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Exploring Alternatives for Sustainable Development of Mixed Vegetable Beef-cattle Family Farm Systems in Southern Uruguay

Exploración de alternativas para el desarrollo sostenible de sistemas de producción hortícola-ganaderos familiares en el sur de Uruguay

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Abstract

Sustainability of most vegetable family farms in Southern Uruguay is threatened by low income and the deterioration of natural resources. This study quantified the effect of the inclusion of different alternatives of livestock production in the structure, and economic and environmental performance of different types of vegetable farms. Based on two farms as case studies, we conducted a model based exploratory study at farm scale. The results suggested that the inclusion of livestock production in vegetable family farms is a key factor in reducing erosion of the cultivated area. To reduce erosion, the model reduced the area of vegetables per farm, while expanding the area of forage production. As a consequence, family farm income (IF) was reduced between 12 % and 31 % depending on the case studied. However, we could design production systems with erosion lower than the tolerance limit for the soil type and higher IF, relative to the target, in both farms. From the livestock production alternatives evaluated, the most appropriate ones to include in vegetable production systems are fattening steers or heifers in cycles of 14 to 18 months, due to lower cost for restocking and less use of concentrates, reducing capital requirements and dependence on external inputs.

Keywords: mixed production systems, livestock production, simulation models, explorative studies

Resumen

La sostenibilidad de la mayoría de los predios hortícolas familiares en el sur de Uruguay está amenazada por ingresosin-suficientes y por el deterioro de los recursos naturales. En este estudio se cuantificó el efecto de la inclusión de diferentesactividades de producción ganadera en la estructura y en los resultados económico-productivos y ambientales de diferentestipos de sistemas de producción (predios) hortícolas. Se realizó un estudio exploratorio a escala predial con modelos desimulación utilizando dos predios como estudio de caso. Los resultados sugieren que la inclusión de activida-des de producciónganadera en los sistemas de producción hortícolas es un factor determinante para reducir la erosión promedio del áreacultivada. Para reducir la erosión el modelo diseñó predios que reducen el área de hortalizas al tiempo que expanden larotación forrajera. Como consecuencia de esto, también se redujo el ingreso familiar (IF) entre 12 % y 31 % según el casoestudiado. Sin embargo, pudimos diseñar sistemas de producción con erosión menor a la tolerable para el tipo de suelo e IFmayor al objetivo, en los dos predios. De las actividades ganaderas evaluadas las más apropiadas para incluir en predios hortícolasson el engorde de novillos o vaquillonas en ciclos de 14 a 18 meses, debido al menor costo para reposición de animales y al menoruso de concentrados, lo que disminuye las necesidades de capital y la dependencia de insumos externos.

Palabras clave: sistemas mixtos, ganadería, modelos de simulación, estudios exploratorios

Introduction

Two-thirds of the world's rural population lives on mixed farms that combine crops and pastures and produce almost half of the world's food (Herrero and others, 2010). To meet the growth in food demand, estimated at 70% in less than 40 years (Lobell and others, 2009), it is necessary to support family producers to develop more productive farms, more efficient in the use of production resources and more friendly to the environment (IFAD, 2011). However, in many regions of the world, family producers are threatened by declining incomes, deterioration of natural resources and lack of access to markets, productive resources and knowledge (Lipton, 2005; IFAD, 2011). It is, therefore, necessary to explore alternatives for the ecological intensification of family production systems.

The department of Canelones (Uruguay) is the region of the country with the highest incidence and severity of soil erosion (MGAP, 2004) and where the highest concentration of family farms is located. An important part of these farms' main source of income is horticulture. Uruguayan horticultural producers have faced, until 2004, a tendency of decreasing vegetable prices (constant weights, CAMM, 2009) and an increase in the costs of inputs and energy. The strategy that many used to maintain their income was to intensify and specialize their farms, cultivating larger areas of fewer crops and increasing the use of inputs, energy and irrigation. This process aggravated the already existing deterioration in soil quality, limiting crop yields and therefore family income (García de Souza and others, 2011). An important cause of this negative spiral is that producers adapt to the changing conditions of their environment by a process of trial and error, and very rarely this adaptation involves a global redesign of their production management (IAASTD, 2008). Dogliotti and others (2005) conducted a study based on a bio-economic model aiming to explore strategies to get out of this negative spiral. This study showed that it would be possible to increase family income on most of the farms and at the same time reduce erosion between 2 and 4 times its current level and reverse the negative balance of soil organic matter. This would be achieved by reducing the area with horticultural crops, combining crops in rotations with green manure, forage crops and pastures, and introducing livestock into the production system, which represents the opposite strategy to that followed by most producers.

The strategy proposed by Dogliotti and others (2005) was evaluated between 2005 and 2010 on 16 family farms in southern Uruguay, selected to represent the diversity of resource availability and soil quality existing in this region. Most farms achieved significant increases in income, productivity of family work, and soil quality assessed by organic C content and estimated erosion rate (Dogliotti and others, 2012). Although this study did not modify the existing animal production system, beef production increased in 9 of the 11 farms that produced it, as a result of an increase in forage production by installing pastures and forage crops in rotation with horticultural crops. We do not know what the potential contribution of beef production to family income and soil conservation in these types of farms could be if the management of the animal production system were improved and if the most appropriate product was selected for each farm according to its availability of resources.

In the last ten years, livestock has become an attractive option for producers in Canelones. According to the information provided by DICOSE (2011) from the annual affidavits of animal stock, from 2002 to 2010 cattle stock in Canelones increased by 43% (72600 heads) and almost half of this increase was attributable to the stratum of farms smaller than 50 ha. In these farms, cattle stock increased by more than 60% in that period. Many of these farms combine livestock with horticulture, this being the most important combined system in the south of the country. Livestock complements well with horticulture because it is an activity with low risk for product placement, has low labor requirements, and generates money inflows with an important weight in cash flow (Cardozo *et. al*., 2008).

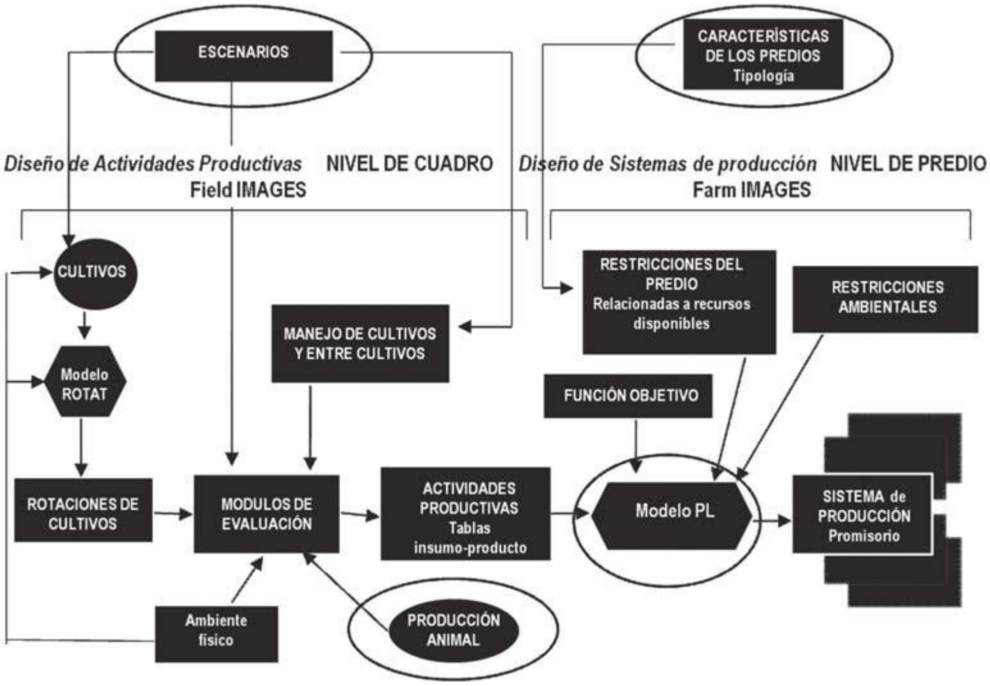
It is necessary to explore the potential of including different livestock production options to increase the productivity of land and labor, without deteriorating the soil and decreasing the amount of input and energy per product unit, in horticultural family farms with different availability of productive resources. Bio-economic models are useful for this purpose since they allow combining detailed information about their components and create alternatives that consider the resource limitations and the objectives of the actors involved (Rossing and others, 1997; Ten Berge and others, 2000).

This study aimed to quantify the effect of including different livestock production activities in the structure of the production system (farm) and the economic-productive and environmental results of different types of horticultural farms, in order to contribute to the design of sustainable horticultural-livestock production systems applicable to the predominant family production in Canelones.

Material and methods

An exploratory study of two main stages was carried out on a farm scale, following the methodology developed by Dogliotti and others (2005) (Figure 1). In the first stage, a great diversity of plant (rotations) and animal production activities were designed, and their resource requirements, economic result and environmental impact were quantitatively estimated. This quantification was performed by setting achievable target yields for each management system according to the method explained by Van Ittersum and Rabbinge (1997). The optimal combination of inputs and management to obtain the target yield was defined, assuming the 'best management practices' principle (Hengsdijk and Van Ittersum, 2002). This combination of target yield, inputs and techniques was specific to the physical environment of Canelones, characterized by the region's climate and soil types.

Figure 1. General outline of the methodology of the exploratory study and its relationship with the models used.



Improving the farms' economic performance, reducing erosion and improving soil fertility were the guidelines of the design process. In the second stage, through a multi-criterion linear programming model, different plant and animal production activities were combined to build a theoretically optimal system according to the optimized objective and the restrictions established at farm level. The farm system was designed using the productive resources available on the farm and predefined critical values of erosion rate and balance of soil organic matter, as restrictions.

Two farms were selected as case studies, belonging to the two main groups of the typology built by Righi and others (2011) for horticultural-livestock farms in Canelones based on information from DIEA (2001). The two most important groups within this typology represent 60 and 13.4% of the horticultural-livestock producers of the department. Both groups include farms with an average total area of 20 to 25 ha, a workforce entirely of family members and a very low level of mechanization. Irrigation is not available for the first group and part of the horticultural area in the second group is irrigated (Dogliotti and others, 2012). The two selected farms were part of the 16 farms participating between 2005 and 2010 in a process of co-innovation of horticultural and horticultural-livestock systems1 (Dogliotti and others, 2012).

Both farms combine horticultural production with livestock. Their main differences are cultivable area, irrigation availability, predominant soil type, slope and minimum FI target (Table 1). Farm 2 represents the majority group and farm[1], the second in importance within the typology.

Table 1. Main characteristics of the farms used as case studies and main factors affected by these characteristics.

Characteristics	Farm 1	Farm 2	Affecting Factor
Total surface (ha)	20	14.5	
Cultivable area (ha)	14.5	10	Maximum area for productive activities
Irrigable area (ha)	1	0	Horticultural crop yield and options
Mechanization level	Low	Low	workforce requirements and production costs
Predominant soils	Brunosols	Vertisols	Crop and pasture yields
Texture horizon A	36% Cl 34% S,	48% Cl 35% S	Erodabildad, organic matter balance
Predominant slope (%)	2.5	3.5	Erosion
Organic matter content (%)	2.3	3.2	Erodabildad, organic matter balance
Tolerable Erosion Level (Mg ha-1 year -1)1	5	5	
FWF available (h year-1)	4800	3600	Availability of workforce for productive activities
FWF available (h ha-1 year-1)	331	360	Availability of workforce for productive activities
Maximum hiring WF (h year-1)	360	300	Availability of workforce for productive activities
Members of the family nucleus (people)	5	2	Minimum household income
Minimum household income ($ year-1)2	421260	168504	

[1]Puentes and Szogi, 1983. 2Average income per capita in rural areas with a population < 5000 inhabitants (INE, 2009) * Number of members of the family nucleus. Cl: clay. S: Silt FWF: Family workforce.

For the design and evaluation of crop rotations, and crops and pastures in different types of soils (first stage, Figure 1), a package of models and computer tools called Field IMAGES was developed, based on the work of Dogliotti and others (2003; 2004). First of all, we created a list of horticultural crops, forage crops and pastures (Table 2) taking into account those that were carried out on the selected farms and the most important for the area. Based on this list and agronomic criteria such as start and end of cycle dates, length of the period between crops, maximum frequencies of species and families, and maximum rotation length (Table 2), Field IMAGES generates all possible rotations using the ROTAT model (Dogliotti and others, 2003). These rotations are then combined with management levels (e.g., level of mechanization, irrigation or rainfed, crop management, management of periods between crops, etc.) to create 'productive activities'. In this study, we distinguish only rotations without irrigation, and an intermediate and a high level of irrigation.

The management of weeds, pests and diseases was designed with cultural management and rational use of chemical products, according to current technical recommendations in the region. The fertilization of crops and pastures was calculated based on the fertility of the soils of the selected farms and the estimated achievable yields. The management of the periods between crops was designed to ensure maximum soil cover and organic matter input, combining green manures and chicken bedding applications (García de Souza and others, 2011).

Each productive activity is then evaluated to generate input-output tables. The achievable yield of each crop in the rotation was estimated based on the potential yield multiplied by reduction factors related to its frequency in rotation, its location in the crop sequence and whether the crop is irrigated or rainfed (Dogliotti and others, 2004). Based on the achievable yield for crops, pastures and green manures in the rotation, the total workforce requirements and throughout the year, production costs and gross margin, erosion and organic matter balance, and monthly forage production per hectare (dry matter, metabolizable energy, crude protein and fiber) were quantified. To allow the possibility of selling the produced forage instead of using it on the farm, the amount of produced bales and the economic results of its production were also estimated.

[1] Projects FPTA 160, FPTA 209 and EULACIAS (INCO-CT-2006-032387).

Table 2. List of selected crops and agronomic rules for the design of rotations and management systems.

N°	Crop	Seeding Date	Length Cycle (d)	Minimum period between crops (d)[1]	Frequency maximum in rotation[2]	Restrictions on crop sequences - Number of next crop[3]														Yield potential Farm 1	Yield potential Farm 2	Irrigation
						1	2	3	4	5	6	7	8	9	10	11	12	13	14	(Mg ha^{-1})	(Mg ha^{-1})	
1	Early garlic	30 Apr	173	5	0,25	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8	8	I-R
2	Red garlic	14-May	207	15	0,25	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	8	8	I-R
3	Early onion	14-Jun	169	15	0,34	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	40	40	I-R
4	Onion Pantanoso CRS	14-Jul	169	15	0,34	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	40	40	I-R
5	Leek	14-Jul	169	15	0,34	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	30	30	I-R
6	Table tomato	19-Oct	183	60	0,25	No	No	No	Yes	Yes	No	Yes	No	Yes	No	No	No	No	No	100	100	I
7	Sweetcorn	31-Oct	135	30	0,34	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	Yes	No	10	10	I
8	Squash	31-Oct	151	30	0,34	No	No	Yes	Yes	Yes	No	Yes	No	Yes	No	No	No	Yes	No	40	40	I-R
9	Sweet Potato	19-Oct	183	60	0,34	No	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	30	30	I-R
10	Melon	19-Oct	119	30	0,34	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	No	No	Yes	No	30	30	I
11	Cabbage	14-Mar	154	30	0,25	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	30	30	I-R
12	Alfalfa	31-Mar	1000	90	0,50	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	No	Yes	No	21	25,5	R
13	Wheat	31-May	198	30	0,34	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	No	Yes	4	4,5	R
14	Conv. grassland.	31-Mar	1365	90	0,50	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	No	Yes	No	21,5	26,5	R

I-R: irrigated or rainfed, I: irrigated only, R: rainfed only. [1]Minimum period after harvest to plant the next crop. [2]In annual crops it is estimated as the number of times the crop is grown divided by the length of the rotation in years. In multiannual crops and grasslands, it is estimated as the length of the crop or pasture cycle divided by the length of the rotation in years. [3]Cells with the word NO mean that the crop whose number appears in the header of the column cannot be grown immediately after the crop whose number appears at the beginning of the row.

This option was called 'horticultural rotations with pastures' (HRP) and the option that uses all forage for feeding farm animals was called 'horticultural-forage rotations' (HFR). Rotations that only included horticultural crops and green manure were grouped as 'Horticultural Rotations' (HR). An option called 'forage rotation' (FR) was created consisting of a five-year rotation: grassland-oats and ryegrass-millet.

A historical series was used as a source of information for the calculation of the economic results. It included prices (2005-2008) of horticultural products (CAMM, 2009), and livestock prices and inputs (DIEA, 2009), transformed at constant prices in July 2009 using the Indexed Unit, and then averaged to obtain a monthly average value of the historical series. For the estimation of erosion, the RUSLE model was used (Renard and others, 1997). Soil erodibility was estimated with the Wischeimer *et al* equation (1971), modified for Uruguayan conditions by Puentes and Szogi (1983). The average annual rain erosivity (400 MJ mm ha^{-1} $year^{-1}$ 10^{-1}) and its distribution throughout the year for Canelones, was taken from Pannone and others (1983). The organic matter balance was simulated for 40 years using the ROT-SOM model developed and adjusted for the region by Dogliotti and others (2004). Monthly forage production was estimated using as sources of information, Garcia (2003) and Diaz Lago and others (1996) for dry matter production, and Mieres (2004) and NRC (2000) for metabolizable energy (ME), crude protein (CP), and neutral detergent fiber (NDF).

The number of productive activities designed and quantified by Field IMAGES far exceeded the computational capacity of the linear programming model. Therefore, from the population of designed activities, a representative sample was selected, following the procedure designed by Dogliotti and others (2005).

The design of livestock activities was oriented to the fattening of animals, seeking to obtain high-quality products that meet the requirements of the industrial sector and at the best price. The activities use as a basis for improved pastures, rotating grazing with very frequent strip change, high instantaneous animal load, supplementation with bale and grains, and strict sanitary management. Production cycles are short and several selling times are sought in the year. The options considered generate variability relative to key aspects of livestock activity such as restocking category, final product, moments of animal entry and exit, length of the fattening cycle, meat production per animal and workforce demand. They were designed using personal expertise and national references (Cardozo and others, 2008; Baldi and others, 2008; Buffa and others, 2008; Caravia and Gonzales, 1998). The animal production activities were evaluated considering the maximum potential intake, and the demands for energy, protein and fiber, estimated based on the initial live weight and the evolution over time of the daily live weight gain established as a target.

Maximum potential intake and ME requirements were estimated based on NRC (1984, 2000). Up to 20% more animal intake was allowed so that the energy and protein density requirements of the diet were similar to those indicated by NRC (1984, 2000). The CP requirements were estimated according to the tables of requirements for each animal category (NRC, 1984) and the minimum requirements of NDF were established at 22% of the maximum potential intake because they are values that allow feed management with a very low risk of digestive and/or metabolic disorders (NRC, 2000) and therefore without very high demands in management and/or qualification of the workforce operating the system.

To design the production system at farm level (second stage, Figure 1), a multi-criterion linear programming model called 'Farm IMAGES' was improved (Dogliotti and others, 2005).

With this model, plant and animal production activities were combined according to the prioritized objective, the restrictions established in other objectives, and the availability of productive resources (soil, water, workforce) of each farm, to design production systems that maximized family income and maintained erosion and organic matter balance below and above tolerable limits, respectively.

Farm IMAGES is a multi-criteria linear programming model that combines continuous and integer decision variables. It maximizes an objective function, which can change in each model run and combines production activities considering technical and socioeconomic constraints specific to each farm. In turn, it determines the area to cultivate with each of the selected production activities and the number of animals. Additionally, it calculates other variables at the farm level such as the type and amount of purchased supplements and the amount of hired workforce (Figure 2). The model was written, compiled and executed using Xpress Optimization Suite 7 (FICO™).

Figure 2. Farm IMAGES model: variables, constraints and target functions. ME: Metabolizable Energy. CP: Crude Protein. NDF: Neutral detergent fiber. WF: Workforce FWF: Family workforce. EEP: Environmental exposure to pesticides. N: Nitrogen.

Restricciones		
Recursos del predio	Complejidad del predio	Ganadería
Disponibilidad de MO	Máx. nº de actividades de producción	Máx. y mín. nº de animales por predio
Área cultivable	Área mín. de cuadro	Máx. y mín. nº de opciones productivas
Área regable	Máx. nº de cultivos diferentes	Máx. y mín. nº de animales de cada opción productiva
	Máx. y mín. área de cada cultivo	Máx. nº de concentrados diferentes para comprar
		Balances de EM, PC y FDN

Variables	
Área de cada actividad de producción	Nº de animales de cada opción productiva
MO contratada por quincena	Cantidad y tipo de concentrados comprados
MOF utilizada por quincena	Cantidad de heno vendido

Funciones Objetivo			
1. Margen Bruto	3. Costos de producción	5. EEP Suelo	7. Erosión Potencial
2. Ingreso Familiar	4. Uso MOF	6. N Surplus	8. Balance Materia Orgánica

The Farm IMAGES model was improved in its ability to design mixed systems including the following modifications: (i) the possibility of considering and combining different types of animal production activities (products and production technologies), (ii) the possibility of including food sources for animals outside the farm, and (iii) the possibility of taking into account the monthly flow of production and quality of forage produced on the farm, as well as the monthly demand for energy, protein and fiber by animals. In order to dimension animal production activities in the production system, the new version of the model resolves a monthly and annual balance between nutrient supply and animal demand (ME, CP and NDF). Nutrient supply can come from the same farm or off-farm sources, product of the purchase of bales (grassland and/or alfalfa), and/or grains (corn and/or wheat bran). The monthly and total animal demand is a function of the number of animals present in each alternative of animal production. The supply of ME, CP and NDF in any month of the year was increased by 20% above that actually produced, as a way of considering the transfer of nutrients from one month to the next (such as standing forage) and/or the use of forage reserves produced on the farm. The overestimation of total supply, which could result from this measure, was avoided by making the annual supply and demand balance adjusted to the actual supply. The model allows for the development of forage stocks calculated based on surpluses from September to March. Quality loss of the forage stocks was estimated according to information published by Mieres (2004) and NRC (2000) and 20% usage losses were assumed. In this study, intake of concentrates and bales was restricted, determining that it does not exceed 1% of the live weight at all times, ensuring pasture was the basis of the feed.

Three simulation cycles were carried out for each farm. In the first cycle, the exchange between family income and soil erosion was analyzed. For this, family income was maximized under increasing restrictions of maximum level of erosion tolerated and always maintaining a positive balance of soil organic matter. In the second cycle, the effect of the type of livestock activity on family income and production costs was studied. For this, the maximum erosion level was set at 5.0 Mg ha^{-1} year^{-1}, and the FI was maximized by restricting the animal production options to a different one in each simulation cycle. Finally, the sensitivity of the results obtained to variations in the prices of livestock and grains, was analyzed.

Results

Plant production activities

Of the total productive activities designed and quantified using the Field IMAGES, 7437 were selected for farm 1 and 7455 activities for farm 2. The set of activities selected for both farms showed a significant diversity in gross margin, direct costs, labor demand, erosion rate, soil organic matter balance, N balance and forage production (Table 3). According to the model's estimates, the soil management technologies proposed for HR, HRP and HFR would be able to maintain a positive balance of soil organic matter, but would not be able to lower the erosion rate below the tolerable maximum for this type of soil, established at 5 Mg ha^{-1} year^{-1} by Puentes and Szogi (1983). HRPs and HFRs that include a pasture phase (grassland or alfalfa) are those that had the least erosion. The FR would achieve an average erosion rate of 2.8 Mg ha^{-1} year^{-1} in both farms and an organic matter balance of 273 and 93 kg ha^{-1} year^{-1} in farms 1 and 2, respectively. The estimated gross margin in non-irrigated HR ranged from 17 to 73 and from 15 to 73 thousand pesos per ha and per year for farms 1 and 2, respectively, while, with irrigation, it varied between 24 and 247 thousand pesos per ha and per year for both farms.

Animal production activities

Six animal production activities were designed: male fattening in long (MCHCL1 and MCHCL2) or short (MCHCC) cycles, heifer fattening (VAQ) and cow fattening (V1 and V2) (Table 4). The category used as restocking varies between male calves, yearlings, formed calves, rejected female calves and cows. This variable affects the restocking cost and therefore the capital requirements to carry out the activity.

The estimated average earnings range from 0.636 to 0.857 kg day^{-1}, which is associated with intensive production systems based on improved pastures and strategic supplementation. The fattening cycle varies from 4 to 17 months which affects the speed of capital circulation. Activities with a long fattening cycle use more labor than those with a short cycle since they remain on the farm for longer and involve the management of two lots of animals at certain times of the year (Table 4).

Exchange between family income and soil erosion

When the FI was maximized without restrictions on the erosion level, the estimated FI was 523 and 256 thousand pesos per year and the estimated erosion was 10.0 and 8.9 Mg ha$_{-1}$ year$_{-1}$ for farms 1 and 2, respectively. As the level of erosion was restricted to the tolerance level of 5 Mg ha$_{-1}$ year$_{-1}$ (Puentes and Szogi, 1983), the FI declined more rapidly in farm 2 (Figure 3). Lowering erosion to a tolerable level would imply a loss of 12% and 31% of FI in premises 1 and 2, respectively. However, even within the tolerable erosion level, the minimum target FI could be exceeded at both farms (Table 1).

In both farms and from the erosion level ≤7.5, the model included livestock in the production system (Table 5). At the erosion level ≤5.0 livestock participated with 6 and 15% of the FI, and accounted for 15 and 19% of the family workforce used in the production system on farms 1 and 2, respectively. The required capital (RC) increased as the permitted erosion levels for both farms decreased. This increase was due to the incorporation of livestock in the production system (Table 5).

Table 3. Minimum, maximum and median values obtained for gross margin, direct costs, labor requirements, erosion rate, soil organic matter balance, N balance and forage production for rotations: horticultural (HR), horticultural pasture (HPR), horticultural forage (HFR) and forage (FR) in farms 1 and 2.

Type soil and farm	Type rotation		Margin Gross ($ ha^{-1})	Direct Costs ($ ha^{-1})	Workforce (hours ha^{-1})	Erosion (Mg ha^{-1})	SOM (kg ha^{-1})	N surplus (kg ha^{-1})	Forage Prod. (kg DM ha^{-1})	Forage Prod. (Mcal ha^{-1})
Brunosol - farm 1	HR	Minimum	50593	18118	586	10.9	395	21.6	0	0
		Maximum	247160	60958	2001	18.2	702	102	0	0
		Median	152887	35732	1186	15.1	498	50	0	0
	HRP	Minimum	23925	11058	236	7.8	245	0.91	0	0
		Maximum	213784	48562	1538	15	591	60.9	0	0
		Median	126722	27861	874	11.3	437	25.2	0	0
	HFR	Minimum	16919	7841	229	7.8	247	40	1941	4557
		Maximum	203754	45937	1532	15	483	105	4500	10961
		Median	118249	25459	862	11.3	382	70	3152	7764
	FR		No	6065	18.2	2.8	273	24.74	4282	10187
Vertisol - Farm 2	HR	Minimum	49011	17942	590	10.7	21	46	0	0
		Maximum	247160	60958	2001	19	333	124	0	0
		Median	158240	36805	1226	15.4	141	72	0	0
	HRP	Minimum	18275	9794	223	6.9	-28	7.4	0	0
		Maximum	213784	48562	1538	14.9	286	70	0	0
		Median	127808	28033	883	11.2	143	34	0	0
	HFR	Minimum	15027	7106	216	6.9	-37	56	2336	5489
		Maximum	203754	45937	1531	14.9	196	122	4994	12185
		Median	118224	25434	868	11.3	93	88	3559	8716
	FR		No	5280	18.2	2.8	93	0.7157	5186	12329

Meat production increased when lowering the allowable erosion level to ≤6.5 and ≤7.5 in farms 1 and 2, respectively (Figure 4). The increase in the importance of livestock increased the grazing area, mainly in the area assigned to the FR. At the same time, the horticultural crop area decreased, but the selection of crops did not vary significantly (Table 6). HR were not part of the solution in any case.

V2 and VAQ, alone or combined, were the animal production activities selected in all cases. Animal production was incorporated into the system as an intensive activity with high loads (417 to 1042 kg LW ha^{-1} average annual livestock), with supplementation using significant levels of concentrate (642 to 1345 kg ha^{-1} $year^{-1}$) and with good production results (321 to 811 kg LW ha^{-1} $year^{-1}$). In farm 2, the average annual load, the use of concentrates and meat production per hectare was always higher than in farm 1 (Table 7).

Table 4. Characterization of the livestock activities designed.

	MCH CL 1	MCH CL2	MCH CC	VAQ	V1	V2
Restocking category	Male calf	Yearling	Steer > 300 kg	Female calf	Cow Rejected	Cow Rejected
Item sold	Steer fat special	Steer fat special	Steer fat special	Heifer fat special	Cow fat special	Cow fat special
Input weight (kg)	160	190	335	150	330	330
Output weight (kg)	505	535	515	417	438	432
Average gain (kg day-1)	0.676	0.676	0.857	0.636	0.720	0.850
Meat production (kg head -1)	345	345	180	267	108	102
Entry time (month)	June	June	May	July	April	July
Departure time (month)	October	October	November	August	August	October
Length of fattening cycle (months)	17	17	7	14	5	4
Restocking cost ($ kg-1)	28.12	26.20	24.58	23.46	20.31	20.22
Sale price ($ kg-1)	29.13	29.13	25.68	27.08	27.08	25.23
Skinny/Fat Ratio	0.97	0.90	0.96	0.87	0.75	0.80
Restocking cost ($ head-1) [1]	4688	5157	8479	3685	6947	6917
Sale ($ head-1) [2]	13598	14404	12213	10427	10963	10059
No. of lots (maximum)	2	2	1	2	1	1
Use of workforce (h year-1)	390	390	203	284	180	110
Primary margin ($ head-1 year -1) [3]	8780	9087	3634	6617	3941	3077
Metabolizable energy required (Mcal head-1 year-1)	9243	9857	4613	6674	3136	2711
Workforce productivity ($ h-1) [4]	225	233	179	233	219	280
Metabilizable Energy Productivity ($ Mcal -1) [5]	0.95	0.92	0.79	0.99	1.26	1.14

MCH CL 1= Long cycle male fattening option 1, MCH CL 2= Long cycle male fattening option 2, MCH CC= Short cycle male fattening, VAQ= Heifers fattening, V1= Cows fattening option 1, V2= Cows fattening option 2. [1]Put on the farm assuming freight of 200 km. [2] Put in slaughterhouse assuming freight of 50 km. [3]Primary margin = Revenue from sale - Restocking cost - Health care cost. [4] Workforce productivity (Assumes lots of 10 animals)= Primary margin *10/Workforce use. 5Metabolizable energy productivity = Primary margin/Metabolizable energy required.

Table 5. Main results of the production systems designed by Farm IMAGES in each farm studied when family income is maximized and the permitted erosion levels are decreased.

Tolerated Level of Erosion	% FI Horti.	% FI Livestock	FWF Use Total (h year-1)	FWF Use Horti. (h year-1)	FWF Use Livestock (h year-1)	HWF Use (h year-1)	Capital required ($ year-1)
Farm 1							
≤9.5	100	-	4631	4631	-	360	217462
≤8.5	100	-	4605	4605	-	360	208938
≤7.5	100	0	4674	4489	185	360	298289
≤6.5	85	15	4625	4015	610	360	338082
≤5.5	91	9	4692	4060	632	360	456911
≤5.0	94	6	4484	3822	662	360	421565
Farm 2							
≤9.5	100	-	3519	3519	-	300	195462
≤8.5	100	-	3519	3519	-	300	191836
≤7.5	74	26	3519	3131	388	300	281097
≤6.5	74	26	3519	2977	542	300	379468
≤5.5	86	14	3344	2774	570	277	308995
≤5.0	85	15	3005	2421	584	109	301585

FI Horti.= % of family income generated by horticulture. % FI Livestock= % of family income generated by livestock. FWF=Family workforce. HWF= Hired workforce

Figure 3. Exchange between family income and soil erosion for the two farms studied.

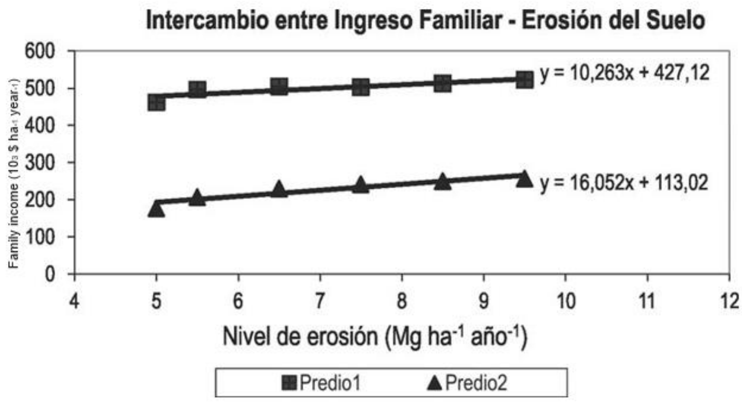


Figure 4. Soil use and meat production in the production systems designed by Farm IMAGES in each farm studied when family income is maximized and the permitted erosion levels are decreased.

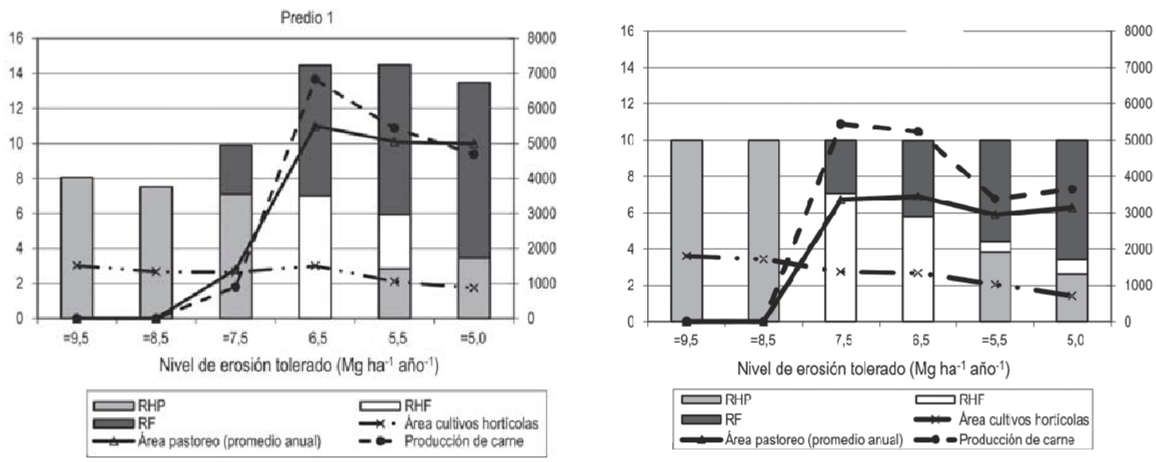


Table 6. Soil use in the production systems designed by Farm IMAGES in each farm studied when family income is maximized and the permitted erosion levels are decreased.

Farm 1

Level of Erosion Tolerated	Area used (ha)	Area irrigated (ha)	Early Garlic (ha)	Onion (ha)	Leek (ha)	Tomato (ha)	Squash (ha)	Sweet Potato (ha)	Cabbage (ha)	Wheat (ha)	Alfalfa (ha)	Millet (ha)	Oats and Ryegrass (ha)	Grassland 4 years (ha)
≤9.5	8.1	1	0.4	-	0.6	0.4	0.91	0.71	-	1.11	3.93	-	-	-
≤8.5	7.5	0.81	0.4	0.4	-	0.4	0.73	0.73	-	1.46	3.4	-	-	-
≤7.5	9.9	0.8	0.4	0.4	-	0.4	0.72	0.72	-	1.12	3.35	0.56	0.56	2.24
≤6.5	14.5	1	-	-	0.59	0.41	1	1	-	1	3	1.5	1.5	5.98
≤5.5	14.5	0.81	0.41	0.41	-	0.41	0.44	0.44	-	1.29	2.54	1.71	1.71	6.85
≤5.0	13.5	0.95	0.58	0.58	-	0.38	-	-	0.2	-	1.73	2	2	8

Farm 2

Level of Erosion Tolerated	Area used (ha)	Area irrigated (ha)	Early Garlic (ha)	Onion (ha)	Squash (ha)	Sweet Potato (ha)	Cabbage (ha)	Wheat (ha)	Alfalfa (ha)	Grassland 3 years (ha)	Millet (ha)	Oats and Ryegrass (ha)	Grassland 4 years (ha)
≤9.5	10	-	0.26	-	1.67	1.41	0.26	1.67	5	-	-	-	-
≤8.5	10	-	0.27	-	1.58	1.58	-	1.7	4.36	0.5	-	-	-
≤7.5	10	-	0.56	-	1.09	1.09	-	1.09	3.27	-	0.59	0.59	2.36
≤6.5	10	-	0.56	-	1.33	0.78	-	1.33	2.33	-	0.85	0.85	3.39
≤5.5	10	-	0.65	0.1	0.65	0.65	-	0.65	1.94	-	1.11	1.11	5.45
≤5.0	10	-	0.47	-	0.47	0.47	-	0.57	1.42	-	1.32	1.32	5.28

Table 7. Characterization of the livestock activities in the production systems designed by Farm IMAGES for each farm when family income is maximized and the permitted erosion levels are decreased. V2= Fattening of cows option 2. VAQ= Heifer fattening.

Erosion Level Tolerated	Livestock Activity	Average Load (kg LW ha^{-1} $year^{-1}$)	Production of meat (kg ha^{-1})	Use of concentrates (kg ha^{-1})
Farm 1				
≤9.5	NO			
≤8.5	NO			
≤7.5	9 V2	417	321	842
≤6.5	22 V2 + 17 VAQ	799	620	1044
≤5.5	19 V2 + 13 VAQ	694	538	868
≤5.0	17 V2 + 11 VAQ	605	469	642
Farm 2				
≤9.5	NO			
≤8.5	NO			
≤7.5	20 VAQ	1042	811	1209
≤6.5	17 V2 + 13 VAQ	981	761	1345
≤5.5	12V2+8VAQ	739	573	814
≤5.0	12V2+9VAQ	750	582	874

Effect of livestock type

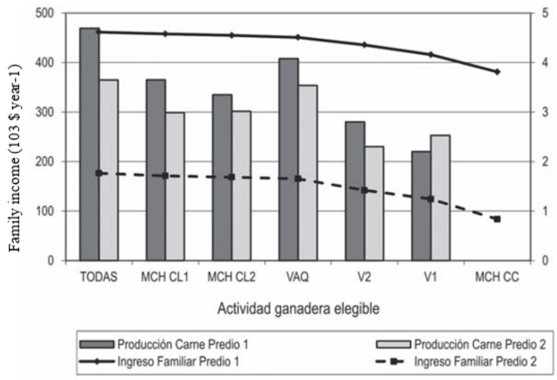
In all the situations studied, when the FI was maximized by changing the animal production option and limiting erosion to ≤5 Mg ha^{-1} $year^{-1}$, the model included livestock, except when the alternative was MCHCC (Figure 5). The change in the chosen animal production option had a different impact on the FI according to the farm considered. In farm 1, the largest reduction observed in FI compared to the situation in which the model was able to freely choose (ALL) was 9%, while in farm 2 the reduction was 30%. In both farms, the greatest effect on FI was observed when the production system did not include animals (when the eligible option was MCHCC), where the reduction was 17 and 53% for farm 1 and farm 2, respectively.

The group of livestock activities made up of MCHCL1, MCHCL2 and VAQ (CL GROUP), when incorporated into the production system, resulted in a FI close to that of ALL, with an average reduction of 2 and 5% for farms 1 and 2, respectively (Figure 5).

On the other hand, the RC for this group was on average 29 and 26% lower than for ALL, for farms 1 and 2, respectively (Table 8). The CL GROUP had in both farms, a distribution of income and use of workforce similar to the system designed with ALL. The inclusion of cow fattening (V1 or V2) did not generate a profitable livestock production activity in itself, reflected by its very low or no participation in the FI (Table 8).

The use of workforce in livestock activities decreased significantly with respect to ALL, especially when the options included were VAQ, V1 and V2. The average restocking cost for the CL GROUP decreased 67% and 61%, and the average concentrate expense decreased 42% and 31% compared to the design with ALL for farms 1 and 2, respectively. When cows were included, the restocking cost increased on average 5% at farm 1 and 37% at farm 2 (Figure 6). In contrast, for options V1 and V2, the use of concentrates increased by an average of 20% for farm 1 and 44% for farm 2 (Figure 6).

Figure 5. Effect of livestock type on family income and meat production in production systems designed by the Farm IMAGES for each farm studied when family income is maximized and eligible livestock activities are changed, with a maximum level of erosion tolerated for the average of the cultivated area of 5 Mg ha^{-1} $year^{-1}$.



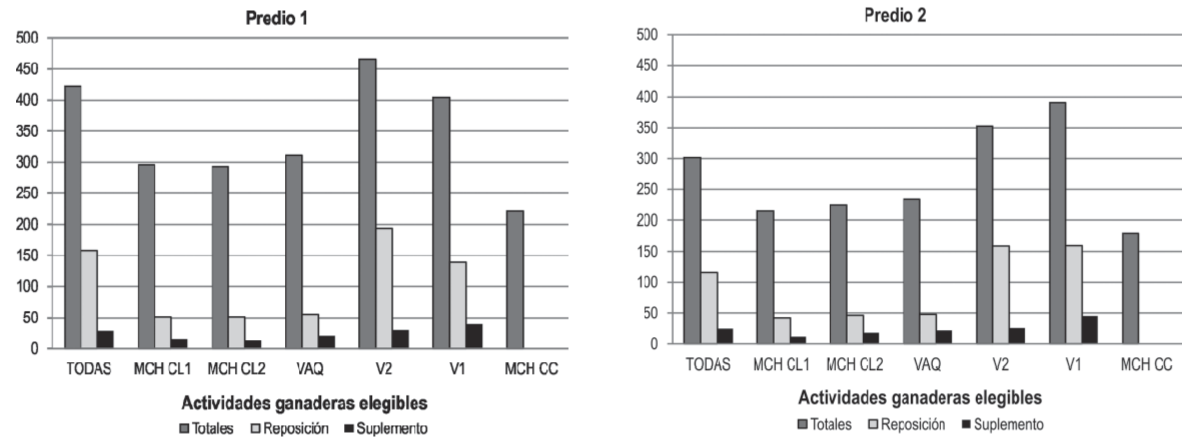
ALL= All designed cattle production activities, MCH CL 1= Long cycle male fattening option 1, MCH CL 2= Long cycle male fattening option 2, MCH CC= Short cycle male fattening, VAQ= Heifer fattening, V1= Cow fattening option 1, V2= Cow fattening option 2.

Table 8. Main results of the production systems designed by the Farm IMAGES for each farm studied when family income is maximized and the eligible livestock activities are changed, with a maximum level of erosion tolerated for the average cultivated area of 5 Mg ha^{-1} year^{-1}.

Eligible cattle activities	Livestock Activity	Average Livestock Area (ha year-1)	Capital required ($ year-1)	% FI Horti.	% FI Livestock	FWF Use Total (h year-1)	FWF Use Horti. (h year-1)	FWF Use Livestock (h year-1)	HWF Use (h year-1)
Farm 1									
ALL	17 V2 + 11 VAQ	10.0	421565	94	6	4484	3822	662	360
MCH CL1	11 MCH CL1	9.1	296105	96	4	4507	3869	638	360
MCH CL2	10 MCH CL2	9.1	293490	96	4	4507	3869	638	360
VAQ	15 VAQ	9.1	310782	97	3	4391	3874	517	360
V2	28 V2	9.2	466016	100	0	4293	3973	320	360
V1	20 V1	6.5	404527	100	0	3939	3596	343	360
MCH CC	NO	-	222253	100	-	3746	3746	-	360
Farm 2									
ALL	12V2+9VAQ	6.3	301585	85	15	3005	2421	584	109
MCH CL1	9 MCH CL1	6.3	214755	86	14	2989	2409	580	120
MCH CL2	9 MCH CL2	6.3	224576	87	13	2989	2409	580	120
VAQ	13 VAQ	6.3	233838	89	11	2878	2420	458	109
V2	23 V2	6.3	352846	99	1	2701	2443	258	90
V1	23 V1	6.3	391229	100	0	2765	2427	338	105
MCH CC	NO	-	179795	100	-	2575	2575	-	90

ALL= All livestock production activities designed. MCH CL 1= Long cycle male fattening option 1. MCH CL 2= Long cycle male fattening option 2. MCH CC= Short cycle male fattening. VAQ= Heifer fattening. V1= Cows fattening option 1. V2= Cows fattening option 2. % FI Horti.= % of family income generated by horticulture. % FI Livestock= % of family income generated by livestock. FWF= Family Workforce HWF= Hired Workforce.

Figure 6. Effect of the type of livestock activity on the production costs of systems designed by the Farm IMAGES for each farm studied when family income is maximized and livestock activities are changed if elected, with a maximum level of erosion allowed for the average area cultivated was 5 Mg ha^{-1} year^{-1}.;. ALL= All livestock production activities designed. MCH CL 1= Long cycle male fattening option 1. MCH CL 2= Long cycle male fattening option 2. MCH CC= Short cycle male fattening. VAQ= Heifer fattening. V1= Cows fattening option 1. V2= Cows fattening option 2.



Sensitivity Analysis

The overall design strategy for sustainable systems was not affected by variations in livestock or grain prices, within the range of +/- 30% of the prices used as a basis for this research (Table 9). For both farms, the production systems included livestock and in most cases the strategy that maximized FI was the combination of V2 and VAQ. The behavior of each livestock option individually relative to ALL remained within this range of price variations.

Discussion

Livestock contributions to the sustainability of Canelones horticultural systems

In this study, using a bio-economic model, we demonstrated that there is potential to increase the productivity of land and labor, and at the same time maintain or improve soil quality in the two selected family farms, through productive systems that improve the integration between horticulture and livestock. The estimated FI at the beginning of the co-innovation process (2007 for farm 1 and 2005 for farm 2), was 75 and 70 thousand dollars for farms 1 and 2, respectively, estimated values at constant prices in July 2009.

The average erosion estimated at the same time using the RUSLE model was 16.9 Mg ha-1 year-1 in farm 1 and 4.0 Mg ha-1 year-1 in farm 2. At the end of the co-innovation process (July 2010), the FI was 199 and 125 thousand $, and the estimated erosion was 7.8 and 4.7 Mg ha-1 year-1, for farms 1 and 2, respectively (Dogliotti and others, 2012). The results obtained in this study suggest that it would be possible to continue increasing the FI by 132% on farm 1 and 41% on farm 2, compared to the FI reached in 2010 and keeping erosion below 5 Mg ha-1 (Figure 3).

Including livestock in horticultural production systems would reduce the average erosion of the cultivated area. By reducing the admitted level of erosion below 7.5 Mg ha-1 year-1, the model reduced the area of vegetables, and included FR in increasing areas. As a result, FI were reduced by 12% and 31% in premises 1 and 2, respectively, but remained above the minimum FI target, in both premises. Including a pasture phase in horticultural rotations reduces the deterioration of soil quality that occurs in the crop phase, and increases crop yields (Do Campo and others, 2010). Animal production gives economic viability to the inclusion of pastures in the horticultural system (Dogliotti and others, 2005). This strategy of designing mixed systems as a basis for sustainability coincides with international (Schiere and others, 2002; FAO, 2009) and national studies in other areas (Morón and Díaz, 2003; Deambrosi and others, 2009).

Table 9. Main outputs of the production systems designed by the Farm IMAGES for both farms when the family income is maximized with a maximum level of tolerated erosion for the average of cultivated area of 5 Mg ha^{-1} year^{-1}.; and the price of livestock and grains is modified.

	Farm 1		
	$ livestock* 0,7/$ $ grain * 1.3	**livestock* 1/ $ grain *1**	**$ livestock* 1.3/ $ grain *0.7**
Family Income ($)	429420	461511	628795
Land use (ha)	6.44 FR + 2.72 HR	10 FR + 3.46 HR	10.77 FR + 3.5 HR
Livestock Activity	1V2+7MCHCL1	17 V2 + 11 VAQ	75V2+25V2
Meat production (kg)	2424	4692	10750
Use of concentrates (kg)	1360	6420	76589
	Farm 2		
	$ livestock* 0.7/$ $ grain * 1.3	**livestock* 1/ $ grain *1**	**$ livestock* 1.3/ $ grain *0.7**
Family Income ($)	145626	176237	333369
Land use (ha)	6.33 FR + 3.67 HR	6.27 FR + 3.73 HR	6.33 FR + 3.67 HR
Livestock Activity	2V2+8MCHCL1	12V2+9VAQ	13V1+75V2+12VAQ
Meat production (kg)	2856	3648	12194
Use of concentrates (kg)	1633	5477	69766

FR: Forage rotation; HRP: Horticultural rotation V2: Cow fattening option 2; MCH CL1: Long cycle male fattening option 1 VAQ= Heifer fattening; V1: Cow fattening option 1.

The estimated minimum erosion for HRP and HFR was 7.8 and 6.9 Mg ha^{-1} year^{-1} in farms 1 and 2, respectively, while the forage rotation had an estimated erosion of 2.8 Mg ha^{-1} year^{-1}. These minimum erosion values constitute a limitation to improving the sustainability of this type of farm. Maximum meat production was obtained in both farms with important areas dedicated to HFR and without significantly decreasing the area of horticultural crops (Figure 4). Lowering HFR erosion below the tolerable maximum would allow for more productive and more sustainable systems from the point of view of soil quality. This can be achieved in two ways, by reducing the frequency of horticultural crops in rotation and/or by introducing new soil management technologies in horticulture that allow reducing erosion while maintaining yields, such as reduced tillage practices (Scopel and others, 2004; Adekalu and others, 2007). In this study, we set the minimum frequency of horticultural crops in the rotations at 0.5, which results in 4 years of horticultural crops and 4 years of pasture in a rotation of 8 years.

Reducing the duration of the horticultural crop phase in rotation results in a significant reduction of the average erosion. García de Souza and others (2011) estimated that it is not possible to maintain a high level of organic matter in soils under horticulture only through the use of green manure and chicken bed if at the same time the amount of tillage is not reduced by longer pasture periods or reduced tillage technologies. These technologies were not considered in this study because they are still in the experimental phase in the region (Alliaume and others, 2012).

Effect of livestock type

The combination of options V2 and VAQ maximized the FI with erosion levels within the tolerable limit, on both farms. However, the results presented suggest that the most appropriate way to include livestock in Canelones' family production systems is by fattening MCHCL1, MCHCL2 or VAQ.

This proposal is based on the fact that although these alternatives do not maximize the FI, the reduction in income (average 3%) is insignificant compared to the reduction in the cost of restocking animals which goes from 61% to 67%. In addition, this group of productive alternatives has lower concentrate costs, with a reduction of between 31 and 42% compared to the combination of activities that maximizes the FI. These qualities of the CL GROUP's activities are very attractive to family producers who generally have capital restrictions, need to decrease their dependence on external inputs and cannot take significant risks. From the point of view of the complexity level of the system and the demand for the producer's attention for proper management, the option of one livestock alternative rather than the combination of two, is preferable.

Conclusions

Research suggests that including livestock in family horticultural production systems would increase land and labor productivity, while improving soil quality, within the limits of current farm resource availability and price conditions in recent years.

Of the evaluated livestock alternatives, the most appropriate to include in horticultural systems are the fattening of steers or heifers in cycles of 14 to 18 months, because the reduction in income is minimal compared to the reduction in the costs of restocking animals and concentrates, which reduces capital needs and dependence on external inputs, two very important qualities for this type of production systems.

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