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Farm intensification and drivers of technology adoption in mixed dairy-crop systems in Santa Cruz, Bolivia

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Abstract

The expanding demand for livestock products in developing countries is expected to drive changes in livestock farming systems, such as intensification and technological development. However, while large commercial farms can take advantage of these new opportunities, semi-subsistence agriculture will be the main option for many poor livestock keepers. Development pathways may depend on local and farm-specific conditions. In this paper we: i) typify mixed crop-dairy systems in Santa Cruz (Bolivia) from the point of view of their structural and socio-economical characteristics; ii) deepen the analysis of farm economics and level of intensification and iii) identify factors associated to the adoption of technologies. Three farming systems (specialized large commercial livestock farms, medium-size agricultural farms, and small semi-commercial mixed farms) were clearly differentiated in terms of structure, production orientation, economics and intensification level. The adoption of technologies (use of concentrates, pasture fertilization, cultivation of cut and carry pastures and use of dairy breeds) was related to distance from the farm to the nearest population, farmer education, farmer age and income. Policies directed towards improving market access and rural infrastructure would reduce transaction costs and increase non-farm employment opportunities. Similarly, investments in education and training would improve management capacity and technology adoption. However, current extension services do not seem to have an effect on technology adoption and, therefore, need to be improved/ better targeted.

Additional key words: agricultural policy, developing countries, farm economics, rural development, subsistence crop-livestock systems.

Resumen

Intensificación y adopción de tecnologías en sistemas de explotación mixta lechería-agricultura en Santa Cruz, Bolivia

La mayor demanda de productos ganaderos en países en vías de desarrollo puede suponer cambios en los sistemas de producción, tales como intensificación y desarrollo tecnológico. Sin embargo, si bien las explotaciones comerciales pueden aprovechar las nuevas oportunidades, la agricultura de subsistencia seguirá siendo la principal opción para muchos agricultores pobres. Las vías de evolución dependerán de condiciones locales y de las propias explotaciones. En este trabajo: i) se tipifican los sistemas de producción de Santa Cruz (Bolivia) desde el punto de vista estructural y socio-económico; ii) se profundiza en el análisis económico de las explotaciones y su nivel de intensificación y iii) se analizan los factores asociados a la adopción de tecnologías. Tres sistemas de explotación (grandes explotaciones comerciales especializadas, explotaciones de tamaño medio y orientación agrícola, y pequeñas explotaciones semi-comerciales mixtas) fueron claramente diferenciados según su estructura, orientación productiva, indicadores económicos y nivel de intensificación. La adopción de tecnologías (uso de concentrados, fertilizantes, cultivo de pastos de corte y acarreo y razas lecheras especializadas) se asoció a la distancia a la población más cercana, el nivel de educación del agricultor, su edad y nivel de ingresos. Políticas orientadas hacia la mejora del acceso a mercados pueden reducir los costos de transacción e incrementar las oportunidades de trabajo fuera de la agricultura. Asimismo, la inversión en educación y capacitación puede mejorar el manejo y la adopción de tecnologías, sin embargo, los servicios de extensión actuales no parecen estar teniendo efecto real sobre el nivel tecnológico y deberían ser mejorados.

Palabras clave adicionales: desarrollo rural, economía de la explotación, países en vías de desarrollo, políticas agrarias, sistemas agrícola-ganaderos de subsistencia.

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Introduction[1]

Many authors after Delgado *et al*. (1999) are in agreement with the prediction of a large expanding demand for livestock and livestock products in developing countries, especially in tropical and subtropical areas. This is a consequence of an increase of disposable income, human population, further urbanization and increased opportunities for trade (Blake and Nicholson, 2004; Powell *et al*., 2004). The enlarged demand for animal-based foods is certainly having implications for livestock production systems and for livestock producers in poor rural areas that are trying to adapt to the changing social, economical, market and trade circumstances (Rao *et al*., 2005). This adaptation can take place in different forms: expansion of cultivation area, intensification of systems of production and closer integration of crop and livestock (Powell *et al*., 2004).

The intensification of production and technological development has been explained as an endogenous process in response to increased population pressure according to the Boserup hypothesis (Boserup, 1965; Lele and Stone, 1989). According to this theory, expansion in the agricultural area leads the intensification/technical change to increase agricultural production per unit on land, which are consequences of population growth that results in decreased availability of land and higher demand for food (Williams *et al*., 1999). Crop-livestock interactions are also considered an evolutionary process (McIntire *et al*., 1992) mainly driven by population density.

However, not all societies experiencing population growth have shown growth in agricultural productivity, which implies that the process of intensification is far from automatic (Williams *et al*., 1999). Specific local conditions are very important in addition to other major driving factors that can determine or modulate the adoption of technologies towards more intensive farming systems (Feder *et al*., 1985).

Among the different factors found in the literature, the most frequently considered are: education and behavioural characteristics of the farmer (Nicholson *et al*., 1999; Baerenklau, 2005); information sources and presence of programmes and organizations for transference (Pender, 2004; Adegbola and Gardebroek, 2007); and access to financial and input/output markets (Nicholson *et al*., 1999; Baltenweck *et al*., 2003), which is closely related to farm location (Staal *et al*., 2002).

Although the «livestock revolution» (Delgado *et al*., 1999) could mean income growth opportunities for many agricultural producers in developing countries, a key question is whether poor smallholders will be able to seize these opportunities. Rao *et al*. (2005) suggest that we are witnessing a dualistic mode of development; a fast growing commercial sector located close to concentrated demand centres, while semi-commercial/subsistence agriculture continues to be the only opportunity for many poor livestock keepers. Steinfeld (2003) points out that there is a possibility of concentrated livestock production and processing in large-scale integrated commercial companies, which would likely displace small-scale livestock farmers and exacerbate rural poverty. According to Pica-Ciamarra (2005), pan-regional policies undifferentiated by household typologies have failed to translate the demand-driven opportunities into incentives for small and local meat/milk producers. For this reason, the livestock revolution has been a missing opportunity for most poor smallholders in the last two decades.

Many forms of agricultural production co-exist in developing countries. This heterogeneity points to the need for a characterization of farming systems that can typify similar groups for the purpose of identifying opportunities and constraints for development (Williams *et al*., 1999; Somda *et al*., 2005). In the Bolivian Department of Santa Cruz, there is a higher political and economic status associated with large beef and milk producers (Fairfield, 2004). The producers have intensified the production systems in recent decades, but small subsistence mixed crop-livestock farms are also very important (Solano *et al*., 2000). In this region, the demand for milk and dairy products like cheese and yoghourt is growing fast (Rushton *et al*., 2004), but small milk producers do not normally have access to formal markets and tend to sell their products directly to the final consumers. For these farmers, the importance of animal husbandry on the family economy and its subsistence is essential for cash-flow generation, saving, risk copping, and to optimally use resources, which otherwise would not be used (Payne, 1990; Preston and Murgueitio, 1994).

This paper focuses on specialized dairy and mixed crop-dairy production systems. The general aim is to

[1] Abbreviations used: FAO (Food and Agriculture Organization), GDP (gross domestic product), GM (gross margin), LU (livestock units), MCA (multiple correspondence analysis), OR (odd ratio), Q (quantiles), WU (working unit).

derive relevant information on systems diversity, level of intensification and drivers of technology adoption in dairy production, which could be useful when designing and implementing more focused development and agricultural policies in the area of the study. To accomplish this, we first established a household typology in the tropical area of Santa Cruz by accounting for the social, economic and structural characteristics of the farms. Second, an in depth analysis of the economic performance was conducted that included household economic margins and sources/structure of incomes and costs, paying special attention to the relative importance of livestock and agriculture. Finally, we analysed the level of economic intensification of farming systems and explored the main factors that can influence the adoption of certain dairy production technologies by farmers.

Methodology

Area of study

The area of study is located in the tropical Department of Santa Cruz, Bolivia, which is the largest department of the country: 370,621 km^2 (24.7% of total area of Bolivia). Four different areas of Santa Cruz were considered: *Zona de Expansion, Area Integrada, San Javier* and *Sara-Ichilo.* These areas amount to 30,828 km^2 (8.32% of Santa Cruz) and are the main milk producing regions of the department (MACA, 2005).

In 2004, Santa Cruz produced 43.4% of the agricultural Gross Domestic Product (GDP) of the country. Agriculture is the main sector of the Santa Cruz economy; the agricultural activities were industrial crops like the soya bean (*Glycine max* L. Merr.), sugar cane (*Saccharum officinarum* L.), sunflower (*Helianthus annuus* L.) (47.3% of agricultural GDP of Santa Cruz) and non-industrial crops, which mainly include cereals such as rice (*Oryza sativa* L.) and maize (*Zea mays* L.) (29.7%) (INE, 2005). Agricultural production is largely dominated by large intensive commercial systems. The expansion of cultivation area, transformed from forest and other natural areas, has been, and continues to be, very large (MACA, 2005), due to access to international markets and strong prices.

Livestock farming produces 15.8% of the total agricultural GDP for Santa Cruz, with beef (6.5%) and milk production (4.9%) being the two most important activities (INE, 2005). Santa Cruz accounts for 28.8% of the total bovine population according to the census in Bolivia and produces 27.9% of the national beef production (MACA, 2005). Milk production in Bolivia is expanding rapidly (25.5% growth from 1997 to 2003) (MACA, 2004), although it is one of the lowest amounts in the region (2.7% of the total production of the Andean Nations Community). Demand for milk and milk products is also growing fast; nevertheless, average milk consumption is only 36 L per capita (well below the 170 L recommended by FAO (PRODISA, 2002), although this figure might not take into account milk products provided by the informal sector (Rushton *et al*., 2004). Santa Cruz is the largest overall producer, with 61.9% of the national production.

Livestock systems are generally extensive pastoral systems, characterised by low inputs (0.9 US$ kg^{-1} beef; 0.07 to 0.13 US$ L^{-1} of milk) and low productivity (150-200 kg of beef ha^{-1}; 3.5-8.6 L head^{-1} day^{-1}) (PRODISA, 2002). In Santa Cruz, small-scale dual purpose farms represent 53% of the total number of dairy farms, whose production is lower than 50 L of milk day^{-1} (PRODISA, 2002).

Survey

Data collection was carried out through a structured survey of cattle or mixed crop-livestock farmers. The total number of cattle farms in the area of study is approximately 7,400 (FEGASACRUZ, 1994). A random sample of 418 farms, stratified by district, was used. The target population consisted of farmers that had dairy activities and therefore, pure beef farms (6.2%) were eliminated from the analysis. Incomplete or non-reliable questionnaires (17.5%) were also discarded. The final size of the sample was 319 farms (4.3% of the population, 5.5% error, 95% confidence interval).

A questionnaire was designed for data collection. The survey was carried out between March and July 1999, using direct structured interviews with farmers. The questionnaire referred to a period of time of one year and was designed to collect quantitative and qualitative information on: 1) family and education level, 2) labour availability and work distribution, 3) crops, pastures and other resources, 4) herd structure, 5) facilities and machinery, 6) decision making and private technical services, 7) pasture and nutrition management, 8) reproductive and milking management, 9) health management and pathology, 10) economic and physical inputs and outputs.

Data analysis and characterisation of systems

A high proportion of collected data was qualitative. Therefore, a methodology able to deal with both qualitative and quantitative data was used. Multiple correspondence analysis (MCA) is a multivariate statistical method that allows for analysing large qualitative data matrixes. Like in other factorial methods, the purpose of MCA is to derive a small number of combinations (dimensions or factors) of a set of variables that retain as much of the information in the original variables as possible (SAS, 1994).

Variables referring to farm structure, orientation of production and productivity, farmer characteristics, technical support and economical performance were considered (Table 1). It is hypothesised that these variables could summarize adequately the diversity of farming situations and are determinants of the likelihood for farmers to intensify production. A correlation analysis was done to check the level of association between variables. Only non-collinear variables were used for multivariate analysis.

Quantitative variables were analysed individually to check if they had a normal distribution. The normal variables were then divided into three classes using the quantile (Q) position (Q1 = 25% lower observations; Q2 = 50% intermediate observations; Q3 = 25% higher observations) to be introduced in MCA. This method of classification had the advantage that the definition of the classes was based on objective criteria, rather than on fixed thresholds (Solano *et al*., 2000).

A cluster analysis, using the main factors obtained in the MCA, was carried out to classify the farms. The centroid distance was chosen as method of aggregation because it uses the same metrics as MCA, i.e. Euclidean distances. The number of groups was selected on the basis of the R^2, a strong increment in the cubic criterion of clustering and pseudoF value and strong decrement in pseudoT value (SAS, 1994).

Economics, intensification and technology adoption

Gross margins and enterprise budgets were calculated considering variable costs: feeding costs, non-permanent labour, cropping costs (seeds, pesticides, etc.), cost of technical advise, sanitary costs and other costs; and fixed costs: animal replacement costs[2], permanent labour, maintenance costs (facilities and machinery) and financial costs from credits. Self-consumption and re-utilization of outputs could not be considered as no data was available.

In economic theory, intensification means the maximization of productivity of the binding production factor, which normally means an increase of consumption of the other factors (Tirel, 1991). In developing countries, the scarcest factor is normally the land which leads to the approach to measure the level of intensification in this work.

A logistic regression model was utilized to identify drivers of adoption for a number of technologies in the total sample and by group. The technologies were chosen because, in general, they imply higher use of external inputs, higher unitary costs and productivity. Therefore, these technologies can be considered as a proxy for intensification, with the objective of identifying the drivers (as described below) that would facilitate their adoption and lead farming systems towards further production intensification.

Logistic regression analysis has been often used to investigate the relationships between the response probability and a set of explanatory variables (SAS, 1994). In this case, farmer *i* adopts a certain technology if the derived benefits B_i are higher that a certain threshold T (Staal *et al*., 2002):

$Y_i = 1$ if $B_i > T \Rightarrow X_i\beta + \alpha_i > T$ farmer *i* decides to adopt
$Y_i = 0$ if $B_i < T \Rightarrow X_i\beta + \alpha_i < T$ farmer *i* decides not to adopt

where X_i is a vector of explanatory variables, β is a vector of coefficients to be estimated and α_i is an independent, farm specific, *ex ante* stock. The model has the form:

$$Y_i = x_i\beta + \alpha_I$$

where x_i is a vector of explanatory variables derived from the survey, β are the corresponding regression coefficients and α_I are intercept parameters.

The binary response variables analysed were: *use of concentrates to feed animals*; *use of fertilizers on pastures*; *cultivation of pastures for cut and carry*; *and use of specialised dairy breeds as main breed in the*

[2] Replacement costs are considered as fixed costs due to the fact that breeding livestock is a fixed asset and in many occasions the purchase of breeding animals constituted an investment.

Table 1. Variables and classes of structure, production, social characteristics, technical advice and economic performance of the farms

Variable	Definition	Classes	Code	No. observations
Agricultural land	Hectares of land used for agricultural and livestock purposes	< 20 ha 20-90 ha > 90 ha	FarmS FarmM FarmL	83 154 82
Pasture	Area of pastures expressed as a percentage of agricultural land	< 50% 50-90% > 90%	PastureLw PastureI PastureH	98 98 123
Herd	Livestcok units (LU): (lactating cows 1.2) + (dry cows) + + (culling cows) + (preweaning calves 0.2) + (1-2 yr old heifers 0.4) + (2-3 yr old heifers 0.8) + (pregnant heifers) + (1-2 yr old steers 0.6) + (2-3 yr old steers) + + (bulls 1.2)	< 20 LU 20-64.7 LU > 64.7 LU	HerdS HerdM HerdL	78 150 91
Labour	No. of working units (WU) from family and hired	< 3 WU 3-6 WU > 6 WU	LabourS LabourM LabourL	75 155 89
Machinery	No. of machines (tractors, cultivators, seed drills, etc.)	0 machines ≤ 5 machines > 5 machines	MachiN MachiLw MachiL	114 109 96
System	Orientation of production in terms of relative importance of milk, meat and agriculture income in the total income of the farm	Agriculture-dairy Agriculture-dual purpose Livestock-dairy Livestock-dual purpose	AgrDairy AgrDualP LivDairy LivDualP	33 60 72 154
Milk production	Milk yield (L) per milking cow of the farm per year	< 776.5 L 776.5-3212 L > 3212 L	MilkLw MilkI MilkH	79 160 80
Farmer education	Level of education	Illiterate Primary/secondary school Technical/university	EducLw EducI EducH	19 246 54
Technical advice	Score of technical advice services used by farmers (animal health, reproduction, nutrition, pastures and crops adviser) with a value of one each	0 ≤ 2.5 > 2.5	TechAdN TechAdLw TechAdH	109 184 26
Gross margin	Agricultural and livestock outputs minus variables costs (as defined in text)	< 2,137.4 US$ 2,137.4-16,905.0 US$ > 16,905.0 US$	GroMargLw GroMargI GroMargH	79 156 84

herd. These technologies could be clearly identified with a pathway of dairy intensification. The explanatory variables were selected based on previous studies on factors influencing technology adoption and development pathways (Nicholson *et al*., 1999; Staal *et al*., 2002, Baltenweck *et al*., 2003; Pender, 2004). These variables included: *distance of farm* to the nearest populated area as indicator of location and access to markets; *level of education* of farmer and *age* of farmer representing characteristics of the household head in relation to management capacity; *size of farm land* and *herd size* because it was considered that technological development could be scale dependent; *level of technical assistance* because it was considered that information and advise can facilitate technology adoption; and finally *family income* considering that economic position of the household influences the possibility of technological investments.

Results

Characterisation of farming systems

The cluster analysis carried out on the main factors obtained from the multiple correspondence analysis (MCA) clearly identified three groups of farms. The main characteristics of each cluster are quantified in Table 2.

Cluster 1 was made up of 98 farms defined as *large commercial livestock farms*. They were the biggest farms, both in terms of animals (172 bovine LU[3]) and land (207 ha of agricultural land), and were dairy oriented. Most of the land was dedicated to pastures (90% of agricultural land), especially cultivated pastures. These farms had a high availability of forestland, which would hypothetically allow them to further increase the cultivation area. They also had a high availability of labour and machinery in the farm; farmers had higher level of education (technical education-university) and private technical support. This group had the highest rate of off-farm activity and, in some cases, farming was only a secondary activity of the household. Milk production per milking cow was the highest (3,369 L cow^{-1} yr^{-1}) of the groups analysed, due to higher use of concentrates (higher feeding costs, see below).

Cluster 2 was made up of 101 farms defined as *medium-size agricultural farms*. These were agricultural farms in which 68% of the land was dedicated to industrial crops, while dairying was a secondary activity. The land area and the herd size were intermediate (44 bovine LU and 91 ha of agricultural land, respectively). Pastures were only 32% of agricultural land, but most of them were cultivated. They had very small areas of forest, suggesting a more expansive use of land. They also had a high availability of labour (family labour, as will be seen below) and machinery but, contrarily to group 1, farmers had a very low level of education (illiterate-primary school), technical support, and pluriactivity. Milk production was intermediate (2,505 L cow^{-1} yr^{-1}).

Cluster 3 was made up of 120 farms defined as *small semi-commercial mixed farms*. These were subsistence farms with diversified agriculture-milk-meat production. They were very small farms (25 ha) and had a small number of bovines (27 LU). A great extension of the land was dedicated to pastures (79%), but in this case, natural pastures were nearly as important as cultivated pastures. Farms had a potential for increasing agricultural

Table 2. Mean values and coefficient of variation (CV) of the variables used in the multiple correspondence analysis (MCA) and other variables describing the groups

Variables MCA[d]	Group 1[a]		Group 2[b]		Group 3[c]	
	Mean	CV	Mean	CV	Mean	CV
Herd (LU)	172.75	1.14	43.73	1.05	26.84	0.75
Agricultural land (ha)	207.04	1.32	91.12	1.16	25.40	1.10
Pasture (% of land)	90.57	0.15	32.48	0.74	79.01	0.30
Labour (no. of workers)	5.69	0.80	5.59	0.65	3.36	0.52
Machinery (score)	4.01	0.84	5.61	0.55	0.70	2.07
Farmer education (score)	3.68	0.40	2.03	0.33	2.09	0.30
Technical advice (score)	1.42	0.93	0.62	0.93	0.84	1.17
Milk production (L dairy cow^{-1} yr^{-1})	3,369.38	0.83	2,505.32	0.62	1,382.06	0.99
Gross margin (US$)	30,893.67	1.38	16,656.27	2.03	3,642.09	2.16
Other variables						
Crops (ha)	23.6	2.8	66.9	1.4	5.0	1.4
Cultivated pastures (ha)	147.5	1.6	18.7	1.0	11.9	1.1
Natural pastures (ha)	36.0	2.7	5.5	4.0	8.5	2.8
Forest (ha)	124.48	2.36	14.01	2.95	21.89	3.01
Pluriactivity[e]	8.52	1.19	4.08	1.87	7.8	1.57

[a] N = 98. [b] N = 101. [c] N = 120. [d] Variable «System» is qualitative and therefore not represented. [e] Expressed in number of months of non-farm and off-farm work by all members of the family.

[3] See Table 1 for calculation of LU.

land due to the relative importance of forestland. They had little availability of labour, but a high level of pluriactivity. Machinery was nearly null. As in the previous group, farmers typically had a low level of education (illiterate-primary school) and technical support. Milk production per cow was very low (1,382 L cow^{-1} yr^{-1}), which indicated the use of low quality forages and little use of concentrates.

Farm economics and intensification level

The economic results and the structure of income and costs were very different in the groups of farms (Table 3, Fig. 1). As would be expected, economic dimension was related to the physical size of the farms, i.e. number of hectares of agricultural land and number of animals. Group 1 obtained substantially higher income and GM than group 2 and around 10 times that of group 3. In this group, if we apply the indicator of poverty for tropical regions of Bolivia given by the International Fund for Agricultural Development (2,570 US$ of income per year per household) 35.8% of farmers in group 3 would be in a situation of poverty. This figure would increase to 68.3% if enterprise budget was considered instead of income.

The sources of agricultural income and structure of costs were very different between groups. In the Group of *large commercial livestock farms*, 91.4% of the income came from livestock, and milk was the main product, as 61.4% of total income came from milk sales. Beef sales represented 26.9% of income. Agriculture had little relevance (8.6% of income). This group had the highest proportion of fixed costs (47.4%), of which permanent salaried labour was the most significant one (27% of total costs), which is the main reason for relatively low margins among this group. Feeding costs were also comparatively important (47.7% of variable costs), related to a main orientation towards milk production. As would be expected, this group had the lowest proportion of cropping costs due to the little relevance of agriculture.

Table 3. Mean values and coefficient of variation (CV) of the variables: gross margin, net margin, incomes and costs, per group

Variable	Group 1[a]		Group 2[b]		Group 3[c]	
	Mean	CV	Mean	CV	Mean	CV
Total income (US$)	52,011.6	1.2	37,041.4	1.7	5,254.3	1.5
Income livestock (%)[d]	91.4	0.2	40.1	0.7	83.2	0.3
— Income milk (%)	61.4	0.5	29.9	0.8	50.0	0.7
— Income beef (%)	26.9	1.0	7.4	1.4	29.1	1.1
— Income small liv. (%)	3.0	3.7	2.8	1.7	4.15	3.4
Income agriculture (%)[d]	8.6	2.1	59.9	0.5	13.4	1.8
— Income soya bean (%)	0.2	6.0	39.4	0.9	1.9	5.6
— Income sugar cane (%)	6.5	2.3	8.2	2.7	0.3	11.0
— Income rice (%)	1.1	6.3	6.5	3.0	6.3	2.7
Total costs (US$)[e]	40,017.4	1.6	25,107.3	2.1	2,784.6	1.0
— Replacement costs (%)	14.7	1.4	2.6	2.6	14.7	1.8
— Feeding costs (%)	25.1	0.9	8.0	1.4	16.7	1.4
— Permanent labour (%)	27.0	0.7	6.4	2.3	16.5	1.7
— Occasional labour (%)	7.5	1.6	5.3	2.0	15.3	1.4
— Cropping costs (%)	7.2	1.8	45.5	0.5	18.2	1.4
Variable costs (%)[f]	52.6	0.4	82.3	0.3	57.9	0.6
Fixed costs (%)[g]	47.4	0.5	17.7	1.2	42.1	0.8
Gross margin (US$)	30,893.7	1.4	16,656.3	2.0	3,642.1	2.2
Net margin (US$)	11,994.2	3.3	11,934.0	2.6	2,469.7	3.2

[a] N = 98. [b] N = 101. N = 120. [d] Only the most important animal products and crops are considered in the table. [e] Only the most important costs are considered in the table. [f] Variable costs were: feeding costs, occasional labour, cropping costs, cost of technical advise, sanitary costs and other costs. [g] Fixed costs were: animal replacement costs, permanent labour, maintenance costs (facilities and machinery) and credits.

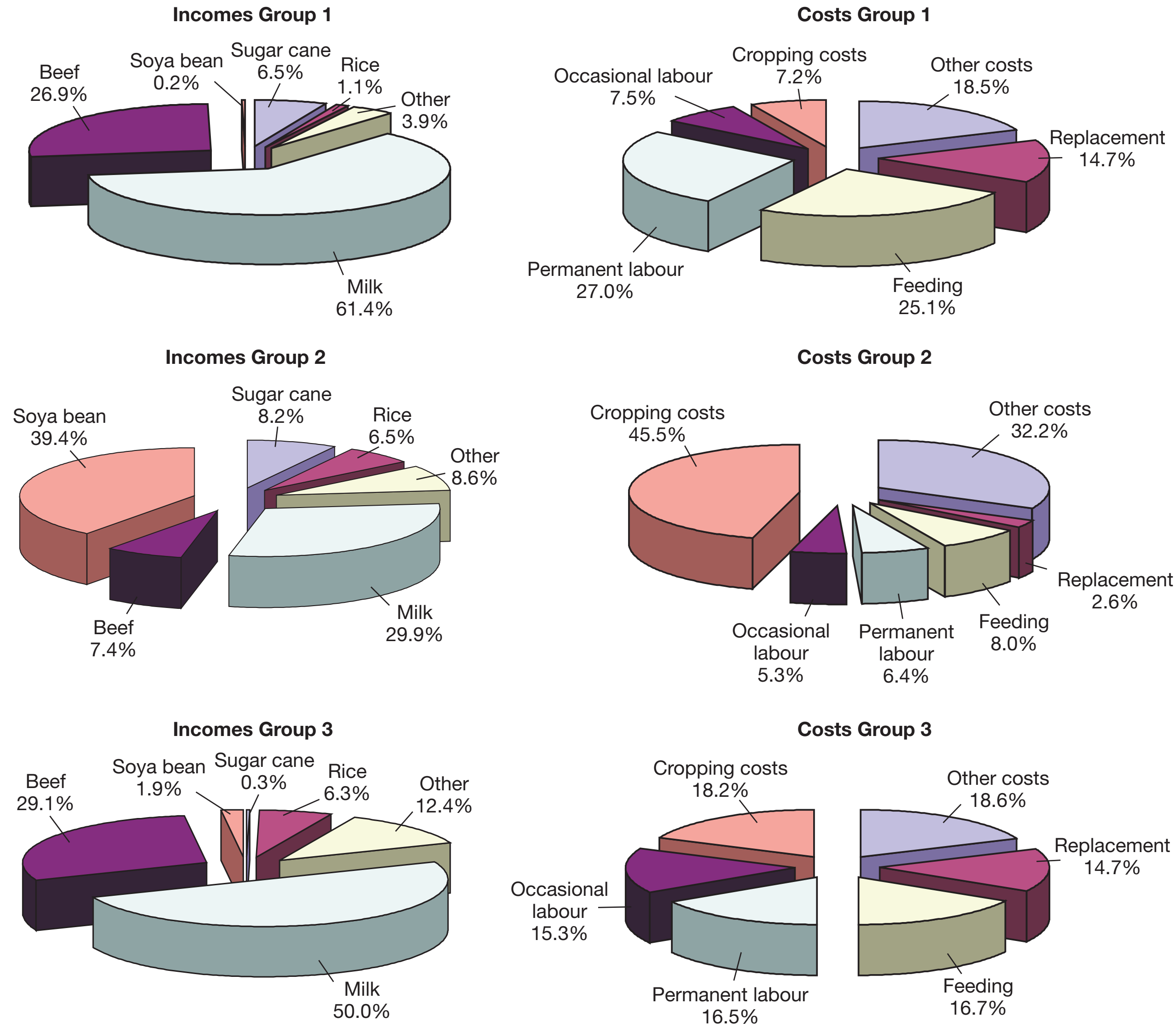

Figure 1. Sources on income and costs per group.

By contrast, in the Group 2 of *medium-size agricultural farms*, most of the income came from agriculture (59.9%), and more specifically from industrial crops such as soya bean (39.4%). Nevertheless, milk sales were still important, as they contributed with 29.9% of total income.

This group had a low proportion of fixed costs (18%), meaning the enterprise budget obtained was close to the gross margin. Cropping costs were the highest, both in-group and between-groups (45.5%). Both permanent and non-permanent labour costs were very low, which meant that hired labour was unusual. Nevertheless, availability of labour was high because these farms used the family labour force (very low level of off-farm work). Feeding costs were also small due to the agricultural orientation of these farms and because the feedstuffs used came mainly from on-farm agricultural production.

In the *small semi-commercial mixed farms* (Group 3), the main income came from livestock farming (83.2%). Milk was the main product, as it contributed to 50% of total income. Incomes derived from small livestock were more important than in the other groups, but still very low, which suggested an on-farm consumption of these products. Although 21% of land was dedicated to crops and cropping costs were very important (see below), agriculture only contributed to 13.4% of the total income, with rice being the most important cash-crop.

These farms had very low total costs, but a high proportion of fixed costs (40%). Off-farm purchases of animals were frequent, but in this case, it should be considered as an investment strategy when there is a cash surplus. Feeding costs were low, but comparatively important (28.8% of variable costs), related to the scarce availability of forages in the dry season, which forced farmers to buy feedstuffs. Hired labour cost was the highest in this group (31.8% of total costs); especially relevant was the cost of non-permanent labour, which was related to higher necessities of labour at sowing and harvest time, and therefore should be assigned to agriculture rather than livestock farming. Cropping costs were the highest in this group (18.2%).

When economic indicators were calculated per hectare it is possible to observe differences in the level of intensification among groups (Table 4).

Group 2 showed, in general, the highest intensification scores. This group obtained higher economic margins per hectare, partly due to lower proportion of fixed costs (low hired labour costs). It also showed the highest total unitary income (\$406.5 ha^{-1}). Total costs per hectare were also the highest in this group, despite the fact the cost of family labour was not accounted for.

Group 1 showed lower unitary margins, incomes and costs per hectare than the previous group, which would indicate a lower level of intensification. Nevertheless, agricultural income and costs were very similar in groups 1 and 2, which could be explained by the similar productivity of the more relevant industrial crops in these groups (sugar cane and soya bean). Due to the great importance of fixed labour costs the net margin obtained per hectare was comparatively very low in this group of farms.

Table 4. Indicators of land economic intensification and labour productivity for each group

Indicator	Group 1	Group 2	Group 3
Gross margin ha^{-1} agricultural land	149.2	182.8	143.5
Net margin ha^{-1} agricultural land	57.9	131.0	97.3
Total income ha^{-1} agricultural land	251.2	406.5	207.1
Agriculture income ha^{-1} crops	426.7	409.9	142.8
Livestock income ha^{-1} pastures	228.7	397.0	222.7
Milk income ha^{-1} pastures	144.3	301.0	136.8
Beef income ha^{-1} pastures	77.7	68.3	49.0
Total costs ha^{-1} agricultural land	193.3	275.5	109.7
Cropping costs ha^{-1} crops	176.8	165.7	108.8
Total Income WU^{-1}	9,140.9	6,626.4	1,563.8
Gross Margin WU^{-1}	5,429.5	2,979.7	1,084.0
Net Margin WU^{-1}	2,108.0	2,134.9	735.0

Group 3 showed the lowest level of intensification in land use. Unitary income from agriculture was very small (\$142.8 ha^{-1}), especially taking into account the relatively high cropping cost (\$108.8 ha^{-1}), which would indicate a major inclination towards the cultivation of staple food crops, as discussed below.

Labour productivity decreased from group 1 to group 3 when expressed in terms of total income or gross margin per working unit (WU), but when fixed costs were considered (net margin WU^{-1}) group 2 showed the highest labour productivity (Table 4).

Technology adoption

In order to identify the main factors or drivers that determined the adoption of certain dairy technologies by farmers, a Logit analysis was carried out both for the whole sample and for each farming system (Table 5).

Globally, the use of concentrates to supplement milking cows and fatten young animals was related, above all, to a higher level of farmer education ($P = 0.01$; odd ratio = 1.54), and also younger age ($P = 0.05$), higher incomes ($P = 0.01$) and smaller land size ($P = 0.1$). Younger educated farmers seemed to be more receptive to use concentrates, which could indicate better management capacity. But structural and economic variables had importance also, as smaller cultivation area and cash availability were also related to the use of concentrates. Some differences were found between groups; for group 1, the most significant factor explaining the use of concentrates was income, although level of education was also significant. Alternatively group 3 drivers were only related to farmer characteristics: education and age. Education had the highest odd ratio (OR = 2.49), which indicated that in this group the probability of using concentrates would increase 2.49 times if level of education increased 1 unit. For group 2 no significant factors were obtained, which may be due to the fact that in these farms animal feeding was mainly based on on-farm feedstuffs.

Very few farms in the global sample and none in group 2 used fertilizer in pastures and therefore no clear pattern was found for this variable. Higher incomes for group 1 and larger land sizes for group 3 showed some significance ($P = 0.1$) though.

The cultivation of cut-and-carry pastures was related to short distances of farms to the nearest population

Table 5. Factors influencing the use of concentrates, fertilizers in pastures, cut and carry pastures and dairy breeds

Variable	Total		Group 1		Group 2		Group 3	
	Estimate	Odds ratio[a]	Estimate	Odds ratio[a]	Estimate	Odds ratio[a]	Estimate	Odds ratio[a]
Use of concentrates								
Distance to population								
Farmer education	**0.432*** **	1.54	**0.328***	1.39			**0.913****	2.49
Farmer age	**–0.016****	0.85					**–0.023***	0.79
Land size	**–0.001***	0.98						
Herd size								
Technical assistance								
Income	**1.9E-5*****	1.02	**4.9E-5*****	1.05				
% Concordant[b]	*74.3*		*84.8*		*59.0*		*68.5*	
–2 Log L[c]	*385.18*		*76.91*		*121.73*		*146.2*	
Use of fertilizer in pastures[d]								
Distance to population					—	—		
Farmer education					—	—		
Farmer age					—	—		
Land size					—	—	**0.007***	1.07
Herd size					—	—		
Technical assistance					—	—		
Income			**1.7E-5***	1.02	—			
% Concordant[b]	*68.1*		*74.3*		—		*63.5*	
–2 Log L[c]	*131.03*		*60.00*		—		*48.30*	
Use of pastures for cut and carry								
Distance to population	**–0.054*****	0.59			**–0.225****	0.11		
Farmer education	**0.540*****	1.72	**0.273***	1.31				
Farmer age					**0.120****	3.33		
Land size	**–0.002****	0.98	**–0.002***	0.99	**–0.047****	0.62		
Herd size					**0.088****	2.40		
Technical assistance								
Income			**1.3E-5****	1.01				
% Concordant[b]	*80.6*		*72.9*		*97.6*		*70.1*	
–2 Log L[c]	*283.44*		*118.16*		*23.42*		*95.47*	
Use of specialized dairy breeds								
Distance to population	**–0.057*****	1.77			**–0.075*****	2.11	**–0.064*****	1.89
Farmer education	**0.257****	1.29						
Farmer age	**–0.023*****	0.79	**–0.026***	0.77				
Land size								
Herd size					**–0.033****	0.72		
Technical assistance								
Income	**6.09E-6****	1.01						
% Concordant[b]	*76.2*		*68.1*		*89.0*		*71.5*	
–2 Log L[c]	*362.67*		*122.13*		*80.41*		*114.21*	

[a] Base change: distance to population 10; farmer education 1; farmer age 10; land size 10; herd size 10; technical assistance 1; income 1,000. [b] Indicates the predictive ability of the model. [c] Fitting ability when comparing different models with the same data, smaller values indicate better fitting. [d] All observations have the same response in group 2 as no farmers used fertilizers. Pr > Chi^2: * Significant at 0.1 probability level. ** Significant at 0.05 probability level. *** Significant at 0.01 probability level. Non-significant estimates are not presented for clarity purposes.

($P = 0.01$), leading to better access to markets, higher levels of education of farmers ($P = 0.01$, with the highest OR = 1.72), and land size ($P = 0.05$). The smaller the cultivation area of crops, the higher necessity of forage intensification. For group 1, distance was not significant but income had some relevance. For group 2, distance and age (OR = 3.33), together with smaller land sizes and larger herd sizes (OR = 2.40), showed significant effects. This group fed animals mainly with on-farm feedstuffs and therefore larger herds and lower land availability was related to the higher cultivation of cut-and-carry pasture. Farmer age, contrarily to the use of concentrates and specialized dairy breeds in the general sample, was positively related to the cultivation of cut and curry pastures (see discussion).

As for cultivation of cut-and-carry pastures, the use of specialized dairy cows as main cattle breed in the global sample was related to shorter distances of farms to population centres ($P = 0.01$; OR = 1.77), and also higher levels of education of farmers ($P = 0.05$; OR = 1.29), younger age ($P = 0.01$) and higher incomes ($P = 0.05$). Again, farms located close to markets, with higher availability of cash and good management capacity of farmers were those that predominantly had adopted this technology. In group 2, small herd size was also linked to larger use of specialized dairy breeds.

In Figure 2 two indicators of farming intensification (total cost per hectare and total income per hectare) were plotted against two driving factors analysed above, distance to markets and education level of the farmer. In general, there is a clear relationship between shorter distances to populations, and therefore easier access to inputs and products markets, and higher economic intensification ratios. Similarly, it can be observed that the higher the education of the farmer, the higher the intensification level of the farm.

Finally, pluriactivity (off-farm activities, i.e. wage-employment in agriculture, plus non-farm activities, i.e work outside agriculture) of the family was plotted against distance to populated areas (Fig. 3) showing that the level of pluriactivity was clearly related to households located closer to urban areas.

Discussion

The coexistence of many different livestock production systems has been described at a global scale before (e.g. Seré and Steinfeld, 1996; Pender, 2004). This study has demonstrated a great diversity of mixed crop-livestock systems in Santa Cruz, both from the productive, social, economic and technological points of view. It is argued that this heterogeneity of farming systems has implications in the development pathways, intensification level, possibilities of technology adoption and, eventually, the possibilities to take advantage of the expanding demand of animal products.

There is a group of large commercial livestock farms that can be considered extensive in terms of land use (large pastoral areas with low stocking rates) and also in economic terms (low-medium incomes and costs per hectare). The high availability of agricultural land allowed these farms to operate obtaining low margins per unit of land. These systems seem to have capacity to evolve and adapt to new socio-economical and market circumstances, depending on relative changes in prices of milk, feedstuffs and labour (Baltenweck *et al.*, 2003). For example, a scenario with an increasing milk price and constant concentrates price could raise the intensification of dairy production if low prices for labour remained. This could prevent further expansion of cultivation, ploughing the forest area still available in this group, although the effects of prices on incentives to conserve land are rather ambiguous and can vary depending on site-specific conditions (Pagiola, 1996).

Mixed crop/livestock systems obtained the highest productivity per unit of land and labour, due to the low labour cost and utilization of family labour. Milk production was a complementary income with variable importance. These systems were market oriented and substantially more intensive in land use (little forest area left) and in economic terms (high input systems). Although intensified production of high-value crops can lead to a reduction of deforestation processes, many studies also argue that profitable production of such crops may accentuate the displacement of forest, especially when demand for agricultural/livestock products and input constraints are not binding (Algensen and Kaimowitz, 2001).

Semi-commercial subsistence farms obtained much lower incomes and economic margins, expressed per farm or per hectare. Therefore, they could be considered very extensive in terms of economic returns obtained and inputs used. Although very diversified, they might be very sensitive to adverse economic and environmental situations, due to the small physical dimension and the lack of economic resources to intensify farming activities. Both livestock and agricultural activities played very important but different roles: livestock products were used to generate regular cash-flow (milk) and capital

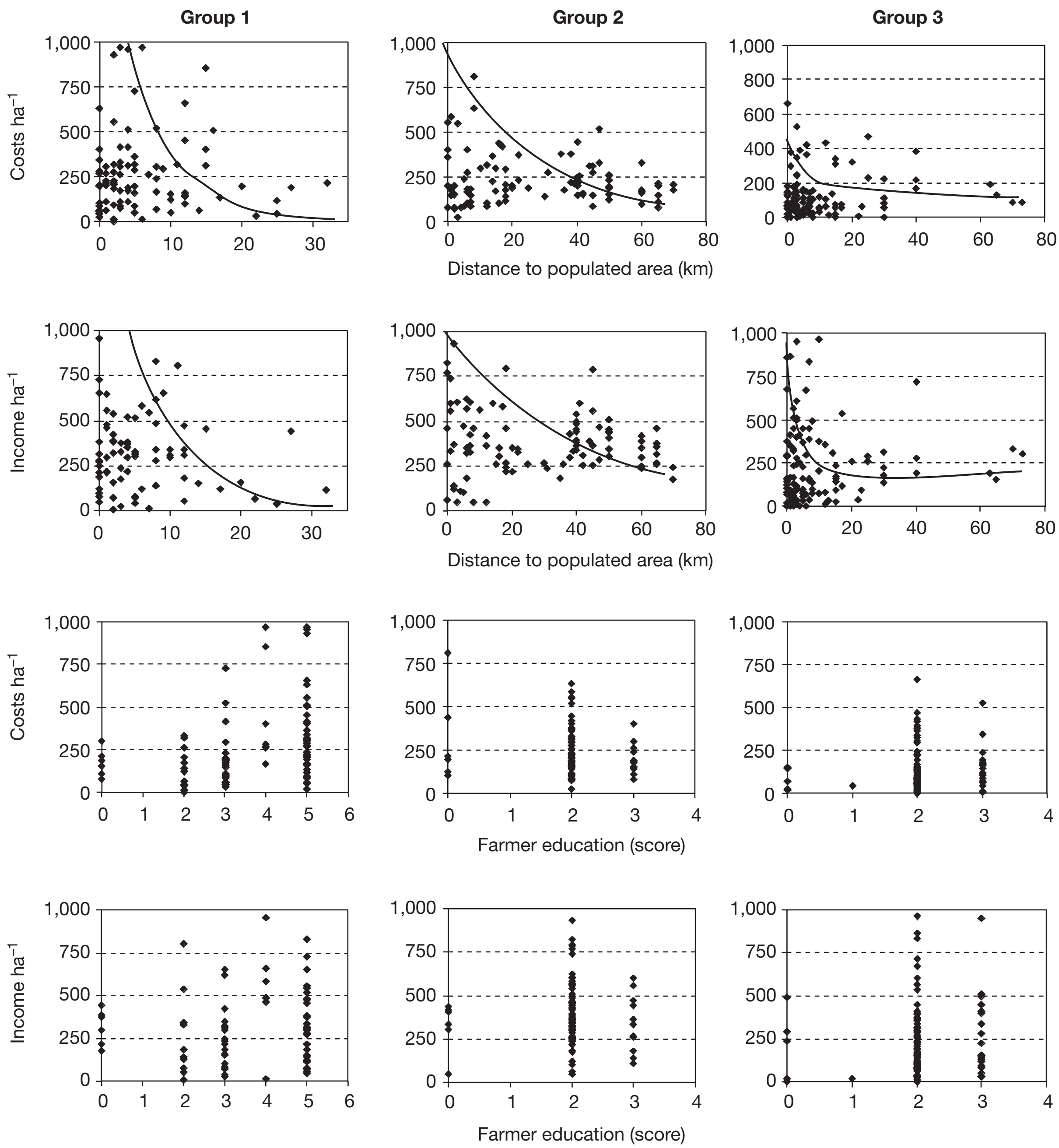

Figure 2. Relationship between intensification indicators (Total costs ha^{-1}; Income ha^{-1}) and drivers of technology adoption (distance to population and farmer education), per group.

savings (live animals) while agricultural products were mainly consumed by the families. Whereas the majority of cost could be inputted to agriculture, i.e. family nutrition, most incomes came from animals, which indicate the importance of livestock as a risk-coping strategy and as a route out of poverty (Bhende and Vetkataram, 1994; Castelán *et al.*, 1997).

Labour productivity was very low in this group of subsistence farming systems and pluriactivity of family members was high, as also was pointed out by Castelán *et al.* (1997) under similar conditions. This could be interpreted as an attempt of the households to alleviate poverty, smooth inter-year and intra-year variations in incomes and consumption and better manage risk to

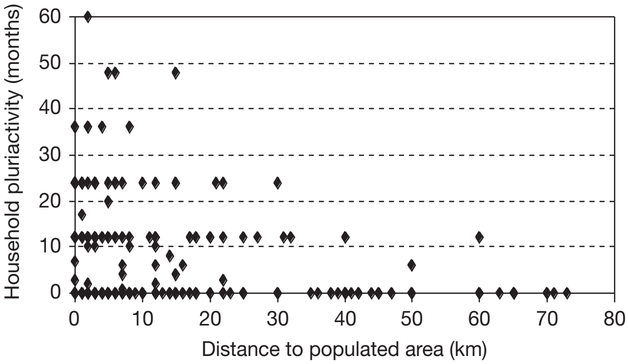

Figure 3. Relationship between level of household pluriactivity and distance to nearest population.

cope with income shocks (Reardon *et al.*, 2001). An increment of the opportunity cost of family labour could lead to a reduction of pressure on land and, therefore, reduce further deforestation (Pender, 2004), but increased non-farm opportunities are clearly linked to household location in relation to populated areas and level of education.

The technologies considered in this research meant higher utilization of external inputs, therefore higher unitary costs and, in principle, higher productivity of dairy production, therefore they could be considered as indicators of farm intensification. Among the several factors assumed to be related to the adoption of these technologies, two of them appeared to be very relevant: distance to populations and markets and level of education of the farmer. Shorter distance to populations indicates easier access to services, inputs and output markets and therefore better opportunities for intensification of farming and household pluriactivity. This can be explained by the reduced transaction costs that affect price and availability of inputs and because of increased labour market opportunities, respectively, as stated in many other studies (Nicholson *et al.*, 1999; Staal *et al.*, 2002; Baltenweck *et al.*, 2003; Pender, 2004).

Farmer education captures management skills and therefore ability to adopt new/complex technologies. Farmer education has been signalled by previous studies as very important drivers of technology adoption (Nicholson *et al.*, 1999; Staal *et al.*, 2002; Baltenweck *et al.*, 2003). It is also very important to notice that, in general, the highest odd ratios in Table 5 corresponded to this factor, i.e. the increase of education level would render high returns in terms of willingness and capacity of farmers to adopt new technologies.

Farmer age was also important as younger farmers seemed to be more willing to use concentrates and specialized dairy breeds. Staal *et al.* (2002) found that farming experience was positively related to uptake of dairy cattle, but in our case, rather than years of experience in farming, innovation attitudes seemed to be more relevant. A similar pattern was found by Nicholson *et al.* (1999) in Kenya, where the probability of adopting cattle dairy breeds decreased with increasing age of the household head. Only in the case of group 2, the relationship between age of the household head and utilization of cut and carry pastures was opposite to the general trend, but this could be due to the high proportion of Menonite farmers, which showed very particular familiar and social structures (Severiche, 1992).

Nevertheless, other factors, apart from location and farmer characteristics, were also important. These were related to scale of operation: land size and income availability. Limited availability of land (negative estimates in Table 5) seemed to drive intensification through use of concentrates, cut and carry pastures and specialized dairy breeds. But this process would also depend on good economic performance. Farmers attitudes toward new technologies are influenced by their resource endowment (Somda *et al.*, 2005) and therefore improved technologies can be hindered for poor farmers due to financial and asset barriers.

The only factor that was not related to technology adoption in any case was the availability of information through technical assistance. Similar findings were obtained in Kenya (Staal *et al.*, 2002) and Honduras (Pender, 2004), where technical assistance apparently had not played a major role in promoting new technologies. This might seem surprising as animal advice services would be expected to be linked to the uptake of technologies such as use of concentrates or specialized dairy breeds. A possible explanation for this is the lack of government support for extension services, which are very deficient, not targeted and don't always offer relevant information.

Despite the endogenous evolutionary process proposed by Boserup (1965) and McIntire *et al.* (1992) that explains intensification and livestock-crop integration in the long-term as linked to population density, we can affirm that there are many local- and farm-specific factors that explain the short-term development pathway and intensification level shown by the different farming systems. In this study, within the same spatial and temporal scale, i.e. same population pressure and economic environment, different levels of intensification and livestock-agriculture integration can be observed. Group 3 of small subsistence farming systems can be considered in the pre-intensification phase. Group 2 of mixed and more integrated agricultural-dairy farms would be placed in a pre-specialization phase. Finally, the first group of large livestock commercial farms could be located in a fully specialized stage, as even if many farms have dairy, agriculture and beef production, those activities are managed separately with low level of integration between them.

The growing demand for animal products, especially milk and dairy products, can benefit dairy systems in the area of this study, but small subsistence farmers have specific infrastructure, technical and economic constraints that can limit considerably their capacity to take advantage of these new opportunities. Hence, research and policy interventions should differentiate according to household typologies, and contemplate diverse technical options to suit the needs of vulnerable farmers, with specific limitations in terms of size, structure, access to markets, management skills and capacity to invest and to bear risk. For example, technology adoption will be very limited for smaller farmers if the new technologies are expensive or require a large amount of resources, such as labour or land.

In our research, shorter distance to populations (indicating easier communication and therefore better access to financial, input/output and labour markets), high level of farmer education and higher incomes were associated with higher levels of technology adoption, especially intensification technologies such as the use of concentrates and specialized dairy breeds. However, the non significance of the technical assistance in relation to the adoption of new technologies by farmers suggests that extension services need to be improved/ better targeted.

The methodology used in this work was useful in identifying recommendation domains (household typology) that should be considered when designing and implementing proactive and more focused development and agricultural policies. Undifferentiated agricultural and institutional policies, aiming at increasing the potential of the dairy sector in Santa Cruz in order to respond to the expanding domestic milk demand, might have very limited effect on the poorest and more vulnerable farmers, which actually could become more marginalized.

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