not profitable under this setup (US$-423). This was mainly due to the negative returns on livestock. However, Cu Jut farm had considerable additional income through self-employment off the farm ($6,500 per year) that could compensate for the loss from farming activities. Furthermore, they had established a pepper crop that was not yet productive but which could be an additional source of crop income. Ea Kar farm was economically profitable in the current setup. On Ea Kar farm, known off-farm income is in the form of invalid military pension (US$322 per year). In terms of value both farms consumed the same amount of farm products (US$552–622).

Table 8: Margin, costs and profits and off-farm income in US$ per year (converted at the exchange rate of US$1 = VND 22302.5).

		Cu Jut farm	Ea Kar farm
		US$	**US$**
Returns	Gross margin crops	2419.46	5093.24
	Gross margin animals	-2593.42	38.41
Costs	Manure/fertilizer costs	180.26	598.07
	Crop protection costs	38	62.59
	Green manure costs	0	0
	Land costs	0	0
	Equipment costs	0	0
	Building costs	0	0
	General costs	0	0
	Hired casual labor costs	30.81	376.74
	Hired regular labor costs	0.2	0
Totals	Operating profit (+return farm.labor)	**-423.23**	**4094.25**
	Own labor costs	2954.6	702.82
	Return to own labor	-0.1	3.92
	Home consumption	621.97	551.78
	Off - farm income	6500	323

In Table 9, the annual labor requirements and availability per farm is presented. More labor was required both for cropping and for livestock management on the Cu Jut farm, most of which was provided by the family. Although less crop labor was required on the Ea Kar farm, nearly 35% of it was hired for specific activities in rice and coffee farming.

Table 9: Labor balance (hours/farm/year).

		Cu Jut farm		Ea Kar farm	
		Regular	Casual	Regular	Casual
Required		Hours/year	Hours/year	Hours/year	Hours/year
	Crop management	2458	24	789	440
	Herd management	1935	12	256	0
Available					
	Own labor	4393	0	1045	0
Balance		**0**	**36**	**0**	**440**

The difference in livestock type and number on the two farms affected the amount and quality of manure available and the management and use of it for different purposes other than fertilization impacted the inputs to SOM. On the Cu Jut farm, on-farm manure was used to fuel the biogas digester while some off-farm manure was imported for rice fertilization. On the Ea Kar farm, on-farm manure was used for fertilization. Neither farms retained residues in the soil as they were burned off on Cu Jut farm and fed to livestock on Ea Kar farm. Overall the SOM balance was slightly negative on Cu Jut farm (-48 kg/ha) and positive on Ea Kar farm (93 kg/ha) because a greater input of manure could offset the SOM degradation (Table 10).

Table 10: Baseline soil organic matter balance at field level (kg/ha).

		Cu Jut farm	Ea Kar farm
Inputs	Root biomass and stubble	464	557
	Surface residue retention	0	0
	Own manure	0	759
	Imported manure	81	0
Outputs	Manure degradation	72	686
	SOM degradation	521	536
	Balance	**-48**	**93**

Overall the nitrogen (N) balance was positive on both farms and was greater on Cu Jut farm (80 kg N/ha) than Ea Kar farm (15 kg N/ha). On both farms, N was imported in the form of feed for livestock, more than double on Cu Jut farm (Figure 5). Pigs reared for production were fed high energy containing feeds (e.g. maize, soybean etc.). Inorganic fertilizers (and manure, on Cu Jut farm) were imported on the farm at a higher rate on Ea Kar farm compared to the Cu Jut farm. Soybean cultivation on Cu Jut farm provided an estimated extra 50 kg N/ha. In terms of outputs, Cu Jut farm exported more N from crops while Ea Kar farm exported more N from livestock products and manure.

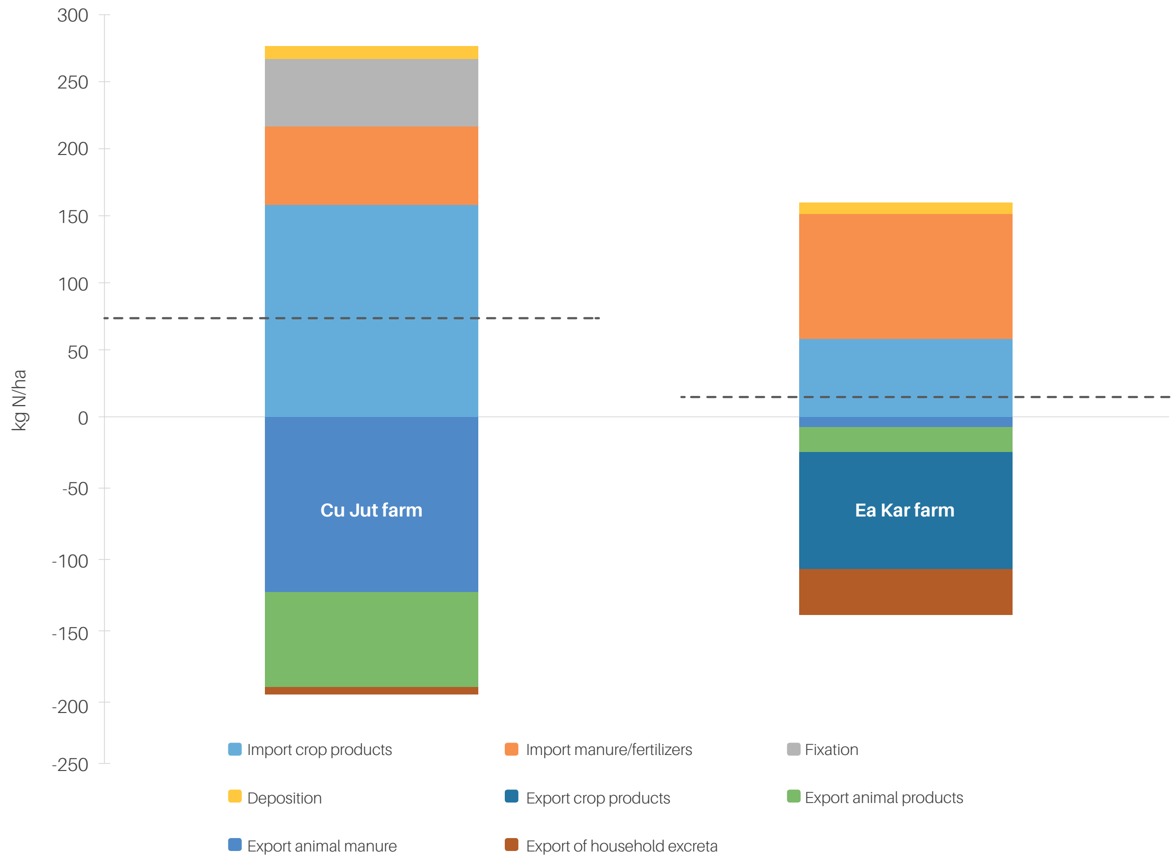

Figure 5: N inputs and outputs at farm level (kg N/ha), N balance in dashlines.

In terms of environmental impacts, total emissions and GHG intensity were close to equal: 10 t CO_2e/ha on Cu Jut farm and 9 t CO_2e/ha on Ea Kar farm. On Ea Kar farm, the main source of emissions was from methane from enteric fermentation and manure while emissions from burnt residues were the main source on Cu Jut farm (Figure 6).

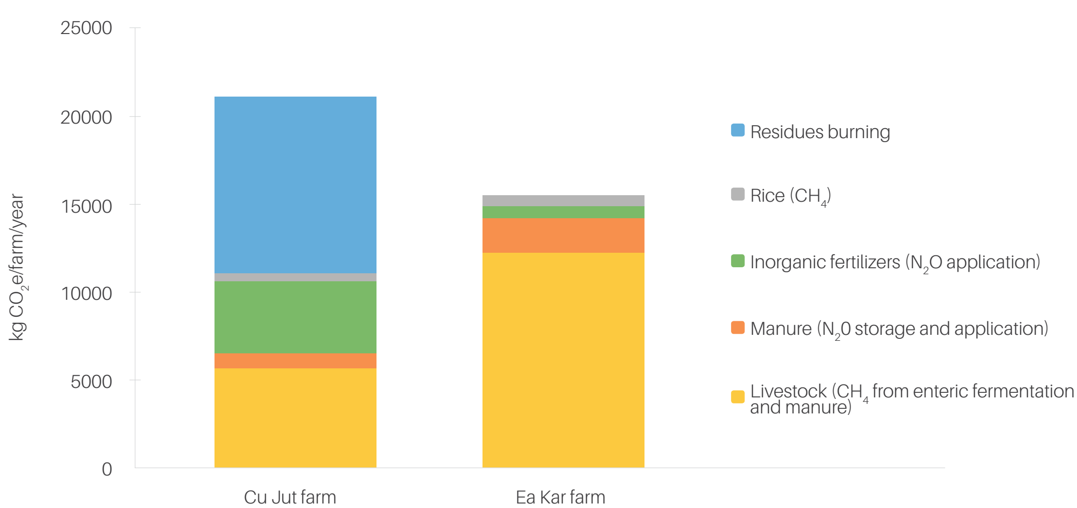

Figure 6: GHG emissions per source (kg CO_2e/farm/year).

3.3 Livestock intensification scenarios

Operating profits increased from the baseline in both scenarios – by 35% in the forage-based scenario and by 59% in the grain-based scenario. The doubling of the animals fattened was more profitable although crop margins decreased with the increase in Napier grass grown under the forage-based fattening scenario. Specializing in forage production required more labor (US$500 more on labor costs) but the increase in animal product margin compensated enough to increase the profitability of the farm. The grain-based specialization was even more profitable as there were fewer costs than in the forage-based scenario and there was some increase in the return from both crop and livestock production compared to the baseline.

Table 11: Baseline and livestock intensification scenarios margin, costs and profits and off-farm income in US$ per year (converted at the exchange rate of 1US$= 22302.5 VND) for Ea kar farm.

		Ea Kar farm	Forage-based cattle fattening sc.	Grain-based cattle fatting sc.
Returns	Gross margin crops	5093.24	4238.99	5481.54
	Risk crop margin	0	0	0
	Gross margin animals	38.41	2837.18	1569.37
Costs	Fertilizers/Manure costs	598.07	577.94	165.53
	Crop protection costs	62.59	92.19	49.14
	Green manure costs	0	0	0
	Land costs	0	0	0
	Equipment costs	0	0	0
	Building costs	0	0	0
	General costs	0	0	0
	Hired casual labor costs	376.74	508.37	316.91
	Hired regular labor costs	0	379.11	0
Totals	**Operating profit (+return farm. labor)**	**4094.25**	**5518.56**	**6519.33**
	Change from baseline		35%	59%
	Own labor costs	702.82	702.84	504.08
	Return to own labor	3.92	5.28	5.82
	Home consumption	551.78	211.64	211.64
	Interest costs	0	0	0
	Depreciation costs	0	0	0

In both scenarios, labor demand for livestock management slightly decreased although the number of animals increased compared to the baseline (Table 12). This is because calves and cows were more labor demanding than steers.

Napier grass production on this farm, which requires time-consuming activities such as irrigation and regular harvesting, was more labor intensive than maize. As a result, in the forage-based scenario, labor demand for crop management increased while it decreased in the grain-based scenario, as reflected previously in the costs of labor in Table 11. On this farm, casual labor was hired for specific tasks, some related to the Napier grass crop. Therefore in the forage-based scenario, casual labor demand increased while it decreased in the grain-based scenario. In the latter scenario, the decrease in both regular and casual demand allowed the farmer to cover almost all of the hours required for the farm work, if he were able to engage in those specialized tasks.

Table 12: Baseline and livestock intensification scenarios labor balance (hours/year) for Ea kar farm.

	Ea Kar farm		Forage-based cattle fattening sc.		Grain-based cattle fattening sc.	
	Regular	Casual	Regular	Casual	Regular	Casual
Required						
Crop management	789	440	1380	594	520	370
Herd management	256	0	229	0	229	0
Available						
Own labor	1045	0	1045	0	1045	0
Balance *	0	440	564	594	-296	370

* *A positive number implicates that labor needs to be hired while a negative number indicates that a surplus of hours are available*

In both scenarios, SOM changed considerably from the baseline (Table 13); under the forage-based cattle-fattening scenario, the SOM balances increased by more than 200% due to the increase in Napier grass area, which was fertilized with manure, while the maize field was fertilized with inorganic fertilizers.

Under the grain-based, cattle-fattening scenario, SOM balance decreased by 99% compared to the baseline. This was because this farmer did not fertilize his maize field with manure. Thus excess manure was sold and root stubble was the only source of OM in the fields.

Table 13: Baseline and livestock intensification scenarios SOM balance (kg SOM/ha) for Ea kar farm.

		Ea Kar farm	Forage-based cattle fattening sc.	Grain-based cattle fatting sc.
Inputs	Root biomass and stubble	557	604	536
	Surface residue retention	0	0	0
	Own manure	759	2377	0
	Imported manure	0	0	0
Outputs	Manure degradation	688	2156	0
	SOM degradation	536	536	536
	Erosion losses	0	0	0
Balance	Balance	93	290	1
	Change from baseline		212%	-99%

N balance at farm level increased in the forage-based scenario and decreased in the grain-based scenario (Table 14). Increased Napier grass production increased the import of inorganic fertilizers and feed imports (initially concentrates for poultry only) increased in both scenarios as additional concentrates were purchased for the cattle. In the grain-based scenario, less fertilizer was purchased because of the difference in fertilizer application for maize compared to Napier grass. In terms of outputs, more animal products were sold compared to the baseline as more beef was produced. In both scenarios, more manure was produced on the farm due to the increase in cattle numbers. Compared to the baseline, in the forage-based scenario there was less manure available to sell after fertilization of Napier grass while in the grain-based scenario, all of the manure was sold. Thus the N balance in the grain-based scenario at the farm level was slightly negative (-8 kg N/ha).

Table 14: Baseline and livestock intensification scenarios N flows and balance at farm level (k N /ha) for Ea kar farm.

		Ea Kar farm	Forage-based cattle fattening sc.	Grain-based cattle fatting sc.
Inputs	Import crop products	60	65	91
	Import animal products	0	0	0
	Import manure/fertilizers	87	118	72
	Fixation	0	0	0
	Deposition	10	10	10
	Non-symbiotic fixation	0	0	0
Outputs	Export crop products	9	9	9
	Export animal products	19	26	26
	Export animal manure	84	48	137
	Export of household excreta	31	10	9
Balance	Inputs	157	193	173
	Outputs	142	92	181
	Balance	15	101	-8

3.4 Optimization and exploration

Figure 7 shows the current farms position relative to the solution space (in blue) delimited by the five objectives. In all four graphs, it shows that there are alternatives to meet the objectives and reduce trade-offs from the current farm configuration. It is thus possible to optimize the current farm for increased profitability while decreasing the negative impact on the environment (e.g. by lowering GHG emissions). However, there is a positive relationship with GHG emission intensity with SOM balance. Increasing SOM on this farm with the current set variables relies mainly on soil inputs in the form of animal manure. However, as seen previously, livestock is currently the largest source of GHG on this farm from emissions directly linked to animal functioning as well as from the manure it produces.

The trade-off between labor and economic profitability is not clear although there are alternative farm configurations that would increase profitability while freeing up family labor (i.e. creating a positive balance) for alternative activities and/or sources of income.

Similarly, the trade-off between the family labor and SOM seems to be negatively correlated; as you SOM increases through alternate farm configurations, family labor balance decreases and becomes negative (indicating that more labor is needed than is currently available from the family). Taking for example farm 236 (gray) and farm 317 (yellow) from the generated farms in the optimization, we can see that GHG emissions and economic profitability are on the complete opposite of the spectrum. Farm 236 ranks well in terms of profitability and GHG emissions, but if we look at the other variables, it does not improve SOM (compared to the baseline it is more or less equal), but it does improve the family labor balance. Farm 317 improves the family labor balance and the SOM balance which is associated with higher GHG emissions compared to the baseline. However this is at the cost of poor economic performance.

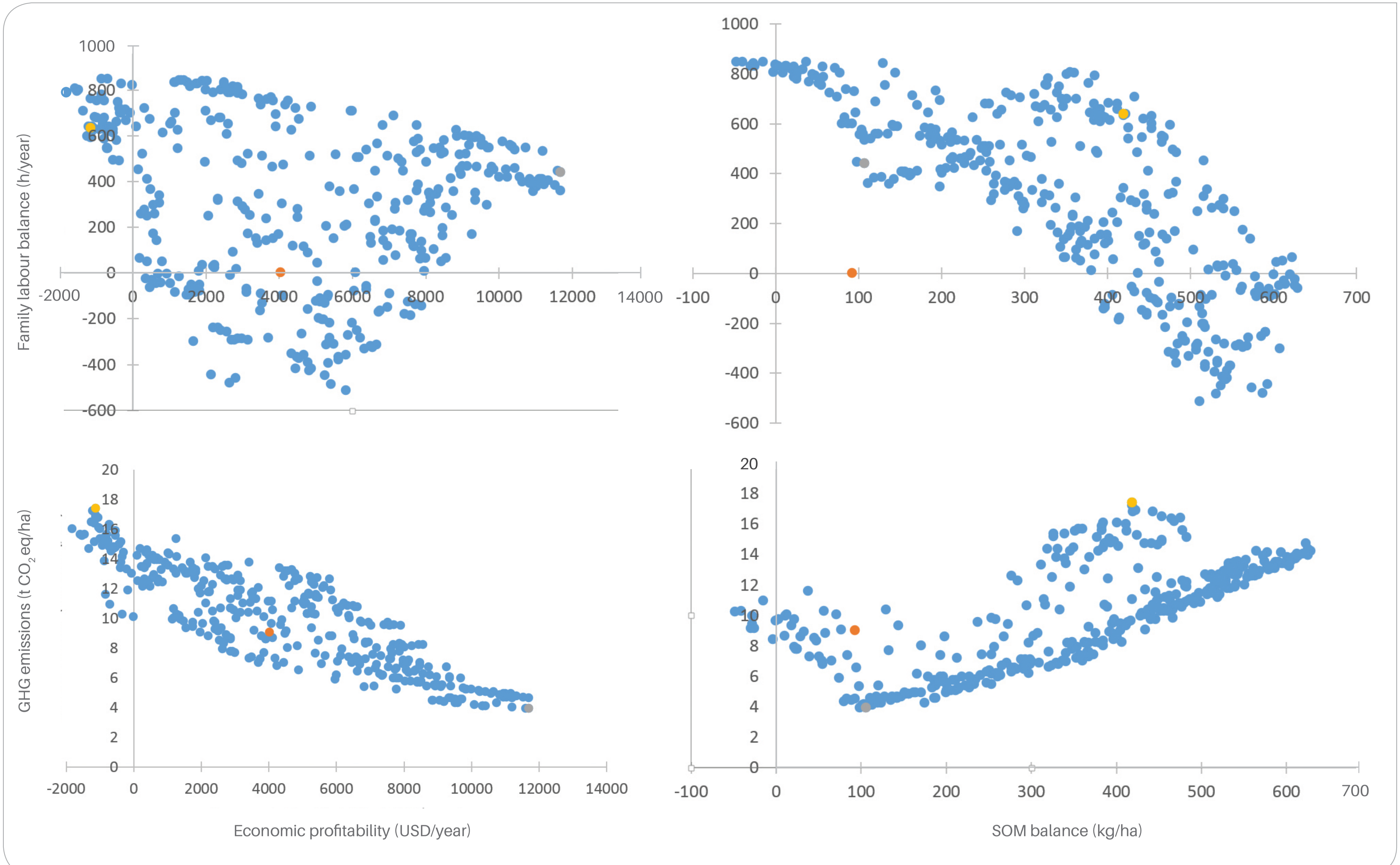

Figure 7: Relations between objective variables for Ea Kar farm.
Current farm performance is indicated by the orange dot. Farm 236 in Gray and Farm 317 in yellow are alternate farms.

4. Conclusions

Comparing the two contrasting study sites of Cu Jut and Ea Kar illustrated the diversity of farming systems and production specialization in the Central Highlands of Vietnam. Ea Kar was more specialized in livestock production, while farmers in Cu Jut focused on cash crop production. Farms sizes were larger in Cu Jut than in Ea Kar and food crop areas were relatively low in both sites (5–8% of total farm size), illustrating the market orientation of all farmers. When examining the differences between farmer groups in terms of exposure to various forages, farmers in Ea Kar had higher areas under feed crops (maize, cassava) and forages (Napier hybrid, guinea grass). Higher forage cultivation correlated with higher cattle ownership (50–80% of TLU composed of cattle).

Using the bioeconomic FarmDESIGN model, two case study farms, one from each district, were compared by quantifying farm productive, economic and environmental performances on an annual basis. The baselines showed that Cu Jut farm was not profitable in its current configuration and especially at the level of livestock production (poultry and swine fed with imported feed), which was running a loss. The household relied mainly on family labor – and when this labor was costed, it was shown to be unprofitable. Although the Cu Jut farm was not profitable, the household economy was positive because of off-farm income. Both farms had high farm-level nitrogen balances due to high rates of feed and fertilizer imports. The SOM balance in Cu Jut was negative (-48 kg/ha) because the on-farm manure was not used for fertilization but for the biogas digester. Furthermore, crop residues on both farms were either fed to livestock (Ea Kar) or burnt (Cu Jut) which didn't contribute to increase inputs to SOM.

Livestock intensification scenarios were only implemented for the farm from Ea Kar. The scenarios represent two possible livestock intensification pathways – forage-based and grain-based cattle fattening. Both strategies led to higher operating profits (+35% for forage-based cattle fattening and +59% for grain-based cattle fattening). Grain-based fattening has lower labor demands if skillfully implemented but it negatively affects SOM balance, in contrary to forage-based fattening. If the Napier grass area was increased, manure application and OM inputs increased. Maize was fertilized with mineral fertilizer and more manure would therefore be sold from the farm. Also the N balance could be negatively affected, decreasing to -8 kg N/ha. Changing the current manure management for fertilization (i.e. applying it to other crops than Napier) could improve the SOM balance and overall farm N balance but at a cost of increasing GHG emissions at farm level.

Using the Ea Kar farm case study, multiple-objective optimization was run with FarmDESIGN. The results indicated that there are alternative farm configurations that would allow us to reduce GHG emissions while accumulating SOM and increasing overall farm profitability. These options should be examined based on their feasibility and the farmers' interests and priorities by taking a closer look at the changes that occurred in the variables selected for the optimization. The exploration of alternative farms configurations with FarmDESIGN confirmed that there is room to maneuver for an already livestock intensive farmer to further intensify his production. Quantitative farm modeling of complex mixed farming systems can assess potential impact, thereby supporting decision-making, targeting, prioritization and program design.

As demand for meat in Vietnam continues to increase, farmers from Cu Jut district may further develop their livestock production, shifting from a traditional to a more intensive system as farmers have been doing in Ea Kar. Sustainable intensification of these livestock systems is needed to increase agricultural production with more efficient use of all inputs – on a durable basis – while reducing environmental damage. Ex-ante impact assessment and quantitative household modeling have indicated that this is possible.

Appendix

Table 15: Farm activity diversity and crop diversity.

Group	Diversity index	Crops (nb)
Cu Jut F0	4.33 (1.72)	2.73 (1.22)a
Cu Jut F3	5.27 (1.49)	4.13 (1.13)b
Ea Kar F5	4.19 (1.42)	3.25 (1.34)ab
Ea Kar F10	4.07 (1.33)	2.71 (1.59)a
ANOVA	0.128ns	0.0175 *

*Values are means with standard error (n=60). Letters indicate significant differences (P<0.05) between groups. Levels of significance: *<0.05, **0.01, ***<0.001, ns, not significant.*

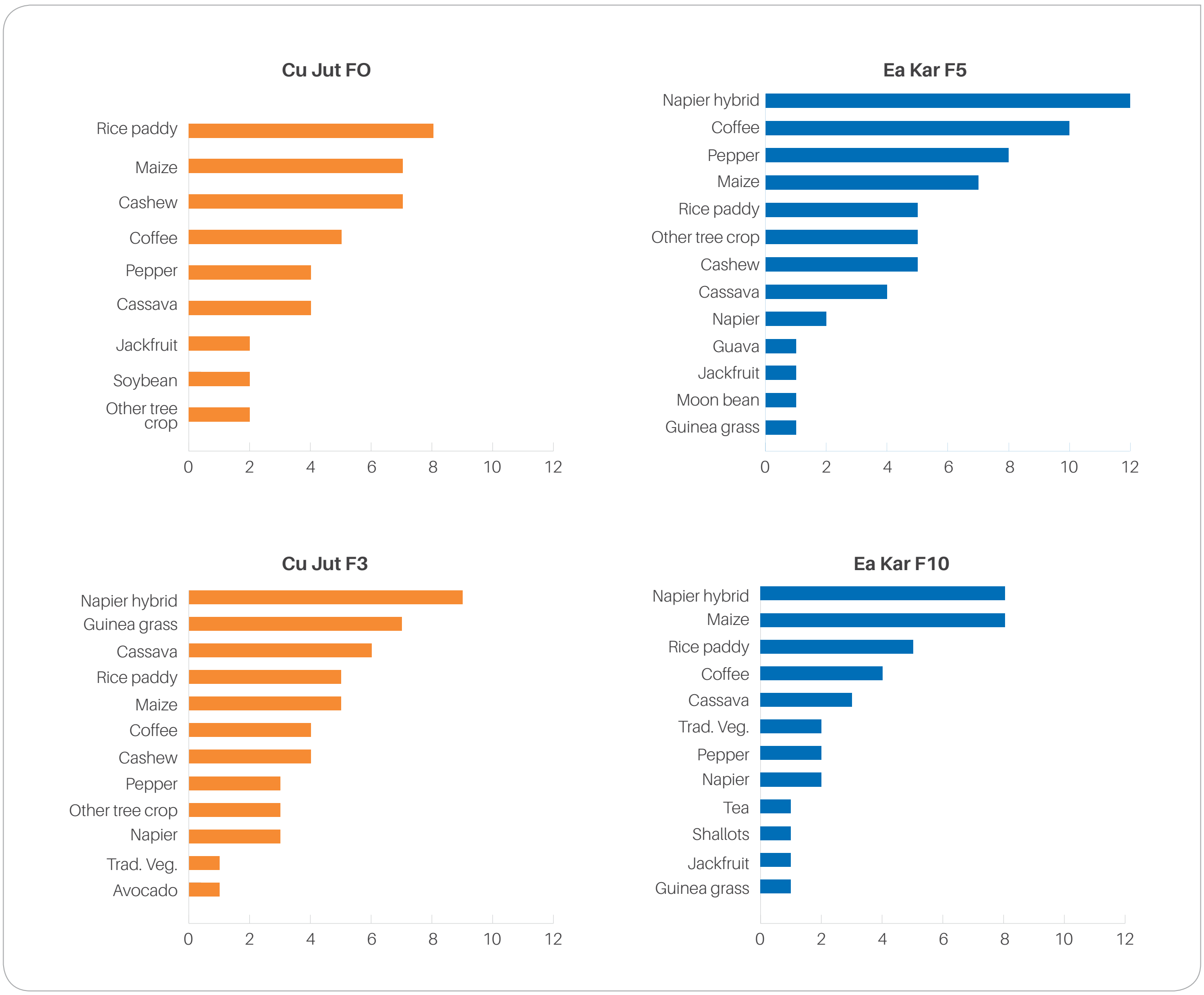

Figure 8: Crop frequency across the four groups (number of households growing the crop).

Table 16: Production orientation (% of field allocated to food crop, cash crop and fodder crop; mean and std. dev.).

Group	Food crop	Cash crop	Fodder crop
Cu Jut F0	4.9 (7.2)	91.2 (12.3)a	3.9 (10.3)a
Cu Jut F3	4.3(6.2)	76.9 (12.4)a	18.8 (13.7)a
Ea Kar F5	8.4 (15)	29.7 (35.4)b	61.9 (34)b
Ea Kar F10	4.3 (9)	26.7 (34.5)b	69 (36.4)b
ANOVA	0.59ns	5.45e-10 ***	1.1e-09 ***

*Values are means with standard error (n=60). Letters indicate significant differences (P<0.05) between groups. Levels of significance: *<0.05, **0.01, ***<0.001, ns, not significant.*

a. Forage technology adoption

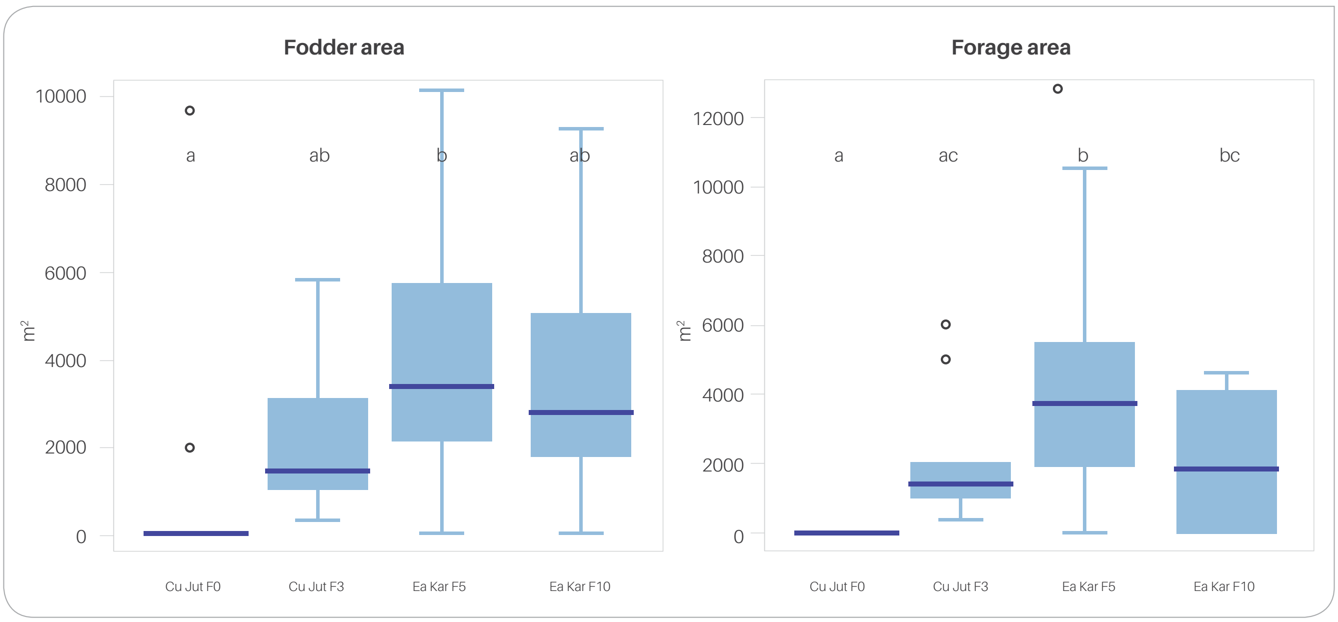

Figure 9: Fodder and forage areas (m^2).
Letters indicate significant differences (P<0.05) between groups. Levels of significance: *<0.05, **0.01, ***<0.001, ns, not significant. Fodder area ANOVA P < 0.00376 ** (although P= 0.052 for the pairwise comparison between Cu Jut F0 and Ea Kar F10), Forage area ANOVA P< 5.39e-07 ***.

b. Socioeconomic characteristics

Table 17: Household and farm size.

Group	Household (nb of people)	Farm size (ha)
Cu Jut F0	4.6 (2)	1.6 (0.8)c
Cu Jut F3	3.7 (1.1)	1.4 (0.4)bc
Ea Kar F5	4 (1.5)	0.9 (0.6)ab
Ea Kar F10	3.6 (1.8)	0.6 (0.5)a
ANOVA	0.384ns	4.83e-05 ***

*Values are means with standard error (n=60). Letters indicate significant differences (P<0.05) between groups. Levels of significance: *<0.05, **0.01, ***<0.001, ns, not significant.*

Table 18: Household income (US$/year).

		Income source (US$)		
Group	Crop	Livestock	Off-farm	Total
Cu Jut F0	2915 (2926)	1078 (2964)	1123 (1686)	5116 (5989)
Cu Jut F3	2563 (3169)	1003 (1267)	615 (720)	4180 (3142)
Ea Kar F5	1114 (1929)	4900 (6953)	1699 (2264)	7714 (6988)
Ea Kar F10	876 (1618)	4802 (6456)	1531 (1502)	7209 (6733)
ANOVA	0.0484 *	0.0439 *	0.625ns	0.296ns

*Values are means with standard error (n=60). Letters indicate significant differences (P<0.05) between groups. Levels of significance: *<0.05, **0.01, ***<0.001, ns, not significant.*
There is no significant difference in expenditures in inputs for crops (Pr=0.296) or in livestock inputs (Pr=0.265) among the four groups.

References

Bui T. 2003. Sustaining coffee production through intercropping system in Daklak province, Vietnam. [MSc Thesis]. Graduate School, Chiang Mai University, Thailand.

Connell J; Stür WW; Horne P. 2010. Forages and farmers: Case studies from South-East Asia. ACIAR, Canberra, and CIAT, Vientiane. ACIAR Monograph 142, 120 pp.

Cortez-Arriola J; Groot J; Rossing WAH; Scholberg JMS; Améndola Massiotti RD; Tittonell P. 2016. Alternative options for sustainable intensification of smallholder dairy farms in North-West Michoacán, Mexico. Agricultural Systems 144:22–32. DOI: 10.1016/j.agsy.2016.02.001

Cramb RA; Purcell T; Ho TCS. 2004. Participatory assessment of rural livelihood in the Central Highlands of Vietnam. Agriculture Systems 81:255–272.

D'haeze D; Deckers J; Raes D; Phong TA; Loi HV. 2005. Environmental and socio-economic impacts of institutional reforms on the agricultural sector of Vietnam: Land suitability assessment for Robusta coffee in the Dak Gan region. Agriculture, Ecosystems and Environment 105:59–76.

Dang TH; Pham HDP; Nguyen NT; Le VD; Pham TH; Espaldon MV. 2001. Impacts of changes in policy and market conditions on land use, land management and livelihood among farmers in Central Highlands of Vietnam. In: Garcia AG (ed.). Sustaining natural resources management in Southeast Asia. Los Baños, the Philippines: SEAMEO Regional Center for Graduate Study and Research in Agriculture (SEARCA).

Groot J; Oomen G. 2012. Farm DESIGN Manual, 1–47. https://sites.google.com/site/farmdesignmodel/download

Groot J; Oomen GJM; Rossing WAH. 2012. Multi-objective optimization and design of farming systems. Agricultural Systems 110:63–77. DOI: 10.1016/j.agsy.2012.03.012

IFAD (International Fund for Agricultural Development). 2011. Enhancing livelihoods of poor livestock keepers through increased use of fodder: Smallholder cattle fattening in Viet Nam. Technical Advisory Note (TAN) 853 CIAT2. IFAD, Rome.

Lapar L; Khanh TT; Hue PT; Dung VT; Hanh TQ; Huong NT. 2015. Livestock and Fish Technical Report: Scoping Study on Pig Value Chains in Dak Lak and Dak Nong. International Livestock Research Institute (ILRI), Nairobi. 81 p.

Long CTM. 2007. The relative sustainability of coffee and mixed farming systems in Dak Lak Province, Vietnam. [MSc Thesis]. Asian Institute of Technology, Thailand.

McElwee P. 2001. Coffee, Christianity and conflict: An update on Vietnam's Central Highlands. Mekong Update and Dialogue 4(3):2–5.

Peters GP; Andrew RM; Boden T; Canadell JG; Ciais P; Le Quéré C; Marland G; Raupach MR; Wilson C. 2013. The challenge to keep global warming below 2 °C. Nature Climate Change 3(1):4–6. DOI: 10.1038/nclimate1783

Pica-Ciamarra U; Otte J. 2011. The 'livestock revolution': Rhetoric and reality. Outlook on Agriculture 40(1):7–19.

Quirke D; Harding M; Vincent D; Garrett D. 2003. Effects of globalisation and economic development on the Asian livestock sector. ACIAR Monograph Series 97e. ACIAR, Canberra. 149 p.

Salemink O. 2003. The ethnography of Vietnam's Central Highlanders: A historical contextualization, 1850–1990. University of Hawaii Press.

Steinfeld H; Gerber P; Wassenaar T; Castel V; Rosales M; de Haan C. 2006. Livestock's Long Shadow: Environmental Issues and Options. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. Available at: http://bit.ly/1gCIHQE

Stür WW; Khanh TT. 2010. Linking fodder to livestock markets in Vietnam – the Ea Kar experience. Presentation given at the FAP Symposium on Feed in Smallholder Systems, Luang Prabang, Laos, 18–19 November 2010.

Stür WW; Phensavanh P; Gabunada F; Horne P; Khanh TT; Phimphachanhvongsod V; Connell J; Holmann F. 2006. A survey of adoption of improved forages in Southeast Asia. Centro Internacional de Agricultura Tropical (CIAT). Tropical Grasses and Legumes: Optimizing Genetic Diversity for Multipurpose Use: Project IP-5: Annual Report 2006.

Stür WW; Tan Khanh T; Duncan A. 2013. Transformation of smallholder beef cattle production in Vietnam. International Journal of Agricultural Sustainability 11(4) :363–381. DOI: 10.1080/14735903.2013.779074

Thai P; Nguyen TS. 2002. Sustainable land use in the mountain area of Vietnam. Hanoi Agricultural Publishing House.

Tri NH. 1997. Rational utilization of land and water resources becomes necessity as an integration component for sustainability agricultural development and environmental protection strategy of Dak Lak province. In Proceedings of the 1st Dak Lak Land Evaluation for Sustainable Development Workshop. 13–15 March 1996, Tay Nguyen Hotel, Buon Ma Thuot, Dak Lak. Dak Lak: Dak Lak Department of Science, Technology and Environment. pp.12–20.

van Wijk MT; Rufino MC; Enahoro D; Parsons D; Silvestri S; Valdivia RO; Herrero M. 2014. Farm household models to analyse food security in a changing climate: A review. Global Food Security 3(2):77–84. DOI: 10.1016/j.gfs.2014.05.001

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