Crop-Livestock Systems

SLP PROJECT ON TRANSREGIONAL ANALYSIS OF CROP-LIVESTOCK SYSTEMS

Crop-Livestock Intensification and Interactions Across Three Continents: Main Report

October 2003

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Acronyms and Abbreviations

AEZ	Agro- Ecological Zone
asl	Above sea level
CIAT	International Centre for Tropical Agriculture
DM	Dry Matter
FAO	Food and Agriculture Organisation
GIS	Geographic Information System
GNP	Gross National Product
HYV	High Yielding Varieties
IITA	International Institute of Tropical Agriculture
ILRI	International Livestock Research Institute
IMF	International Monetary Fund
OECD	Organisation for Economic Cooperation and Development
PPE	Precipitations over Potential Evapo- transpiration ratio
PPP	Purchasing Power Parities
SD	Standard Deviation
TLU	Tropical Livestock Unit

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Executive summary

The objective of the trans-regional analysis of crop-livestock systems is to identify common underlying factors that determine the evolution of smallholder crop-ruminant systems. Three levels of analysis are considered: broad (or village-level), farm and spatial, and household dimensions. The focus is on crop-ruminant interactions, and systems where milk is an important output. An original conceptual framework was developed and used to identify and test the relationships between the levels of crop-livestock intensification and interaction, and their driving factors.

The first level of analysis uses data from farmers' group interviews in 48 sites located in 15 countries of Sub-Saharan Africa (Kenya, Tanzania, Ethiopia, Madagascar, Nigeria and Niger), Asia (Thailand, Nepal, Bangladesh, Sri Lanka and India) and Latin America (Bolivia, Columbia, Costa Rica and Peru). Secondary data from existing GIS databases complemented the survey data. The results show consistent patterns of intensification and crop-livestock interaction, which are generally in line with the predictions of the household model. Indicators of crop intensification retained in the analysis are the use of hybrid and/or high-yield varieties (HYV), the use of inorganic fertiliser, market orientation and extent of fallowing practiced in the area. Significant driving factors that vary across sites are the population density, extent of extension services and cost of land. Livestock intensification is captured using the type of feeding system as well as the feeding strategies (land allocated to fodder and feed purchases). Key findings are those that relate choice of livestock practices to relative labour and land costs, and to market access. Indicators of crop-livestock interactions used are the extent of manure use, feeding crop residues and animal traction, for which market accessibility, labour cost and population density explain a significant part of their variability.

The second level of analysis is at the spatial and farm dimension. Five case studies are analysed, first independently then combined: Colombia, India, Kenya, Sri Lanka and West Africa (Niger/ Nigeria). The combined use of GIS-derived and survey data allow us to test the hypotheses of the conceptual framework. The same indicators of crop and livestock intensification and crop-livestock interactions as in level 1 are used. It emerges from the analysis that three driving forces are at play in the majority of the case studies: farmers' education level, market access and human population pressure. The pooled analysis does not reject the existence of common driving forces at play. Although country- level specificities do exist, especially in terms of climatic characteristics and market access and need to be taken into consideration, it can be shown that livestock intensification is usually driven by the three factors mentioned above. As for the level of crop- livestock interactions, market access and population pressure also emerge as key driving forces.

The third and last level analyses the crop-ruminant systems at the household dimension. The model used integrates biological, social and economic aspects of smallholder farming systems. Although the analysis has not been completed for all the case studies, the results show the potential of the model to test the hypothesis of the conceptual framework at this level of analysis.

The findings of the different levels of analysis can be used for planning and policy interventions since the analysis challenges the traditional practice of using exclusively climatic characteristics to identify recommendations domains for livestock intensification and interactions between crop and livestock (e.g. uptake of planted fodder and stall-feeding).

In fact, costs of labour and land, proximity to markets and ability by farmers to understand the technology (through education) are significant driving factors of the evolution of agricultural systems. Further work is needed to translate the quantitative results presented in this report into more readable planning and policy recommendations through the development of recommendations domains that take into account the different driving forces identified by the analysis.

Introduction

The Livestock Revolution predicts a major increase in the share of developing countries in total livestock production and consumption. While this fact is now well documented, little is known on where and how the increase in livestock production will take place. In fact, previous research efforts have mainly targeted crop production systems, but less is known theoretically and empirically about evolution and innovation in livestock production systems. Given that livestock production systems in the developing countries vary widely, an understanding about pathway of innovations will help policy makers to facilitate the process. The trans- regional analysis of crop-livestock systems project aims at filling this gap by identifying common underlying factors that determine the evolution of smallholder crop-ruminant systems of different levels of intensity. Implied planning and policy interventions that improve opportunities for the rural poor in an environmentally sustainable way are then drawn.

The principal behind transregional analysis of crop-livestock systems is that, under a set of assumptions or hypotheses, data from different sites can be "pooled", and then analysis conducted on multi-site data simultaneously, in order to reveal significant common patterns. Three levels of analysis are considered: broad or village- level dimension, spatial and farm dimension, and household dimension of crop-livestock interactions. The focus is on crop-ruminant interactions, and systems where milk is an important output. Conceptually, these levels form a step-wise process of investigation, and involve increasing levels of detail. At each level, cases across continents are jointly evaluated by pooling multi-site data, using appropriate models of interaction and intensification. This allows the identification and quantification of common relationships between driving forces, modifying factors, and outcomes.

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Theoretical framework

This part reports the theoretical foundations that were developed to support the analysis that is presented in the following parts. It is organised in three sections: the first section briefly reviews the existing literature on crop- livestock interactions while the second presents the original conceptual framework developed for this analysis. The last section presents the different levels of analysis as well as the indicators used in the empirical analysis.

Crop-livestock interactions and intensification

The general model of crop-livestock interactions and intensification originates in the work of Boserup (1965), Lele and Stone (1989) and McIntire et al (1992). Intensification is described as an endogenous process in response to increased population pressure. As the ratio of land to population decreases, farmers are induced to adopt technologies that raise returns to land at the expense of a higher input of labour. The direct causal factor is relative factor price changes, in accordance with the theory of induced innovation (Hayami and Ruttan, 1985).

Besides population growth, other factors have been identified in the literature as determinants of the structure of crop-livestock systems. Environmental characteristics play a significant role in determining the nature and evolution of crop-livestock systems (McIntire et al., Powell and Williams, 1993). In humid areas with high disease challenge for large ruminants, levels of interaction are likely to be low since livestock are fewer. Other driving factors mentioned in a number of studies (Powell and Williams) are economic opportunities, cultural preferences, climatic events (e.g. drought that lead to livestock losses), lack of capital to purchase animals and labour bottlenecks at some periods of the year (e.g. harvests) that may prevent farmers from adopting technologies like draft power.

Crop-livestock interactions are sometimes seen within an evolutionary framework. As first described by McIntire et al., the effect of population density on crop-livestock interactions can be described by an inverted "U" relationship (Figure 1). As population density increases, the level of interaction increases and reaches a maximal level at intermediate level of population density, after which specialization and lower interaction occurs at higher density.

At low levels of population density, crop and livestock production systems are extensive and the sole interactions are through markets and contracts (e.g. manure contracts). With population growth, systems intensify due to changing relative factor prices. Both the net demand for agricultural products and the opportunity costs of land increase, bringing about the need for on-farm crop-livestock interactions, mainly through more efficient exploitation of nutrient resources, crop residues and manure. Because of transaction costs and other market constraints, on farm interactions are preferred to exchanges through contracts. At higher levels of intensification, markets develop and crop-livestock interactions become less attractive. There is a return to specialization and dependence on purchased inputs.

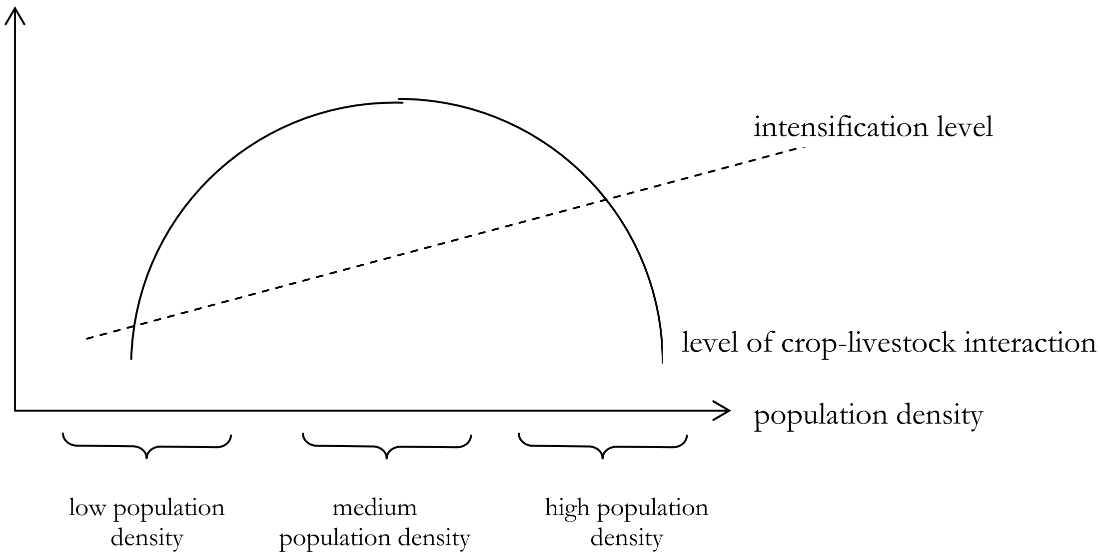


Figure 1. Levels of crop-livestock interactions and intensification, within climatic zone (from McIntire et al, 1992).

Table 1 (Pingali, adapted by Powell and Williams) summarizes the evolution of mixed farming systems in the case of Sub- Saharan Africa, and lists other factors influencing crop-livestock interactions besides population density. The inverted "U" relationship between crop-livestock interactions and population density is apparent. In fact, phase I is the pre-intensification phase when crops and livestock are independent activities. Phase II corresponds to the emergence of crop-livestock interactions. Phase III is the diversification phase while phase IV is the specialization phase (Powell and Williams).

Table 1: Determinants of mixed farming evolution

	Phases in evolution of mixed farming systems			
	I	II	III	IV
Determinants of mixed farming evolution				
population density	Low	high	high	high
transport infrastructures	Low	low/ moderate	moderate	high
urbanization	Low	low/ moderate	moderate	high
Production methods				
power source	Human	animal	motor	motor
soil fertility	Fallows	manure	fertilisers	fertilisers
animal feed	natural pasture	crop residues and pastures	crop residues and pastures	improved pastures and purchased feed

Source: Pingali, adapted by Powell and Williams, 1993.

However, the above characterization of intensification and interaction does not adequately reflect several confounding factors, namely agro-climate and income levels. In low potential climatic zones, the final stages of specialization may not occur. Further, in the Boserup framework higher population densities are associated with relatively lower labour opportunity costs. However, the McIntire et al framework of specialization at the final stages implies rising labour opportunity costs that drive the need to substitute capital for labour. What is implied in Figure 1, but not necessarily stated, is that overall population density can rise at the same time that opportunity costs of labour are rising, if industrial/urban enterprises draw labour from the market. Recent decades in the Tiger economies of SE Asia provide an example.

One aim of this analysis is thus to differentiate the effects of population density changes with those of changes in relative labour opportunity costs. Also, we intend not to necessarily adopt an evolutionary approach to intensification. Urbanisation, rural flight, economic decline, and other factors can lead to unexpected trends in rural population density and labour values, so that rural population densities can either increase or decrease, as can real incomes/wages.

Conceptual framework

A conceptual framework is developed to formally identify the determinants of the levels of intensification and interaction in smallholder crop-livestock systems. At the centre of that framework is a household utility model that predicts household choices in allocation of land and labour to livestock and crops in response to changing prices and factor values. The model is built on two parts: the first part addresses the issue of intensification while the second part looks at crop- livestock interactions. Separating the two issues (intensification and interaction) may seem artificial but allows handling relatively simple models without missing out any important implications.

Crop- livestock intensification

The household is assumed to maximize utility $U=U(c, Lp)$, which is a positive function of the consumption level c and leisure Lp. The consumption level is limited by a cash constraint, function of the crop and livestock production levels, output price and inputs expenses (including labour). The maximisation of the utility is also constrained by a time constraint and a land constraint.

We assume a perfect labour market, although the cost of hiring labour is higher than the cost of family labour because of the existence of supervision costs. The household faces a perfect land rental market, so that she can hire in land.

At the beginning of the period, the household produces crops and rears livestock using only family labour L_0 and land H_0 . She then faces the following choices:

- *Statu quo.* The crop production function is written as $f_c(l_0, H_{co}, Z_c)$ and the livestock production function is defined by $f_l(l_0, H_{l0}, Z_l)$ where l_0 is the family labour working on farm, H_{c0} and H_{l0} are the land used for crop and livestock activities respectively, and Z_c and Z_l represent other factors affecting crop and livestock production respectively. The production functions f_c and f_l are standard well- behaved production functions with positive and diminishing returns to labour and land.

- intensify crop activities. The household can decide to increase the use of labour (weeding, land preparation...), either by increasing family labour by L_{fc} or by hiring external labour L_{hc}. She also can increase her area under cultivation by hiring in land (H_{cr}). A third possibility is to increase the production by purchasing inputs (e.g. fertilizer, improved seeds…), denoted by E_c.
- intensify livestock activities. In the same way as for the crop activities, the household can decide to increase the use of labour (either family labor L_{fl} and/ or hired labour L_{hl}), renting land (H_{lr} to grow fodder for example) and purchasing inputs (e.g. feeds, veterinary services…) denoted by E_l.
- intensify both crop and livestock activities, by combining crop and livestock intensification.

The price of consumption goods is p_f while the prices of crop and livestock products are p_c and p_l respectively. Prices of purchased inputs are p_{ei} and wage rate is w.

The model takes into account the interactions between crop and livestock activities by introducing an interactive term among the inputs. One input of the crop production function I_c is function of the land allocated to livestock activities (considered to represent a certain number of animals) and represents the contribution of the livestock activities to the production of crops (i.e. manure and draft power). Also, one input of the livestock production function I_l is function of the land allocated to crop activities and represents the contribution of the crop activities to the production of livestock products (i.e. crop residues). Extensification (clearing new land) is ruled out in this framework.

To examine this problem, we build on the theoretical framework developed by Pagiola and Holden (2001) and Sadoulet and de Janvry (1995). The household's problem is summarized as follows:

$$\max_{\left\{\begin{matrix} c, L_p, L_0, L_{fc}, L_{hc}, L_{fl}, L_{hl}, \\ H_{c0}, H_{cr}, H_{l0}, H_{lr}, E_c, E_l \end{matrix}\right\}} U(c, L_p)$$

$$\text{st}\begin{cases} p_f c \leq p_c f_c(L_o, L_c, H_c, I_c, E_c) + p_l f_l(L_o, L_l, H_l, I_l, E_l) - w.\sum_{i=c,l} L_{hi} - r.\sum_{i=c,l} H_{ri} - \sum_{i=c,l} p_{ei} E_i \\ L = L_p + L_0 + L_{fc} + L_{fl} \\ H = H_{c0} + H_{l0} \end{cases}$$

$$L_{fc}, L_{hc}, L_{fl}, L_{hl}, H_{cr}, H_{lr}, E_c, E_l \geq 0$$

where:

$L_c = L_{fc} + L_{hc}$ labour for crops= family labour + hired labour (intensification)

$L_l = L_{fl} + L_{hl}$ labour for livestock= family labour + hired labour (intensification)

$H_c = H_{c0} + H_{cr}$ land for crops= own land +rented land

$H_l = H_{l0} + H_{lr}$	land for livestock= own land +rented land
$I_c = \alpha H_l \quad \alpha \succ 0$	interaction crop- livestock: use of manure and draft power for crop activities
$I_l = \beta H_c \quad \beta \succ 0$	interaction crop- livestock: use of crop residues for livestock activities

The first constraint is the cash constraint and stipulates that the household consumption expenditures must be lower or equal to the farm profits (equal to the value of the crop and livestock production minus the cost of inputs, including hired labour and rented land).

The second constraint is the time constraint: total time endowment L equals leisure time plus time spend on the farm, plus time related to the intensification process (both on crops and livestock) if the household decides to intensify.

The third constraint is the land constraint. Total land size H equals land allocated to crop and livestock activities.

The household's problem is solved with a Lagrangian:

$$\mathcal{L} = U(c, L_p) +$$

$$\lambda\left[p_c f_c(L_o, L_c, H_c, I_c, E_c) + p_l f_l(L_o, L_l, H_l, I_l, E_l) - p_f c - w.\sum_{i=c,l} L_{hi} - r.\sum_{i=c,l} H_{ri} - \sum_{i=c,l} p_{ei} E_i \right]$$

$$+ \mu\left[L - L_p - L_0 - L_{fc} - L_{fl}\right] + \gamma\left[H - H_{c0} - H_{l0}\right]$$

The first-order conditions are in annex 1. From equations (A1), (A2) and (A3), we have:

$$(1) \quad \frac{\mu}{\lambda} = p_f \frac{\partial U / \partial L_p}{\partial U / \partial c} = p_c \frac{\partial f_c}{\partial L_0} + p_l \frac{\partial f_l}{\partial L_0}$$

Equation (1) shows that the ratio of the Lagrange multiplier associated with the cash constraint over the multiplier associated with the time constraint can be interpreted as the household opportunity cost of labour – or household shadow wage- (Pagiola and Holden) since it is equal to the ratio (evaluated at the market price for consumption goods) of the increased utility resulting from increased leisure time over the increased utility resulting from increased consumption. Equation (A3) shows also that it equals the value of the marginal productivity of family labour.

Using the Kuhn- Tucker condition (A4a), the household will allocate no family labour to crop intensification, i.e. $L_{fc} = 0$ if $p_c \frac{\partial f_c}{\partial L_c} \prec \frac{\mu}{\lambda}$ or $p_c \frac{\partial f_c}{\partial L_c} \prec p_f \frac{\partial U / \partial L_p}{\partial U / \partial c}$ using equation (1). The condition means that the household does not allocate family labour for crop intensification if the returns from crop intensification are lower than the household shadow wage (i.e. if the returns are lower than the cost). Besides the simplicity of the results, we can see that households are more likely to allocate family labour to achieve crop intensification:

- the higher the output price for crops
- the higher the family labour productivity (which depends on the technology used)
- the lower the opportunity cost of family labour (which depends on alternative labour opportunities and household members' characteristics- education level…)
- the lower the price of consumption goods.

In the same way, we derive from equation (A4b) that households will not hire labour for crop intensification (i.e. $L_{hc} = 0$) if $p_c \frac{\partial f_c}{\partial L_c} \prec w$. Since we have assumed that the labour market is perfect, this result is not surprising since it shows that households do not hire labour if the value of the marginal productivity is lower than the wage rate.

Households are more likely to hire labour for crop intensification:

- the higher the output price for crops
- the higher the marginal productivity of labour
- the lower the wage rate.

Similar implications can be drawn from equation (A5a) for family labor for livestock intensification, (A5b) for hired labor for livestock intensification, (A6b) for renting land for crop intensification, (A7b) for renting land for livestock intensification, (A8a) for purchased inputs for crop intensification and (A8b) for purchased inputs for livestock intensification. By solving the different Kuhn- Tucker conditions, one can identify the determinants of intensification, denoted by I_L^*. The model shows that livestock (crop) intensification is a positive function of the livestock (crop) output price, family labour productivity and marginal productivity of purchased inputs; and a negative function of the opportunity cost of family labour, wage rate, and price of purchased inputs. More formally:

$$I_L^* = I_L^*(+p_l, +\frac{\partial f_l}{\partial L_l}, +\frac{\partial f_l}{\partial E_l}, -w_f, -w, -p_{el}; Z_{l,c})$$

where $w_f = p_f \frac{\partial U / \partial L_p}{\partial U / \partial c}$ is the opportunity cost of family labour.

Following Boserup's theory, human population density is one of the other determinants of livestock (crop) intensification Z_l (Z_c) since intensification is seen as an endogenous process triggered by population pressure. Another important factor is the climatic potential.

Crop- livestock interactions

As in the model presented above, the household is assumed to maximize utility *U=U(c, Lp)*, which is a positive function of the consumption level *c* and leisure *Lp*. The consumption level is limited by a cash constraint, function of the crop and livestock production levels, output price and inputs expenses (including labour). The maximisation of the utility is also constrained by a time constraint and a land constraint.

The crop production function has three inputs: labour L_c, land H_c and the effect of manure/ draft power noted I_c. The term I_c captures the crop- livestock interaction and is assumed to be equal to a fixed proportion (α) of the quantity of labour allocated to the livestock activities. Thus:

$$I_c = \alpha . L_l$$

Similarly to the crop production function, the livestock production function has three inputs: land, labour and the interaction term.

The crop and livestock production functions are thus written as follows:

$f_c = f_c(L_c, I_c, H_c)$	where $I_c = \alpha.L_l$	L_c is labour and H_c is land allocated to crop activities
$f_l = f_l(L_l, I_l, H_l)$	where $I_l = \beta.L_c$	L_l is labour and H_l is land allocated to livestock activities

The production functions f_c and f_l are standard well- behaved production functions with positive and diminishing returns to the inputs.

Using the same method as above, the household's problem is solved by maximizing the Lagrangian:

$$L = U(c, L_p) + \lambda.\left[p_c f_c(L_c, H_c, I_c) + p_l f_l(L_l, H_l, I_l) - p_f c\right]$$
$$+ \mu.\left[L - L_c - L_l - L_p - \alpha.L_l - \beta.L\right] + \gamma.\left[H - H_c - H_l\right]$$

where $I_c = \alpha.L_l$ and $I_l = \beta.L_c$

The choice variables are c, L_p, L_c, L_l, H_c, H_l, α and β.

At the beginning of the period, the farmer chooses whether to use manure and/ or draft power (use of livestock resources for crop activities α) and whether to use crop residues as animal feed (use of crop resources for livestock activities β). The new constraints can then be written as: $\alpha, \beta \geq 0$

As in the previous model, the derivations of the first order conditions show that the ratio of the Lagrange multiplier associated with the cash constraint over the multiplier associated with the time constraint can be interpreted as the household opportunity cost of labour – or household shadow wage. In fact:

$$(2)\ \frac{\mu}{\lambda} = p_f \frac{\partial U / \partial L_p}{\partial U / \partial c}$$

The first order conditions associated with the crop- livestock interactions terms are in annex 1.

Using the Kuhn- Tucker conditions, the farmer chooses not to use manure/ draft power , i.e. α=0 if

$$\lambda.p_c.\frac{\partial f_c}{\partial I_c} - \mu \prec 0$$

$$\Leftrightarrow p_c.\frac{\partial f_c}{\partial I_c} \prec \frac{\mu}{\lambda}$$

$$\Leftrightarrow p_c.\frac{\partial f_c}{\partial I_c} \prec p_f \frac{\partial U / \partial L_p}{\partial U / \partial c}$$

The farmer decides not to use manure/ draft power for his crop activities if the returns from crop- livestock interactions in terms of increased returns to crop production are lower than the household shadow wage (i.e. returns are lower than costs).
Similarly, the farmer chooses not to use crop residues, i.e. β=0 if

$$\lambda . p_l . \frac{\partial f_l}{\partial I_l} - \mu \prec 0$$

$$\Leftrightarrow p_l . \frac{\partial f_l}{\partial I_l} \prec \frac{\mu}{\lambda}$$

$$\Leftrightarrow p_l . \frac{\partial f_l}{\partial I_l} \prec p_f \frac{\partial U / \partial L p}{\partial U / \partial c}$$

The farmer decides not to use crop residues as livestock feed if the returns from crop-livestock interactions in terms of increased returns to livestock production are lower than the household shadow wage (i.e. returns are lower than costs).

The determinants of crop-livestock interactions (*CL**) are identified by solving the different Kuhn- Tucker conditions. The level of crop- livestock interactions is a positive function of the livestock and crop output prices and the "responsiveness" of crop- livestock interactions to crop/ livestock returns[1]; and a negative function of the opportunity cost of family labour. More formally:

$$CL^* = CL^*(+p_{l,c}, +\text{"responsiveness"}, -w_f; Z_{l,c})$$

where $w_f = p_f \frac{\partial U / \partial L_p}{\partial U / \partial c}$ is the opportunity cost of family labour.

Following Mc Intire et al., human population density is one of the other determinants of crop-livestock interaction $Z_{l,c}$. Another factor is the climatic potential.

Levels of analysis and choice of indicators

The principal behind transregional analysis of crop-livestock systems is that data from different sites can be "pooled" to some degree, and then analysis conducted on multi-site data simultaneously, in order to reveal significant common patterns. This type of pooled analysis requires some assumptions or hypotheses:

1. Livestock-feed technologies available in (sub) tropical developing countries are basically common
2. Underlying relationships between driving forces and crop-livestock outcomes are common across systems.
3. Feed resources, rather than land resources are the primary resource in animal agriculture, and feed availability per animal remains the basic constraint (quantity and quality).

[1] e.g. in a given environment, is draft power a good alternative to hand ploughing/ tractor?

Levels of analysis

Three levels of analysis are considered: broad or village-level dimension, spatial and farm dimension, and household dimension of crop-livestock interactions. The focus is on crop-ruminant interactions, and systems where milk is an important output. Conceptually, these levels form a step-wise process of investigation, and involve increasing levels of detail. At each level, cases across continents are jointly evaluated by pooling multi-site data. This allows the identification and quantification of common relationships between driving forces, modifying factors, and outcomes. Given the level of analysis of each level, the objectives are:

Table 2: Project outputs, by level of analysis

Level of analysis	Outputs
Level 1- broad or village-level dimension	To identify common patterns of intensity in smallholder crop-livestock systems, To refine measures and indicators, and To begin to identify existence of common relationships between driving forces and outcomes.
Level 2- spatial and farm dimension	Test the patterns and common relationships identified in level 1 using detailed household, agro-climatic, infrastructure, and market access data.
Level 3- household dimension	Model and test the decision-making process at the farm level that underlies the common relationships confirmed in the 2 first levels.

Based on the literature review and on the practices present in the surveyed sites, the following indicators of intensification and crop livestock interactions are used in the analysis:

Indicators of crop intensification

Since the focus of the trans-regional analysis of crop-livestock systems is on the livestock side (because crop intensification has been relatively well studied in the literature), the analysis of crop intensification is limited to the following indicators.

- on the input side: use of hybrid/high yield varieties; use of inorganic fertiliser and fallow *versus* continuous cropping
- on the output side: market orientation, although subsistence production can be very input intensive.

Indicators of livestock intensification

- on the input side: main type of feeding system; feeding strategies; planting fodder; feed purchases; and existence of a fodder market. For sites where dairying is a major activity: main breed, rearing male calves on farm; use of mechanical procedures for milking and preparing feed.
- on the output side: market orientation (milk and meat); level of milk production

Indicators of crop-livestock interactions

- use of crop residues as animal feed
- use of animal manure for soil fertility maintenance
- use of animal traction

Village-level dimension of crop- livestock systems

This part describes the analysis at the village-level. It is organised in four sections. The next section describes the data collection and gives an overview of the data. The data analysis is presented in the third section. The conclusion in the fourth section highlights the relative consistency of the results across the various sites included in the analysis: relative costs of factors of production, human population density and market access are identified as main drivers of farming systems alongside the more traditional climatic factors considered in the literature.

Sites description

A total of 48 sites in 15 countries of Sub-Saharan Africa, Asia and Latin America were surveyed. Maps of the surveyed sites are presented in Annex 2 (Figure A1). The data collection was realized in half-day or one-day visits to specific areas, chosen to reflect useful comparisons of population density, climatic characteristics, level of agricultural intensification and crop-livestock practices. Farmer-group interviews (6 to 12 farmers per group per site) were used to collect the needed data using a checklist (Text A1 in Annex 2) covering a wide range of crop-livestock practices and interactions. Information gathered included: basic information (annual rainfall, cropping seasons, human and ruminant population density, distance to major urban centres, and assessment of the road infrastructures), general information (food sources and food habits, sources of income, off-farm opportunities, education level, access to facilities, and availability of agricultural equipment), systems of production (land holding, crops and cropping seasons, livestock population including species/breed, land rental market, and animal traction), indicators of intensification (cattle/buffalo keeping strategies, mechanization, use of hired labour, indicators of milk performances, fodder or crop residue markets, use of hybrid/high yield varieties or seeds, pressure on land, in-organic fertiliser use, animal manure use and market). The data collection was carried out by members of the project team assisted by national partners, from November 2000 to October 2001.

Plate 1: Farmers' group interview, Tanzania

A total of 18 sites were surveyed in the semi- arid zone, 8 in the sub-humid zone, 6 in the humid area, and 16 in the highlands[2]. Besides the natural climatic characteristics, the use of irrigation facilities needs to be taken into account. Of the 48 sites surveyed, 20 use irrigation facilities to grow rice, of which 9 are in the semi- arid zone, 5 in the humid and sub- humid zone and 6 in the highlands. The variability in the sites climatic conditions is illustrated in Diagram 1 that shows the minimum and maximum of the length of growing period, elevation and rainfall. A more detailed site description is in Table A1 in annex 2.

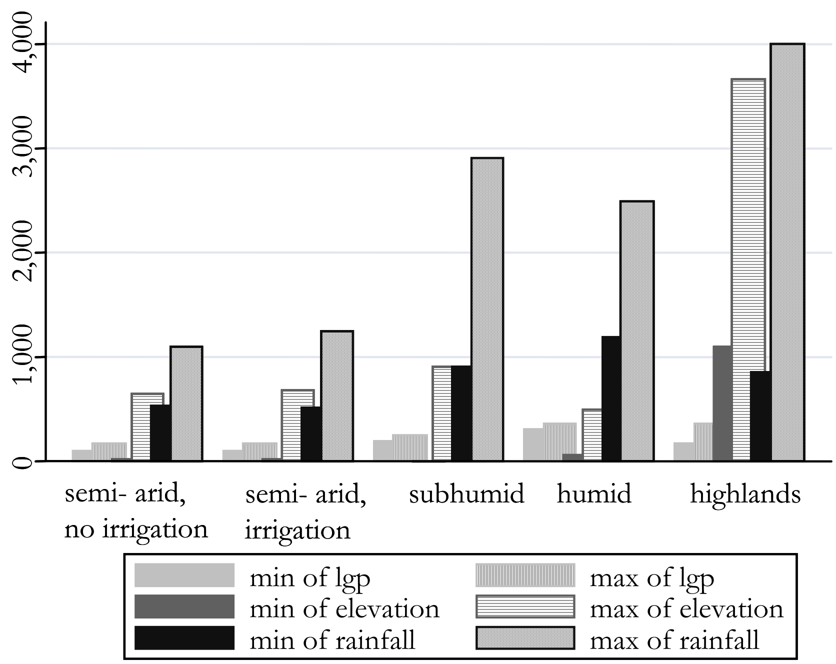
The countries surveyed include:

Asia: Thailand, Nepal, Bangladesh, Sri Lanka and India (Gujarat and Pondicherry)

Sub- Saharan Africa: Kenya, Tanzania, Ethiopia, Madagascar, Nigeria and Niger

Latin America: Bolivia, Columbia, Costa Rica and Peru

Diagram 1: Characteristics of the sites: elevation (meters above sea level), rainfall (mm/year) and length of growing period (LGP in days)



The surveyed countries reflect a wide spectrum of income levels. Figure 2 presents the relationship between GNP per capita (current $ and PPP $[3]) for the visited countries, as well as whole milk and meat consumption per capita. Overall, the relationship between the country level of wealth, and milk and meat consumption is positive, i.e. as the GNP per capita increases, the levels of consumption of these two products increases. Two countries contradict the general tendency: Kenya exhibits a higher milk consumption

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2 Semi-arid, sub-humid and humid area are defined as area with, respectively, 50 to 180, 180 to 270, and more than 270 days of growing period. Highlands are defined as sites above 1,000 m asl. This definition follows Jahnke (*in* McIntire et al.). Data on length of growing period are extracted from the global AEZ FAO database.

3 "PPPs are the rates of currency conversion that equalise the purchasing power of different currencies by eliminating the differences in price levels between countries. In their simplest form, PPPs are simply price relatives which show the ratio of the prices in national currencies of the same good or service in different countries." OECD Website.

than the general relationship would predict due to its tradition of milk consumption (Murdock, 1959). On the other hand, Thailand has a lower milk consumption than predicted, again due to lack of traditions of milk consumption.

Figure 2: GNP per capita - whole milk and meat consumption per capita

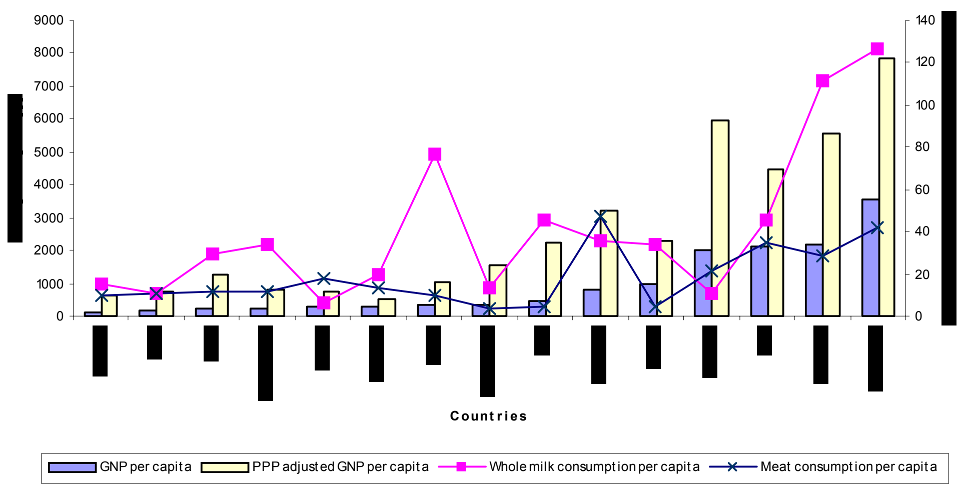


Figure A2 in annex 2 presents the relationship between milk consumption, imports and exports per capita. In all the surveyed countries, with the exception of Costa Rica, milk net imports are positive showing that domestic milk production does not satisfy the domestic demand (either quantitatively or the types of domestic dairy products do not satisfy the domestic demand). Three countries, Sri Lanka, Nigeria and Thailand have a ratio of net imports per capita to milk consumption per capita above 0.5, meaning that net imports supply at least half the total milk consumption. Data on meat consumption, imports and exports per capita are presented in Figure A3 in Annex 2. Countries where a large proportion of the population is vegetarian show very low levels of meat consumption, while Latin America countries exhibit the highest levels of meat consumption per capita. Low income levels are another reason for low levels of meat consumption.

The surveyed sites were georeferenced to obtain secondary data at the site-level. Data on human population density (number of inhabitants/km^2) and cattle and buffalo density (number of animals/km^2) are extracted from the ILRI GIS database. Tropical livestock unit (TLU) density data are extracted from Thornton et al (2002). Data on length of growing period, rainfall and elevation are extracted from the global AEZ FAO database.
Mean human population density, TLU and big ruminant density by climatic zone are presented in Table 3 below, where big ruminant density is the simple average of cattle and buffalo densities. TLU includes cattle, buffalo, sheep, goat, horse, mule, ass and pigs. Human population density is highest in the sub-humid zone (and not in the highlands as expected) and lowest in the humid zone. As expected, TLU and big ruminant density is the lowest in the humid zone, likely due to high disease challenge. Also, livestock density is low in the semi-arid areas where animal carrying capacity is lower than in the other zones. The well-known result of positive relationship between human and livestock population density is validated in the studied sites (correlation coefficient with big ruminant density = 0.71, significant at 1%). Also, the correlation between human

population and TLU density is strong (0.69, significant at 1%). The last column of Table 3 shows buffalo densities for the sites where buffalo are present. Because of the limited number of observations by climatic zone, no correlation analysis is carried out.

Table 3: Effect of climatic zone on human population density (hab/ km^2), density (number of animals/ km^2) of TLU (tropical livestock unit), ruminant (cattle and buffalo) and buffalos.

climatic zone	human population density	TLU density	Big ruminant density	buffalo density
semi- arid (no irrigation)	226	47 (9)	41 (9)	24 (4)
semi- arid (irrigation)	333	66 (9)	47 (9)	18 (6)
sub humid	466	87 (8)	81 (8)	7 (7)
humid	111	39 (6)	34 (6)	20 (2)
highlands	318	61 (16)	71 (16)	23 (3)

Note: Figures in parentheses are number of sites.

When analyzing crop-livestock interactions, it is necessary to assess the importance of the livestock activities in the studied systems. Table 4 presents the percentage of farmers with different types of livestock in the surveyed sites while Table 5 presents the main sources of income.

Table 4: Percentage of farmers with livestock, by climatic zone

	Cattle			Buffalo				
climatic zone	Local breed	Cross-bred	High grade	Local breed	Dairy	Goat	Sheep	Donkey
semi- arid (no irrigation)	60	9	8	8	37	64	41	10
semi- arid (irrigation)	46	9	25	28	26	32	16	14
sub humid	47	31	26	16	4	33	0	6
humid	32	57	28	60	45	5	11	30
highlands	45	13	40	37	27	17	28	20

Cattle, irrespective of breed, are the main type of livestock kept in the studied villages. In all the areas except the humid zones, local breed cattle are the most common in terms of the proportion of farmers that keep them. Crossbred cattle are defined as crosses between local and dairy breed animals. Goat and sheep are very common in the semi-arid areas. Other studies (Powell and Williams) showed the importance of smaller stocks in these areas due to their lower feed requirements and the lower costs. As expected, high-grade cattle are more common in the highlands due to the lower disease incidence. Data on buffalo are calculated only for the sites where buffalo are present.

For the majority of farmers, farm activities provide them with their major source of income, in all the areas. Off-farm employment is the second most important activity, especially in the semi-arid where climatic variability encourages farmers to diversify their activities. Other sources of income (own business and temporary activities) are also important activities in the semi-arid and sub-humid zones.

Table 5: Percentage of farmers for which the activity is the main source of income, by climatic zone

climatic zone	Farm activities	Off- farm employment	Remittances	Rent	Other sources
semi- arid (no irrigation)	80	14	1	1	4
semi- arid (irrigation)	79	14	0	0	7
sub humid	84	11	2	0	4
humid	86	12	0	0	1
highlands	79	14	2	4	2

Data analysis

Crop intensification

Table A2 in Annex 2 presents the three main crops grown in the area. The determinants of crop intensification identified by the household model were listed in the previous section. Recalling that data were collected at the village level and given data availability, the indicators listed in Table 6 are used in the analysis.

Table 6: Crop intensification- determinants derived from the household model and indicators used in the empirical analysis

Determinants from household model	Indicators used in the empirical analysis
output price for crops	not available
family and hired labour productivity	% farmers with at least primary education and extent of extension services for crop activities
opportunity cost of family labour	% farmers with off-farm opportunities and distance to nearest large urban center
wage rate	wage rate in current and PPP $
rental rate	rental rate in current and PPP $
marginal productivity of purchased inputs	not available
price of purchased inputs	price of fertiliser

The level of education (more precisely the percentage of village farmers with at least primary education) captures the average labour productivity in the area. This follows a common approach taken in the literature, for example Feder et al. (1985) show that the education level is usually positively associated with the adoption of agricultural technologies in developing countries since it enhances farmers' abilities to manage new/complex technologies. Extension services are either substitute for, or complement education; therefore the level of extension services for crop activities in the area is also used to capture labour productivity.

Different indicators of crop intensification are used in the analysis: use of hybrid and/or high- yield varieties, use of inorganic fertiliser, market orientation, and fallow. The analysis aims at testing whether the driving forces listed in Table 6 are in play. Sites are grouped into two categories representing low and high levels of intensification. The threshold used to group the sites is chosen based on two factors: significance and practicability. Significance depends on the indicator under consideration, although a threshold of 50% is usually used. Practicability refers to data issues whereby the two categories created should have a sufficient number of observations.

The first indicator of crop intensification is the **use of hybrid and/or high- yield varieties (HYV)**. Of the 43 sites for which data is available, only in two sites do farmers not use hybrid seeds/HYV (both sites are in Madagascar). Table 7 presents the average percentage of farmers using these seeds and the average percentage of the area cultivated with them for the sites where hybrid varieties/HYVs are used. The statistics are calculated by market orientation, i.e. whether the crop is mainly grown for sale, home consumption or both. As expected, the use of hybrid varieties/HYVs is higher for crops grown mainly for sale, compared to crops grown mainly for home consumption. Also, the use of hybrid varieties/HYVs is higher for crops grown for both home consumption and for sale, compared to crops grown only for home consumption.

Table 7: Use of hybrid varieties/high yield varieties (HYVs)

Reason to grow the crop	% farmers using hybrid/ HYV			% of the surface planted		
	Mean	SD	Difference	Mean	SD	Difference
Both home consumption and sale (B)	70	36	H	80	31	H
Mainly home consumption (H)	58	36	B, S	59	42	B
Mainly sale (S)	77	32	H	66	41	

Note: The column "difference" indicates the crop category with which the difference is statistically significant at 10%.

Looking at the determinants of crop intensification, sites were grouped according to the extent of hybrid varieties/ HYV use. Sites where at least half of the farmers use these varieties on a regular basis are characterized by higher human population density and higher land rental rate (both in current and PPP $) as Table 9 shows. The results are consistent with the predictions of the model since higher population density is expected to induce intensification. And as expected, sites where hybrid/HYV seeds are more used are characterised by higher extension services for crop activities.

The second indicator of crop intensification is the **use of inorganic fertiliser**. In all the sites but 4, fertiliser is used. Table 8 shows that fertiliser is usually applied to food crops, then to cash crops, although the difference between the percentage of farmers applying fertiliser on food and cash crops is not statistically significant. A statistically lower percentage of farmers use fertiliser on fodder and pasture.

Table 8: Use of fertiliser

Variable	Mean	SD.
% of farmers using fertiliser on food crops	54.67	45.85
% of farmers using fertiliser on cash crops	43.23	48.92
% of farmers using fertiliser on fodder	9.21	24.67
% of farmers using fertiliser on pasture	7.33	21.61

Looking at the determinants of fertiliser use, Table 9 shows that sites where a majority of farmers use fertiliser are those nearer to a large urban center, with higher access to extension services and higher population density, whose cost of labour is lower and cost of land is higher. Also, these sites are characterized by a lower labour cost to land ratio. These results are consistent with the predictions of the household model.

Before moving to the analysis of another indicator of crop intensification, it may be interesting to look at the use of inorganic fertiliser in relation to the use of manure (for soil fertility management). Due to data limitations, the analysis relates percentages of farmers (those using inorganic fertiliser *versus* those using manure) in order to identify whether the two practices are complementary (farmers tend of use simultaneously fertiliser and manure) or substitute (farmers apply either manure or fertiliser). It may have been more accurate to analyse not only the percentage of farmers using soil fertility management practices, but also the extent of the area where manure and fertiliser are applied. Sites are classified according to the percentage of farmers using manure. In 31 sites (or 65%), over half of the farmers apply manure. When comparing the sites classification according to the extent of manure use and of fertiliser use (Table 10), no specific pattern arises. For example, of the 11 sites where less than half of the farmers use fertiliser, approximately half of the sites are characterised by low manure use and half by high manure use. An interesting result is that over half of the surveyed sites (26 sites) present simultaneous usage of relatively high levels of manure and fertiliser.

Table 9: Determinants of crop intensification

Variables	% of farmers using hybrid/HYV			% of farmers using fertiliser			% of food crops sold/ bartered			% of farmers using fallow		
	<50%	>50%	Sig.	<50%	>50%	Sig.	<50%	>50%	Sig.	<5%	>5%	Sig.
number of sites	12	26		11	37		30	17		35	9	
% farmers with at least primary education	60	73		62	69		65	75		67	61	
% farmers with access to extension services	25	50	5	28	48	10	31	65	1	41	54	
% farmers with off- farm income	23	17		14	18		19	14		17	20	
Distance to nearest big city (km)	56	36		80	43	10	55	45		40	49	
Human population density	209	365	5	164	344	5	338	232	10	349	222	10
Casual wage rate (current $)	33	35		96	36	1	59	36		37	28	
Casual wage rate (PPP $)	108	131		244	134	1	186	119	10	137	104	
Land rental rate (current $)	68	141	10	82	187	5	191	109	10	193	52	5
Land rental rate (PPP $)	297	636	10	217	852	5	843	416	10	883	209	5
Wage rate/ rent (current $)	0.98	0.95		2.33	0.52	1	1.13	0.72		0.50	2.08	1

The columns "sig." give the levels of statistical difference between the two categories (e.g. < or > 50% farmers using hybrid/HYV

Table 10: Use of fertiliser versus use of manure (number of sites)

	< 50% of farmers use fertiliser	> 50% of farmers use fertiliser	Total
< 50% of farmers use manure	6	11	17
> 50% of farmers use manure	5	26	31
Total	11	37	48

The third indicator of crop intensification is **the market orientation**. Table 11 presents data on the percentage of crop sales in total production, differentiating food and cash crops. As expected, the percentage of cash crop sales is much higher than the one for food crops. However, sales to formal outlets (defined as organized marketing channels like farmers' cooperative or marketing board) are relatively limited for both types of crops. Availability of formal marketing channels is expected to foster crop intensification by ensuring farmers of a guaranteed outlet for their production.

Table 11: Market orientation

Variable	Mean	SD
% of the food crop production that is sold or bartered	44	31
% of the food crop sales to formal outlets	22	39
% of the cash crop production that is sold or bartered	88	26
% of the cash crop sales to formal outlets	39	45

Determinants of market orientation are analysed when differentiating the sites by the extent of food crop marketing. Table 9 shows that sites where over half of the food crops are sold or bartered are those with higher access to extension services and lower labour cost (measured in PPP $), a result consistent with the household model. However, sites with high food crop market orientation are also those with lower population density and lower land rental rate. These two results are difficult to interpret; market orientation measured as proportion of food crops that is sold may not be a good indicator of intensification.

The fourth and last indicator of crop intensification is the practice of **fallow** *versus* continuous cropping. Sites are differentiated according to the extent of fallow practice (whether the percentage of farmers practising fallow is below or above 5%). Although the number of sites where fallow is practised is low, Table 9 shows that sites where farmers practice fallow are characterised by lower population densities, lower rental rates and higher ratio of wage rate over rent. These results are consistent with the predictions of the conceptual framework.

Livestock intensification

The determinants of livestock intensification defined in the household model were listed in a previous section. Given the data availability, the indicators listed in Table 12 are used in the analysis.

Table 12: Livestock intensification- determinants derived from the household model and indicators used in the empirical analysis

Determinants from household model	Indicators used in the empirical analysis
output price for livestock	milk and meat price
family and hired labour productivity	% farmers with at least primary education and extent of extension/veterinary services for livestock activities
opportunity cost of family labour	% farmers with off-farm opportunities and distance to nearest large urban center
wage rate	wage rate in current and PPP $
rental rate	rental rate in current and PPP $
marginal productivity of purchased inputs	not available
price of purchased inputs	feed price in current and PPP $

Different indicators of livestock intensification are considered: type of feeding system, feeding strategies, decision to plant fodder, existence of a fodder market, and decision to purchase feed. As in the case of crop intensification, the analysis aims at testing whether the driving forces listed in Table 12 are in play and sites are grouped into two categories representing low and high levels of intensification.

The first indicator of livestock intensification is **the main type of feeding system**. Five types were distinguished: grazing unimproved pasture, grazing improved pasture, mainly grazing (including tethering) with some stall feeding, mainly stall feeding with some grazing, and stall feeding only. Zero-grazing systems as practiced in Kenya are shown in Plate 2.

Plate 2: Zero-grazing unit, Kenya

The main feeding systems (i.e. most common in the surveyed villages) in the surveyed sites are the most two extensive ones (grazing and mainly grazing) and the most intensive one (see Table 13).

Table 13: Main feeding system (number of sites)

Main feeding system	Number
grazing unimproved pasture	13
grazing improved pasture	1
mainly grazing	13
mainly stall feeding	8
stall feeding only	13

Climatic conditions have been identified in the literature as important determinants of the livestock intensification process. At the same time, it is possible to observe, within climatic zones, a variety of farming systems. Table 14 presents the distribution of the surveyed sites by climatic zone and main type of feeding system. Although the main type of feeding system in semi-arid areas is grazing, for one third (semi-arid without irrigation) or one half of the sites (semi-arid with irrigation), animals are either mainly or entirely stall-fed. In consequence, the subsequent analysis aims at identifying the determinants of the intensification level without referring to agro-climates.

Table 14: Site distribution by climatic zone and feeding system (number of surveyed site)

1	Semi arid-no irrigation	Semi arid-with irrigation	Sub humid	Humid	Highlands	Total
Grazing (unimproved and improved pasture)	4	2	2	1	4	14
	(45)	(22)	(25)	(17)	(25)	(29)
Mainly grazing	2	2	3	4	3	13
	(22)	(22)	(38)	(66)	(19)	(27)
Mainly stall feeding	2	2	1	0	3	8
	(22)	(22)	(12)	(0)	(19)	(17)
Stall feeding	1	3	2	1	6	13
	(11)	(34)	(25)	(17)	(37)	(27)
Total	9	9	8	6	16	48
	(100)	(100)	(100)	(100)	(100)	(100)

Note: Numbers in parentheses indicate the percentage of sites within the climatic zone. Percentages thus add to 100 by column.

Determinants of the main type of feeding system are analyzed in Table 15. The indicator of labour productivity- percentage of farmers with at least primary education- displays the expected positive relationship with the level of intensification. Although representing primarily labour productivity, this indicator captures as well farmers' ability to adopt new technologies associated with the intensification process. The second indicator of opportunity cost of family labour, which is distance to the nearest urban center, shows that sites where stall-feeding is the dominant system are those closest to a market. The indicator captures also the farmers' market accessibility. As expected, there is a positive relationship between population density and level of intensification since human density is significantly lower in the least intensified sites. The relationship between cost of labour and intensification levels is as expected negative: the intensification process is labour-intensive and is likely to occur primarily in sites where labour costs are relatively low. Comparison of the ratio wage rate/land rental rate shows that it is highest in the least intensified sites. Finally, while milk prices (both in current \$ and PPP \$) are relatively constant across systems, the ratio wage rate/milk price is significantly lower in the most intensified sites, a result consistent with the predictions of the household model. The relationship between price of dairy meal and intensification level does not present a clear pattern.

Table 15: Livestock intensification- type of feeding system

	All sites					Dairying important activity				
	Grazing	Mainly grazing	Mainly stall feeding	Stall feeding		Grazing	Mainly grazing	Mainly stall feeding	Stall feeding	
Variable	(1)	(2)	(3)	(4)	Sig.	(1)	(2)	(3)	(4)	Sig.
Number of sites	13	14	8	13		11	10	8	13	
% farmers with at least primary education	55	64	72	81	1-4	61	73	72	81	1-4
% farmers with access to extension/ veterinary services	59	61	68	73		55	61	68	73	
% farmers with off- farm income	16	15	22	16		16	13	22	16	
Distance to nearest big city (km)	47	94	36	21	1-4; 2-4; 3-4	52	124	36	21	1-2; 1-4; 2-3; 2-4; 3-4
Human population density	152	379	368	329	1-2; 1-3; 1-4	160	450	368	329	1-2; 1-3; 1-4
Casual wage rate (current $)	60	68	33	32	1-4; 2-4	67	90	33	32	1-4; 2-3; 2-4
Casual wage rate (PPP $)	168	179	167	127		182	233	167	127	2-4
Land rental rate (current $)	71	182	208	193	1-2; 1-3; 1-4	85	243	208	193	1-2; 1-3; 1-4
Land rental rate (PPP $)	267	750	1140	809	1-2; 1-3; 1-4	322	1060	1140	809	1-2; 1-3; 1-4
Wage rate/rent	2.37	0.64	0.30	0.34	1-2; 1-3; 1-4	1.64	0.64	0.30	0.34	1-2; 1-3; 1-4
Milk price (current $)						0.22	0.24	0.21	0.25	
Milk price (PPP $)						0.80	0.84	0.98	0.87	
Wage rate/milk price						301	360	182	141	1-4; 2-4
Price of dairy meal (current $)						0.15	1.23	0.14	0.17	1-2; 2-3; 2-4
Price of dairy meal (PPP $)						0.48	3.00	0.65	0.57	1-2; 1-3; 2-3; 2-4
Price of dairy meal/milk price						0.71	4.93	0.64	0.71	1-2; 2-3; 2-4

The columns “sig.” give the pairs of categories (e.g. grazing (1)) for which the variable (e.g. % farmers with primary education) is statistically different.

The second indicator of livestock intensification deals with **the feeding strategies**. The household model postulates that feed resources, rather than land, are the main constraints to animal agriculture since feed resources can be imported from outside the system. The different off-farm feed resources are listed in Table 16. The proportion of the free feed resources in total feed intake is difficult to assess and the collected data are thus scanty. In the majority of the sites (37%), farmers collect fodder from off-farm (e.g. road sides grass). Off-farm fodder is particularly important in the semi-arid and sub humid. Landless farmers in India rely exclusively on off-farm feed resources, mainly gathered. The percentage of fodder gathered from off-farm (in total animal feed intake) varies from 5 to 100%, with an average of almost 40% (using available data from 20 sites of the 37 sites where farmers collect this type of fodder).

Access to communal land (grazing land) is another source of off-farm feed. Communal land is available mainly for farmers in the semi-arid areas. On average in the sites with communal land, almost 80% of livestock-keepers have access to communal land (ranging between 3% and 100%); animals graze on average 6.5 hours a day (ranging between 1.5 and 14 hours) during 10 months in a year (ranging between 4 and 12 months).

Transhumance whereby a part or the whole herd migrates to greener pastures for some parts of the year is practiced typically in the semi-arid areas of West Africa (Plate 3). Transhumance and grazing on communal land has historically been important feeding strategies for farmers in the semi- arid areas (Bayer and Waters-Bayer). No transhumance is observed in the Highlands, except in one site in the Tanzanian highlands. In this area, farmers in the highlands own also land in the lowlands where oxen are moved in during land preparation. On average, 37% of livestock-keepers send their animals on transhumance (ranging between 5% and 80%) during 8 months (ranging between 4 and 12 months), sending 58% of the herd (ranging between 20% and 90%).

Plate 3: Transhumance Fulani herd, Nigeria

Table 16: Off- farm feed resources

Climatic zone	% sites where farmers		
	Collect fodder from off- farm	Access to communal land	Transhumance
semi-arid- no irrigation	100	100	44
semi-arid- with irrigation	100	89	33
sub humid	88	63	0
Humid	33	33	0
Highlands	63	56	6

Own-farm feed resources are pasture (improved and unimproved), fodder and crop residues. Table 17 presents the average percentages of land under different own farm resources, over the total farmed land. Land allocated to livestock (in total farmed land) varies from 73% in the sub-humid zone to 90% in the semi-arid areas with irrigation. Recalling that land allocated to livestock includes the area under crops whose residues are fed to livestock, it is not surprising to observe a relatively high average of 81%.

Pasture (natural and improved) occupies less than one-fifth of the land in all the climatic zones, except in the humid area where it occupies more than onehalf. The percentages of land allocated to fodder, an indicator of intensification, are relatively small; in the highlands, the percentage is slightly higher but the high standard deviation reflects the variability across sites within the climatic zone. The most important feed resources, in terms of percentage of land, are crop residues (except in the humid climatic zone as noted above).

Table 17: Percentage of land uses (in total land)

Climatic zone	Natural pasture		Improved pasture		Fodder		Crop used as feed	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
semi-arid- no irrigation	7.3	13.4	0.2	0. 7	0. 8	1.7	67.3	37.6
semi-arid- with irrigation	5. 7	8.0	0.0	0.0	1.1	1.7	83.1	9.7
sub humid	12.5	28.9	5.3	9. 8	7.5	13.7	48.1	33.1
Humid	24. 7	12.7	28.3	24.2	7.9	13.6	13.5	20.3
Highlands	6.9	17.0	8.1	23.3	13.8	23.9	56.4	33.9

Note: Sum by climatic zone does not equal to 100 because not all land is allocated to livestock activities

When analyzing livestock intensification, both feed and land resource constraints need to be taken into account. Staal et al. (2001) defined two main axes of intensification, both centered on the feed constraint. The first axis of intensification is the usual measure of plant intensification measured as the intensity of land cultivation. The second axis captures the feed imports into the production system. A measure of crop intensification is calculated as the weighted sum of the yields of crude protein (kg DM/ha) for the different feed types (land in pasture, fodder including fodder trees and crops whose residues are fed to the animals), where the weights are the percentages of land under different feed types. The indicator is thus the average number of kilograms of crude protein available per hectare per year. The higher the land allocated to livestock and the higher the protein content of the different feed types available on farm, the higher the measure of on-farm feed resources availability. The second axis of intensification, feed imports into the production system, is captured by the extent of feed purchases measured by the percentage of farmers in the area purchasing fodder and crop residues. Both axes thus represent the extent of feed availability in the area, on-farm feed for the first axes and feed imports for the second axes. The off-farm feed resources as defined in Table 16 need also to be taken into account. Sites where farmers rely on these "free" feed resources are expected to have lower on-farm feed resources. To explore this hypothesis, sites were grouped according to the extent of free feed resources use. Table 18 presents the different source of feed. In 23 sites (48% of the sites), farmers use two free off- farm resources, namely access to communal land (for animal grazing) and feed gathering (e.g. cut- and- carry road side grass). In 11 sites (23%), farmers rely on one free feed resources (either grazing on communal land (3 sites), transhumance (1 site) or feed gathering (7 sites). In the remaining 14 sites, farmers do not collect free feed at all in 7 sites and use the 3 possible off- farm feed resources in the other 7 sites. Table 18 shows that the measure of on-farm feed availability (crude protein availability per hectare per year) is negatively correlated with the extent of use of free off-farm resources. While results should be taken with caution due to the limited number of observation, Student tests on the equality of means shows that on-farm feed availability for systems 1 and 2 (with no or only one free off-farm resource) is significantly higher than for systems 3 and 4 (with 2 or 3 free off-farm resource). Two groups thus emerged from this analysis: on one hand, sites with high levels of on-farm feed availability and low access to free off-farm resource; on the other hand, sites with low levels of on-farm feed availability and good access to free off-farm resource.

Table 18: Crude protein availability (kg/ha/year) by extent of free off-farm resources use

Extent of free off-farm resources use	On farm feed availability			
	No. of sites	Mean	SD	T- test
1. no free off-farm resource	7	598	387	3, 4
2. one free off-farm resource	11	581	585	3, 4
3. two free off-farm resources	23	223	221	1, 2
4. three free off-farm resources	7	160	99	1, 2

Table 19: Percentage of farmers purchasing fodder and/or crop residues by extent of free off-farm resources use

Extent of free off-farm resources use	% farmers purchasing fodder and/or crop residues		
	Mean	SD	T- test
1. no free off-farm resource	2	4	2, 3, 4
2. one free off-farm resource	46	41	1, 3
3. two free off-farm resources	22	39	1, 2
4. three free off-farm resources	24	31	1

Note for Table 18 and Table 19: One free off- farm resource refers either to grazing on communal land, transhumance or feed gathering. The two free off- farm resources are access to communal land and feed gathering. The three free off- farm resources are grazing on communal land, transhumance and feed gathering.

The "T-test" column gives the types of system (1 to 4) that differ significantly (at 10%) from the one under consideration.

The other axis of intensification, purchased feed (fodder and crop residues) is analyzed and presented in Table 19. Sites with no access to free off-farm feed resources are characterized by significantly lower fodder purchases. Sites with access to one free off-farm feed resource (category 2) present high lower of feed purchases, although the difference is not statistically significant with category 4 (sites with access to three free off-farm feed resources).

Sites are grouped along the two axes of intensification, on-farm feed resources and feed purchases. For on-farm feed availability, the observed median is used as the threshold between the two categories, high and low. For feed purchases, the threshold of 10% of farmers purchasing fodder and/or crop residues is used to differentiate sites with low or high feed purchases. Table 20 presents the number of sites falling in each category. Of the 48 surveyed sites, one third of the sites fall into the "least intensified" category (low own farm feed availability, low feed purchases). However, the large majority of these sites (15 over 16 sites) have good access to free feed resources (defined as above as access to at least two free off-farm feed resources). Sites in this category thus rely on off-farm resources. A small number of sites (15%) fall in the second category, relying as well on off-farm feed resources and complementing with fodder and crop residues purchases. The third and fourth categories rely less on off-farm resources and present both high levels of own-farm availability, a result consistent with Table 18.

Table 20: Axes of intensification

Category	Own farm feed availability	Extent of feed purchases	No. of sites	% sites with access to free feed resources
1	low	low	16	94%
2	low	high	7	86%
3	high	low	14	36%
4	high	high	11	36%

Since the indicator of own-farm feed availability combines feed resources from grazing pasture (relatively low labour requirement) and cut-and-carry forage/crop residues feeding (relatively high labour requirement), linking determinants of intensification with the measure of on-farm availability may not be suitable. The on-farm strategies of intensification are now analysed in more details.

The third indicator of livestock intensification is **the decision to plant fodder** (Plate 4). Planting fodder diverts land resources from other crop activities, thus showing farmers' specialization in livestock production. Table 21 presents average percentage of land under fodder and other statistics when categorizing sites by main type of feeding system. As expected, sites where mainly or only stall feeding is the main type of feeding system show higher levels of land allocated to fodder, although the difference of means across groups is not statistically significant.

Plate 4: Planted forage in the lowlands and food crop on terraces, Madagascar

Table 21: Percentage of land allocated to fodder (over total cropped land), by main type of feeding system

Main type of feeding system	mean	median	SD	minimum	maximum
grazing	3.6	0.0	7.4	0.0	27.0
mainly grazing	3.9	0.0	9.2	0.0	35.0
mainly stall feeding	11.8	0.5	31.6	0.0	90.0
stall feeding only	11.4	5.0	15.3	0.0	50.0

Looking at the determinants of intensification, two groups are differentiated depending on the percentage of land allocated to fodder crops: less than 5% of the land (including sites where no fodder crops are grown) and at least 5%. The 5% threshold was chosen for two reasons: (1) having less than 5% of land under fodder does not seem to reflect livestock intensification and (2) the number of sites across groups is relatively comparable. Also, whether the production system is dairying oriented is considered an important factor. The first analysis is conducted for all the sites using a subset of determinants (i.e. those concerning dairying are not used); the second analysis include only the sites where dairying is an important livestock activity using all determinants. Sites where dairying is an important livestock activity are those for which at least half the milk production is sold; forty-two sites (87.5% of the sites) meet the condition.

Table 23 presents the average values of the determinants of livestock intensification for the two categories of sites, those with less than 5% of land planted in fodder crops and those with more than 5%. Of the 9 determinants retained in the analysis, only 3 differ significantly across the 2 groups. The percentage of farmers with at least primary education is statistically higher in the sites where livestock intensification is higher, confirming a well-know result of the literature than intensification involving the adoption of new technologies requires an associated minimum education level. The second determinant that is statistically different across groups is the percentage of farmers with off-farm income, reflecting family labour opportunity cost according to Table 12. Table 23 shows that livestock intensification is negatively correlated with off-farm opportunities, a result consistent with the outcomes of the household model since sites with less labour opportunities are more intensified. Finally, more intensified sites are those where the ratio of labour to land cost is lower. This result is again consistent with the household model; fodder cultivation being labour-intensive, farmers are more likely to allocate some land to fodder cultivation if labour costs relative to the cost of land are lower.

Turning to sites where dairying is an important activity, six additional determinants are considered as shown in Table 23. Only one variable is statistically different across the two groups of sites. Milk price is significantly higher in the sites where livestock intensification is higher, a result consistent with the household model since intensification is positively associated with output price levels.

The fourth indicator of livestock intensification is **the existence of a fodder market**. A fodder market is assumed to be a good indicator of intensification since it reflects the demand for purchased fodder. Of the surveyed 48 sites, 26 (54%) have a fodder market. As expected, the percentage of farmers purchasing fodder and crop residues is significantly higher (at 1%) in the sites where there is a fodder market, compared to sites where there is none (39.5% farmers *versus* 7.9%). Looking at the factors differentiating sites with and without a fodder market, Table 22 shows that 78% of the sites in the semi-arid area have a fodder market, a significantly higher proportion than in the other zones. Also, there is no site in the humid zone with a fodder market, a situation statistically different to the one in the sub-humid areas and highlands where half of the sites have a fodder market.

Table 22: Proportion of sites with a fodder market, by climatic zone

Climatic zone	Proportion of sites with a fodder market			
	Mean	SD	Min	Max
semi-arid- no irrigation	0.78	0.44	0	1
semi-arid- with irrigation	0.78	0.44	0	1
sub humid	0.50	0.53	0	1
Humid	0.00	0.00	0	0
Highlands	0.50	0.52	0	1

Table 23 shows that sites with a fodder market are closer to an urban center and have higher output prices (milk price in PPP $), two results that are consistent with the intensification process. However, few determinants unexpectedly differ significantly between the two groups. It suggests that the presence of a fodder market in a village, by reflecting total feed demand in the area, is not a clear-cut indicator of livestock intensification.

Table 23: Livestock intensification- land in fodder and presence of a fodder market

	Land in fodder						Presence of a fodder market					
	All sites			Dairying important activity			All sites			Dairying important activity		
	Land in fodder			Land in fodder			Presence of a fodder market			Presence of a fodder market		
Variable	< 5%	>5%	Sig.	< 5%	>5%	Sig.	Yes	No	Sig.	Yes	No	Sig.
Number of sites	29	19		25	17		26	22		21	21	
% farmers with at least primary education	62	75	10%	67	79	-	54	83	1	58	86	1
% farmers with access to extension/veterinary services	70	57		71	55		70	59		71	58	
% farmers with off-farm income	20	12	10%	19	13	-	18	16		17	16	
Distance to nearest big city (km)	46	61	-	50	67	-	35	71	10	40	73	
Human population density	322	273	-	346	285	-	303	302		331	311	
Casual wage rate (current $)	44	60	-	47	68	-	42	60		48	62	
Casual wage rate (PPP $)	154	170	-	165	189	-	147	175		169	179	
Land rental rate (current $)	147	181	-	172	199	-	177	141		216	149	
Land rental rate (PPP $)	671	724	-	798	781	-	782	574		951	609	
Wage rate/rent	1.33	0.45	5%	0.91	0.50	-	0.95	1.00		0.86	0.61	
Milk price (current $)				0.21	0.26	5%				0.23	0.23	
Milk price (PPP $)				0.85	0.89	-				0.94	0.79	10
Wage rate/milk price				225	267	-				201	284	
Price of dairy meal (current $)				0.37	0.47	-				0.16	0.66	10
Price of dairy meal (PPP $)				1.09	1.22	-				0.64	1.65	
Price of dairy meal/milk price				1.59	1.85	-				0.71	2.68	10

The columns "sig." give the levels of statistical difference between the two categories (e.g. land in fodder < or > 5%).

The fifth indicator of livestock intensification is **the decision to purchase feed (**Table 24**)**. Two feed categories are considered: fodder and crop residues, and concentrates. The analysis of the decision to purchase fodder and crop residues was presented in Table 19 when comparing the levels of feed purchases across sites differing by their levels of access to off-farm feed resources. The present analysis aims at identifying the determinants of the extent of fodder and crop residues purchases in the same way as the decision to grow fodder (Table 25).

Table 24: Extent of fodder and crop residues purchases, by climatic zone

Climatic zone	% of farmers purchasing fodder and crop residues			
	Mean	SD	Min	Max
semi-arid- no irrigation	29	45	0	100
semi-arid- with irrigation	45	40	0	100
sub humid	20	39	0	100
humid	0	0	0	0
highlands	24	34	0	100

Comparing the extent of feed purchases by climatic zone shows that semi-arid farmers and farmers in the highlands import significantly more feed than farmers in the humid zone. Due to the lower overall feed availability, farmers in the semi-arid areas rely more on external (i.e. off-farm) feed resources than in the humid area. On the other hand, farmers in the highlands are expected to purchase feed to intensify their animal production. The extent of fodder and crop residues purchases may thus not be a very good indicator of intensification since it seems to be climatic zone-driven. These results are consistent with those in Table 22 that records the proportion of sites with a fodder market by climatic zone.

Looking at the determinants of intensification as presented in Table 25 the only variable that differs significantly across groups is the ratio of cost of labour to cost of land. The result is consistent with the predictions of the household model since sites where farmers purchase fodder are those where the cost of land compared to the labour cost is relatively high. The fact that only this variable differs significantly across the sites confirms the conclusion drawn from Table 24: the percentage of farmers purchasing fodder and crop residues does not seem to be a very powerful indicator of livestock intensification across climatic zones.

Results relative to **the decision to purchase concentrates** are presented in Table 25 and Table 26. Table 26 shows that concentrate purchases does not seem to be climatic zone specific, although more farmers in the sub humid zone on average purchase concentrates.

Table 25: Livestock intensification: fodder/ crop residues and concentrates

	Purchase fodder and crop residues						Purchase concentrates					
	All sites			Dairying important activity			All sites			Dairying important activity		
	% of farmers purchasing			% of farmers purchasing			% of farmers purchasing			% of farmers purchasing		
Variable	< 10%	> 10%	Sig.	< 10%	> 10%	Sig.	< 50%	> 50%	Sig.	< 50%	> 50%	Sig.
number of sites	30	18		27	15		20	28		14	28	
% farmers with at least primary education	69	65		73	71		54	77	1	62	77	10
% farmers with access to extension/veterinary services	66	63		64	65		56	71		51	71	10
% farmers with off-farm income	16	17		17	15		16	17		15	17	
Distance to nearest big city (km)	64	32		69	34		79	32	5	106	32	1
Human population density	288	326		304	353		193	380	1	203	380	5
Casual wage rate (current $)	55	42		60	46		55	47		73	47	
Casual wage rate (PPP $)	165	152		176	172		145	170		183	170	
Land rental rate (current $)	139	192		155	226		55	229	1	70	229	1
Land rental rate (PPP $)	587	838		652	987		218	1011	1	261	1011	1
Wage rate/rent	1.35	0.46	5	0.99	0.38	10	2.02	0.35	1	1.83	0.35	1
Milk price (current $)				0.24	0.22					0.27	0.21	1
Milk price (PPP $)				0.88	0.84					0.89	0.85	
Wage rate/milk price				264	208					285	221	
Price of dairy meal (current $)				0.54	0.17					1.05	0.15	1
Price of dairy meal (PPP $)				1.40	0.65					2.56	0.57	5
Price of dairy meal/milk price				2.19	0.75					4.14	0.70	5

The columns "sig." give the levels of statistical difference between the two categories (e.g. % farmers purchasing < or > 10%).

Table 26: Extent of concentrate purchases, by climatic zone

Climatic zone	% of farmers purchasing concentrates			
	Mean	SD	Min	Max
semi-arid- no irrigation	33	49	0	100
semi-arid- with irrigation	62	48	0	100
sub humid	87	33	5	100
humid	54	41	0	100
highlands	56	44	0	100

Looking at Table 25, concentrates purchases are more common in sites where the level of education and availability of extension services is higher, closer to an urban center and with higher population density. The first result is consistent with the theory of adoption of agricultural technologies whereby education level has a positive effect on the adoption decision. The second result can be interpreted at the light of the transaction costs theory: the lower the distance, the lower the transaction costs and subsequently higher net output prices and lower net input prices, and the higher the incentive to intensify. The third result- a positive relationship between the decision to purchase concentrates and population density- is again consistent with the "population-driven" intensification theory. Besides these three variables, a number of prices differ between the two groups. Land rental rate (current and PPP $) is significantly higher in sites where concentrates purchases are more common. Also, the ratio of wage rate over land rate is significantly lower in these sites. This result is consistent with one of the household model outcomes whereby increased cost of producing feed (i.e. increased cost of land) brings about the substitution of purchased feed for own feed. In sites where dairying is a major activity, dairy meal price (both in current and PPP $) and the ratio of dairy meal price over milk price are significantly lower where concentrates purchases are higher. These results are again consistent with the household model whereby input price has a negative effect on the intensification process. Finally, milk price is lower in sites where intensification, measured as the extent of concentrates purchases, is higher. Although this result contradicts the predictions of the model, the ratio of dairy meal price over milk price has the expected effect on the intensification process.

Dairy intensification

The level of dairy intensification is captured using four indicators: the dominant breed in the herd, rearing male calves on farm, use of mechanical procedures for milking and preparing feed and market orientation. The driving forces considered in this analysis are similar to those used for the livestock intensification part. However policy and public investment played a key role in dairy development, but these factors are difficult to capture at the level of analysis considered here (village- level data). This should be kept in mind when interpreting the results.

The dominant cattle/buffalo breed in the area is identified as the breed kept by the highest percentage of farmers in the surveyed village. Intensification is measured as the shift from "low-producing" animals to "high-producing" animals. In the case of cattle, the shift is equivalent to the one from local breed cattle, to crossbred and finally to high-grade animals. Table 4 shows that local breed cattle are the dominant breeds in the semi-arid, sub-humid and highlands areas. A total of 18 sites where buffalos are present were surveyed and few are in the humid (2 sites) and highlands (3 sites) areas. Data on the buffalo breed distribution are thus difficult to interpret due to lack of data.

Looking at the determinants of **the dominant cattle breed in the area**, Table 27 shows that education level is lower in the areas where local breed cattle is the dominant breed. This result is consistent with the previous results. A number of indicators are different across groups: wage rate, milk price, wage rate/milk price and price of dairy meal. The results are however contradictory with the prediction of the household model.

Table 27: Dairy intensification: dominant cattle breed

Variables	Mean in sites where the dominant cattle breed is			Statistical difference between
	local (1)	crossbred (2)	high grade (3)	
number of sites	27	9	12	
% farmers with at least primary education	51.70	85.89	88.83	1-2; 1-3
% farmers with access to extension/ veterinary services	63.44	81.89	56.08	2-3
% farmers with off-farm income	17.22	18.89	14.08	
Distance to nearest big city (km)	53.85	41.50	54.45	
Human population density	279.31	357.23	312.92	
Casual wage rate (current $)	34.64	53.07	81.42	1-3
Casual wage rate (PPP $)	126.29	182.11	215.97	1-2; 1-3
Land rental rate (current $)	134.08	189.21	199.71	
Land rental rate (PPP $)	701.13	790.02	616.88	
Wage rate/rent	1.32	0.49	0.59	
Milk price (current $)	0.25	0.20	0.24	2-3
Milk price (PPP $)	1.03	0.81	0.67	1-2; 1-3
Wage rate/milk price	158.72	260.27	339.79	1-2; 1-3
Price of dairy meal (current $)	0.14	0.67	0.58	1-2; 1-3
Price of dairy meal (PPP $)	0.57	1.77	1.43	1-2
Price of dairy meal/milk price	0.57	2.83	2.38	1-2; 1-3

The last column gives the pairs of categories (e.g. local (1)) for which the variable (e.g. % farmers with primary education) is statistically different.

The second indicator of dairy intensification is the extent of **rearing male calves on farm**.

Table 28: Dairy intensification- keeping male calves and milk sale

	% of farmers keeping male calves on farm			% of farmers selling milk		
Variable	<50%	>50%	Sig.	<50%	>50%	Sig.
Number of sites	15	27		14	34	
% farmers with at least primary education	90	62	1	47	76	1
% farmers with access to extension/veterinary services	51	72	10	66	65	
% farmers with off- farm income	17	16		15	17	
Distance to nearest big city (km)	23	76	5	32	60	
Human population density	316	324		257	321	
Casual wage rate (current $)	55	55		36	56	
Casual wage rate (PPP $)	155	185		119	176	
Land rental rate (current $)	166	195		59	203	1
Land rental rate (PPP $)	511	986		302	861	1
Wage rate/rent	0.43	0.96	10	1.91	0.62	1
Milk price (current $)	0.26	0.22	5	0.27	0.22	5
Milk price (PPP $)	0.77	0.92	10	1.13	0.81	5
Wage rate/milk price	231	247		154	251	
Price of dairy meal (current $)	0.18	0.56		0.11	0.46	
Price of dairy meal (PPP $)	0.52	1.55		0.43	1.27	
Price of dairy meal/milk price	0.74	2.32		0.45	1.92	

The columns “Sig.” give the levels of statistical difference between the two categories (e.g. % farmers keeping male calves on farm < or > 50%).

If dairy production aims primarily to produce milk, male calves are disposed rapidly after birth. Sites are grouped according to the extent of keeping male calves on farm. Table 28 presents the results of the statistical analysis. Sites where less than half of the livestock-keepers keep male calves are more intensified. As expected, intensified sites are those where the farmers' level of education is high, that have good market access and where relative cost of labour to land is low. The result concerning access to extension services (low access associated with high level of intensification) is however counter-intuitive.

The third indicator of dairy intensification is **the use of mechanical procedures for milking and preparing feed**. The use of mechanical procedures for milking is common (measured as the majority of the farmers using the technique) in only 3 sites, while in only 6 sites is the technique of mechanical feed preparation common. Because of data availability, a statistical analysis cannot be conducted.

The fourth indicator of dairy intensification is **the market orientation**. Sites are classified according to the percentage of farmers selling milk on a regular basis. Table 28 presents the results of the statistical analysis. A number of determinants differ significantly across the two groups. As expected, education level and land rental rate are higher in the sites where milk marketing is higher. The ratio of wage rate over land rental rate is lower in sites where milk orientation is higher, a result consistent with the outcomes of the household model. Milk price is significantly lower in sites where more farmers market milk, a result consistent with a number of studies showing a negative relationship between milk sale price and dairy development.

Crop intensification and livestock intensification processes

An interesting issue is to look at the relationship between crop and livestock intensification processes. Do crop and livestock intensification processes occur in the same sites? Or do sites specialise either in crop or livestock intensification?

To answer this question, three different types of analyses were conducted:

- mean comparison tests using different sites classifications
- correlation analysis between the different indicators of intensification
- correlation analysis on combined indicators of intensification

Mean comparison tests using different sites classifications

For this analysis, three indicators of crop intensification are retained, based on data availability and on the results of the previous analyses: the use of hybrid varieties/ HYV; fallow; and the use of fertiliser. For livestock intensification, three indicators are also used: the main type of livestock feeding system; the extent of land in fodder; and the extent of concentrates purchases.

- *Sites classified by levels of livestock intensification*

When classifying sites by main type of feeding system and in order to have sufficient number of sites per class, two main types of systems (based on the four original ones) are differentiated: only or mainly grazing *versus* only or mainly stall-feeding. Table 29 shows that the extent of hybrid varieties/HYV does not differ significantly across the two groups. However, based on the two last indicators of crop intensification, results suggest that crop and livestock intensification processes are complementary as they occur in the same sites: in fact, the percentage of farmers practicing fallow (using fertiliser) is significantly lower (higher) in sites where the main type of livestock feeding system is only and/or mainly stall feeding, compared with sites where livestock is mainly or only grazed. A similar conclusion can be drawn when sites are differentiated by the extent of concentrates used: the percentage of farmers using hybrid/HYV and those using fertilizer is significantly higher in sites where the majority of farmers purchase concentrates. However, when sites are classified by the extent of land planted with fodder, no statistical difference is observed.

Table 29: Crop intensification, by level of livestock intensification

	Number of sites	% of farmers		
		using hybrid/ HYV	practicing fallow	using fertiliser
Feeding system:				
Only or mainly grazing	27	72	10	69
Only or mainly stall-feeding	21	76	2	88
Difference significant at (%)		-	10	5
Land in fodder:				
Less than 5%	29	76	7	79
Above 5%	19	69	5	74
Difference significant at (%)		-	-	-
% of farmers purchasing concentrates:				
Less than 50%	20	56	11	64
Above 50%	28	86	4	87
Difference significant at (%)		1	-	5

- *Sites classified by levels of crop intensification*

Another way to look at the data is to classify the sites according to the extent of crop intensification and compute the indicators of livestock intensification by extent of crop intensification.

When sites are classified by the extent of use of hybrid varieties/HYV, results presented in Table 30 show that only the last indicator of livestock intensification- the extent of concentrates purchases- differs significantly across the sites: 67% of farmers purchase concentrates in sites where crop intensification is higher, compared to 21% in sites with low crop intensification. When sites are classified by the extent of fallow extent, results shown in Table 30 are similar to those when differentiating sites by the extent of use of hybrid varieties/HYV. Finally, when sites are classified by the extent of fertiliser use, results presented in Table 30 show that two of the three indicators of livestock intensification are significantly higher in crop-intensified sites. However, when using the extent of land planted with fodder as indicator of livestock intensification, results show that crop and livestock intensification processes do not occur in the same sites.

Therefore, the processes of crop and livestock intensification are generally complementary in the surveyed sites with the exception of the negative relationship between land in fodder and fertilizer use. This last correlation may be explained by the fact that farmers tend to use manure (and not fertilizer) on planted fodder.

Table 30: Livestock intensification, by level of crop intensification

	Number of sites	% of farmers with mainly/only stall feeding	% of farmers purchasing concentrates	% of land planted in fodder
% of farmers using hybrid/ HYV:				
Less than 50%	12	50	21	11
Above 50%	26	44	67	4
Difference significant at (%)		-	1	-
% of farmers practising fallow:				
Less than 5%	35	50	66	8
Above 5%	9	40	32	4
Difference significant at (%)		-	5	-
% of farmers using fertiliser:				
Less than 50%	11	18	36	13
Above 50%	37	52	64	5
Difference significant at (%)		5	5	10

Correlation analysis between the different indicators of intensification

The same indicators as in the previous section are used in the analysis (for livestock intensification: percentage of farmers practicing mainly/only stall-feeding, percentage of land under fodder, and percentage of farmers purchasing concentrates; for crop intensification: percentage of farmers using hybrid/HYV; percentage of farmers practicing fallow; and percentage of farmers using fertiliser). A correlation analysis shows that only a limited number of the coefficients are significant. Table 31 shows only the correlation coefficients significant at 10% or lower. The coefficients are relatively low and thus suggest weak correlation. The strongest correlation links the extent of concentrates purchases with the use of hybrid varieties/HYV, suggesting that, based on these two indicators, livestock and crop intensification processes occur in the same sites. Table 31 shows as well that the correlation between land in fodder and the use of fertiliser is negatively correlated, a result consistent with Table 30.

Table 31: Correlation coefficients between indicators of crop and livestock intensification

	% of farmers with mainly/only stall feeding	% of land planted in fodder	% of farmers purchasing concentrates
% of farmers purchasing concentrates	0.34		
% of farmers using hybrid/HYV			0.4859
% of farmers using fertiliser	0.288	-0.2788	0.2977

Note: Only significant coefficients at the 10% level or below are presented.

Correlation analysis on combined indicators of intensification

Lastly, correlation analysis is conducted on combined indicators of intensification. Crop intensification is captured by the extent of fertiliser use[4] (percentage of farmers using fertiliser in the village). Livestock intensification is captured by two variables summarising four primary indicators, namely the type of feeding system, the percentage of land in planted fodder, the percentage of farmers purchasing fodder and crop residues and the percentage of farmers purchasing concentrates[5]. Variables are combined using principal component analysis (PCA) and by retaining the two first components, for which the Eigenvalue is above 1 (Table 32) (see Kobrich et al. for a discussion on principal component analysis). These components explain 73% of the variance in the four variables (last column).

Table 32: Livestock intensification, components of the principal components analysis

Component	Eigenvalue	Cumulative Variance explained
1	1.88	0.47
2	1.05	0.73
3	0.66	0.90
4	0.42	1.00

Table 33 shows the vectors associated with the two first components retained in the analysis. The values range from (-1) to (+1) with (-1) indication high negative correlation and (+1) high positive correlation. The first vector is positively associated with the type of feeding system and the two indicators of off-farm feed supply (extent of fodder and crop residues purchases and extent of concentrates purchases), while the second indicator is positively associated with the extent of on-farm feed availability (percentage of land in planted forage).

Table 33: Livestock intensification, vectors of the principal components analysis

Variable	1	2
Type of feeding system[1]	0.59	0.14
% land in planted fodder	0.15	0.94
% farmers purchasing fodder and crop residues	0.53	-0.06
% farmers purchasing concentrates	0.58	-0.32

[1] defined as 1= only grazing, 2=mainly grazing, 3=mainly stall feeding and 4= only stall feeding

Based on the two vectors, two indicators of livestock intensification are generated; based on the scoring coefficients, the first indicator is defined as "feeding system/off- farm feed supply" and the second indicator as "on-farm feed supply".

The final step is to obtain correlation coefficients between the vectors obtained after the PCA, and the indicator of fertilizer use. The analysis does not show any strong correlation. Only the correlation between the indicator of crop intensification and the

[4] Results were poor when combining primary indicators of crop intensification using principal component analysis. It was therefore decided to use only one primary indicator.

[5] Compared to the analyses conducted in the previous sections, an additional indicator (percentage of farmers purchasing fodder and crop residues) is used in the PCA. Since a PCA aims at capturing as much variability as possible, more variables were used in the analysis.

"on-farm feed supply" indicator of livestock intensification (-0.32) is statistically significant at conventional level of significance (3%) and suggests that crop and livestock intensification processes are substitute (negative relationship between the two indicators). Also, the correlation between the indicator of crop intensification and the "feeding system/off-farm feed" indicator of livestock intensification is low (0.23 at 11% significance). As the correlation coefficients are low, no definite conclusion can be drawn from this exercise.

Crop-livestock interactions

The determinants of crop-livestock interaction defined in the household model were listed in a previous section. Given the data availability, the indicators listed in Table 34 are used in the analysis.

Table 34: Crop-livestock interaction- determinants derived from the household model and indicators used in the empirical analysis

Determinants from household model	Indicators used in the empirical analysis
output price for crop and livestock	milk and meat price
opportunity cost of family labour	% farmers with off-farm opportunities and distance to nearest large urban center
wage rate	wage rate in current and PPP $
rental rate	rental rate in current and PPP $
marginal productivity of purchased inputs	not available
price of purchased inputs	feed price in current and PPP $

Three indicators of crop-livestock interactions are used: the use of own crop residues on farm, using manure on farm and use of cattle for ploughing. As in the case of crop and livestock intensification, the analysis aims at testing whether the driving forces listed in Table 34 are in play and sites are grouped into two categories representing low and high levels of crop-livestock interaction.

The first indicator is **the use of own crop residues for animal feeding.** Table 35 shows that farmers in the semi-arid areas devote significantly more land to crop for animal feeding than in the other areas. The extent of crop residues use is significantly lower in the humid zone.

Table 35: Crop-livestock interactions by climatic zone

	% land in crops residues for animal feeding		% farmers using manure on farm		% sites where cattle/buffalo used for ploughing	
	Mean	SD	Mean	SD	Mean	SD
semi-arid (no irrigation)	67	38	73	34	89	33
semi-arid (irrigation)	83	10	79	35	78	44
sub humid	48	33	84	25	75	46
humid	14	20	20	25	33	52
highlands	56	34	71	36	56	51

Table 36: Crop-livestock interaction

Variable	% land in crop residues for animal feeding			% farmers using manure on farm			Use of cattle/buffalo for ploughing		
	<50%	>50%	Sig.	<50%	>50%	Sig.	Yes	No	Sig.
number of sites	18	30		17	31		32	16	
% farmers with off-farm income	19	16		13	19		17	16	
Distance to nearest big city (km)	78	36	5	89	31	5	36	83	5
Casual wage rate (current $)	90	26	1	75	36	5	33	83	5
Casual wage rate (PPP $)	239	111	1	203	135	10	128	222	5
Land rental rate (current $)	182	149		117	182		131	219	10
Land rental rate (PPP $)	607	746		402	819	10	664	748	
Wage rate/rent	0.98	0.98		0.66	1.13		1.01	0.91	
Human population density	227	347	10	168	376	1	295	317	

The columns "Sig." give the levels of statistical difference between the two categories (e.g. % land in crop residues for animal feeding < or > 50%).

Looking at the determinants of crop-livestock interactions, Table 36 shows that sites where at least one half of the land is planted with crops whose residues are fed to the animals are closer to an urban center and have lower labour cost. The second result is expected since feeding crop residues is labour intensive. The relationship between human population density and the use of crop residues is positive, suggesting that the surveyed sites are in the increasing part of the curve in **Figure 1**.

The second indicator of crop-livestock interactions is **the use of manure on farm**. Table 35 shows that farmers in the humid zone use significantly less manure. The use of manure does not differ significantly across the other zones.

Sites are classified according to the extent of use of manure on farm, measured as the percentage of farmers using manure on a regular basis. Table 36 presents the results of the statistical analysis. The determinants that differ significantly across the two groups are similar to those identified for the use of crop residues. An additional determinant differs across groups, the land rental rate: sites where at least one half of the farmers use manure are characterized by higher land rental rates. As the land becomes more valuable, farmers invest in soil fertility maintenance by applying manure.

The third indicator of crop-livestock interactions is **the use of livestock for ploughing**. Table 35 presents the proportion of sites where cattle/buffalo is used for ploughing by climatic zone. Farmers in semi-arid areas use on overall more cattle/buffalo for ploughing compared to the humid and highlands areas.

Looking at the determinants of crop-livestock interactions, Table 36 shows that fewer determinants differ significantly across the two groups. The results are the same for the distance to an urban center and for labour cost. However, human population density does not differ significantly. Also, the land rental rate is higher in sites where cattle/buffalo is not used for ploughing. This last result can be explained by the relatively lower rental rates in the semi-arid areas where the use of cattle/buffalo ploughing is more common (Table 35). In general, the results using this indicator of crop-livestock interactions do not conform to the other crop-livestock interaction results. This can be explained by the fact that, contrary to the other two indicators, the use of livestock for ploughing has two alternatives, namely hand/hoe ploughing and mechanical (tractor) ploughing. This indicator will thus not be used in the subsequent analyses.

In order to capture **the general level of crop-livestock interactions**, a general indicator of interactions is computed as the simple average percentage of farmers feeding crop residues to animal and using animal manure. Although this indicator cannot be interpreted as "percentage of farmers practicing crop-livestock interactions" in a specific site since it combines two unique measures of interactions, the higher the indicator, the higher the general level of crop-livestock interactions in the area. Using this indicator, it is possible to represent graphically the relationship between human population density and the general level of crop-livestock interactions, thus testing the McIntire *et al.* hypothesis. Because an inverted-U shaped relationship is hypothesized, a regression linking the indicator of crop-livestock interactions on the left-hand side and human population density and the population density squared on the right-hand side is run. Following the conceptual framework, other variables need to be introduced in the analysis, namely output price, price of consumption goods and opportunity cost of labour. Because of data unavailability, the two first factors are not directly introduced in the regression, but captured through the indicator of agro-climatic characteristics. The opportunity cost of labour is captured through the percentage of farmers with off-farm jobs. If hired labour is used for crop-livestock activities (e.g. preparing crop residues for animal feeding), the wage rate in the area is likely to have an influence on the level of crop-livestock interactions. Because a number of variables were not significant at conventional levels (including the squared term of human population density- possibly due to multicollinearity), a step-wise regression (using the threshold of 10% of significativity) is run. Results are presented in Table 37. A test of specification (Ramsey test or RESET) does not detect any misspecification or an omitted variable. Moreover, the Cook-Weisberg test for heteroscedasticity also failed to reject the constant variance hypothesis.

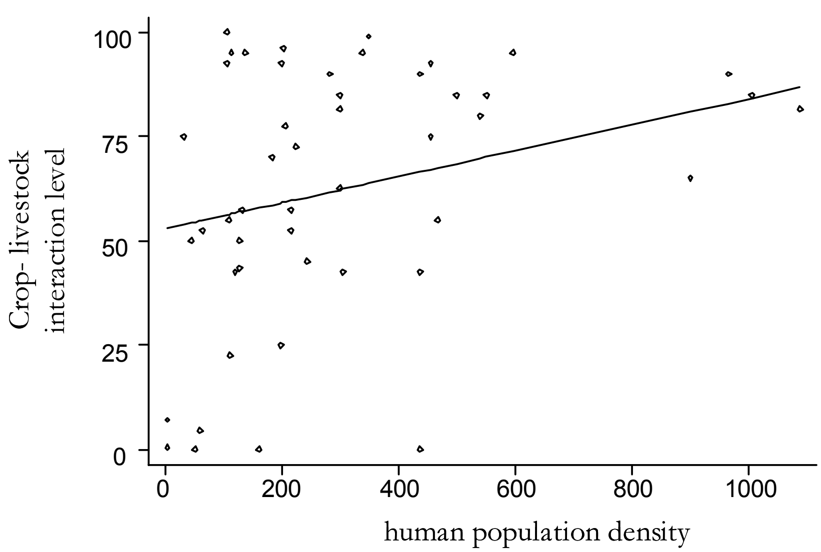
Table 37: OLS regression of general indicator of crop-livestock interactions

Indicator of crop-livestock interactions	Coef.	T- statistics	P>t
Human population density	0.03	2.32	0.03
Yearly casual wage rate	-0.01	-2.68	0.01
Length of growing period (days)	-0.14	-3.18	0.00
Constant	91.72	9.29	0.00
Adjusted R-squared	0.47		
No. of observations	47		

The coefficients have the expected sign, i.e. human population density is positively correlated with the level of crop-livestock interactions while the level of crop-livestock interactions is lower in sites with higher labour costs. As noted before, the relationship between crop-livestock interactions and human population density is linear (and not quadratic), thus rejecting the McIntire et al. hypothesis for the studied sites.

Controlling for the other explanatory variables (held at the sample mean levels), Figure 3 shows the observed level of crop-livestock interaction as well as the fitted relationship, function of the human population density variable.

Figure 3: Relationship between crop-livestock interactions (%) and human population density (persons/km^2)



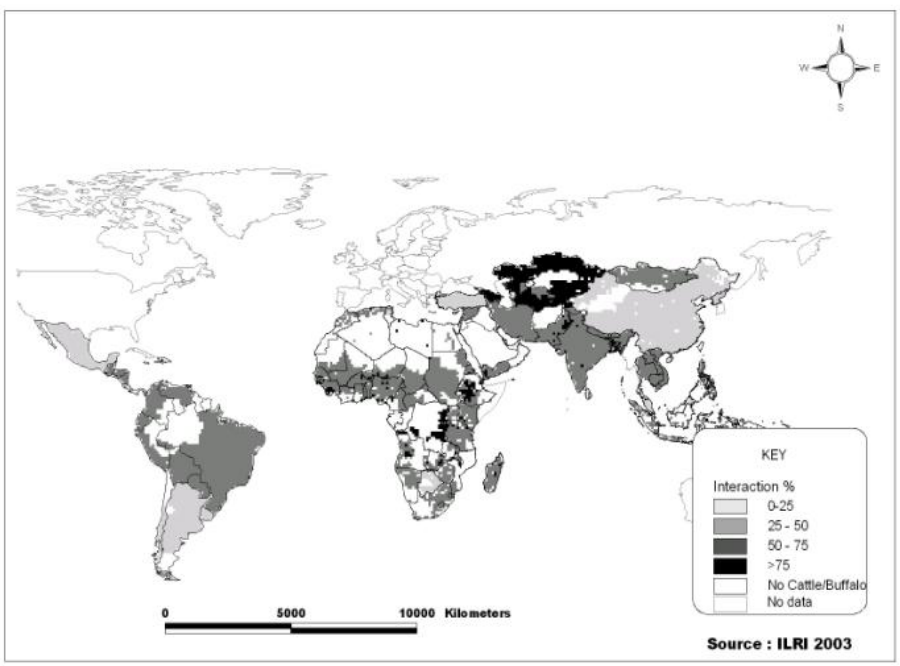
It would have been expected that sites with high levels of population density and relatively low levels of crop-livestock interactions belong to the high-income group. Sites were differentiated by income groups (based on the country-level GDP per capita), but because of the limited number of observations by group, no clear pattern emerges. Moreover, no site-level measure of income is available, thus the need to use a country-level measure of income that does not distinguish accurately across sites.

Other indicators of crop and livestock intensification were tested using a similar method but no significant trends were found.

Extrapolation

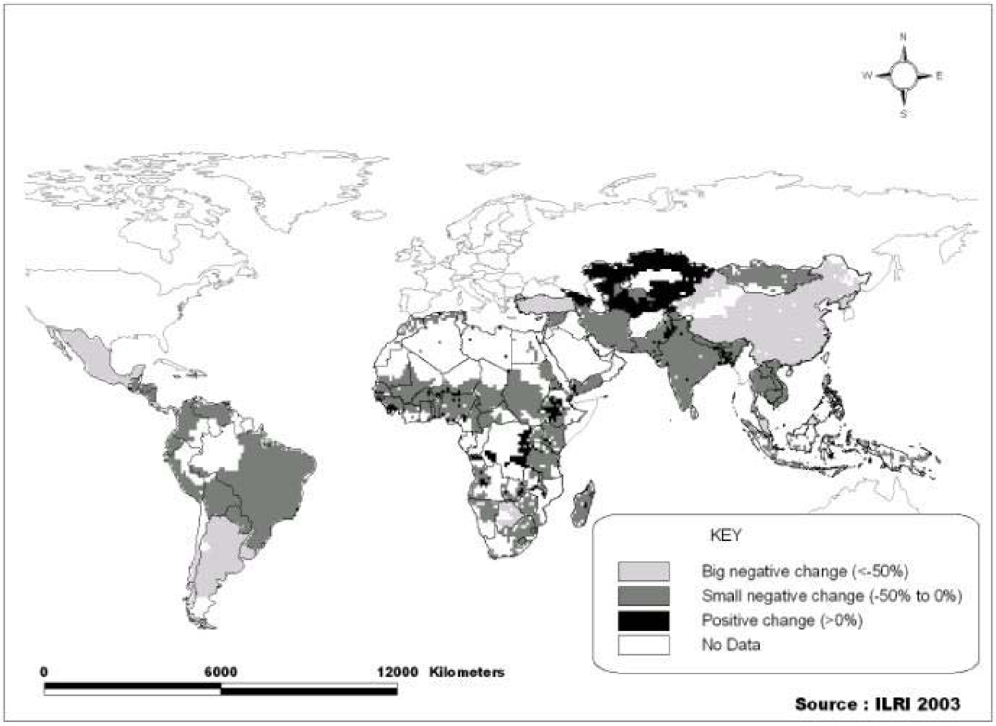
The data collected for this analysis have the interesting characteristics to be widely distributed across three continents. Besides representing a wide range of climatic conditions and agricultural intensification that allowed us to test the hypotheses of the conceptual framework, the data can also be used to predict and extrapolate the evolution of the farming systems both in space (i.e. other regions not covered by the survey) and in time. Given the relationship between the level of crop-livestock interactions and its determinants (Table 37), it is possible to predict the system evolution for the three continents under study using GIS global datasets for the levels of human population density, the annual GDP per capita (a good proxy for the wage rate[6]) and length of growing period. Human population density and length of growing period GIS layers are extracted from the ILRI GIS database while country-level GDP per capita are extracted from the World Economic Outlook dataset May 2001 (IMF, 2002).

Figure 4: Predicted levels of crop-livestock interactions (0-100) for 2000



[6] The correlation coefficient between the observed site-level wage rate and GDP per capita is 0.7, significant at 1%.

Figure 5: Predicted change in levels of crop-livestock interaction: 2000 and 2025



Using spatial analysis techniques (Arc View, ESRI, 1999), it is then possible to predict the level of crop-livestock interactions, restricting the predictions to areas with existing cattle/buffalo population. Assuming no change in the relationship and no climate change (i.e. no change in the length of growing period), crop-livestock interaction levels are predicted for 2025 using predictions for GDP per capita for 2025 based on the average growth rate between 1990 and 2000 and existing predictions for human population density (Reid et al., 2000).

The resulting predicted levels of crop-livestock interaction for 2000 are presented in Figure 4 while Figure 5 shows the predicted change in levels of crop-livestock interaction between 2000 and 2025. Results show that the estimated levels of crop-livestock interactions are in general lower in Latin America (where growing periods are relatively longer and labour costs higher), and higher in Africa. Comparing the two figures shows that the interaction level is likely to decrease since for the majority of countries, the increase in labour costs will be higher than the increase in population density. While these results are based on strong assumptions (change in labour costs similar to those during 1990-2000 and no climate change), they point to areas in Asia (especially China) and Africa (South Africa region) where mixed systems will be less sustainable in the long term.

Conclusions

Although agro-climatic characteristics are important to understand smallholder crop-livestock systems, socio-economic factors do play a role in explaining crop-livestock intensification and interaction levels. Costs of the primary factors of production, land and labour, determine partly the structure of crop-livestock smallholder production systems. Also, human population density, education level and access to markets are important factors. Although crop-livestock integration on its own cannot increase agricultural productivity substantially (McIntire et al.), mixed farming seems to offer the best path to intensify agricultural production with the potential of low environmental degradation (Sere et al., 1995).

The results show consistent patterns of intensification and crop-livestock interactions, which are generally in line with the predictions of the household model. Table 38 and Table 39 summarise the findings. This consistency may be regarded as remarkable, given the huge range of systems covered, from the Andean highlands in Bolivia to the humid tropics of Bangladesh and Sri Lanka. Key findings are those that relate choice of crop and livestock practices to relative labour and land costs, and to market access. For example, use of planted fodder is closely linked to low relative opportunity costs of labour. However, this understanding is rarely applied to fodder promotion efforts, which tend to uniformly recommend fodder cultivation based on climatic zone, and do not recognize the strong negative effect of labour costs, consistent across the three continents. Similar results are found for stall-feeding and intensive feeding systems, which depend heavily on low labour costs, and land scarcity. Nevertheless, stall-feeding is still promoted in areas where land is not scarce, and labour relatively is. It is hoped that livestock planners and scientists will take notice of these results, and condition their promotion of technologies accordingly. The spatial and temporal interpolations identify areas where major changes in farming systems will take place with the likely collapse of crop-livestock systems.

However, village-level data hide farmers' heterogeneity, raising the need for micro-analyses of crop-livestock interactions to formulate policy recommendations to improve smallholders' access and adoption of efficiency-improving technologies. In fact, farmers are a heterogeneous population and crop-livestock interactions are likely to differ across households (and maybe within households if some family members have their own activities, e.g. women are engaged in small scale vegetables growing using high levels of inputs). One of Scoones and Wolmer's main criticism to the crop-livestock integration analyses is their inability to account for social differentiation. On the same lines, Cuffaro points out that the Boserup model does not take into account the questions of distribution and entitlements since it postulates that increasing food needs induce endogenously the adoption of a new technology to increase food production for the whole community. There is however a certain heterogeneity across farmers, raising the need for a micro-analyses. The next step of the project is to analyse the extent of crop-livestock interactions at the farmer's level using household survey data from Kenya, Sri Lanka, India, Nigeria, and Colombia. Finally, farm-household optimisation models from the same sites will be used to further understand the crop-livestock linkages and choices.

Table 38: Livestock and dairy intensification: summary results of the statistical analysis

	Feeding system	Land in fodder	Fodder market	Purchase fodder	Purchase concen-trates	Cattle breed	Male calves on farm	Milk market-ing
Farmer education level	✓	✓	✗		✓	✓	✓	✓
Access to extension services					✓		✗	
Market access	✓		✓		✓		✓	
Costs of factors of production	✓	✓	✓	✓	✓	✗	✓	✓
Human population density	✓				✓			

✓, ✗ and ? indicate that the results are consistent (not consistent and indecisive) with the predictions of the conceptual framework.

Table 39: Crop intensification and crop-livestock interaction: summary results of the statistical analysis

	Hybrid/ HYV	Fertiliser	Food crops marketing	Fallow	Crop residues	Manure	Ploughing
Farmer education level							
Access to extension services	✓	✓	✓				
Market access		✓			✓	✓	✓
Costs of factors of production	✓	✓	?	✓	✓	✓	?
Human population density	✓	✓	✗	✓	✓	✓	

✓, ✗ and ? indicate that the results are consistent (not consistent and indecisive) with the predictions of the conceptual framework.

Spatial and farm dimensions of crop-livestock systems

This part presents the analysis of crop- livestock interactions at the spatial and farm dimensions for the different case studies: Colombia, India, Kenya, Sri Lanka and West Africa (Niger and Nigeria). The specific objectives of the second level of analysis are to statistically test the patterns and common relationships between driving forces and levels of crop- livestock intensification and interaction. These relationships were described in the first level of analysis (broad dimension) in the previous part. The next section presents the results of the country-level analyses while the second section summarizes the outcomes of the analysis on the "pooled" or combined dataset. Some comments on the outcomes of this second level of analysis are offered in the last section.

Table 40: Crop- livestock intensification and interactions- determinants derived from the household model and indicators used in the empirical analysis

Determinants from household model	Indicators used in the empirical analysis
Output price for crops and livestock products	Market access indicators
Labour productivity and opportunity cost of family labour	Household head's characteristics and household labour availability

The household dependency ratio, land size, human population density and climatic characteristics are additional driving forces.

Individual case studies

Colombia case study

A total of 545 dairy farms were surveyed during the period February to November of 2000 in five regions of Colombia that produce more than 80% of milk of the country. The data collection exercises were implemented by different universities (faculties of animal production). The specific objectives of the Colombia case study were to (1) identify and quantify the effect of technologies on the increase in milk productivity in dual purpose and specialized dairy systems in different regions of Colombia; and (2) analyze the relationship between productivity, technological level, and profitability. Refer to Holman et al. (2003) for more details.

Data collected concentrate on land use data, information on livestock (meat and milk) production including pasture management, animal feed supplementation and health and reproduction practices, labour management and farm infrastructures. Surveyed households were georeferenced and a detailed digitised road network was used to derive indicators of market access at the farm level. Three indicators are introduced in the analysis: the distance from the farm to the nearest (digitised) road which captures the farmer's accessibility to the public road network; total distance to the nearest Cabecera (municipal capital) broken down by road types which captures accessibility to the input and output markets; and finally travel time to the capital city.

Due to the nature of the surveyed farms, the analysis concentrates on livestock intensification. Four indicators are retained in the analysis: applying fertiliser on pasture; cut- and- carrying feed (besides grazing that all farmers practice), planting forage and keeping zebu cattle (at least half the herd has at least 75% Zebu genes). Table 41 presents the variables introduced in the analysis. Fertiliser is applied on 60% of the farm while feeding cut-and-carry forage and planting forage are relatively uncommon in the area with 28% and 24% respectively of the farmers practicing them. Approximately 70% of the farms have a majority of exotic cattle (by opposition to Zebu cattle).

Table 41: Colombia case study- statistics of variables used in the intensification analysis

Variable	Mean	Std. Dev.	Min	Max
1 if farmer uses fertiliser on pasture	0.60	0.49	0	1
if yes, amount of fertiliser (bulk/ha)	7.50	7.96	0.40	44.00
1 if cut and carry	0.28	0.45	0	1
1 if planted forage	0.24	0.43	0	1
1 if at least half the herd is mainly Zebu	0.21	0.41	0	1
Age of the owner of the farm	51.07	12.77	20.00	91.00
Years of formal education	10.99	5.19	0.00	23.00
Land size (ha)	119.15	225.51	1.00	2600.00
1 if the farmer has access to health advices	0.57	0.50	0	1
km to the nearest Cabecera, road type 1	5.61	6.64	0.00	36.72
km to the nearest Cabecera, road type 2	2.01	3.46	0.00	36.84
km to the nearest Cabecera, road type 3	0.58	1.81	0.00	13.36
travel time to Bogota (hours)	6.44	4.94	0.26	19.92
km farm- road network	1.26	2.31	0.00	23.95
Human population density (hab/ km2)	195.61	406.90	4.00	4384.00
Precipitation over potential evapo-transpiration PPE	1.77	0.95	0.58	3.59

Results of the econometric analyses of livestock intensification are presented in Table 42. The goodness of fit indicators show very low levels of sensitivity or specificity and results should therefore be interpreted with caution. However some interesting results emerge and are consistent with the other case studies results. Older household heads are less likely to intensify livestock production (significant lower probability to use fertiliser and higher to have Zebu cattle) and the education level has a positive effect on intensification (cut and carry and planted fodder). The market access indicators give somehow contradictory results: as expected, farmers with longer travel time to Bogota have a lower probability of applying fertiliser and keeping Zebu animals, but at the same time are more likely to use the cut and carry system and to devote some land to planted forage. On the other hand, human population density has the expected positive effect on livestock intensification in three of the four regressions, although the marginal effects are relatively limited. The indicator of agro-climatic characteristics has a positive effect on the decisions to cut and carry fodder and to plant fodder, but negative on the decision to apply fertiliser on pasture: the greater the agro- climatic potential, the lower the need to invest resources to increase feed production. Finally, farmers in areas of higher agro-climatic potential have a higher likelihood to raise Zebu cattle maybe due to the higher disease challenge for exotic cattle.

Table 42: Colombia case study- econometric analyses of livestock intensification, Logit regressions

		Fertiliser on pasture		Cut and carry		Planted forage		Zebu	
variable	change	Marg. Effect	P>z	Marg. Effect	P>z	Marg. Effect	P>z	Marg. Effect	P>z
Age of the owner of the farm	10	**-4.97**	**0.01**	-0.18	0.91	0.38	0.80	**3.75**	**0.00**
Years of formal education	1	0.69	0.15	**1.11**	**0.01**	**1.02**	**0.01**	0.02	0.96
Land size (ha)	100	-2.66	0.27	0.05	0.95	0.00	1.00	0.90	0.34
1 if the farmer has access to health advices	1			-1.24	0.96	3.50	0.89	-5.14	0.85
km to the nearest Cabecera, road type 1	1	0.65	0.13	-0.52	0.10	**-0.56**	**0.06**	0.25	0.27
km to the nearest Cabecera, road type 2	1	-1.32	0.16	-0.94	0.18	-0.46	0.47	-0.56	0.27
km to the nearest Cabecera, road type 3	1	-1.70	0.29	-1.24	0.44	-2.75	0.10	0.78	0.43
travel time to Bogota (hours)	1	**-3.60**	**0.00**	**4.43**	**0.00**	**3.40**	**0.00**	**4.11**	**0.00**
km farm- road network	1	1.62	0.37	0.87	0.44	1.54	0.16	-0.25	0.80
Human population density (hab/ km2)	100	**2.42**	**0.03**	**0.95**	**0.05**	**0.86**	**0.04**	0.40	0.39
PPE	0.1	**-1.88**	**0.00**	**1.25**	**0.00**	**1.21**	**0.00**	**1.06**	**0.00**
Sensitivity		84.00%		38.41%		26.02%		37.38%	
Specificity		53.54%		93.46%		95.55%		93.47%	
Positive predictive value		73.26%		68.83%		65.31%		60.61%	
Negative predictive value		68.83%		80.14%		80.04%		84.74%	
Correctly classified		71.89%		78.42%		78.61%		81.58%	
Number of obs		498		505		505		505	
Pseudo R2		0.14		0.15		0.12		0.23	
Log likelihood		-288.64		-251.16		-246.44		-199.67	

Data on amounts of fertiliser applied to pasture are available (bulk/ha) and a tobit analysis is fitted to the data. Results are shown in Table 43. They are similar to the results obtained with the decision to apply fertiliser (yes/no), with some additional significant variables: the land size and some indicators of market access. As expected, farmers with larger land holdings and those further from the nearest cabecera on tracks (road type 3) apply lower levels of fertiliser. However, the distance from the farm to the nearest road network have a positive effect on the amounts of fertiliser applied.

Table 43: Colombia case study- econometric analysis of the amount of fertiliser applied on pasture (bulk/ha)

		Amounts of fertiliser	
variable	change	Marg. Effect	P>z
Age of the owner of the farm	10	**-0.11**	**0.01**
Years of formal education	1	0.00	0.98
Land size (ha)	100	**-0.01**	**0.01**
km to the nearest Cabecera, road type 1	1	0.11	0.12
km to the nearest Cabecera, road type 2	1	-0.06	0.77
km to the nearest Cabecera, road type 3	1	**-0.70**	**0.08**
travel time to Bogota (hours)	1	**-0.69**	**0.00**
km farm- road network	1	**0.54**	**0.07**
Human population density (hab/ km2)	100	**0.00**	**0.01**
PPE	0.1	**-3.65**	**0.00**
Number of obs		485	
Pseudo R2		0.04	
Log likelihood		-1186.78	

India case study

A total of 797 households covering 60 villages were surveyed between August and December 2001 in the State of Gujarat. The questionnaire are divided into sections covering: household composition, labour availability and use; farm activities and facilities; livestock inventory; cattle feeding, dairying with emphasis on milk production and milk marketing; livestock management and health services; household income and sources; and co-operative membership/assistance from NGO and milk consumption. Information on whether the households belong to tribal group or not was also collected. The tribal as compared to non-tribal group are poor, less educated, live in communal housing, and seek for off-farm work in non-tribal holdings. Along with data collection, each surveyed household was geo-referenced using a GPS (geographic positioning system) unit and a detailed road network of the area was digitized using available maps. Distances from the farm to the nearest road and to the nearest large urban centres were computed using geographical information systems software. Moreover, the information on each household's geographic position enables to link the household data with GIS layers. Mean population densities and data on agroclimatic characteristics (area suitability for crop and livestock production (PPE -annual precipitation over overall potential evapo-transpiration ratio) are extracted from the ILRI GIS databases.

Of the 797 households for which data are available, 10% have no land and no livestock. Table 44 details the farmers' characteristics:

Table 44: India case study- farmers' characteristics

	Number of farmers	% farmers
No land and no livestock	80	10.0
Land and no livestock	91	11.4
No land and livestock	75	9.4
Land and livestock	551	69.2
Total	797	100

The analysis concentrates on agricultural households i.e. the three last categories.
Three types of analyses are presented, focusing on crop intensification; livestock/ dairy intensification; and crop- livestock interactions.

Crop intensification

Although the focus during data collection was on livestock activities, crop- related information are also available. Detailed plot information on types of crops grown by season as well as use of manure and fertiliser were collected.
Three indicators are used to assess crop intensification: fertiliser use, practise of fallow and growing cash crop.
Looking at the extent of fertiliser use, data show that more than 98% of landowners purchase fertiliser. The second indicator shows that more than 96% of landowners do not have fallow land (Table 45). Crop intensification measured by these two indicators is thus very high in the area.
For the last indicator, growing cash crops, the following crops are considered: castor, cotton, cumin, cut flower, groundnuts, sesame, sugarcane and sunflower. Among farmers with land, 57% grow these cash crops.

Table 45: India case study- statistics of variables used in the crop intensification analysis

Variable	Mean	Std. Dev.	Min	Max
1 if fertiliser use	0.96	0.21	0.00	1.00
1 if fallow	0.04	0.19	0.00	1.00
1 if grow cash crops	0.57	0.50	0.00	1.00
1 if BAIF village	0.55	0.50	0.00	1.00
years of farming experience	27.17	13.22	0.00	60.00
years of formal education	6.81	4.74	0.00	16.00
1 if non-tribal	0.66	0.47	0.00	1.00
land size (ha)	2.64	4.20	0.01	80.00
number of adults	4.59	2.46	0.00	24.00
ratio female adults over total adults	2.19	1.28	0.00	12.00
dependency ratio	0.28	0.21	0.00	1.00
PPE	0.54	0.19	0.28	0.92
population density	357.43	205.71	14.01	1062.86
km village- nearest road	2.48	1.66	0.00	6.40
kms to nearest urban centres	35.02	19.70	2.26	72.14

Goodness of fit indicators of the econometric analysis (Table 46) are satisfactory with an overall percentage of correctly classified observations of 78.2%. Two survey variables have a significant marginal effect on the probability of growing cash crops: farmer's experience and land size. As expected, land size has a positive effect on the decision due

to higher land availability; more experienced farmers have however a lower probability of growing cash crops; more experienced farmers are also older ($p<0.01$), thus maybe less willing to invest time and resources into market- oriented farming. Two GIS- derived variables have a significant and negative effect: the village population density and the distance homestead to the nearest urban centre. The further the household from a urban centre where demand for agricultural products is likely to be concentrated, the lower the returns to farming, and thus the lower the incentive to grow cash crops. As for the population density variable, the general prediction of a positive effect of human pressure on intensification does not hold: this result can be explained by the fact that in the Indian context, food security is an issue, therefore as population density increases, farmers allocate land more to food crops than to cash crops.
It is worth noticing that the farmer type (tribal versus non- tribal) is not significant in the econometric analysis although statistically (without controlling for other factors) 84% of the non-tribal farmers grow cash crops as compared to 43% of the tribal group.

Table 46: India case study- econometric analysis of crop intensification

variable	change	Marginal effect	P>z
1 if BAIF village	1	11.39	0.60
years of farming experience	10	**-5.95**	**0.00**
years of formal education	1	0.57	0.28
1 if non-tribal	1	23.53	0.39
land size (ha)	1	**12.21**	**0.00**
number of adults	1	3.64	0.11
ratio female adults over total adults	0.1	-0.08	0.83
dependency ratio	0.1	-1.09	0.35
PPE	0.1	-1.87	0.28
population density	100	**-6.02**	**0.00**
km village- nearest road	1	1.27	0.37
kms to nearest urban centres	1	**-0.82**	**0.00**
Sensitivity		82.92%	
Specificity		72.04%	
Positive predictive value		79.42%	
Negative predictive value		76.43%	
Correctly classified		78.19%	
Number of obs		642	
Pseudo R2		0.30	
Log likelihood		-308.26	

Livestock intensification

The following indicators were used in the analysis: use of concentrates; decision to stall feed cattle and buffaloes (as opposed to grazing and some combination of grazing and stall- feeding); growing forage; applying fertiliser on pasture/ fodder and keeping high-producing dairy animals.

Looking at the extent of **concentrates use**, data show that more than 84% of cattle/ buffaloes keepers feed concentrates, either from farm sources (e.g. home-mixed) or purchased (e.g. ready made dairy meal). Looking at this indicator, livestock intensification is thus very high in the area.

Table 447: India case study- statistics of variables used in the livestock intensification analysis

Variable	Mean	Std. Dev.	Min	Max
1 if stall feeding	0.43	0.50	0	1
1 if growing fodder	0.38	0.48	0	1
1 if applying fertiliser on pasture and/or fodder	0.40	0.49	0	1
1 if keeping high producing animals	0.65	0.48	0	1
1 if BAIF village	0.59	0.49	0	1
years of farming experience	25.78	14.30	0.00	60.00
years of formal education	6.51	4.71	0.00	16.00
1 if non-tribal	0.62	0.49	0	1
land size (ha)	2.38	4.17	0.01	80.00
number of adults	4.61	2.44	0.00	24.00
ratio female adults over total adults	2.20	1.28	0.00	12.00
dependency ratio	0.28	0.21	0.00	1.00
Proportion village farmers with livestock ext s.	0.89	0.19	0.00	1.00
Proportion village farmers selling to dairy coop	0.46	0.46	0.00	1.00
village human population density	371.76	216.61	14.01	1062.86
proportion livestock keepers using communal land	0.64	0.32	0.00	1.00
PPE	0.55	0.19	0.28	0.92
km village- nearest road	2.38	1.70	0.00	6.40
kms to nearest urban centres	33.11	19.17	2.26	71.84

For the other four indicators, data show more variability thus allowing us to conduct more in- depth analyses. Data on **type of feeding system** show that 43% of the cattle/ buffalo keepers exclusively stall- feed their animals, as opposed to 57% of farmers who either graze with or without limited stall feeding. The analysis is run on 621 farmers having cattle and/or buffalos. Goodness of fit indicators are relatively good, with an overall percentage of correct predictions of 80%. Results of the econometric analysis show that farming experience, land size and extent of milk sales to cooperatives are positively correlated with the decision to stall feed. Experienced farmers are more likely to intensify because of their likely exposure to different technologies. Also, farmers assured of an outlet for their milk production like a village cooperative are induced to invest resources into dairying, thus to intensify. The somehow counter- intuitive result of a positive relationship between land size and decision to stall feed can be explained by the entry cost requirements of building a shed: since land size being a relatively good proxy of the household's wealth[7], it is not surprising to find that large farmers are more likely to stall- feed their animals. In fact, survey data show that the average cost of a shed is Rs 9,348 or approximately US$200 (median is Rs 5,000 or approximately US$110, using 421 observations). Another survey- derived variable that has a significant marginal effect on the decision to stall feed is the proportion of livestock keepers using communal land; this indicator captures communal land availability in the area. As communal land decreases, farmers are induced to stall- feed their animals as the analysis shows. Lastly, two GIS- derived variables have a significant effect: the distance from the village to the nearest road (village- nearest road) and the distance between the village nearest road and

[7] Data show that land size is significantly higher (P<0.01) among households with "good" houses ("*Pucca*") compared to those with "*Kachha*" or lower standard houses, thus supporting the positive relationship between land size and wealth.

the nearest large urban centre (nearest urban centres). One would expect a negative relationship between distance and decision to stall- feed since farmers located further away from a demand centre are less induced to invest into market- oriented dairying. While the nearest urban centres distance has the expected negative relationship, the village- nearest road has a positive effect. Although this result is counter- intuitive and suggests that intensification occurs in distant locations, it should be kept in mind that these distances are very short (mean of 2.4km); therefore this result cannot be generalised.

The second indicator is the decision to **plant fodder** on own farm. Planting fodder translates into less land allocated to other activities, thus capturing livestock intensification. The analysis is conducted on the 551 farmers having both livestock and land. The model correctly classifies 77% of the observations. Results show that the likelihood of planting forage is lower in areas where dairy cooperatives are more active (in terms of percentage of farmers selling milk to cooperatives) and in areas where communal land is more available. The first result is counterintuitive and no valid explanation could be found. Farmers with access to communal land have lower incentives to devote part of their land in fodder, thus explaining the second result. The indicator of agro- climatic potential and distance to the nearest urban centre have a positive (negative) effect on the decision to grow forage on farm; both results are consistent with the model predictions. Finally, like in the case of stall- feeding, the distance from the village to the nearest road has a positive effect on forage planting; the same comment applies.

The third indicator is the practise of **applying fertiliser on either planted forage and/ or pasture**. Goodness of fit indicators are satisfactory since the percentage of correctly classified observations is 75%. The analysis is conducted on 162 households that grow either pasture and/ or fodder. Two survey household characteristics have a significant effect on the decision to apply fertiliser, the number of household adult members and the ratio of female adults over total number of households. The first variable has a negative effect on the level of intensification, a result difficult to interpret; on the other hand, the higher the ratio of female adults in the household, the higher the intensification level: this result is consistent with the observation that women are responsible for the majority of the dairying- related activities in India. The extent of extension services in the area is negatively related with the level of intensification, a result that at first glance seems counter- intuitive; however such a result is not uncommon in the literature and can be related to the "program placement bias" whereby extension services are operated in areas which are most in need, thus the negative observed effect between extent of extension services and intensification level. The last survey variable that has a significant effect on the probability of applying fertiliser is the extent of dairy cooperative development in the area: as expected, the effect is positive as in the case of the stall- feeing decision analysis. Two GIS- derived variables have a significant effect on the intensification level: the better the agro- climatic potential of the area, the higher the farmer's likelihood to intensify the on- farm fodder production. Finally, distance to the nearest urban centre has a positive effect on the level of intensification, a result difficult to interpret.

The fourth and last indicator of livestock intensification is the decision **to keep high producing cattle and/or buffaloes**. During the data collection, cattle breeds were categorised as non- descript (ND), crossbred with European breeds namely Holstein-Friesian and Jersey, and Indian pure breeds (Gir and Kankrej). Buffaloes were categorised as non- descript (ND) and pure breed (Surti, Mehsani, Jafrabadi and Murrah).

Since some ND animals are crosses of high- producing pure breed animals, it is not possible to categorise ruminants according to the breeds as stated by the farmer. For these reasons, the differentiation between high and low producing animals is based on milk production performances. Cows with milk production by lactation above (below) 1500 liters are classified as high (low) producing animals; buffaloes with milk production by lactation above (below) 1000 liters are classified as high (low) producing animals. Since not all livestock holders keep lactating animals and because of missing data, the analysis is conducted on 565 households. The percentage of correctly predicted observations is 73%. Results show that both the farmer's experience and education level have a positive effect on the decision to keep high producing animals: previous examples in the literature have showed the positive effect of human capital on the likelihood of adopting this technology (Staal et al. 2002). A surprising result is the negative and significant effect of human population density on the level of intensification. In the Indian context, this result can be explained by the fact that as human population density increases, farmers are concerned about food security and choose to invest resources and time in food crop activities and not on livestock intensification. The last survey variable with a significant effect on the decision to keep high- producing ruminants is the access to communal land: as in the case of stall feeding, lower access to communal land induce farmers to intensify. Finally, the three GIS- derived variables have a significant effect: similar to the results found for the second and third indicator of livestock intensification, the area agro- climatic potential affects positively the farmer's likelihood to intensify. Finally, the effect of distances on intensification level is similar to the effect on the first and second indicators.

Table 48: India case study- econometric analysis of livestock intensification

variable	change	Stall- feeding		Planted fodder		Fertiliser on pasture/forage		Keeping high producing animals	
		Marg. effect	P>z	Marg. effect	P>z	Marg. effect	P>z	Marg. effect	P>z
1 if BAIF village	1	0.70	0.98	-2.42	0.92	18.25	0.72	16.31	0.45
years of farming experience	10	**3.78**	**0.06**	1.88	0.35	2.12	0.60	**3.75**	**0.03**
years of formal education	1	0.57	0.33	0.90	0.12	1.59	0.17	**1.01**	**0.04**
1 if non-tribal	1	12.49	0.71	47.05	0.27	38.62	0.68	18.48	0.50
land size (ha)	1	**2.07**	**0.02**	0.29	0.57	0.36	0.81	1.47	0.17
number of adults	1	-2.30	0.31	0.38	0.86	**-8.15**	**0.04**	-0.20	0.92
ratio female adults over total adults	0.1	0.18	0.65	0.24	0.52	**1.34**	**0.05**	0.19	0.60
dependency ratio	0.1	0.81	0.51	1.15	0.33	-2.72	0.24	0.48	0.66
Prop. village farmers with livestock extension services	0.1	-1.38	0.32	0.88	0.55	**-8.29**	**0.01**	-1.25	0.38
Prop. village farmers selling to dairy coop	0.1	**2.26**	**0.00**	**-1.68**	**0.00**	**3.10**	**0.01**	0.01	0.99
village human population density	100	0.59	0.66	-1.16	0.36	-1.05	0.75	**-3.60**	**0.00**
Prop. livestock keepers using communal land	0.1	**-11.67**	**0.00**	**-4.84**	**0.00**	3.06	0.11	**-2.39**	**0.00**
PPE	0.1	2.92	0.15	**5.28**	**0.01**	**10.43**	**0.03**	**3.62**	**0.04**
km village- nearest road	1	**11.33**	**0.00**	**7.99**	**0.00**	-0.71	0.84	**3.85**	**0.01**
kms to nearest urban centres	1	**-1.01**	**0.00**	**-0.30**	**0.09**	**1.94**	**0.00**	**-0.36**	**0.02**
Sensitivity		78.11%		73.61%		66.67%		88.62%	
Specificity		82.02%		79.10%		80.21%		43.88%	
Positive predictive value		76.38%		69.43%		69.84%		74.83%	
Negative predictive value		83.43%		82.30%		77.78%		67.19%	
Correctly classified		80.35%		76.95%		74.69%		73.10%	
Number of obs		621		551		162		565	
Pseudo R2		0.36		0.27		0.18		0.15	
Log likelihood		-273.22		-267.62		-89.36		-308.34	

Crop- livestock interaction

Three indicators of crop- livestock interactions are analysed: the use of crop residues as livestock feed; use of manure; and use of draft power.

Levels of crop- livestock intensification are high, with 92.5% of livestock owners feeding crop residues. Also, 83.2% of landowners use manure and 81.4% use draft power. Partly due to the high levels of intensification, the econometric analyses conducted on these indicators were not conclusive and are therefore not presented. Table 49 shows the statistical analysis, presenting variables means and statistical levels of differences across groups.

Data on land preparation show that few farmers use manual (hand and hoe) methods (2% of landowners) only, or in combination with draft power and/ or tractor. Three categories of farmers are thus differentiated: farmers using animal draft power (only or with manual land preparation), using tractor (only or with manual land preparation), and both draft power and tractor (only or with manual land preparation).

Villages assisted by the NGO BAIF record higher use of manure and higher use of tractor for land preparation than other villages. BAIF promotes crop- livestock interactions, so the first result is consistent with the expectations.

As expected more experienced farmers have higher levels of crop- livestock interactions (manure use and feeding of crop residues). Also, feeding crop residues and using tractors for land preparation is more common among educated farmers, a result consistent with the livestock intensification results. The use of manure and feeding of crop residues is more common among the non- tribals who are more aware of the economic benefits of these practices. Partly related to their level of education, results show that the use of tractors is higher among non- tribals. Land size is statistically higher among farmers feeding crop residues (1.2 *versus* 2.4 ha) hence the availability of by- products. However, land size is lower among users of draft power as farmers with large land holdings are compelled to use tractors. Households with higher number of adults and higher ratios of female adults have higher levels of crop- livestock interactions since these activities are labour intensive. Levels of crop- livestock interactions as captured by feeding crop residues are higher, the higher the human population density, a result consistent with the theoretical model. When comparing human population density by methods of land preparation, no clear result emerges. Agro- climatic characteristics (PPE) are more favourable among farmers not feeding crop residues, since availability of pasture increases with better climate. Also, tractor use is more common in areas with good agro-climatic conditions since it allows the farmers to practice continuous cropping. Finally, the higher the distance from the village to the nearest urban centre, the lower the level of crop- livestock interactions (use of manure), as predicted by the conceptual framework. As explained in the analysis of livestock intensification, the somehow contradictory result obtained for the distance from the village to the nearest road can be explained by the very low distances captured by this variable.

Table 49: India case study- statistical analysis on crop- livestock interactions indicators

Variables	Use of manure			Feeding crop residues			Land preparation			
	no	yes	Sig	no	yes	Sig	Draft power	Tractor	Both	Sig
Number of observations	108	533		45	558		331	86	194	
1 if BAIF village	0.48	0.57	10	0.56	0.60		0.49	0.62	0.62	1-2; 1-3
years of farming experience	24.69	27.70	5	12.36	26.93	1	26.61	27.62	28.32	
years of formal education	6.51	6.87		5.11	6.65	5	6.20	8.66	6.98	1-2; 2-3
1 if non-tribal	0.57	0.68	5	0.16	0.66	1	0.62	0.79	0.65	1-2; 2-3
land size (ha)	2.29	2.56		1.18	2.41	1	2.25	2.46	2.81	1-3
number of adults	4.25	4.66	5	4.38	4.63		4.60	4.29	4.66	
ratio female adults over total adults	1.97	2.23	5	2.07	2.21		2.19	1.93	2.28	
dependency ratio	0.28	0.28		0.26	0.28		0.28	0.24	0.30	2-3
Proportion village farmers selling to dairy coop	0.45	0.44		0.40	0.47		0.39	0.57	0.49	1-2; 1-3
village human population density	340.74	360.94		276.18	382.78	1	363.92	402.98	322.91	1-3;2-3
PPE	0.54	0.53		0.60	0.55	5	0.53	0.65	0.52	1-2; 2-3
km village- nearest road	2.22	2.53	5	1.71	2.44	1	2.69	2.12	2.45	1-2
kms to nearest urban centres	40.24	33.91	5	33.79	32.38		32.61	30.10	38.51	1-3;2-3

Kenya case study

The Kenya case study builds on the work conducted by the Smallholder Dairy Project (R&D), a collaborative project between the Kenyan Agriculture Research Institute (KARI), the Kenyan Ministry of Agriculture and ILRI. Three datasets are combined, corresponding to three surveys conducted in different districts in Kenya, namely Kiambu in Central Province (1996), 8 districts of Central, Easter and Rift Valley Provinces (1998) and 7 districts of Western and Nyanza Provinces (2000). More details are available in the survey reports.

The three surveys share a number of questions, thus enabling to combine the datasets. A total of 3,294 households were surveyed, of which 87% are agricultural households. The questionnaires are divided into sections covering: household composition, labour availability and use; farm activities and facilities; livestock inventory; cattle feeding, dairying with emphasis on milk production and milk marketing; livestock management and health services; household income and sources; and co-operative membership and milk consumption. Along with the survey data, each surveyed household was geo-referenced using a GPS (geographic positioning system) unit and a detailed road network of the area was digitized using available maps from Surveys of Kenya. Road types vary widely, especially in the rural areas where many roads are only passable during the dry seasons, with the network of tarmac roads only connecting the main urban centres. In this study, three types of roads are considered, tarmac roads, other all-weather-roads ("murram" roads) and dry-weather roads. Moreover, the information on each household's geographic position enables to link the household data with GIS layers. Mean population densities within 5 km around the farm are derived using the Kenya 1989 census data. Data on agroclimatic characteristics, the area suitability for crop and livestock production (PPE -annual precipitation over overall potential evapo-transpiration ratio) are extracted from the database "Almanac Characterization Tool" of Texas A&M University (Corbett 1999).

Three types of analyses are presented, focusing on crop intensification; livestock/ dairy intensification; and crop- livestock interactions.

Crop intensification

Given data availability, crop intensification is analysed using the following indicators: use of fertilizer (whether the farmer applies fertilizer on at least half the cropped area) and extent of fallow land.

Only agricultural households are included in the analysis and the variables mean and other statistics are presented in Table 50.

The decisions to use fertilizer and to have land in fallow are analysed using Logit analyses.

Table 51 shows the results of the econometric estimations by presenting the marginal effects, i.e. the predicted change in the decision probability of a change in the explanatory variables.

Table 50: Kenya case study- variables used in the crop intensification analysis

Variable	Mean	Std.	Min	Max
1 if farmer applies fertiliser on at least half the cropped area	0.61	0.49	0	1
1 if the farmer has some fallow	0.37	0.48	0	1
Age of the household head (years)	49.09	14.22	15	97
1 if the household head in a man, 0 if woman	0.78	0.41	0	1
Years of education of the household head	7.88	4.53	0	17
Number of adults in the household	3.59	2.03	0	22
Proportion of female adults in total number of adults	0.53	0.21	0	1
Dependency ratio	0.42	0.25	0	1
Land acreage	4.53	8.10	0.02	140.28
travel time to Nairobi (hours)	3.02	1.71	0.09	5.53
km to the nearest large urban center on road type 1	22.66	19.04	0.00	123.36
km to the nearest large urban center on road type 2	8.93	11.30	0.00	49.03
km to the nearest large urban center on road type 3	2.46	3.56	0.00	34.02
km farm- road network (Euclidian distance)	0.56	0.59	0.00	4.59
Human population density (hab/ km2)	487.77	330.30	23.18	4544.27
Precipitation over potential evapo-transpiration PPE	0.91	0.22	0.46	1.34

Goodness-of-fit results are satisfactory with overall percentages of correct predictions at 63.70% for the decision to use fertilizer and 72.38% for the decision to have some land in fallow, although the specificity (percentage of correctly classified non- fertilizer users over observed number of non- fertilizer users) is very low for the fertilizer decision regression.

Survey variables that have a significant effect on the decision to use fertilizer are the age of the household head and the land acreage (negative effect) as well as his/ her education (positive effect). Older farmers have a shorter time horizon and are thus less induced to invest in soil fertility maintenance strategies. The larger the land holding, the lower the need to intensify agricultural production and therefore the lower the likelihood to use fertilizer. The positive effect of the education level is consistent with the results of other studies showing that education induces the adoption of agricultural innovations.

As for the decision to have fallow land, age of the household head and land acreage have a positive and significant effect on the decision for reasons similar to those explained for the fertilizer use.

Table 51: Kenya case study- marginal effects of explanatory variables on the decision to use fertilizer and to have fallow land

		Fallow		Fertiliser	
variable	change	Marg. Effect	P>z	Marg. Effect	P>z
Age of the household head (years)	10	**2.44**	**0.00**	**-2.28**	**0.00**
1 if the household head in a man, 0 if woman	1	-5.35	0.66	3.39	0.75
Years of education of the household head	1	0.18	0.46	**0.63**	**0.01**
Number of adults in the household	1	0.88	0.13	0.81	0.14
Proportion of female adults in total number of adults	0.1	0.09	0.85	-0.08	0.87
Dependency ratio	0.1	-0.02	0.97	0.36	0.39
Land acreage	1	**1.24**	**0.00**	**-0.60**	**0.00**
travel time to Nairobi (hours)	1	**10.85**	**0.00**	**-5.23**	**0.00**
km to the nearest large urban center on road type 1	1	**-0.31**	**0.00**	0.01	0.86
km to the nearest large urban center on road type 2	1	0.07	0.42	**0.31**	**0.00**
km to the nearest large urban center on road type 3	1	-0.20	0.44	0.04	0.87
km farm- road network (euclidian distance)	1	-0.04	0.98	-1.79	0.28
Human population density (hab/ km2)	100	**-7.38**	**0.00**	-0.09	0.79
Precipitation over potential evapo-transpiration	0.1	**4.12**	**0.00**	**4.01**	**0.00**
Sensitivity		56.07%		91.37%	
Specificity		81.92%		19.58%	
Positive predictive value		64.45%		64.43%	
Negative predictive value		76.13%		58.73%	
Correctly classified		72.38%		63.70%	
Number of obs		2813		2810	
Pseudo R2		0.20		0.04	
Log likelihood		-1480.27		-1803.55	

A number of GIS variables are significant in both regressions. Travel time to the capital Nairobi has a significant and expected sign on both indicators of crop intensification since farmers located further away from the main demand center are less likely to intensify their crop activities. However, the results of the road type differentiated distances to the nearest urban centers are contradictory. The effect of human population density is, as expected, negative on the decision to have fallow land (low intensification level).

Livestock/ dairy intensification

Given data availability and the specificity of the Kenya case study, the focus of the analysis is on dairying. The following indicators of dairy intensification are retained in the analysis: type of feeding system; use of agro- industrial by- products; purchases of fodder and crop residues; and decision to keep grade cattle (crossbred and/ or pure breed cattle).

Table 52: Kenya case study- variables used in the livestock intensification analysis

Variable	Mean	Std.	Min	Max
1 if the farmer keeps grade cattle (cross and pure breed)	0.62	0.49	0	1
1 if feeding system in stall feeding (mainly or only)	0.34	0.48	0	1
1 if the farmer feeds concentrates	0.36	0.48	0	1
1 if the farmers purchases fodder and crop residues	0.40	0.49	0	1
Age of the household head (years)	50.63	13.85	18	97
1 if the household head in a man, 0 if woman	0.78	0.41	0	1
Years of education of the household head	7.92	4.55	0	17
Number of adults in the household	3.84	2.11	0	22
Proportion of female adults in total number of adults	0.53	0.21	0	1
Dependency ratio	0.41	0.25	0	1
Land acreage	5.45	9.32	0.03	140.28
proportion of farmers with access to livestock extension services	0.90	0.19	0	1
travel time to Nairobi (hours)	2.91	1.71	0.09	5.52
km to the nearest large urban center on road type 1	15.12	18.72	0.00	85.12
km to the nearest large urban center on road type 2	4.93	7.28	0.00	38.54
km to the nearest large urban center on road type 3	2.62	3.50	0.00	27.27
km farm- road network (euclidian distance)	0.56	0.59	0.00	4.59
Human population density (hab/ km2)	480	312	23	3368
Precipitation over potential evapo-transpiration PPE	0.91	0.22	0.46	1.34

Goodness- of- fit indicators are satisfactory with percentages of overall correctly classified observations ranging from 64% to 82%. The sensitivity (percentage of correctly classified users over observed number of users) is however low in the case of fodder and crop residues purchases.

Table 53: Kenya case study- marginal effects of explanatory variables on the decision to intensify livestock production

		Stall feeding		Use of concentrates		Fodder purchases		Grade cattle	
variable	change	Marg. Effect	P>z	Marg. Effect	P>z	Marg. Effect	P>z	Marg. Effect	P>z
Age of the household head (years)	10	-0.14	0.89	1.19	0.22	**-2.88**	**0.01**	**1.60**	**0.08**
1 if the head in a man, 0 if woman	1	-1.83	0.91	-3.12	0.83	6.25	0.65	5.68	0.65
Years of education of the household head	1	**1.14**	**0.00**	**1.80**	**0.00**	0.15	0.65	**1.35**	**0.00**
Number of adults in the household	1	**-1.46**	**0.05**	0.34	0.59	0.42	0.54	0.71	0.27
Proportion of female adults in total number of adults	0.1	-0.42	0.51	**-1.19**	**0.05**	-0.11	0.86	0.72	0.20
Dependency ratio	0.1	**-1.29**	**0.02**	-0.34	0.50	-0.22	0.70	**-1.44**	**0.01**
Land acreage	1	**-1.17**	**0.00**	0.01	0.96	**-0.74**	**0.00**	**0.73**	**0.00**
proportion of farmers with access to livestock extension services	0.1	-1.13	0.11	**-1.60**	**0.01**	-0.42	0.56	-0.88	0.11
travel time to Nairobi (hours)	1	**-11.98**	**0.00**	**-11.14**	**0.00**	-0.20	0.89	**-8.15**	**0.00**
km to the nearest urban center, type 1	1	**-0.29**	**0.01**	**-0.39**	**0.00**	0.02	0.84	**-0.56**	**0.00**
km to the nearest urban center, type 2	1	**-0.94**	**0.00**	**-1.63**	**0.00**	0.21	0.36	**-1.41**	**0.00**
km to the nearest urban center, type 3	1	-0.15	0.70	**-1.92**	**0.00**	**-0.95**	**0.02**	-0.15	0.67
km farm- road network	1	-3.26	0.17	**-4.76**	**0.02**	-1.91	0.43	**-4.07**	**0.03**
Human population density (hab/ km2)	100	**6.88**	**0.00**	-0.15	0.73	**3.09**	**0.00**	-0.49	0.18
PPE	0.1	-0.78	0.38	**4.45**	**0.00**	**1.61**	**0.08**	**11.50**	**0.00**
Sensitivity		62.37%		54.89%		35.98%		85.28%	
Specificity		91.54%		84.87%		82.97%		50.73%	
Positive predictive value		78.89%		66.43%		58.11%		73.43%	
Negative predictive value		82.75%		77.52%		66.38%		68.34%	
Correctly classified		81.73%		74.29%		64.35%		71.98%	
Number of obs		1959		1972		1683		2298	
Pseudo R2		0.31		0.21		0.07		0.15	
Log likelihood		-859.32		-1012.57		-1052.60		-1298.09	

The age of the household head has a different effect on livestock intensification depending on the indicator: negative on the decision to purchase fodder and positive on the decision to keep grade cattle. The same result is obtained with the land size variable: as expected, farmers with small land holdings are more likely to intensify (decision to stall feed and to purchase fodder) while these farmers are less likely to keep grade cattle. A likely explanation for the difference is the entry cost requirement to purchase a dairy cow: older farmers and those with more land are more likely to have the liquidity needed to purchase a dairy animal.

Education level has the usual positive effect on intensification (stall feeding, purchasing concentrates and keeping grade cattle). Dependency ratio has a negative effect on intensification (stall feeding and grade cattle) due to higher financial needs of a larger family that could influence negatively the livestock activities. A surprising result is the negative effect of extension services availability on the use of concentrates.

GIS- derived distances have the expected negative effect on intensification. Moreover, looking at the decision to use concentrates, the effect of road quality on intensification is consistent with the transaction costs theory: distances on poor quality roads have a larger negative effect than distances on good quality road. Areas with higher population density have higher levels of intensification while good agro- climatic characteristics are also favorable to intensification.

Crop- livestock interaction

Given data availability, two indicators of crop- livestock interactions are used to capture the extent of the interactions: feeding crop residues and use of manure The variables mean and other statistics are presented in Table 54.

Table 54: Kenya case study- variables used in the crop- livestock analysis

Variable	Mean	Std. Dev.	Min	Max
1 if the farmer applies manure on at least half the cropped area	0.47	0.50	0	1
1 if the farmer feeds crop residues	0.84	0.37	0	1
Age of the household head (years)	49.09	14.22	15	97
1 if the household head in a man, 0 if woman	0.78	0.41	0	1
Years of education of the household head	7.88	4.53	0	17
Number of adults in the household	3.59	2.03	0	22
Proportion of female adults in total number of adults	0.53	0.21	0	1
Dependency ratio	0.42	0.25	0	1
Land acreage	4.53	8.10	0.02	140.28
proportion of farmers with access to livestock extension services	0.90	0.20	0	1
travel time to Nairobi (hours)	3.02	1.71	0.09	5.53
km to the nearest large urban center on road type 1	22.66	19.04	0	123.36
km to the nearest large urban center on road type 2	8.93	11.30	0	49.03
km to the nearest large urban center on road type 3	2.46	3.56	0	34.02
km farm- road network (euclidian distance)	0.56	0.59	0	4.59
Human population density (hab/ km2)	487.77	330.30	23.18	4544.27
Precipitation over potential evapo-transpiration PPE	0.91	0.22	0.46	1.34

As for the analysis of crop and livestock intensification decisions, the decisions to feed animals with crop residues and to use manure are analysed using Logit analyses.

Table 55 shows the results of the econometric analysis by presenting the marginal effects of a change in the explanatory variables on the probability to feed crop residues and to use manure on at least half the cropped area. The specificity in the regression analysis of the decision to feed crop residues is relatively low (39%) although the overall percentage of correct predictions is 88%. For the decision to use manure, the model predicts correctly 69% of the observations.

Only one survey variable has a significant effect on the decision to feed crop residues: farmers with larger land have a lower probability to feed crop residues. As land size increases, farmers have other alternatives to feed their animals, e.g. planted fodder and pasture. Also, large farmers have a lower need to increase land productivity, *ceteris paribus*, and have thus a lower probability to apply manure.

Table 55: Kenya case study- marginal effects of explanatory variables on the decision to feed crop residues, to use manure and to use livestock for ploughing

		Manure on at least half the cropped area		Feeding crop residues	
variable	change	Marg. Effect	P>z	Marg. Effect	P>z
Age of the household head (years)	10	**3.93**	**0.00**	0.19	0.66
1 if the household head in a man, 0 if woman	1	0.02	1.00	0.50	0.98
Years of education of the household head	1	0.14	0.59	0.07	0.59
Number of adults in the household	1	0.85	0.17	-0.03	0.91
Proportion of female adults in total number of adults	0.1	-0.42	0.41	-0.05	0.86
Dependency ratio	0.1	-0.28	0.55	-0.43	0.08
Land acreage	1	**-0.99**	**0.00**	**-0.19**	**0.00**
travel time to Nairobi (hours)	1	**-7.26**	**0.00**	**-4.87**	**0.00**
km to the nearest urban center, type 1	1	**-0.24**	**0.00**	**-0.15**	**0.00**
km to the nearest urban center, type 2	1	-0.09	0.36	0.06	0.26
km to the nearest urban center, type 3	1	**-0.76**	**0.01**	0.07	0.62
km farm- road network (euclidian distance)	1	**-3.06**	**0.10**	**-1.42**	**0.07**
Human population density (hab/ km2)	100	**3.25**	**0.00**	**2.22**	**0.00**
PPE	0.1	-0.67	0.34	**3.57**	**0.00**
Sensitivity		58.86%		97.44%	
Specificity		77.17%		38.70%	
Positive predictive value		69.04%		89.19%	
Negative predictive value		68.45%		74.40%	
Correctly classified		68.68%		87.95%	
Number of obs		2810		2000	
Pseudo R2		0.11		0.31	
Log likelihood		-1727.72		-607.15	

A number of GIS variables have a significant effect. As expected, distances have a negative effect on crop- livestock interactions decisions: as market access decreases (i.e. higher distances), farmers have fewer incentives to increase agricultural and livestock productivity by investing in crop- livestock interactions. The estimated effect of human population density is positive and consistent with the predictions of the conceptual framework. Area agricultural suitability plays also a role in explaining crop- livestock interactions as the estimated positive effect of the indicator (precipitation over potential evapo-transpiration) on the decision to feed crop residues shows.

Sri Lanka case study

The Sri Lanka survey was conducted in 1999 on 3,665 households and data is available for a total of 3,548 households. The proportion of households with cattle and/or buffalo is 52% (1,845 households). The questionnaire covers household composition, land size, assets, food expenditures and especially dairy products expenses, herd composition, milk production data, animal feeding and cooperative membership.

GIS- variables introduced in the analyses are distances (km), population density (number of inhabitants/km^2), elevation (m.a.s.l.) and a general indicator of agricultural potential, the ratio of precipitations over evapo-transpiration (PPE). GIS- derived variables are evaluated at the gn- division level, which is the lowest administrative level in Sri Lanka.

Except for the distance variables, all the GIS- variables are extracted form the ILRI GIS datasets.

GIS- distances introduced in the regression analysis are:
- distances to the nearest urban center, by road type. Three road types are differentiated, namely wide tarmac roads (type 1), single- carriage roads- tarmac or gravel- (type 2) and gravel roads of 1-2 m wide (type 3). Distance to the nearest urban center is introduced in order to capture the organization of the raw milk informal market. In fact, traders operate in a ten-kilometer fringe around urban centers.
- travel time to the capital city Colombo.
- distance from the farm to the nearest road. This variable captures the farmer's accessibility to the road network.

Distances on road types 2 and 3 are only introduced once because the different distances on types 2 and 3 are highly collinear due to the fact that these roads connect farmers to the main roads.

The analysis focuses on livestock/ dairy intensification.

Livestock/ dairy intensification

Given data availability and the specificity of the Sri Lanka case study, the focus of the analysis is on cattle and buffalo rearing. The following indicators of intensification are retained in the analysis: keeping grade cattle; using of the cut-and-carry method to feed the animals; and feeding concentrates to milking cows and pregnant heifers.

Table 56 presents the variables used in the analysis, their means (for livestock keepers) and other simple statistics. Two types of variables are used in the analysis: survey variables and GIS- derived variables.

Table 56: Sri Lanka case study- variables used in the livestock intensification analysis

Variable	Mean	Std. Dev.	Min	Max
1 if the farmer keeps grade cattle/ buffalo	0.55	0.50	0	1
1 if concentrates are fed, 0 if not	0.42	0.49	0	1
1 if cut-and-carry method is used, 0 if not	0.56	0.50	0	1
Age of the household head (years)	49.52	12.00	19.00	91.00
1 if the household head in a man, 0 if woman	0.95	0.22	0	1
Years of education of the household head	6.73	3.22	0.00	14.00
Number of adults[1] in the household	3.70	1.37	0.00	9.00
Proportion of female adults in total number of adults	0.48	0.17	0.00	1.00
Dependency ratio[2]	0.26	0.23	0.00	1.00
Land acreage	2.82	5.22	0.00	96.00
proportion of dairy coop members in the area	0.27	0.32	0.00	1.00
km to the nearest urban center on road type 1	2.16	2.85	0.00	24.50
km to the nearest urban center on road type 2	2.03	2.85	0.00	17.56
km to the nearest urban center on road type 3	2.00	2.91	0.00	32.31
travel time to Colombo (hours)	1.64	0.87	0.04	4.40
km farm- road network (euclidian distance)	0.80	0.80	0.00	6.98
Human population density (hab/ km2)	556.39	551.93	10.34	3701.77
Precipitation over potential evapo-transpiration	1.19	0.24	0.63	1.62
Elevation (m)	259.24	351.12	0.00	1710.00

[1] Adults are defined as members above 15 years

[2] Dependency ratio is defined a number of household members below 15 and above 65 over total number of household members.

Because the dependent variables are binary, reflecting the farmer's decision concerning animal production techniques (yes/ no), Logit analyses are conducted to assess the effect of the explanatory variables on the farmer's decision. Table 57 shows the results of the analyses by presenting the estimated marginal effects of the explanatory variables on the farmer's decision. The results show the predicted change in the probability of adoption of a change in the explanatory variables.

The goodness-of-fit indicators (percentages of correct predictions) are good, ranging from 65% for the decision to cut- and- carry feed to 70% for the decision to feed concentrates (overall predictions).

Table 57: Sri Lanka case study- marginal effects of explanatory variables on the livestock intensification decisions

		Grade cattle/ buffalo		Concentrates		Cut and carry	
variable	change	Marg. Effect	P>z	Marg. Effect	P>z	Marg. Effect	P>z
Age of the household head (years)	10	-0.53	0.71	1.29	0.42	**3.71**	**0.01**
1 if the household head in a man, 0 if woman	1	9.70	0.71	**4.25**	0.89	-1.45	0.96
Years of education of the household head	1	**2.36**	**0.00**	**2.46**	0.00	**0.97**	**0.04**
Number of adults in the household	1	0.22	0.88	-1.85	0.23	0.15	0.91
Proportion of female adults in total number of adults	0.1	-0.22	0.81	1.51	0.15	0.25	0.78
Dependency ratio	0.1	0.64	0.41	-1.05	0.22	0.99	0.20
Land acreage	1	0.17	0.54	-0.23	0.47	0.23	0.38
proportion of dairy coop members in the area	0.1	**2.99**	**0.00**	**1.18**	**0.02**	**0.77**	**0.09**
km to the nearest urban center on road type 1	1	**-2.03**	**0.00**	**-1.83**	**0.01**	**-1.04**	**0.05**
km to the nearest urban center on road type 2	1	**-1.61**	**0.00**	-0.91	0.14	-0.66	0.24
km to the nearest urban center on road type 3	1	**-1.16**	**0.02**	**-2.02**	**0.01**	**-1.66**	**0.00**
travel time to Colombo (hours)	1	**-7.47**	**0.01**	**-6.93**	**0.03**	**-9.22**	**0.00**
km farm- road network (euclidian distance)	1	-1.71	0.41	**-4.72**	**0.04**	-2.21	0.27
Human population density (hab/ km2)	100	**2.34**	**0.00**	**1.50**	**0.00**	**1.57**	**0.00**
Precipitation over potential evapo-transpiration	0.1	**-2.34**	**0.01**	1.53	0.15	**-2.10**	**0.02**
Elevation (m)	100	**5.63**	**0.00**	**3.51**	**0.00**	**4.88**	**0.00**
Sensitivity		74.30%		59.01%		74.45%	
Specificity		57.65%		78.80%		53.51%	
Positive predictive value		69.75%		68.02%		67.60%	
Negative predictive value		63.05%		71.55%		61.66%	
Correctly classified		67.10%		70.22%		65.36%	
Number of obs		1377		1115		1377	
Pseudo R2		0.14		0.15		0.10	
Log likelihood		-809.51		-646.84		-849.84	

Survey variables that have a significant effect on dairy intensification in Sri Lanka are the household head education level (for three indicators), the extent of dairy cooperative membership (for the three indicators), the sex (feeding concentrates) and age of the household head (cut and carry). As expected, the education level has a positive effect on the adoption of intensification- related technologies: education has been shown to induce the adoption of agricultural technologies in a number of countries (Feder *et al.* 1984). Dairy cooperatives provide farmers with an assured outlet for the milk produced, an important issue recalling that milk is a highly perishable and bulky product. Men and older household heads are more likely to intensify livestock production.

A number of GIS variables have a significant effect on dairy intensification decisions. As expected, the further the farm from the nearest urban center and Colombo, the lower the incentives to intensify. Road infrastructures thus seem to be a key factor in explaining dairy intensification levels. Human population densities have a significant effect on the dairy intensification, highlighting the strong local demand for milk and milk products (curd, yoghurt, etc…). Finally, agro- climatic characteristics have a significant effect on dairy intensification: farms situated at higher altitude are more intensified, reflecting better attention to animal health care and suitable climatic conditions for high- producing animals.

West Africa

In total data from 807 households was used for the analyses: 634 from Nigeria and 173 from Niger. The data set used for Nigeria is from two surveys conducted in 1998 and 1999 which comprised of 11 villages; 7 from the Northern Guinea Savanna (NGS) and 4 from Sudan Savanna (SS) (Okike 2002a). These surveys were designed to collect information on crop-livestock integration, agricultural intensification and economic efficiency. For Niger, data for 173 households from the "Fakara dataset" (data on >500 households from surveys conducted in 1988/1999) were extracted and a follow-up survey was conducted in May 2002 in order to update the dataset and obtain missing information on socioeconomic aspects (45, 67 and 62 households from Kodey, Tigo Tegui, and Banizoumbou, respectively).

For Nigeria the grouping of farmers was done by wards and the 42 wards were georeferenced. Although these wards were politically different, they had practically similar market access characteristics and were considered as capable of being represented by a single georeference point, at the centre of the village. Also the 62 markets that were used regularly in the 11 study villages were georeferenced. In Niger, there was only one village with a primary market, and 2 types of secondary markets: general and specialized (livestock, grains and vegetables).

Three road types were distinguished (from the original 9 road types for Nigeria and 4 for Niger) (see Okike, 2002a and b). The following distance variables were computed, by road types:

- distance to the nearest market (either primary or secondary) by road types
- dummy: availability of a primary market in the village
- distance to the nearest secondary market, by road type and by products
- distance to the nearest main urban center

Four households from the Niger dataset were excluded due to missing data on the land size variable. Of the 803 households retained in the analysis 7 (less than 1%) have livestock but no land, 58 (7%) have land but to livestock and 538 (92%) are mixed farmers.

Crop intensification

Two indicators are used to measure crop intensification: the use of fertilizer and the practice of fallow. The analysis is run on land owners- 795 farmers. Table 58 describes the variables used in the analysis. Approximately 65% of farmers use fertilizer while fallow is practiced by 17%.
Because there are few roads of types 2 and 3, distances on these two roads are combined. In the econometric analysis, the variable distance on types 2 and 3 is highly correlated (-0.72, P<0.01) with the human population density; therefore, only one of the two variables is kept in the regression.

Table 58: West Africa case study- statistics of variables used in the crop intensification analysis

Variable	Mean	Std. Dev.	Min	Max
1 if use of fertiliser	0.65	0.48	0	1
1 if practice of fallow	0.17	0.38	0	1
1 if fulani, 0 if hausa	0.21	0.40	0	1
Age of the owner of the farm	46.55	12.07	20	100
Years of formal education	4.78	3.60	0	15
number of adults	5.50	3.56	0	47
ratio female adults over total adults	0.42	0.17	0	1
dependency ratio	0.47	0.19	0	1
Land size (ha)	7.97	11.18	0.18	181.82
PPE	0.52	0.19	0.23	0.76
population density	188.04	117.25	29	404
travel time village- nearest road	0.20	0.32	0.00	1.08
kms to nearest urban centres, road type 1	77.43	48.50	28.36	187.36
kms to nearest urban centres, road type 2 and 3	10.80	11.23	0.00	36.24

Table 59 presents the results of the econometric analysis. Goodness of fit indicators are satisfactory with overall percentages of correctly predicted observations of 76% for the fertilizer use regression and 88% for fallow.
Survey variables with a significant effect on crop intensification are the education level, number of adults, dependency ratio and land size. As expected, education has a positive effect on intensification since more educated farmers have a lower probability to have land in fallow. Higher number of household adults has a positive effect on having land in fallow while households with more dependent are more likely to use fertilizer. The first result is difficult to interpret and the result shows that the effect is very limited as one additional adult translated into 0.68% increase of having fallow. On the other hand, a 10% increase in the dependency ratio increases the probability of using fertilizer by 3.2% that can be explained by the need to increase food production. Land size has a positive effect on using fertilizer, although limited; since land is a relatively good proxy of wealth, it is not surprising to observe a positive relationship between land size and fertilizer. On the other hand, as land size decreases, the probability of having land in fallow decreases, a result consistent with the conceptual framework.
GIS- derived variables have a strong effect on crop intensification: the higher the area agro- climatic conditions (PPE), the higher the crop intensification as measured by the two indicators. Also, the general result of a positive effect of human population density on intensification holds: an increase of 100 inhabitants per km^2 increases the probability of using fertilizer by more than 5% while decreases the likelihood of having land in fallow by 4.1%. The results on the access to market variables are difficult to interpret: as

expected, the higher the travel time from the village to the nearest road, the lower the crop intensification. In fact, farmers located 1 hour further away are less likely to use fertilizer by almost 25%. However, the higher the distance to the nearest urban center, the higher the crop intensification. This result can be explained by the fact that urban centers are not the only market places; distance to the nearest urban center may thus not be the most relevant market access for the farmers in these areas.

Table 59: West Africa case study- econometric analysis of crop intensification

		Fertiliser		Fallow	
Variable	change	Marg.	P>z	Marg.	P>z
1 if fulani, 0 if hausa	1	-9.58	0.66	1.41	0.96
Age of the owner of the farm	10	-1.34	0.46	0.41	0.63
Years of formal education	1	0.98	0.15	**-1.07**	**0.02**
number of adults	1	0.86	0.24	**0.68**	**0.01**
ratio female adults over total adults	0.1	-0.36	0.76	0.01	0.99
dependency ratio	0.1	**3.21**	**0.00**	0.25	0.65
Land size (ha)	1	**0.88**	**0.00**	**0.18**	**0.01**
PPE	0.1	**9.51**	**0.00**	**-3.07**	**0.00**
population density	100	**5.44**	**0.02**	**-4.10**	**0.00**
travel time village- nearest road	0.1	**-2.48**	**0.00**	-0.16	0.74
kms to nearest urban centres, road type 1	1	**0.15**	**0.01**	**-0.07**	**0.03**
Sensitivity		85.14%		69.78%	
Specificity		57.76%		91.62%	
Positive predictive value		79.03%		63.82%	
Negative predictive value		67.51%		93.47%	
Correctly classified		75.60%		87.80%	
Number of obs		795		795	
Pseudo R2		0.23		0.36	
Log likelihood		-395.17		-234.77	

Livestock intensification

Two indicators of livestock intensification are available: feeding concentrates and cutting-and-carrying fodder and crop residues. Data show that 63.5% of farmers feed concentrates while cut- and-carry is practiced by only 12% of the surveyed farmers in Nigeria. The type of feeding system was not documented in the Niger survey and the analysis is therefore conducted on the Nigerian sub sample.

Results of the econometric analysis of the decision to feed concentrates are shown in Table 60. Although the overall percentage of correctly predicted observations is satisfactory at 69%, the specificity (the proportion of farmers that do not feed concentrates that are correctly classified by the model) is low (33%) and results should be interpreted with caution. Results show that education level and labour availability influence positively the likelihood of feeding concentrates, an activity that requires some technical skills and is relatively labour intensive. Two other survey variables have a positive effect: the dependency ratio and the land size. The positive effect of the dependency ratio can be explained by the farmer's greater need to increase milk and meat production, although more dependents may translate into more acute financial constraint and decrease the likelihood of purchasing inputs like concentrates. Land size being a proxy for wealth and financial capacities, the positive effect of and size is expected. Finally, as predicted by the model, intensification is driven by market access since the distance to the nearest urban center by road types 2 and 3 has a negative effect on the decision to feed concentrates.

Table 60: West Africa case study- econometric analysis of the decision to feed concentrates

Variables	change	Marginal effect	P>z
1 if fulani, 0 if hausa	1	9.43	0.66
Age of the owner of the farm	10	-1.10	0.57
Years of formal education	1	**1.54**	**0.02**
number of adults	1	**3.20**	**0.00**
ratio female adults over total adults	0.1	0.28	0.80
dependency ratio	0.1	**3.33**	**0.00**
Land size (ha)	1	**0.94**	**0.00**
1 if livestock extension services	0.1	1.01	0.72
PPE	0.1	0.53	0.70
travel time village- nearest road	1	3.59	0.59
kms to nearest urban centres, road type 1	1	-0.01	0.90
kms to nearest urban centres, road type 2 & 3	1	**-0.51**	**0.04**
Sensitivity		88.32%	
Specificity		35.19%	
Positive predictive value		70.39%	
Negative predictive value		63.33%	
Correctly classified		68.96%	
Number of obs		741	
Pseudo R2		0.09	
Log likelihood		-443.03	

Because of the limited number of livestock keepers using the cut- and- carry method to feed their animals, an econometric analysis cannot be conducted and a comparison of means across groups is presented in Table 61.

Table 61: West Africa case study- statistical analysis of the decision to cut-and-carry fodder and crop residues

Variables	no	yes	Sig.
number of observations	551	74	
1 if fulani, 0 if hausa	0.22	0.22	
Age of the owner of the farm	44.14	43.22	
Years of formal education	6.04	6.09	
number of adults	5.53	6.46	5
ratio female adults over total adults	0.40	0.41	
dependency ratio	0.48	0.49	
Land size (ha)	5.87	10.43	5
1 if livestock extension services	0.15	0.14	
PPE	0.59	0.62	10
population density	228.13	188.36	1
travel time village- nearest road	0.24	0.22	
kms to nearest urban centres, road type 1	82.24	105.01	1
kms to nearest urban centres, road type 2 & 3	6.20	5.52	

Farmers who cut-and-carry fodder have more adults, a result consistent with the observations that this activity is labour intensive. Land size is higher and agro-climatic conditions are more favourable among farmers who cut- and- carry. Finally, and contrary to the outcomes of the conceptual framework, population density is significantly lower where farmers are more intensified. Also, these farmers are located in distant areas.

Crop- livestock interactions

Three indicators of the levels of crop- livestock interactions are used: use of manure, feeding crop residues and using draft power.
Data show that 92.5% farmers apply manure, thus reflecting the high level of crop-livestock interactions in the area. Fertilizer use is lower than manure (65% versus 92%) with 61% farmers applying both manure and fertilizer. Because of the sample imbalance (high proportion of farmers using manure), an econometric analysis does not give satisfactory results and a mean comparison across group is therefore conducted. Table 62 shows that a number of driving forces differ significantly across farmers' type. As expected, the proportion of Fulani is higher among manure users due to their higher herd size. Younger and more educated household heads are more likely to use manure; younger farmers have a longer time- horizon, thus the need to invest into soil fertility maintenance. Among farmers using manure, the number of adults and the ratio of female adults are lower; the significantly lower proportion of female adults among Fulani can explain the last result. Farmers using manure have significantly lower land size as farmers with large land holdings have less need to invest into soil fertility maintenance. As expected, manure use is positively correlated with access to extension services and population density. Also, farmers using manure are located closer to urban centers (on road types 2 and 3), although further away from the nearest road.

Table 62: West Africa case study- characteristics of farmers differentiated by manure use

Manure	no	yes	Sig.
Number of observations	60	736	
1 if fulani, 0 if hausa	0.05	0.22	1
Age of the owner of the farm	51.35	46.16	1
Years of formal education	2.28	4.98	1
number of adults	6.32	5.44	10
ratio female adults over total adults	0.49	0.42	1
dependency ratio	0.44	0.47	
Land size (ha)	11.15	7.72	1
1 if livestock extension services	0.05	0.12	5
PPE	0.44	0.53	1
population density	103.27	194.96	1
travel time village- nearest road	0.01	0.21	1
kms to nearest urban centres, road type 1	76.07	77.54	
kms to nearest urban centres, road type 2 and 3	17.47	10.26	1

The second indicator of crop- livestock interactions is feeding livestock with crop residues. Almost half the livestock keepers (40.8%) feed crop residues. The third indicator of crop- livestock interactions is draft power: 4601% of agricultural farmers use draft power. Table 63 shows the results of the econometric analysis. Goodness of fit indicators are satisfactory with overall percentages of correctly predicted observations of 70% for the crop residues and 63% for the draft power regression. Survey household variables that have a significant and positive effect on the level of crop livestock interactions are the level of education, number of adults, proportion of female adults on the likelihood of using draft power and land size on the likelihood of feeding crop residues. The first results can be explained by the labour requirement of draft power while higher land availability translates into higher crop residues and thus higher feeding. The indicator of agro- climatic characteristics (PPE) has a negative effect on the probability of feeding crop residues and a positive effect on the probability of using draft power: farmers in areas with more favourable climate have access to more natural pasture, thus the lower need to rely on crop residues. The positive effect of PPE on draft power is difficult to interpret. Other unexpected results are the negative effect of population density on the probability of feeding crop residues and the positive effect of distances on the probability of using draft power.

Table 63: West Africa case study- econometric analyses of the levels of crop- livestock interactions

		Crop residues		Draft power	
variable	change		P>z		P>z
1 if fulani, 0 if hausa	1	5.68	0.78	-5.53	0.78
Age of the owner of the farm	10	-1.80	0.34	1.12	0.55
Years of formal education	1	-0.85	0.22	**1.76**	**0.01**
number of adults	1	0.72	0.22	**1.27**	**0.05**
ratio female adults over total adults	0.1	0.92	0.43	**3.78**	**0.00**
dependency ratio	0.1	0.19	0.86	1.53	0.17
Land size (ha)	1	**0.30**	**0.10**	0.21	0.35
1 if livestock extension services	1	3.90	0.88	2.40	0.92
PPE	0.1	**-7.39**	**0.00**	**7.41**	**0.00**
population density	100	**-5.47**	**0.02**	not incl.	
travel time village- nearest road	1	4.02	0.54	**18.99**	**0.01**
kms to nearest urban centres, road type 1	1	**-0.12**	**0.03**	-0.05	0.30
kms to nearest urban centres, road type 2 & 3	1	not incl.		**0.60**	**0.02**
Sensitivity		47.52%		55.31%	
Specificity		85.41%		70.09%	
Positive predictive value		68.92%		61.33%	
Negative predictive value		70.51%		64.66%	
Correctly classified		70.06%		63.27%	
Number of obs		795		795	
Pseudo R2		0.12		0.06	
Log likelihood		-470.46		-513.48	

Combined analysis

The essence of the trans-regional analysis of crop-livestock systems is to test whether the forces driving the evolution of crop-livestock systems are similar across the different systems. If this is the case, then the relationships observed at the country-level (previous section) are valid when conducting the analysis on the pooled (or combined) dataset. The objective of this section is to test this hypothesis.

The analysis is run on the pooled data that are presented in Table 64. The analysis presented in this document does not include the Colombia data due to the unavailability of some key indicators of driving forces (explanatory variables) for this dataset (some household heads' characteristics and the household composition).

Table 64: Pooled analysis- number of observations

	India	Kenya	S/Lanka	W/Africa	Total
land & no livestock	91	820	1,119	58	2,088
no land & livestock	75	0	273	7	355
land & livestock	551	2,046	1,474	738	4,809
Total	717	2,866	2,866	803	7,252

Before presenting the results of the main analysis, it is worth noticing that some driving factors are strongly country-specific. Table 65 shows that the climatic characteristics and travel time have an important country-effect: country dummies alone explain more than half the variation of these two variables (Adj. R^2 are above 0.5).

Table 65: Pooled analysis- OLS results of some driving forces on country dummies

	PPE		Travel time	
Variables	Coef.	P>t	Coef.	P>t
country dummy: Kenya (base=India)	0.37	0.00	-0.38	0.00
country dummy: Sri Lanka (base=India)	0.66	0.00	-0.46	0.00
country dummy: West Africa (base=India)	-0.02	0.13	0.67	0.00
constant	0.54	0.00	0.59	0.00
Number of observations	7251		7250	
Adj. R2	0.55		0.60	

In order to "purge" the results of these country-level specificities, country-level dummies are introduced in the econometric analysis of crop and livestock intensification. The introduction of country dummies does not however mean that the hypothesis of "trans-regionality" is rejected but that driving forces are country- specific. Not including the country dummies would mitigate the possible effect of these factors of the level of intensification.

Table 66 presents the results of the econometric analysis of crop intensification using the pooled dataset. Although other indicators were available, only the indicator of fallow use gave sound results in terms of goodness-of-fit.

Table 66: Pooled analysis- econometric analysis of crop intensification (fallow), Logit analysis

		Fallow	
variable	change	Marg.	P>z
1 if male, 0 female	1	1.45	0.90
Age of the owner of the farm	10	**2.14**	**0.00**
Years of formal education	1	**-0.59**	**0.00**
number of adults	1	-0.01	0.97
ratio female adults over total adults	0.1	0.48	0.15
dependency ratio	0.1	**-0.58**	**0.05**
Land size (ha)	1	**1.37**	**0.00**
PPE	0.1	**4.23**	**0.00**
population density	100	**-3.56**	**0.00**
km farm to road network	1	-0.34	0.68
travel time to the nearest urban centre (hours)	1	**7.51**	**0.00**
country dummy: Kenya (base=India)	1	32.00	0.21
country dummy: West Africa (base=India)	1	10.15	0.71
Sensitivity		33.99%	
Specificity		93.02%	
Positive predictive value		65.81%	
Negative predictive value		78.08%	
Correctly classified		76.29%	
Number of obs		4276	
Pseudo R2		0.2	
Log likelihood		-2104.3	

Note: the Sri Lanka case study is not used in the analysis due to lack of information on the dependent variable.

A number of survey-derived variables are significant with the expected effect: younger and more educated farmers, as well as households with more dependents, are less likely to keep some land in fallow. On the other hand, households with large land holdings are less likely to intensify. These results are consistent with the predictions of the conceptual framework. The same conclusion can be drawn when looking at the effect of GIS-derived variables: farmers with limited market access and in areas with low population density are more likely to have fallow. Controlling for country- specificities through dummies, results show that intensification is negatively related with climatic potential.

Table 67 reports the results of the econometric analysis of livestock intensification. Two indicators are used: whether the farmer feeds concentrates and whether cattle are stall-fed. For both indicators, the level of education is positively related with the intensification decision. Labour availability has also a positive effect on the uptake of feeding concentrates. A third significant survey variable is land size: farmers with larger land holdings are more likely to feed concentrates, a result that seems counter-intuitive. However, this positive relationship can be explained by the fact that feeding concentrates is likely to be a decision tied to liquidity availability, with farmers with large land sizes being less liquidity-constrained. As in the case of crop intensification, farmers with better market access and in areas more densely populated record higher levels of intensification.

Table 67: Pooled analysis- econometric analysis of livestock intensification, Logit analysis

		Concentrates		Stall feeding	
variable	change	Marg.	P>z	Marg.	P>z
1 if male, 0 female	1	-4.84	0.66	-7.93	0.47
Age of the owner of the farm	10	0.72	0.30	0.38	0.56
Years of formal education	1	**2.33**	**0.00**	**1.44**	**0.00**
number of adults	1	**1.29**	**0.00**	0.08	0.84
ratio female adults over total adults	0.1	-0.14	0.75	-0.05	0.91
dependency ratio	0.1	0.35	0.36	-0.36	0.32
Land size (ha)	1	**0.51**	**0.01**	-0.15	0.47
1 if livestock extension services	1	3.38	0.67	-7.66	0.34
PPE	0.1	**-0.81**	**0.04**	**-3.32**	**0.00**
population density	100	**1.81**	**0.00**	**1.99**	**0.00**
km farm to road network	1	-0.92	0.25	-0.45	0.57
travel time to nearest urban centre (h)	1	**-4.26**	**0.09**	**-9.26**	**0.00**
country dummy: Kenya (base=India)	1	**-53.33**	**0.00**	**-31.22**	**0.03**
country dummy: Sri Lanka (base=India)	1	**-42.65**	**0.02**	-23.03	0.18
country dummy: W/Africa (base=India)	1	-18.11	0.31	**-38.54**	**0.05**
Sensitivity		54.43%		40.38%	
Specificity		79.40%		89.11%	
Positive predictive value		70.71%		68.34%	
Negative predictive value		65.60%		71.97%	
Correctly classified		67.48%		71.18%	
Number of obs		4775		4590	
Pseudo R2		0.12		0.13	
Log likelihood		-2904.79		-2635.57	

Finally, Table 68 presents the results of the econometric analysis of crop-livestock interactions using the pooled dataset. The indicator is the use of crop residues for animal feeding. Feeding of crop residues is more likely among households with older heads, with few members but higher proportion of female adults, and those with fewer dependents. Availability of extension services boosts the level of crop-livestock interactions as does market access. The two last results are consistent with the predictions of the conceptual framework but some of the survey variable results are counter-intuitive.

Table 68: Pooled analysis- econometric analysis of crop-livestock interaction, Logit analysis

	Crop residues	
variable	Coef.	P>z
1 if male, 0 female	0.04	0.76
Age of the owner of the farm	**0.01**	**0.04**
Years of formal education	-0.01	0.25
number of adults	**-0.04**	**0.04**
ratio female adults over total adults	**0.57**	**0.01**
dependency ratio	**-0.49**	**0.01**
Land size (ha)	0.01	0.11
1 if livestock extension services	**0.30**	**0.00**
PPE	-0.28	0.18
population density	0.00	0.00
km farm to road network	-0.06	0.12
travel time to the nearest urban centre (hours)	**-0.36**	**0.00**
country dummy: Kenya (base=India)	**-1.01**	**0.00**
country dummy: Sri Lanka (base=India)	**-4.80**	**0.00**
country dummy: West Africa (base=India)	**-2.25**	**0.00**
constant	**2.11**	**0.00**
Sensitivity	84.95%	
Specificity	79.05%	
Positive predictive value	83.48%	
Negative predictive value	80.82%	
Correctly classified	82.32%	
Number of obs	4922	
Pseudo R2	0.40	
Log likelihood	-2040.97	

Conclusions

Table 69 and Table 70 summarize the results of the analysis for selected indicators of livestock intensification and crop- livestock interactions. The other indicators are summarized in tables presented in Annex Part 3. The combined use of household survey data and GIS- derived variables in econometric analyses proves to be a powerful tool to better understand intensification and crop- livestock interactions levels. Three driving forces are at play in the majority of the case studies: farmers' education level, market access and human population pressure.

The pooled analysis does not reject the existence of common driving forces at play. Although country- level specificities do exist, especially in terms of climatic characteristics and market access and need to be taken into consideration in the empirical analysis, it can be shown that livestock intensification is usually driven by the three factors mentioned above. As for the level of crop- livestock interactions, market access and population pressure (although not when using as indicator whether crop residues are fed to livestock) also emerge as key driving forces.

Table 69: Summary table for livestock intensification- intensified feeding system

	Colombia	India	Kenya	Sri Lanka	W/ Africa[4]	Combined[5]
Age/ experience of the head[1]		+		+		
Gender of the head	n.i.	n.i.				
Education of the head	+		+	+		+
Land size		+	-		+	
Number of adults	n.i		-		+	
Ratio female adults over total adults	n.i					
Dependency ratio	n.i		-			
Access to extension services						
Market access to main urban centers[2]	-	+	+	+	-	+
Local market access[3]		-				
Human population density	+		+	+	-	+
Climatic characteristics	+			-	+	-
Correctly classified	78%	80%	82%	65%	n.a	71%
Number of observations	505	621	1959	1377	625	4590

n.i is not included and n.a. not applicable

[1] of the farm owner for Colombia

[2] market access to main urban centers is defined as access to main urban centers and/or country capital (the higher the distance farm- urban center, the lower the market access)

[3] local market access is defined as access to the road network (the higher the distance farm- road network, the lower the local market access)

[4] results of a statistical analysis (comparison of means)

[5] the combined dataset does not include the observations of Colombia. Country dummies are included among the explanatory variables.

Table 70: summary table for crop-livestock interactions-feeding crop residues

	India[4]	Kenya	W/ Africa	Combined[5]
Age/ experience of the head[1]	+			+
Gender of the head	n.i.			
Education of the head	+			
Land size	+	-	+	
Number of adults				-
Ratio female adults over total adults				+
Dependency ratio				-
Market access to main urban centers[2]		+	+	+
Local market access[3]	-	+		
Human population density	+	+	-	
Climatic characteristics	-	+	-	
Correctly classified	n.a.	87.95%	70.06%	82.32%
Number of observations	603	2000	795	4922

n.i, n.a, [1], [2], [3], [4] and [5] : see Table 69 notes

Household dimension of crop-livestock systems

This part describes the analysis at the household level. It is organised in three sections. The first section describes the data collection and the model used for the analysis. The data analysis is presented in the second section while conclusions are offered in the third section.

Data collection and model

From the 5 sites selected in level 2, 4 sites were used in level 3: India, Kenya, Niger/Nigeria and Sri Lanka. Longitudinal monitoring surveys coupled with extension staff interviews were used to collect the data needed for the analysis.

The Integrated Modelling Platform for Animal/Crop Systems (IMPACT) model is used for the analysis. The model was jointly developed by Edinburgh University and ILRI (Herrero, 1999; Herrero and Fawcett, 2002; Castelán-Ortega et al., 2003). It is a generic hybrid between simulation and optimisation models and utilises data from obtained from surveys, PRAs, experiments and even other models. IMPACT includes a mathematical programming household model that provides a holistic view of a farm by integrating soils, crops and livestock interactions and is run using the software Xpress^{MP} (Guéret et al., 2000). The model has been adapted to the smallholder systems in Kenya by modifying the enterprises and integration between them. The livestock simulator is used to model milk output under different feeding systems.

The basics of the optimisation module has three elements: and an objective function which can be minimisation of nutrient losses, maximisation of gross margin or minimisation of concentrate use, subject to a set of activities: livestock by categories, crop management strategies, feed resources and a set of constraints, e.g., farm size, seasonal cropping calendars, labour availability.

The model can be used to: quantify interactions between the system's components; represent farmer's management practices; determine the impacts of management strategies on use of land and other resources; quantify nutrient balances at the whole systems level; quantify the effect of weather variability and trade-offs (economic, environmental and social) involved in using different farm resources

Data analysis

Table 71 presents some characteristics and results for two case studies, Kiambu (Kenya) and Nuwara (Sri Lanka). Sensitivity analyses show the importance of outputs prices (crop and livestock) in shaping the farm activities with respect to land and labour allocation.

Table 71: Characteristics and results for two case studies (level 3)

Case studies	Kenya- Kiambu	Sri Lanka- Nuwara
Farming systems	Crop- dairy in the coffee zone	Vegetables- dairy
Basic information	1 ha, 5 family members	0.1 ha, 5 family members
Livestock activities	- 1 dairy cow and 1 calf - milk production: 1,800 l/lactation	- 1 dairy cow and 1 calf - milk production: 2,100 l/lactation
Results	- food security is met but one third of the maize (staple food) needs to be purchased - milk sales represent three quarters of the gross margins - sale of coffee and vegetables	- almost all food requirements are purchased - sale of crops represents four fifth of the gross margins (mainly carrots)

Conclusions

Although the analysis has not been completed for all the case studies, the results show the potential of the model to test the hypothesis of the conceptual framework at the household level which is the most detailed level of analysis. Additional sensitivity analyses need to be completed, especially with respect to the key factors identified by the conceptual framework and the results of the previous levels.

Conclusions

The objective of the trans-regional analysis of crop-livestock systems is to identify common underlying factors that determine the evolution of smallholder crop-ruminant systems. Based on the existing literature, an original conceptual framework was developed to formally identify the factors that theoretically influence the structure of these systems. Empirically, the strategy was to consider different dimensions, or scales, of analysis in order to capture factors that are at play at each of these dimensions. Three dimensions were considered: broad- or village-level-dimension; farm and spatial dimension; and household dimension. The challenge was then to analyse pooled data from sites characterized by different levels of agricultural intensity.

Results of the different levels of analyses show that costs of factors of production (captured at a large scale), market access, demographic pressure and education level (captured at the broad and more detailed dimensions) are key determinants of the evolution of smallholder crop-ruminant systems. The other main result of the analysis is the fact that driving forces are relatively consistent across sites, thus not rejecting the hypothesis of "trans-regionality".

Based on these results, planning and policy interventions that could improve opportunities for the rural poor in an environmentally sustainable way can be suggested. Uptake of planted fodder or stall- feeding is usually promoted based on climatic characteristics without recognition of the farmers' socio-economic constraints. Market access for example is key to uptake of stall- feeding: one additional hour of travel time between the farm and a major urban center diminishes the likelihood of stall feeding by approximately 4% in general (pooled dataset) with impact as large as 12% in Kenya and 9% in Sri Lanka.

The next step is to use such quantitative relationships to predict spatially and temporally the structure and evolution of crop-livestock systems across the three continents under study.

References

Bayer, W., and A. Waters-Bayer. "Relations between cropping and livestock husbandry in traditional landuse systems in tropical Africa." Animal Research and Development, 1987, 57-68.

Boserup, E., 1965, The condition of agricultural growth: the economics of agrarian change under population pressure. London.

Castelán-Ortega, O.A., Fawcett, R.H., Arriaga-Jordán, C., Herrero, M. 2003. A decision support system for smallholder campesino maize-cattle production systems of the Toluca valley in Mexico. Part I – integrating biological and socio-economic models into a holistic system. Agricultural Systems 75, 1-21

Cuffaro, N. "Population growth and agriculture in poor countries: a review of theoretical issues and empirical evidence." World Development 25, no. 7(1997): 1151-1163.

Environmental Systems Research Institute (ESRI), 1999. Arcview Version 3.2, 380 New York Street, Redlands, CA, USA.

Feder, G., R.E. Just, and D. Zilberman. "Adoption of agricultural innovations in Developing Countries: a survey." Economic Development and Cultural Change 33(1985):255-298.

Guéret, C., Prins, C., Sevaux, M., 2000. Application of optimization with Xpress-MP. Dash Optimization Ltd. www.dashoptimization.com

Hayami, Y. and Ruttan, V.W., 1985, Agricultural development: an international perspective. London, The John Hopkins University Press.

Herrero, M. 1997 Modelling dairy grazing systems: an integrated approach. PhD thesis, University of Edinburgh. Edinburgh, Scotland.

Herrero, M., Fawcett, R.H. 2002. A generic household model for assessing the impact of interventions in crop-livestock systems. Proceedings of the 17th Symposium of the International Farming Systems Association, 17-20 November 2002, Lake Buena Vista, Florida, p 106.

F. Holmann, L. Rivas, J. Carulla, L.s A. Giraldo, S. Guzman, M. Martinez, B. Rivera, A. Medina, and A. Farrow. 2003 Evolution of Milk Production Systems in the tropics of Latin America and its interrelationship with markets: An analysis of the Colombian case. Internal paper, CIAT, Colombia.

Kobrich, C., T. Rehman, and M. Khan. "Typification of farming systems for constructing representative farm models: two illustrations of the application of multi-variate analyses in Chile and Pakistan." Agricultural Systems 76, no. 1(2003): 141-157.

Lele, U. and Stone, S.S., 1989, Population pressure, the environment and agricultural intensification: variations on the Boserup hypothesis: Washington D.C.: World Bank MADIA discussion paper 4. p. -79

McIntire, J., Bourzat, D., and Pingali, P., 1992, Crop-livestock interaction in Sub-Saharan Africa. The World Bank Wahington, D.C., p. 1-246.

Murdock, G. P, 1959. Africa: Peoples and their Culture History. New York, McGraw Hill.

Okike, I., 2002a, Transregional Analysis of Crop-Livestock Systems: Understanding intensification and evolution across three continents– the case of Nigeria, West Africa. ILRI/IITA consultant's report on the local system (level 2).

Okike, I., 2002a, Transregional Analysis of Crop-Livestock Systems: Understanding intensification and evolution across three continents – the case of Niger Republic, West Africa. ILRI/IITA consultant's report on the local system (level 2).

Powell, J.M. and Williams, T.O., 1993, An overview of mixed farming systems in sub-Saharan Africa: International Livestock Centre for Africa. Livestock and sustainable nutrient cycling in mixed farming systems of sub- Saharan Africa. Volume II: technical papers. Addis Ababa, Ethiopia.

Reid, R.S., R.L. Kruska, U. Deichmann, P.K. Thornton and S.G.A. Leak., 2000. Human population growth and the extinction of the tsetse fly. Agriculture, Ecosystems and Environment 77, 227-236.

Scoones, I. and Wolmer, W., 2000, Pathways of change: crops, livestock and livelihoods in Africa. Institute of Development Studies, University of Sussex, p. 1-204.

Seré, C., Steinfeld, H. and Groenewold, J. 1995. World livestock systems: Current status, issues and trends. In: Gardiner, P and Devendra, C. (eds), Global Agenda for Livestock Research. Proceedings of a Consultation, 18–20 January 1995, International Livestock Research Institute (ILRI), Nairobi, Kenya, pp. 11–38.

Staal, S.J. and Baltenweck, I. 2002. Conceptual framework for studying patterns of intensification of smallholder crop-livestock systems: locally, regionally and trans-regionally. Transregional Analysis Project Report, ILRI/CIAT/IITA/UoP. Draft.

Thornton, P.K., Kruska, R.L., Henninger, N., Kristjanson, P.M., Reid, R.S., F. Atieno,A.N. Odero, and T. Ndegwa. 2002. Mapping Poverty and Livestock in the Developing World. ILRI (International Livestock Research Institute), Nairobi, Kenya. 124 pp.

World Economic Outlook dataset, International Monetary Fund, 2002. http://www.imf.org/external/pubs/ft/weo/2001/01/data/index.h

Annexes

Annex Part 1

Conceptual framework

See main text for notations.

Crop-livestock intensification: the first- order conditions are:

$$(A1)\ \frac{\partial L}{\partial c}=\frac{\partial U}{\partial c}-\lambda p_f=0$$

$$(A2)\ \frac{\partial L}{\partial L_p}=\frac{\partial U}{\partial L_p}-\mu=0$$

$$(A3)\ \frac{\partial L}{\partial L_0}=\lambda\left[p_c\frac{\partial f_c}{\partial L_0}+p_l\frac{\partial f_l}{\partial L_0}\right]-\mu=0$$

$$(A4a)\ \frac{\partial L}{\partial L_{fc}}=\lambda p_c\frac{\partial f_c}{\partial L_c}-\mu\le 0;\ L_{fc}\ge 0;\ \frac{\partial L}{\partial L_{fc}}.L_{fc}=0$$

$$(A4b)\ \frac{\partial L}{\partial L_{hc}}=\lambda\left[p_c\frac{\partial f_c}{\partial L_c}-w\right]\le 0;\ L_{hc}\ge 0;\ \frac{\partial L}{\partial L_{hc}}.L_{hc}=0$$

$$(A5a)\ \frac{\partial L}{\partial L_{fl}}=\lambda p_l\frac{\partial f_l}{\partial L_l}-\mu\le 0;\ L_{fl}\ge 0;\ \frac{\partial L}{\partial L_{fl}}.L_{fl}=0$$

$$(A5b)\ \frac{\partial L}{\partial L_{hl}}=\lambda\left[p_l\frac{\partial f_l}{\partial L_l}-w\right]\le 0;\ L_{hl}\ge 0;\ \frac{\partial L}{\partial L_{hl}}.L_{hl}=0$$

$$(A6a)\ \frac{\partial L}{\partial H_{c0}}=\lambda\left[p_c\frac{\partial f_c}{\partial H_c}+\beta p_l\frac{\partial f_l}{\partial I_l}\right]-\gamma=0$$

$$(A6b)\ \frac{\partial L}{\partial H_{cr}}=\lambda\left[p_c\frac{\partial f_c}{\partial H_c}+\beta p_l\frac{\partial f_l}{\partial I_l}-r\right]\le 0;\ H_{cr}\ge 0;\ \frac{\partial L}{\partial H_{cr}}.H_{cr}=0$$

$$(A7a)\ \frac{\partial L}{\partial H_{l0}}=\lambda\left[\alpha p_c\frac{\partial f_c}{\partial I_c}+p_l\frac{\partial f_l}{\partial H_l}\right]-\gamma=0$$

$$(A7b)\ \frac{\partial L}{\partial H_{lr}}=\lambda\left[\alpha p_c\frac{\partial f_c}{\partial I_c}+p_l\frac{\partial f_l}{\partial H_l}-r\right]\le 0;\ H_{lr}\ge 0;\ \frac{\partial L}{\partial H_{lr}}.H_{lr}=0$$

$$(A8a)\ \frac{\partial L}{\partial E_c}=\lambda\left[p_c\frac{\partial f_c}{\partial E_c}-p_{ec}\right]\le 0;\ E_c\ge 0;\ \frac{\partial L}{\partial E_c}.E_c=0$$

$$(A8b)\ \frac{\partial L}{\partial E_l}=\lambda\left[p_l\frac{\partial f_l}{\partial E_l}-p_{el}\right]\le 0;\ E_l\ge 0;\ \frac{\partial L}{\partial E_l}.E_l=0$$

Crop-livestock interaction: the first- order conditions are:

$$(A9)\ \frac{\partial L}{\partial \alpha} = \lambda.p_c.\frac{\partial f_c}{\partial I_c}.\frac{\partial I_c}{\partial \alpha} - \mu.L_l \leq 0\,;\alpha \geq 0\,;\frac{\partial L}{\partial \alpha}.\alpha = 0$$

$$= \lambda.p_c.\frac{\partial f_c}{\partial I_c} - \mu \leq 0$$

$$(A10)\ \frac{\partial L}{\partial \beta} = \lambda.p_l.\frac{\partial f_l}{\partial I_l}.\frac{\partial I_l}{\partial \beta} - \mu.L_c \leq 0\,;\beta \geq 0\,;\frac{\partial L}{\partial \beta}.\beta = 0$$

$$= \lambda.p_l.\frac{\partial f_l}{\partial I_l} - \mu \leq 0$$

Annex Part 2

Level 1: Village –level dimension of crop-livestock systems- Location of the surveyed sites, macro-economic indicators and sites description

Text A1: Data collection via farmer group interviews – Check list

A. BASIC INFORMATION

Number of farmer participants in the PRA:
Percentage of women among participants:
Average annual rainfall (mm/year):
Number of cropping seasons and periods of the year:
Human population density
Cattle/ buffalo population, density, data on transhumance
Distance to major urban centres, specify (km):
Overall assessment of the road infrastructures in the area:

B. GENERAL INFORMATION

Sources of income- farm activities, all farm activities, wages/ salaries, Remittances, Income from rent (plots, houses, etc…), Other sources of income
Sources of agricultural income: all livestock activities, dairy activities, sale of crop products, sale of crop residues, other farm activities
Off- farm opportunities for the household head
Education level of the household heads
Access to facilities Electricity, Piped public water, Phone
Equipment: Pickup or car, Tractor, Hand-tractor, Mechanical fodder chopper, Other

C. SYSTEMS OF PRODUCTION

Crops grown
Livestock population (including percentage of farmers keeping each species/ breed)
Cropping seasons
Land holding for agricultural activities (% of landless farmers, Average land holding, etc..)
Land rental market
Animal traction

D. MARKETING OF FARM PRODUCTS

Sales of crops
Milk consumption and sale
Outlets for milk marketing
Information about milk outlets for dairy farmers
Livestock marketing
Marketing of other livestock products
Sales of male calves:

E. AVAILABILITY OF SERVICES

Livestock services
Crop services
Other services

F. INFORMATION ON LIVESTOCK ACTIVITIES

Type of livestock feeding system
Supplementation
Land allocated to livestock activities- pasture, fodder crops, crops used as feed (crop residues)
Access to communal land and transhumance
Types of fodder
Use of crop residues as livestock feed

Feed purchases
Fodder market
Livestock diseases
Livestock Mortality

G. INDICATORS OF INTENSIFICATION

Cattle/ buffalo keeping strategies: % of adult females in the herd, % of farmers keeping and rearing male calves on farm, etc..
Use of mechanical procedures for milking and preparing feed & feeding
Animal fattening strategies
Use of hired labour
Sources of reproductive services
Indicators of milk performances
Use of Hybrid/ High Yield Varieties or Seeds
Pressure on land
In-organic fertiliser use
Animal Manure
Market for manure

H. OTHER INDICATORS OF DETERMINANTS OF INTENSIFICATION

Milk price ($/kg)
Agricultural land rental price (rent per ha per year in $)
Agricultural land purchase price ($/ha)
Price of compounded dairy meal ($/kg)
Price of the most common inorganic fertilizer ($/kg and type)
Heifer price (36 months animal, in $), by breed
Monthly casual wage ($)
Monthly wage rate for a school teacher ($)
Monthly wage rate for a mid-level civil servant ($)

I. OTHER INFORMATION

Main type of foodstuff

J. COMPETITIVENESS OF DAIRY ACTIVITIES

Individual farmers' case studies

Figure A6: Countries surveyed

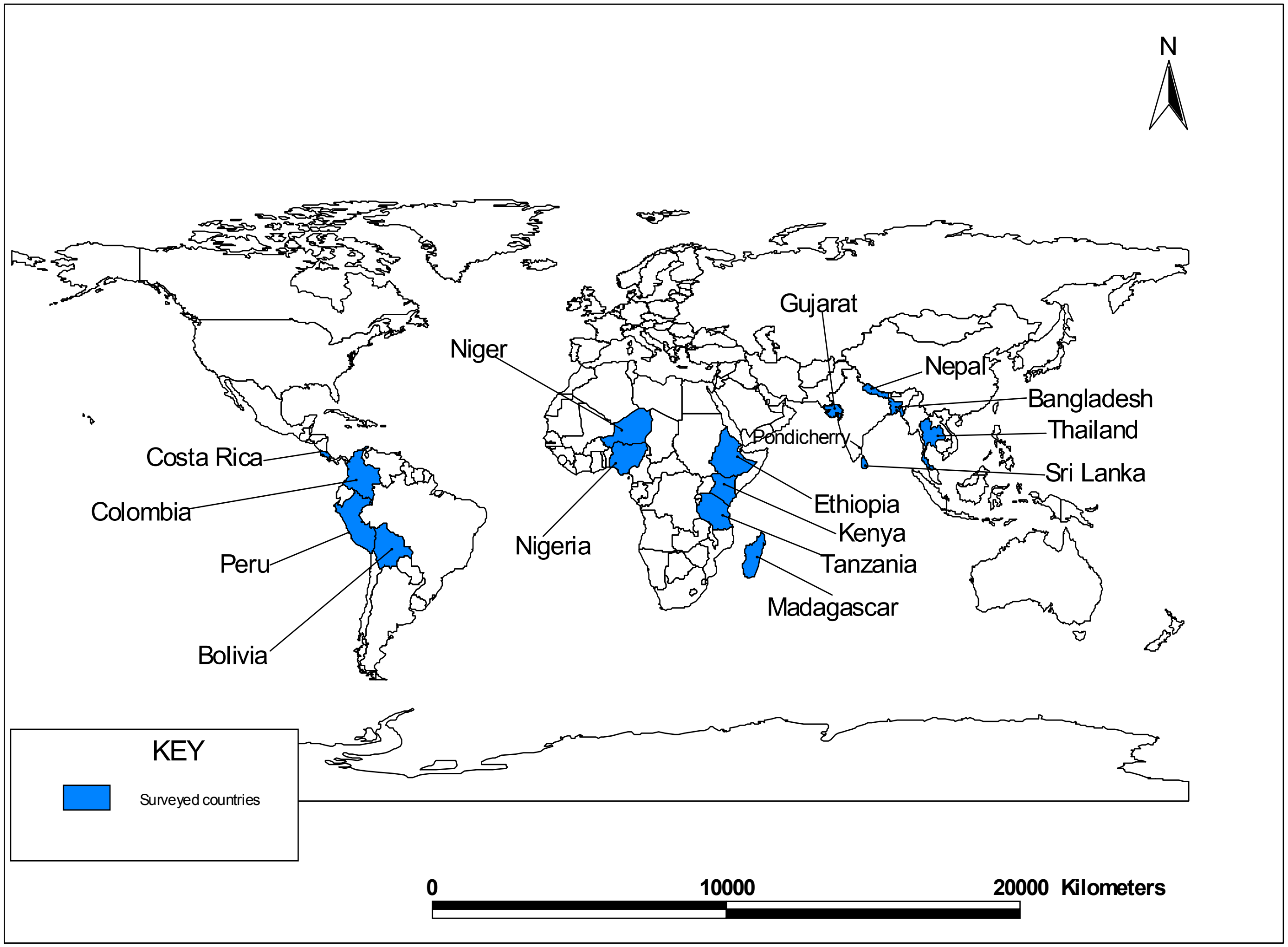
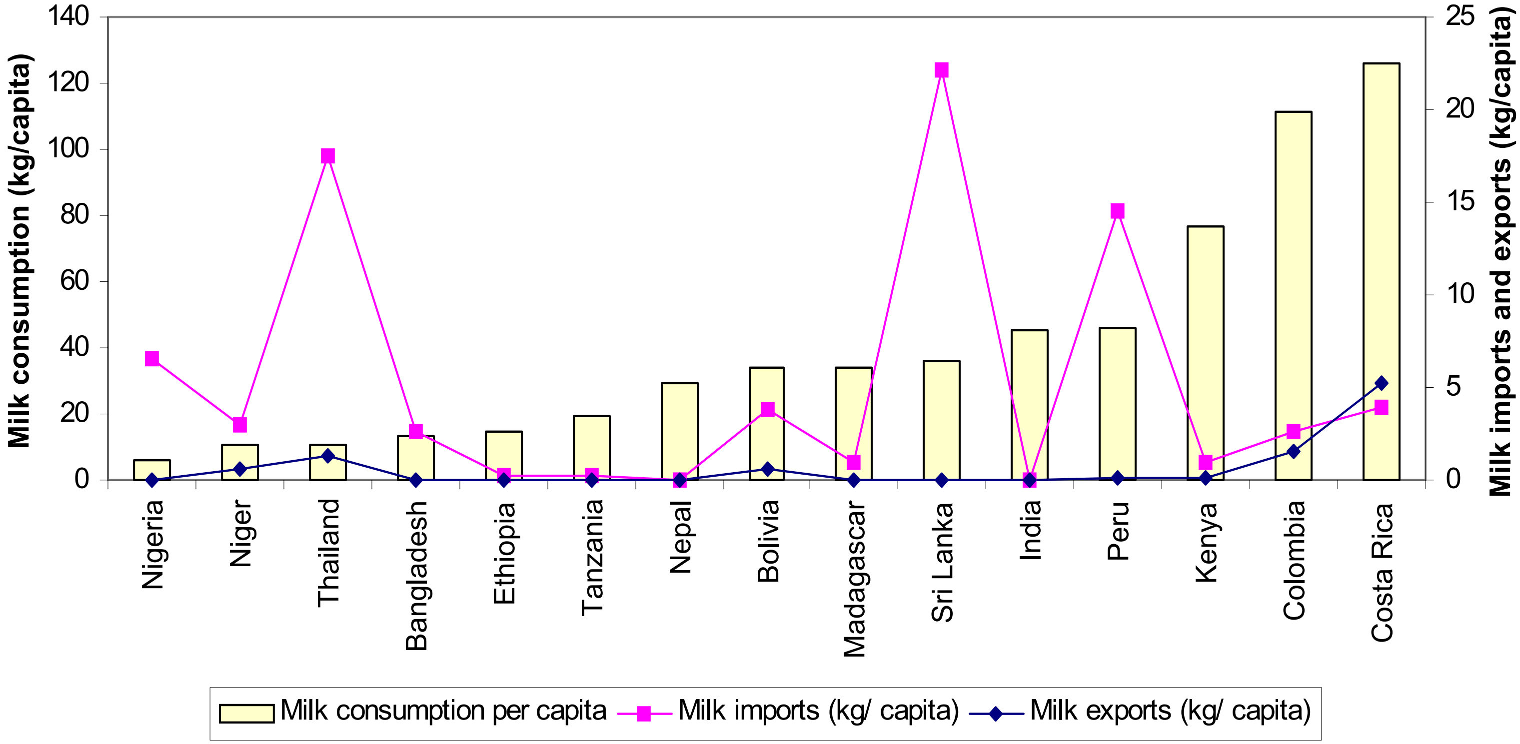
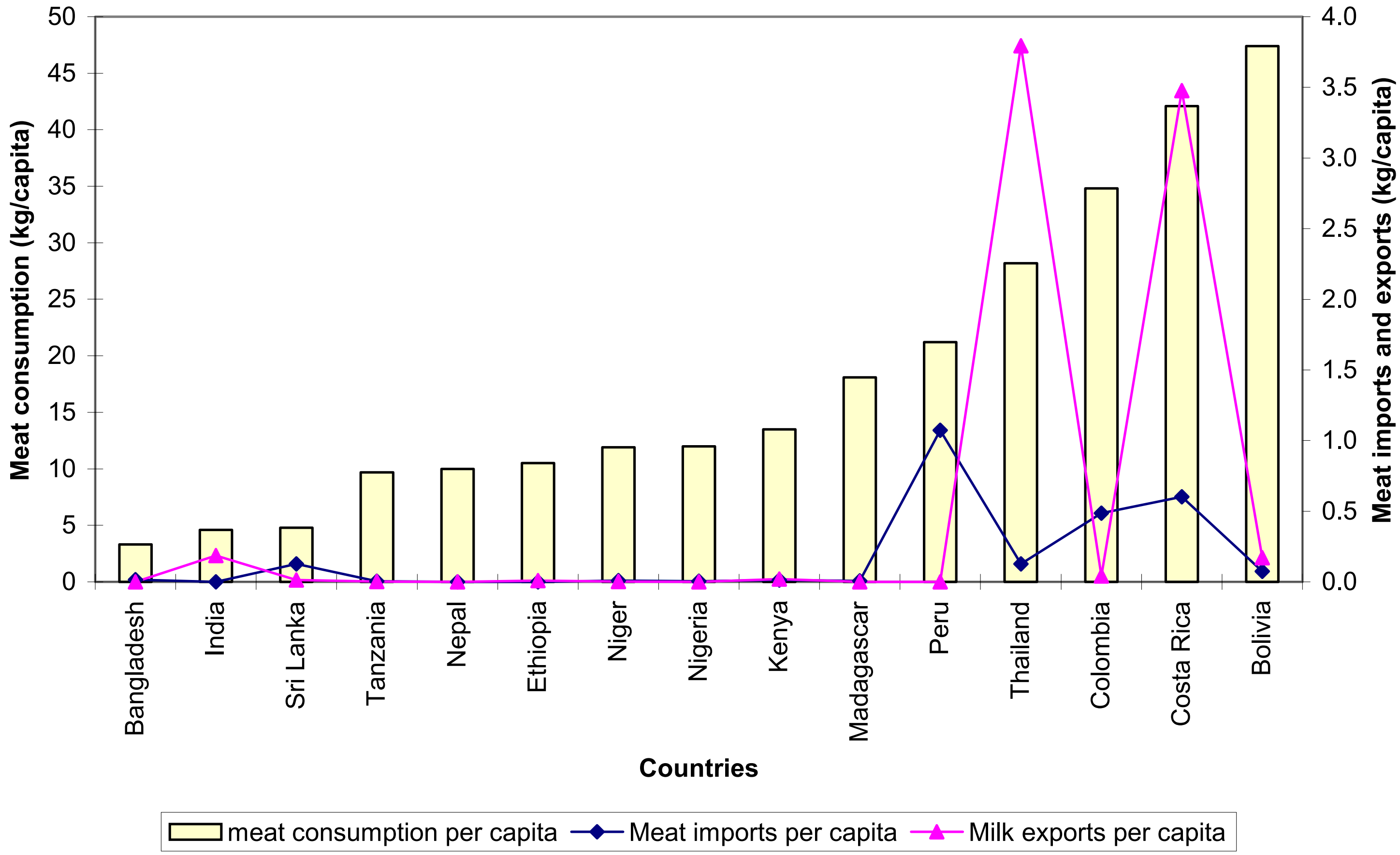


Figure A2: Milk consumption, imports and exports per capita



Source: FAOSTAT-FAO Statistical database, URL:http://apps.fao.org/

Figure A3: Meat consumption, imports and exports per capita



Source: FAOSTAT-FAO Statistical database, URL:http://apps.fao.org/

Table A1: Characteristics of the sites (rainfall (mm), elevation (m asl), length of growing period (days)), institution responsible for the data collection, number of farmers involved and percentage of women participating in the farmers' interview.

Agro- climate and Country	Area/village	Rainfall	Elevation	LGP	Institution	No farmers	% women
semi- arid, no irrigation							
India Gujarat	Gaidiya	850	30	134.5	BAIF	12	17
India Gujarat	Ishvariya	692	38	104.5	BAIF		
India Gujarat	Paruna	650	180	134.5	BAIF	22	
India Gujarat	Pipaliya- tribals	850	30	134.5	BAIF	14	14
Niger	Guidan Matche Daya	612	401	104.5	ILRI Niamey & ILRI Nairobi	15	0
Niger	Katanga	536	190	104.5	ILRI Niamey & ILRI Nairobi	12	0
Niger	Maradi	577	388	104.5	ILRI Niamey & ILRI Nairobi	12	0
Nigeria	Sule Tankarka	627	364	104.5	IITA & ILRI Nairobi	11	0
Nigeria	Tsibiri	1102	652	164.5	IITA & ILRI Nairobi	12	0
semi- arid, irrigation							
India Gujarat	Pipaliya- non tribals	850	30	134.5	BAIF	18	17
India Gujarat	Vegi	1000	30	134.5	BAIF	20	0
India Pondicherry	Konterekuppam	1250	30	104.5	U. of Peradeniya	12	2
India Pondicherry	Uruvaiyar	1250	30	104.5	U. of Peradeniya	10	0
Nepal	Kushma Village	1120	105	164.5	U. of Peradeniya	18	0
Nepal	Sunwat	1120	105	164.5	U. of Peradeniya	9	0
Niger	Dembou	514	182	104.5	ILRI Niamey & ILRI Nairobi	11	0
Nigeria	Bunkure	880	444	134.5	IITA & ILRI Nairobi	20	0
Nigeria	Turawa	1093	694	164.5	IITA & ILRI Nairobi	15	0
subhumid							
Bangladesh	Niloski Village	2850	60	224.5	U. of Peradeniya	8	0
Bangladesh	Poolbariya Village	2900	60	224.5	U. of Peradeniya	12	58
Bangladesh	Rabwa Village	2500	60	224.5	U. of Peradeniya	10	0
Costa Rica	North Pacific Region	2005	128	194.5	U. of Edinburgh & ILRI Nairobi	80	3
Sri Lanka	Khatagasdigiliya	1000	105	254.5	U. of Peradeniya	8	2
Sri Lanka	Niraviya	1000	90	224.5	U. of Peradeniya	10	

Table A1 (cont.)

Agro- climate and Country	Area/village	Rainfall	Elevation	LGP	Institution	No farmers	% women
Thailand	Bansalah	900	910	224.5	U. of Peradeniya	10	10
Thailand	Thung kra thin	1300	0	224.5	U. of Peradeniya	10	10
humid							
Bolivia	Central area of Santa cruz	1300	372	314.5	U. of Edinburgh & ILRI Nairobi	101	
Bolivia	Northwest of Santa cruz	1600	180	365	U. of Edinburgh & ILRI Nairobi	101	
Colombia	Dry coastal area	1198	70	314.5	CIAT	100	33
Peru	Peru	1890	240	314.5	CIAT	16	19
Sri Lanka	Hangurankette	1750	500	365	U. of Peradeniya	9	1
Sri Lanka	Kulayapitiya	2500	90	365	U. of Peradeniya	10	20
highlands							
Colombia	Highland Coffee area	2412	1165	365	CIAT		53
Costa Rica	Central Region	4000	1520	365	U. of Edinburgh & ILRI Nairobi	50	16
Ethiopia	Areka	990	1928	254.5	ILRI Addis-Ababa	5	20
Ethiopia	Debre zeit	880	1829	194.5	ILRI Addis-Ababa	5	20
Ethiopia	Guntuta	1100	2350	224.5	ILRI Addis-Ababa	5	0
Ethiopia	Tumano	1150	2600	164.5	ILRI Addis-Ababa	6	20
Kenya	Kabete	1050	1829	254.5	ILRI Nairobi	9	44
Kenya	Ol Kalou	855	2134	284.5	ILRI Nairobi	11	18
Madagascar	Ambatomirahavavy	1400	1477	194.5	FOFIFA & ILRI Nairobi	7	14
Madagascar	Atsimondrano	1400	1459	224.5	FOFIFA & ILRI Nairobi	5	40
Nepal	Belbhanjyang village	3300	2000	224.5	U. of Peradeniya	10	10
Nepal	Nirmal Pokhari	3000	1520	224.5	U. of Peradeniya	12	0
Sri Lanka	Hawaeliya	2500	1300	365	U. of Peradeniya	10	0
Tanzania	Aleni chini	1200	3658	254.5	SARI & ILRI Nairobi	10	40
Tanzania	Ilikwerei	979	1219	254.5	SARI & ILRI Nairobi	12	8
Tanzania	Mudio village	1000	1091	254.5	SARI & ILRI Nairobi	15	0

Table A2: Three first major crops grown, by site

Country	Area/ village	CROP1	PER1	WHY1	CROP2	PER2	WHY2	CROP3	PER3	WHY3
India Gujarat	Gaidiya	Vegetables	100	B	Pigeon peas	50	B	Peas	50	B
India Gujarat	Ishvariya	Groundnut	85		Sorghum	5	H	Vegetables	4	H
India Gujarat	Paruna	Peas	100	H	Maize	100	B	Pigeon peas	100	H
India Gujarat	Pipaliya- non tribals	Vegetables	100	H	Peas	100	B	Fruit trees	100	B
India Gujarat	Vegi	Maize	100	H	Sorghum	72	H	Fruit trees	70	S
India Pondicherry	Konterekuppam	Irrigated rice	67	B	Groundnut trees	17	B	Sugarcane	17	S
India Pondicherry	Uruvaiyar	Vegetables	100	H	Coconut	100	B	Irrigated rice	100	B
Nepal	Kushma Village	Wheat	100	B	Rain-fed rice	100	B	Irish potatoes	100	B
Nepal	Sunwat	Fruit trees	100	H	Irrigated rice	100	B	Irish potatoes	100	H
Niger	Dembou	Millet	100	H	Courge	100	S	Gombo	100	S
Niger	Guidan Matche Daya	Vegetables	100	B	Groundnut trees	100	S	Cotton	100	S
Niger	Katanga	Maize	100	H	Gombo & Wandzoi	100	H	Groundnut trees	100	S
Niger	Maradi	Millet	100	H	Groundnut trees	80	S	Maize	80	H
Nigeria	Bunkure	Cow peas	100	B	Late millet	100	B	Irrigated rice	90	B
Nigeria	Sule Tankarka	Millet	100	B	Benmi seeds	90	B	Sesame seeds	90	S
Nigeria	Tsibiri	Sweet potatoes	100	H	Maize	100	B	Vegetables	100	B
Nigeria	Turawa	Cotton	100	S	Vegetables	100	S	Sorghum	90	B
Bangladesh	Niloski Village	Vegetables	100	B	Banana	100	S	Irrigated rice	100	B
Bangladesh	Poolbariya Village	Banana	100	S	Vegetables	100	B	Rain-fed rice	50	B
Bangladesh	Rabwa Village	Vegetables	100	B	Jale	100	S	Rain-fed rice	100	B
Costa Rica	North Pacific Region	Maize	10	B	Sugarcane	10	H	Rain-fed rice	10	S
Sri Lanka	Khatagasdigiliya	Rain-fed rice	100	B	Vegetables	80	S	Chillies	80	S
Sri Lanka	Niraviya	Rain-fed rice	100	B	Chillies	80	S	Irrigated rice	80	B
Thailand	Bansalah	Fruit trees	40	S	Vegetables	30	H	Baby corn	20	S
Thailand	Thung kra thin	Fruit trees	100	H	Coconut	50	H	Rain-fed rice	40	S
Bolivia	Central area of Santa cruz	Maize	43	B	Soyabean	30	S	Sorghum	30	B
Bolivia	Northwest of Santa cruz	Banana	60	H	Fruit trees	60	H	Maize	45	H
Colombia	Dry coastal area	Fruit trees	54		Maize	34		Sugarcane	34	
Peru	Peru	Rain-fed rice	50	H	Maize	50	H	Banana	43	H

Table A2 (cont.)

Country	Area/ village	CROP1	PER1	WHY1	CROP2	PER2	WHY2	CROP3	PER3	WHY3
Sri Lanka	Hangurankette	Fruit trees	90	B	Vegetables	80	H	Banana	80	B
Sri Lanka	Kulayapitiya	Coconut	100	B	Rain-fed rice	80	B	Vegetables	80	H
Colombia	Highland Coffee area	Irrigated rice	15		Coffee	12		Fruit trees	9	
Costa Rica	Central Region	Sorghum	20	H	Vegetables	15	S	Maize	10	B
Ethiopia	Areka	Banana	100	H	Sweet potatoes	100	H	Maize	100	H
Ethiopia	Debre zeit	Teff	100	S	Wheat	100	S	Wheat	100	S
Ethiopia	Guntuta	Wheat	100	H	Teff	100	H	Pulses	100	H
Ethiopia	Tumano	Eucalypus trees	100		Teff	100	H	Pulses	100	S
Kenya	Kabete	Maize	100	H	Beans	100	H	Banana	80	H
Kenya	Ol Kalou	Beans peas	100	B	Maize	100	H	Irish potatoes	100	B
Madagascar	Ambatomirahavavy	Cassava	100	H	Irrigated rice	99	H	Vegetables	80	B
Madagascar	Atsimondrano	Irrigated rice	75	H	Vegetables	70	B	Sweet potatoes	1	B
Nepal	Belbhanjyang village	Irrigated rice	100	H	Vegetables	80	S	Maize	80	B
Nepal	Nirmal Pokhari	Vegetables	100	B	Sorghum	83	B	Maize	83	B
Sri Lanka	Hawaeliya	Vegetables	100	B	Irish potatoes	40	S			
Tanzania	Aleni chini	Beans	100	B	Maize	100	H	Pigeon peas	90	B
Tanzania	Ilikwerei	Banana	100	B	Maize	80	B	Beans	40	B
Tanzania	Mudio village	Beans	100	H	Maize	100	H	Banana	90	H

PER1-PER3 records the percentage of farmers in the village/ area growing the specific crop.
WHY1-WHY3 records the main reason for growing the specific crop: S for sale, H for home consumption and B for both.

India – Gujarat (Baroda)

The village (Pipaliya and Gaidiya) chosen for the PRA is situated in the State of Gujarat in the District of Baroda.
Total land area of the village Pipaliya is 256 ha: area under agricultural land is 217 ha, pasture land (23 ha), and the rest is waste land (17 ha). There are 120 families of which 30 are non-tribals (NT) and 90 tribals (T). Total village population was around 425 and literacy rate around 40%. 25% of the land is irrigable, and borewells is the main source for irrigation. Main crops of the village are cotton, banana, castor, wheat, sorghum and millet. Number of landholders are 90 (NT) and 30 were landless (T). Total ruminant population was about 511 (207 cows, 178 buffaloes and 126 goats).

Total land area of the village Gaidiya is 182 ha: area under agricultural land is 146, the rest is waste and pasture land. There are 65 families with a population of about 400 and all families belong to tribals. Literacy rate is very low. There are no irrigation facilities and crops of the village are cotton, castor, sorghum and millet. Number of land holders are 61, and 4 families were landless. Total ruminant population was about 212 (20 cows, 32 buffaloes and 160 goats).

Typical tribal residential area, with buffaloes tethered in front of their compound

India - Union Terrritory of Pondichery

The Union Terrritory of Pondichery is situated in the southern region of India. It is an Union of 4 territories (regions): Pondichery (293 sq km.), Karaikal (160 sq km.), Yanan (20 sq km.) and Mahe (9 sq km.). The administrative headquarters of these 4 regions is in Pondichery, situated 160 km south to Chennai in the East Coast of India.
The two villages (Konterekuppam and Uruvaiyar) chosen for the PRA are situated in the region of Pondichery, which has a tropical climate with temperatures ranging from 20-37 degrees Celsius. The average annual rainfall is 1250 mm.
Paddy rice is the main crop, cultivated 3 times a year. Other crops cultivated include sugarcane, millets, cassava, groundnut, mango and banana. A recent trend observed in Pondichery is the conversion of crop fields to casuarina fields which is less laborious and more economic. Casurina is cultivated for use as fence posts, and timber for housing purposes. This may in the long run affect the availability of agricultural byproducts for livestock feeding.

Kenya

Two areas were selected, Kabete location near Nairobi and Ol-Kalou. Both sites have two rainy seasons, the long rains from March to June and the short rains from October to December. The first site is characterised by good agro-climatic conditions for farming and privileged market access, due to its proximity with the Kenya capital city and relatively good road infrastructure. The second site, Ol-Kalou, is situated in an area with poor infrastructure where roads become impassable during the rainy season, preventing dairy farmers from marketing their milk. Livestock activities are the main source of income for the majority of the farmers in both sites. Maize is the principal food crop, followed by potatoes, beans and vegetables that are also marketed. Because of land availability (average of 2 ha), farmers in the Ol-Kalou area practise extensive grazing. Fodder, mainly Napier grass, is also fed and farmers supplement their animals (mainly the lactating cows) with dairy meal. On the other hand, cattle are stall-fed in Kabete with use of cut-and-carry fodder (Napier grass) and crop residues from the farm and roadsides. Most farmers supplement their cattle with dairy meal. Because of the relatively small land size (average of 0.6 ha per farm), most farmers in Kabete location use manure to sustain soil fertility:

Farmer harvesting Napier grass from his own field

The example of Mr. Gitau (name changed to respect anonymity) is revealing: the farmer has 2 animals, a 9-year-old Friesian crossbred cow and an in-calf Aryshire heifer. The farmer applies manure on the food crops on a regular basis. Every week, the cowshed is cleaned and the feed refusals removed and heaped in one place. Slurry is then poured onto the heap. The heap is allowed to decompose for two months before being taken to the farm. Surplus manure is traded with Napier grass and maize stovers from other farmers in the neighborhood. Farmer uses fertilizer (DAP) occasionally when manure is too wet to transport to the crops. When fertilizer is used, it is applied to maize, cabbage and potatoes only.

Madagascar

Milk production in Madagascar is concentrated in the "dairy triangle", an area including Antananarivo and the Antsirabe region that offers good agro-climatic conditions for dairying and where the main dairy processors are located, providing a reliable outlet for smallholders milk production. In the village of Ambohimangakely, 15 km east of Antananarivo, irrigated rice production is the principal activity; farmers also grow vegetables for home consumption. Dairying is the main activity for less than 10% of the farmers. Local breed cattle graze on communal land while grade cattle are usually confined. During the rainy season when natural forage is available, farmers cut and carry fodder from communal land. To meet feed requirements during the dry season, farmers grow elephant grass; also rice fields are used to grow out-of-season forages (rye grass, oat and cloves). Some farmers also feed forage maize and rice straws. On-farm concentrates are fed to grade cattle. The morning milk is usually sold to neighbors at 3,000 Fm per liter (US$ 0.46) and evening milk to traders who buy milk at the farm-gate at 2,250-2,500 Fm per liter (US$ 0.35- 0.38).

Farmer milking his cow

Besides direct sales to individual consumers and deliveries to collection centers, farmers in Madagascar can use the service of a trayeur-cycliste" ("milker cyclist") to sell their milk. These are private traders who come to the farm and milk the animals themselves. The milk of different farms is mixed without formal testing, thus raising the problem of milk contamination. Usually, only the morning milk is sold while the evening milk is reserved for the calf and for home consumption.

Milker cum trader on a bicycle

Nepal- Pokhara Valley

Two districts (Tanahun and Kaski) in Pokhara valley were chosen for the study.
The village **Belbaanjyang** is situated in the district of Tanahun, 2000 m asl with annual rainfall of about 3300 mm The average land size in this village is about 1 ha, of which a third is irrigable. The farmers are engaged in the cultivation of food crops (rice, maize, millet), cash crops (vegetables) and fruit trees. In addition to growing rice during the rainy season, most farmers rely on water from the mountains for a second crop of rice. Most farmers rear a variety of livestock, which generates about 35% of their household income: buffaloes (local and dairy breeds), cattle (pure, crossbred, local), goats and poultry. The feeding system for ruminants is based on grasses from roadsides and paddy field bunds, and tree fodders either owned or purchased.

The village of **Nirmal Pokhari** is situated in the district of Kaski, 1700 m asl with annual rainfall of about 3000 mm. The average land size in this village is about 1.2 ha, of which a third is irrigable. The farmers are engaged in the cultivation of food crops (rice, wheat, maize, millet), cash crops (vegetables and potatoes) and fruit trees. In addition to growing rice/wheat during the rainy season, most farmers rely on water from the mountains for a second crop of rice. As with Belbaanjyang village, farmers rear a variety of livestock, which generates about 45% of their household income. Stall feeding system for ruminants is based on grasses from roadsides and paddy field bunds, and tree fodders either owned or purchased, and rice straw supplemented with rice bran during the dry season.

Typical cropping system on terrace in the mid-valley of Pokhara, with rice, fodder scrubs and trees on the bunds

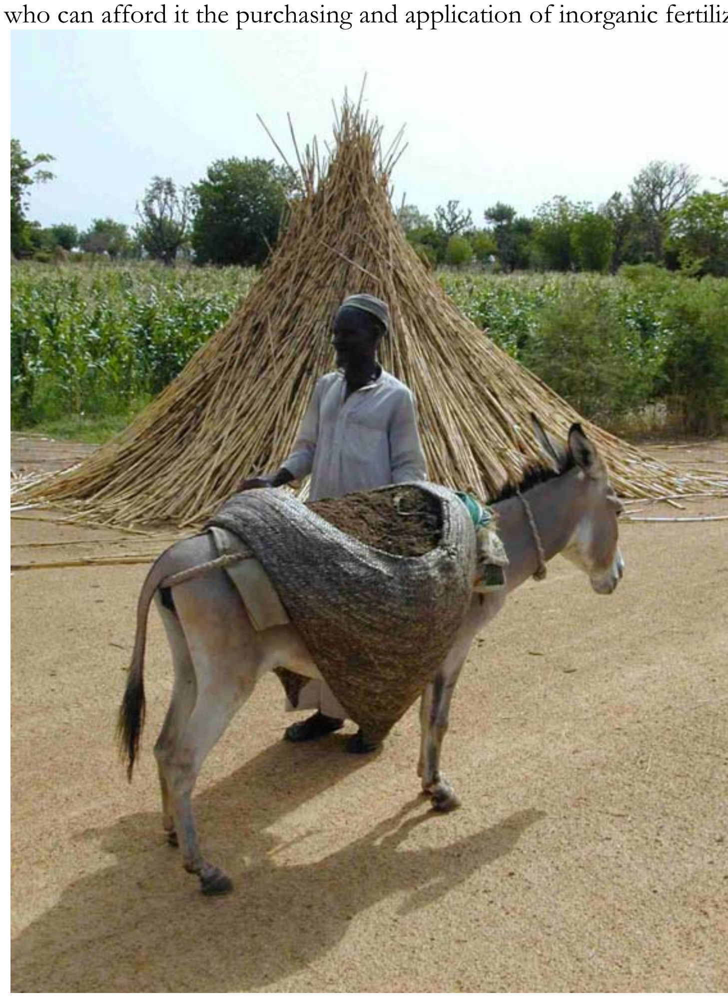
Niger

Crop and livestock activities in Niger are traditionally separated. The example of Abdullai (name changed) is revealing of the current tendency towards integration of the two activities. Abdullai is an old man, from the Peulh ethnic group. Traditionally, he keeps livestock- a large herd that needs to be sent on transhumance during the cropping season because of lack of grazing areas. When his sons take the animals on transhumance, he keeps two lactating cows near the village, to supply the villagers with milk. Unlike his ethnic group traditional habits, the family started crop farming. Abdullai gives two main reasons: there are less grazing areas in the neighbourhood and he thinks that he should take advantage of the interactions between crop and livestock activities. He now uses manure on his own fields, instead of grazing his animals on the villagers' fields. There are thus less "contrats de parcage" (manure contracts) whereby the animals belonging to the Peulhs graze on the villagers' fields. Adbullai shares his experience on livestock with the other villagers and advises them on feed and veterinary issues.

Cattle grazing on crop residues

Nigeria

Four sites were selected, two villages, Tsibiri and Turawa, in the Northern Guinea Savannah zone and two villages, Bunkure and Sule Tankarkar, in the Sudan Savannah zone. Like in Niger, farmers traditionally specialise in either crop or livestock activities, although the tendency for both groups is to integrate the two activities. Crop farmers depend heavily on manure to maintain soil fertility. Animal manure is packed and transported to the farm on a donkey, bicycle or oxen cart. This is usually done during the dry season (March to May) when the demands on labour are low. The manure is left on the field until right before the rains start, then it will get spread around. The most common practice is for a farmer to put manure on a piece of land on which he plans to cultivate tomatoes or onions. The following year he will rotate with a cereal or grain crop. This way, both years the production will benefit from the manure. Few farmers are able to purchase manure because of the lack of manure availability in the area. Other methods for enhancing soil fertility are the burning of weeds, the application of cornstalks ashes, and for those farmers who can afford it the purchasing and application of inorganic fertilizer.



Manure sale

Sri Lanka – Highlands

Nuwara Eliya district is part of the upcountry region (hill country), which is about 1000-1400 m asl with mild temperatures throughout the year (11-17 degrees Celsius). The temperature conditions favour the rearing of high-grade cattle. Nuwara Eliya, the hill capital of Sri Lanka, in addition to its reputation of superior quality high-grown tea is also famous for up-country vegetables. The high (2000–4000 mm) and rather well distributed rainfall pattern favours continuous production of vegetables.

Land terrain is steep with mountains and valleys. In general the soil type is red yellow podzolic, with an acidic pH. Major part of the upcountry region is mountainous and occupied by tea (tea estates), which is managed by management companies. The workers in the estate sector rear 1-2 high-grade cows with the main objective of selling milk, and manure is a by-product, which is usually sold to manure traders.

The village sector whose primary occupation is agriculture occupies the valleys, and the main activity is vegetable farming. Because the soils are acidic, these crop farmers heavily depend of organic manure for farming. For majority of farmers, the main objective of rearing cattle is for manure production, and the additional objective is for milk. Considerable quantities of cattle manure (own and purchased) are used for cultivation of vegetables, which is their main source of income.

Manure heaps, ready to be mixed with soil

Manure market

Sri Lanka – Mid country area

The mid-country area of Sri Lanka is characterized by the "forest garden farm" system. Nearly every house is surrounded by a garden with a large variety of perennial crops and trees (jak, kapok, coconut, coffee, cacao, clove, banana, etc.). Paddy is cultivated in the low lying areas or valleys. Annual rainfall is about 1500 -2000 mm and well distributed over the year. In general, there is a drier period from January/February-March/April and July-September. The elevation is about 500 m asl. Annual ambient temperature is between 20-28 degrees Celsius. Land terrain is undulating, and, in general, the soil type is loamy. This area is popular for spice crops like pepper, nut meg, cloves, for brewerage crops such as coffee and cacao, and for fruit crops (banana, mangoes, papaya). Apart from income from crops and livestock, many households derive income from regular off-farm employment and casual labour.

Animals are mostly kept under a cut-and-carry feeding system. A substantial part of the fodder is collected off-farm, from roadsides and other public property like railway reservation, etc..

Kandyan Forest garden farm system

Sri Lanka – Coconut plantations

Kuliyapitiya is part of the Coconut triangle, which occupies about 400,000 ha of land, covering the wet and intermediate zones of Sri Lanka. Coconut is also a crop well adapted to saline or the coastal belt.

Land terrain is flat and in general the soil type is sandy loam. The main crop grown in these areas is Coconut, which is planted 8x8 m, and there are 126 palms per ha. In young or new plantations (<5 years), there is sufficient light and there are possibilities for inter-cropping with annuals (vegetables, pine apples, passion fruit, etc.). Again the possibilities of intercropping arise when the coconut plantations are around 20-25 years of age. However only a small proportion of coconut land is intercropped with cash crops, but livestock keeping is a popular activity among smallholder coconut growers. Livestock keeping, mainly cattle and buffaloes, is part of the coconut triangle production systems particularly with smallholders. The animals are allowed to graze in the natural pastures/weeds growing in the coconut land. The comfortable micro-climate provided by the shade of coconut trees enables to keep crossbred cattle and buffaloes.

Sri Lanka- Dry Zone

Irrigated:

The area selected is Niraviya, which is a part of the Anuradhapura district and comes under the Mahaweli settlement scheme. Farmers within the district and those who lost their land due to the mahaweli river diversion project were resettled and were provided land (1.2 ha.) and money to build their houses. Irrigation water is available during the dry season, which can last up to 5-7 months. Usually farmers grow 1 crop of rice during the monsoon (rainy) season and another rice crop with irrigation. In the upland, which is about 0.4 ha, they grow vegetables, chillies and a few fruit trees, and have a stable for animals. Animals are mostly kept under a cut and carry feeding system. A substantial part of the fodder is collected off-farm, from roadsides and from paddy fields.

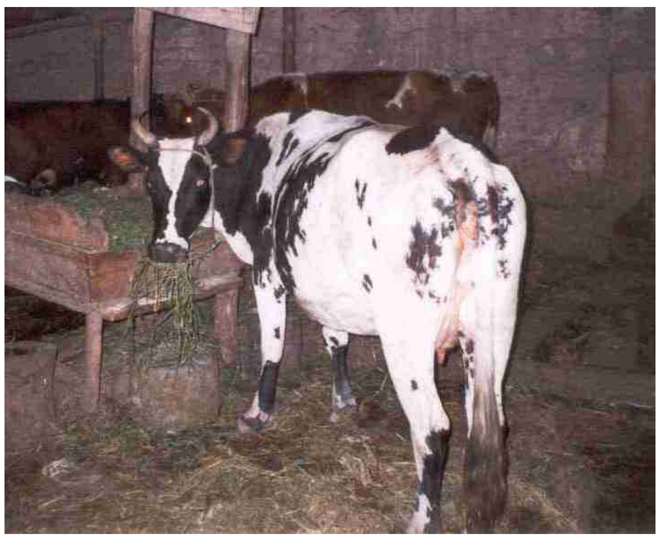
Rain-fed:

Anuradhapura district is a part of the North Central Province, and the area selected is Khatagasdigiliya, which represents a traditional system of agriculture as compared to the Mahaweli settlement scheme. The dry period can last up to 6-7 months, with little or no irrigation facilities. Many farmers own 1-5 ha of land and grow 1 crop of rice during the monsoon (rainy) season and vegetables or leave the land fallow for the rest of the season. In the homestead or upland, they grow vegetables, chillies and a few fruit trees, and have a night paddock for animals. Many farmers own large herds (25-200 heads) of indigenous/Zebu cross cattle and buffaloes that are mostly kept under a grazing management system with limited night feeding. Many farms will have a few goats and chicken. These villages have access to forest/scrub jungle areas where they allow their animals to graze.

Large cattle herd in the dry zone

Tanzania

Three areas were selected, Ilikwerei village near Arusha, Aleni Chini village in Rumbo district and Mudio village in Hai district. Due to the proximity to an important urban centre, dairying in Ilikwerei village is a profitable activity and the majority of farmers keep improved (European breed) cattle under an intensive system. On the other hand, Aleni Chini village lies on the slopes of Mount Kilimandjaro, at 55 km from Moshi on a dry-weather road. The main agricultural activity is coffee. The majority of farmers keep crossbred dairy cattle mainly for home consumption; in fact less than 10% of the cattle-keepers sell milk on a regular basis, mainly to neighbours and to the local market. Feed availability and lack of organised marketing channels are the major constraint to dairying. In contrast, dairying in Mudio village is an important agricultural activity: approximately 90% of farmers sell milk on a regular basis and market outlets are more diverse than in Rumbo district because farmers have the option to sell their production to traders. While milk traders buy milk at a lower price than individual consumers (160Tsh or US$0.20 compared to 200Tsh or US$0.25), they provide some services: loans if animals fell sick and they pay usually at the end of the month, thus allowing the farmers to save money. The other options to sell the milk production are direct sales to neighbours and sale on the local market.



Crossbred cow feeding on roadsides grass

Thailand

Bangkok Region

The PRA site selected was the village of Thung Kra Thin, which is about 80 km away from the city of Bangkok, and receives an annual rainfall of 1200-1400 mm. About 40% of the farmers grow rice (rain-fed) and baby corn (3-4 crops per year), all the households in the village have fruit trees mainly papaya, and many farmers have planted fodder (Napier) and grass (para). About 70% of the farmers rely on dairy as their main source of income, and the use of mechanical choppers to process fodder and bucket type of milking machine to milk the cows are common among them. Apart from their own feed resources, dairy farmers depend heavily on baby corn stover. Many farmers purchase baby corn stover, usually on an area basis (50-60 US$/ha), and harvesting/transportation is done by the farmer. According to the farmers, residue from 1 ha of baby corn is sufficient to feed their animals (50% of the diet) for 3-4 weeks. Farmers also purchase rice straw whenever it is available.

Chiang Mai Region

The village chosen was Bansalah in the district of Sanpatong, which is about 40 km away from the city of Chiang Mai, receiving an annual rainfall of about 900 mm.

For majority (80-90%) of farmers in this village, the main source of income is dairy activities (milk and sale of male calves). Average land holding is about 0.5 ha (range 0.2-1.2 ha). About 25% of the farmers in this village set aside about 60% of the land for growing fruit trees (langkem – small liches) intercropped with grasses (guinea ruzi, para, and Napier). One of the farmers in this village who has 200 trees of langkem intercropped with grasses claims that he obtains 150 US$/tree/year from langkem. Majority (80-90%) of the farmers rear high grade cattle and 70-80% own bucket type milking machine and mechanical feed chopper. Feeding is essentially based on planted and roadside grasses, baby corn stover, husks and commercial concentrates. Some farmers have access to waste from the aubergine (egg plant) factory, which according to them is a good source of feed.

The manure market is rather well organized: all dairy farmers sell manure either in the wet form (0.01 US$/kg) or dry form (0.02 US$/kg) to middlemen, who in turn sell it to merchants. The merchants re-dry the manure and sell it to traders who distribute to vegetable growers and fruit orchards in south of Chiang Mai.

Annex Part 3

Summary tables of the analysis

The following notes apply to the tables below:

n.i is not included and n.a. not applicable
[1] of the farm owner for Colombia
[2] market access to main urban centers is defined as access to main urban centers and/or country capital (the higher the distance farm- urban center, the lower the market access)
[3] local market access is defined as access to the road network (the higher the distance farm- road network, the lower the local market access)
[4] results of a statistical analysis (comparison of means)
[5] the combined dataset does not include the observations of Colombia. Country dummies are included among the explanatory variables.

Crop intensification

Table 72: Crop intensification- land in fallow

	Kenya	W/ Africa	Combined
Age/ experience of the head[1]	+		+
Gender of the head		n.i.	
Education of the head		-	-
Land size	+	+	+
Number of adults		+	
Ratio female adults over total adults			
Dependency ratio			-
Market access to main urban centers[2]	?	+	-
Local market access[3]			
Human population density	-	-	-
Climatic characteristics	+	-	+
Correctly classified	72.38%	87.80%	76.29%
Number of observations	2813	795	4276

Table 73: Crop intensification- fertiliser

	Kenya	W/ Africa
Age/ experience of the head[1]	-	
Gender of the head		n.i.
Education of the head	+	
Land size	-	+
Number of adults		
Ratio female adults over total adults		
Dependency ratio		+
Market access to main urban centers[2]	+	-
Local market access[3]		+
Human population density		+
Climatic characteristics	+	+
Correctly classified	63.70%	75.60%
Number of observations	2810	795

Livestock intensification

Table 74: Livestock intensification- keeping high producing cattle/ buffalo kept

	Colombia	India	Kenya	Sri Lanka
Age/ experience of the head[1]	-	+	+	
Gender of the head				
Education of the head		+	+	+
Land size			+	
Number of adults	n.i			
Ratio female adults over total adults	n.i			
Dependency ratio	n.i		-	
Access to extension services				n.i
Market access to main urban centers[2]	+	+	+	+
Local market access[3]		-	+	
Human population density		-		+
Climatic characteristics	-	+	+	-
Correctly classified	81.58%	73.10%	71.98%	67.10%
Number of observations	505	565	2298	1377

Table 75: Livestock intensification- planting fodder

	Colombia	India
Age/ experience of the head[1]		
Gender of the head	n.i	n.i
Education of the head	+	
Land size		
Number of adults	n.i	
Ratio female adults over total adults	n.i	
Dependency ratio	n.i	
Access to extension services		
Market access to main urban centers[2]	?	+
Local market access[3]		-
Human population density	+	
Climatic characteristics	+	+
Correctly classified	78.61%	76.95%
Number of observations	505	551

Table 76: Livestock intensification- fertilizer on pasture and/or forage

	Colombia	India
Age/ experience of the head[1]	-	
Gender of the head	n.i	n.i
Education of the head		
Land size		
Number of adults	n.i	-
Ratio female adults over total adults	n.i	+
Dependency ratio	n.i	
Access to extension services		-
Market access to main urban centers[2]	+	-
Local market access[3]		
Human population density	+	
Climatic characteristics	-	+
Correctly classified	71.89%	74.69%
Number of observations	498	162

Table 77: Livestock intensification- concentrates

	Kenya	Sri Lanka	W/ Africa	Combined
Age/ experience of the head[1]				
Gender of the head		+	n.i	
Education of the head	+	+	+	+
Land size			+	+
Number of adults			+	+
Ratio female adults over total adults	-			
Dependency ratio			+	
Access to extension services	-	n.i		
Market access to main urban centers[2]	+	+	+	+
Local market access[3]	+	+		
Human population density		+	n.i	+
Climatic characteristics	+			-
Correctly classified	74.29%	70.22%	68.96%	67.48%
Number of observations	1972	1115	741	4775

Crop- livestock interactions

Table 78: Crop-livestock interactions- manure

	India (stat)	Kenya	W/ Africa (stat)
Age/ experience of the head[1]	+	+	-
Gender of the head	n.i		n.i
Education of the head			+
Land size		-	-
Number of adults	+		-
Ratio female adults over total adults	+		-
Dependency ratio			
Market access to main urban centers[2]	+	+	+
Local market access[3]	-	+	-
Human population density		+	+
Climatic characteristics			+
Correctly classified	n.a.	68.68%	n.a.
Number of observations	641	2810	796

Project Outcomes

Follow up project

Another key project outcome is the new project that builds directly on the outcomes and some of the data emanating from this SLP project. The new project, a collaboration between ILRI, the Kenya Agricultural Research Institute, the Kenya Ministry of Agriculture, the University of Peradeniya (Sri Lanka), BAIF (India), and Wageningen University (The Netherlands) goes one step further than the SLP project, to conduct modeling of crop-livestock system change in a spatial and temporal context. Focus countries for this project are Kenya and India. This new project, entitles Trajectories of Change (TOC) in Crop-Livestock Systems, is supported by the Dutch Ecoregional Fund, and will run from 2003 to 2005.

Project outputs

Internal reports

I. Baltenweck and S. Staal. 2002. Conceptual framework for the transregional analysis: crop-livestock intensification and interactions. Internal paper, ILRI, Nairobi.

F. Holmann, L. Rivas, J. Carulla, L.s A. Giraldo, S. Guzman, M. Martinez, B. Rivera, A. Medina, and A. Farrow. 2003 Evolution of Milk Production Systems in the tropics of Latin America and its interrelationship with markets: An analysis of the Colombian case. Internal paper, CIAT, Colombia.

I. Baltenweck, S. Staal, M.N.M. Ibrahim, V. Manyong, T. Williams, M. Jabbar, F. Holmann, B.R. Patil, M. Herrero, P. Thornton and T. de Wolff. 2003. Level 1 report: broad dimension of crop- livestock intensification and interactions across three continents. Internal report.

I. Baltenweck, S. Staal, M.N.M. Ibrahim, V. Manyong, T. Williams, M. Jabbar, F. Holmann, B.R. Patil, M. Herrero, P. Thornton and T. de Wolff. 2003. Level 2 report: farm and spatial dimensions of crop- livestock intensification and interactions across three continents. Internal report.

Book chapters

I. Baltenweck, S. Staal and M.N.M. Ibrahim. 2003. Demand-driven crop-ruminant intensification: transregional analysis to understand patterns of change using village level data from three continents. In Demand-driven crop-ruminant intensification: transregional analysis to understand patterns of change using village level data from three continents, Nottingham University Press in press

Poster presentations

I. Baltenweck, S.J. Staal and N.M.N. Ibrahim. 2002. Demand-driven crop-ruminant intensification: transregional analysis to understand patterns of change using village level data from three continents. Contributed paper, BSAS International Conference, Merida, November 2002.

V.M. Manyong, I. Okike and T. Williams. 2003. Measuring intensification of crop-livestock integration in West African savannas: a Tobit analysis of GIS-derived village level variables and farm characteristics. Contributed Poster, 25th International Conference of IAAE, Durban, August 2003.

I. Baltenweck, S.J. Staal and N.M.N. Ibrahim. 2003. Intensification and interactions: understanding patterns of change in crop- ruminant systems using village- level data from three continents. Contributed Poster, 25th International Conference of IAAE, Durban, August 2003.

Conference papers

I. Baltenweck, S.J. Staal and N.M.N. Ibrahim. 2002. Demand-driven crop-ruminant intensification: transregional analysis to understand patterns of change using village level data from three continents. Contributed paper, BSAS International Conference, Merida, November 2002.

Book in preparation

Crop-ruminant interactions in smallholder dairy systems in the tropics: a trans-regional analysis. Eds I Baltenweck, S J Staal and P K Thornton(subject to change). See outline in annex. Publisher being sought.