Exploring options for sustainable farming systems development for vegetable family farmers in Uruguay using a modeling toolkit

Marion Casagrande[a], Santiago Dogliotti[b], Jeroen Groot[a], Verónica Aguerre[c], Ahmed Abbas[a], Alfredo Albín[c], Frits Claassen[d], Pablo Chilibroste[b], Walter Rossing[a]

[a]*Biological Farming Systems Group, Wageningen University, The Netherlands, marion.casagrande@wur.nl*
[b]*Facultad de Agronomía, Montevideo, Uruguay*
[c]*INIA, Instituto Nacional de Investigación Agropecuaria, Canelones, Uruguay*
[d]*Operations Research and Logistics Group, Wageningen University, Wageningen, The Netherlands*

Abstract: *Economic and environmental sustainability of family-based vegetable production systems in south Uruguay are seriously compromised after two decades of decreasing prices and strategies based on specialization and intensification. This paper presents a model-based exploration of alternative livelihood strategies in terms of income generation and resource use, under three different future scenarios defined by local experts. We present here the results obtained for a real farm belonging to one of the most abundant farm types of the region. We designed new production activities, evaluated them with economical and environmental indicators and finally combined them at farm-scale to elucidate win-win situations and trade-offs. Results are aimed to be used for defining policy briefs to support ongoing local innovation processes.*

Keywords: *alternative livelihood strategies, scenarios, model based explorative study, sustainability.*

Introduction

Faced with continued decreases of product prices on the internal market and increasing costs of inputs and energy over the past 20 years, vegetable family farms in Uruguay have been intensifying and specializing their production systems, putting more pressure on already deteriorated soils and on limited farm resources.

In order to identify alternative options for vegetable growers in Southern Uruguay, researchers from the Faculty of Agronomy in Montevideo, later joined by Wageningen University started a series of learning cycles. The first extended learning cycle comprised the one-year long interactions of many generations of students of the Faculty of Agronomy with farm families, which are part of the curriculum, and the associated relations which developed between the farmers and the Faculty. Dogliotti et al. (2005) completed a next cycle, involving a formal model-based diagnosis of the problems in pilot farms, and an assessment of alternatives. In this approach, existing and potential farming systems for a number of selected farms were evaluated in terms of objectives thought relevant for the farmers, including environmental objectives (soil fertility, exposure to pesticides, nutrients balances) and social-economic objectives (family income, gross margin, labor availability). The results showed great promise for ecological-economic win-win situations if farmers would drastically alter their strategies and base them on wider rotations, fewer crops in contrast with historical trend of specialization and use of (green) manure. These results constituted the hypotheses to be tested during a third learning cycle, which was implemented during the EULACIAS[1] project. In this project 16 farms were diagnosed and redesigned in very close interaction with the farm family and the most promising farm strategy was tested in the farmer practice. Positive results were found after 2-3 years of interaction with most farmers.

The question is what these results mean for the vegetable farmer population as a whole, and how this informs regional policy, farmer union activities and the research agenda. For this purpose a farm typology was combined with a set of scenarios in a model-based exploration of development options for each of the farm types. Here we describe the approach and present preliminary results of the

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[1] EU FP6-2004-INCO-dev-3; contract nr 032387 ; http://www.eulacias.org/

exploration of options for a real farm belonging to one of the two most abundant farm types. The ultimate goal is to contribute to construction of policies that foster sustainable family farming in Southern Uruguay.

Materials and methods

Study area

The study area was located in the temperate region of Canelones, South Uruguay. This region concentrates more than 50% of the vegetable producers of the country and it is the region with highest incidence of soil erosion in the country. The main structural problems of horticultural farms in the area are (i) deteriorated soil quality, (ii) limited surfaces of productive areas, (iii) insufficient irrigation water. Availability of off-farm labor is becoming a problem in the region and experts predict that it will be increasingly scarce and expensive.

Farm typology

Seven representative types of vegetable production farms were identified in the region using a quantitative typology method based on cluster analysis, multidimensional scaling and similarity percentages analysis (Righi et al., 2009). The types differed particularly in use of off-farm labor, mechanization endowment and irrigation potential. The farms participating in the EULACIAS project were classified in terms of the typology. In this way, a link between results from the project and the population at larger scale was made.

Description of scenarios

Scenarios of major agricultural changes for vegetable farms in Uruguay for a time horizon of 10 years were defined by local experts using Delphi methods (Contini et al., 2010). Three scenarios were identified associated with optimistic and pessimistic trends in prices of products and inputs: an ‘organic’ scenario, an ‘integrated supply chain’ scenario (where farmers have contracts with vegetable industries) and a ‘conventional’ scenario (a continuation of current systems). In this study we used the optimistic trend of the scenarios, variations in prices and inputs are available in Table 1.

Table 1. Evolution of prices (in %) defined by experts for each scenario compared with current prices of conventional agriculture for a time horizon of 10 years.

Scenario	Trend	Labour price	Product price	Machinery costs	Seeds price	Fertilizer price	Manure price	Transport price
Organic	Optimistic	+ 30%	+ 69%	+ 15%	+ 25%	+ 15%	+ 15%	+ 15%
Supply chain	Optimistic	+ 30%	+ 15%	+ 15%	+ 25%	+ 15%	+ 15%	+ 15%
Conventional	Optimistic	+ 30%	+ 30%	+ 15%	+ 25%	+ 15%	+ 15%	+ 15%

N.B. pesticide prices and costs of packing were assumed to remain the same.

Design methodology

The prototyping approach aims at systematic development of innovative farming systems (Vereijken, 1997). It has 5 main steps: (i) making a hierarchy of objectives, (ii) linking the objectives to parameters to quantify them, (iii) designing a theoretical prototype and farming methods, (iv) testing the prototype on farms and (v) disseminate the prototype. Modeling has proven to be efficient in previous studies for both systematic designing of prototypes (step iii) and testing ‘in silico’ of promising options (step iv) before implementing them on real farms (Dogliotti et al., 2004, 2005).

The construction of prototypes at field scale is both future-oriented (10 years time horizon) and target-oriented. This means that the optimal sets of inputs required to realize a target yield are identified (van Ittersum and Rabbinge, 1997). These input sets are specific to the physical environment, characterized in this study by the regional climatic and the soil types. Reduction of erosion and improvement of soil fertility and economic results of the farm directed the design process of this study.

Modeling toolkit

Based on the previous work of Dogliotti et al. (2003, 2004, 2005) a modeling toolkit was developed to carry out an explorative study. This toolkit was divided into two parts: (i) one that generates and evaluates production activities at field level and (ii) another one that selects combinations of production activities at farm level to match specified technical and socio-economic constraints, while maximizing family income (Fig. 1). Compared to the tools developed earlier, main new features are that this toolkit can handle different scenarios and that software handles both generation and evaluation. Selection of 'best options' and trade-offs between objectives is handled by an interactive multiple goal linear programming model inspired by Farm Images (Dogliotti et al., 2005).

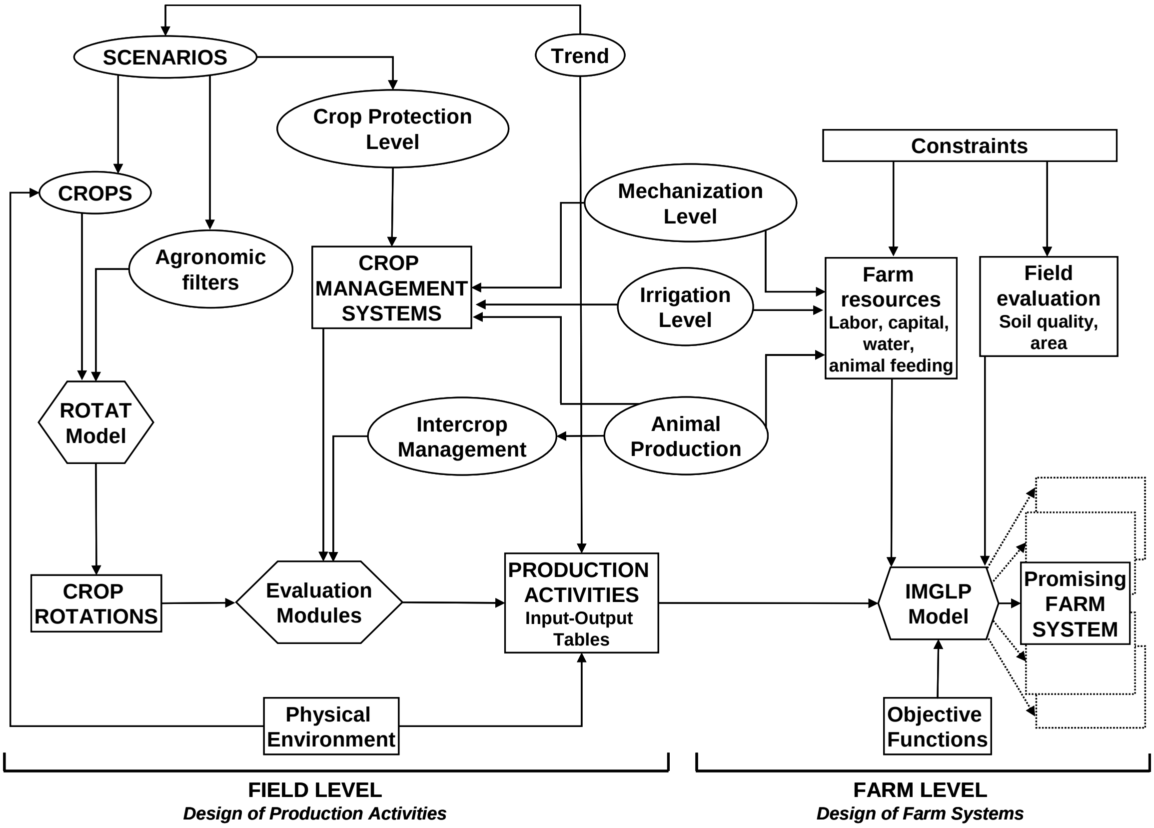

Figure 1. Overview of the modeling toolkit.

At field scale, generation of crop rotations is based on ROTAT (Dogliotti et al., 2003). The rotations are later combined with management levels (e.g. irrigation) to create what are denoted 'production activities'. Each production activity is then evaluated with sustainability indicators that represent economic (labor requirements, production costs, gross margin) and environmental (nutrient balances, evolution soil organic matter balance, evolution of erosion, exposure to pesticides) considerations, to provide input/output tables (Dogliotti et al., 2004).

At farm scale, an 'optimal' combination of production activities is calculated with the improved Farm Images model, using it in a fashion that allows exploration of the window of opportunity and trade-offs among multiple socio-economic and environmental objectives, subject to constraints (Fig. 1). Socio-economic objective functions at farm-scale were gross margin ($\$U.yr^{-1}$), family income ($\$U.yr^{-1}$), capital requirements ($\$U.yr^{-1}$) and ratio of family labor used over the total family labor available. Environmental objective functions were environmental exposure to pesticides for soil (EEP soil) (kg-days.yr^{-1}), N surplus (kg.$ha^{-1}.yr^{-1}$), erosion (Mg.$ha^{-1}.yr^{-1}$) and soil organic matter (SOM) balance (kg. $ha^{-1}.yr^{-1}$).

Case study farm

The case study farm is representative for the larger farm category of the region (Righi et al., 2009). The farm is small (3.2 ha) and specialized in vegetables (i.e. without cattle raising), with a low supply of irrigation water, enough to cover at most 1.5 ha. Crops are grown on a Typical Argiudoll soil, with on average 3% slope and 1.8% organic matter content. Family labor on farm provides 4437 man hours per year and the farm can hire an extra 200 man hours per year at most. The level of mechanization is low.

The modeling toolkit was used to explore promising options for innovative systems in this farm under the 3 defined scenarios with an optimistic trend. For the generation of rotations, the maximum number of crops per rotation, the maximum rotation length and the number and the list of candidate crops were based on expert knowledge (Table 2). Other agronomic filters such as the crop or group frequency in the rotation (i.e. the number of times a crop is grown in the rotation divided by the rotation length) or the minimum number of years before repeating a crop were also controlled by the user (Dogliotti et al., 2003). In case of the 'organic' scenario, there were 15 candidate crops, a maximum number of crops per rotation set to 9 and a maximum rotation length of 8 years because organic farming requires higher diversification of crops with lower crop frequencies. Intercrops were designed in order to improve soil quality based on expert knowledge and results of previous studies (Dogliotti et al., 2004, 2005). Three levels of irrigation (none, intermediate and high) were applied to the generated rotations to create the production activities. At farm level, for running the IMGLP, for each scenario we set the maximum number of crops per farm and the maximum number of production activities (Table 2). We also set the minimum family labor use to 50% to keep the farming system familial and we set a minimum soil erosion value for each scenario, approaching recommended local target values for soil erosion reduction (Table 2). For each scenario we performed 2 to 3 optimization rounds where we optimized all objective functions one by one.

Table 2. Criteria for design of production activities at field and farm level for the case study farm, using the modeling toolkit.

	Organic	Conventional	Supply chain
Maximum number of crops per rotation	9	6	6
Maximum rotation length (yr)	8	6	6
Number of candidate crops	15	12	12
Maximum number of crops per farm	10	7	7
Maximum number of production activities per farm	3	3	3
Minimum soil erosion (Mg.ha^{-1}.yr^{-1})	5.5	6.3	5

Results and discussion

Generation of rotations and production activities

At field scale, the ROTAT model generated 2800, 3495 and 9147 rotations for 'conventional', 'organic' and 'supply chain' scenarios, respectively. After applying the three possible levels of irrigation, 5672, 7048 and 19734 productions activities were created for the 'conventional', 'organic' and 'supply chain' scenarios, respectively. The larger number of rotations and production activities for the 'supply chain' scenario is mainly due to a higher diversity of candidate crops belonging to different vegetable families (e.g. Alliaceae), compared with the 'conventional' scenario and higher crop frequencies allowed in the rotations compared with the 'organic' scenario.

Selected production activities

Using the IMGLP model, either one or three production activities (i.e. crop rotations with the associated irrigation level) were found to optimize family income while respecting environmental and farm endowment constraints (Table 3). The 'organic' and 'conventional' scenarios had one production activity selected: leek/alfalfa/tomato/green beans/cabbage/red beet for the 'organic' scenario (8 years rotation, high irrigation level) and early-garlic/alfalfa/sweet potato/sweet maize (6 years rotation, high irrigation level) for the 'conventional' scenario. Three production activities were selected for the 'supply chain' scenario: chickpea/early onion /alfalfa/tomato (6 years rotation, high irrigation level), chickpea/onion/alfalfa/early onion (6 years rotation, high irrigation level) and chickpea/alfalfa/onion/tomato (6 years rotation, intermediate irrigation level). The number of crops on the farm was always lower than the maximum allowed.

The area used for the 'organic' scenario was only 69% of the total farm area (Table 3) because of the combination of limited family labor and the low ability of the farm to hire labor. Production activities in each scenario required irrigation but were not always using the full potential of 1.5 ha due to other constraints (likely labor and environmental constraints) (Table 3). In cases where the irrigated area was limiting, exploring the effects of increasing the irrigated area of this farm with the modeling toolkit could provide insights on the opportunity of setting up financial subsidies or technical advice for increasing irrigation ability on this type of farm.

Labor and economic performances of selected production activities

Best economic results (gross margin, family income and return to assets) were reached with 'organic' and 'supply chain' scenarios, but they required higher capital and production costs (Table 3). Assuming a 50% increase of the current averaged value of family income in small towns and rural areas in the coming ten years, this target value would reach 378,590 $U (but vegetable farmers' income is supposed to be lower). In our study, the only 'supply' chain scenario could reach this level. To head towards an organic or supply chain future, which provided better economic results in our study, farmers might need policy support for access to capital.

Family labor use was higher than the 50% threshold for all scenarios (Table 3). For all scenarios labor productivity was higher than the extrapolated price of labor at the end of the 10 year time horizon (assuming 30% increases over 10 years, i.e. 55 $\$U.hr^{-1}$). The 'organic' and 'supply chain' scenarios resulted in the highest labor productivity (Table 3).

Table 3. Selected production activities and their economic and environmental performances for the 'organic', 'conventional' and 'supply chain' scenarios.

	Organic	Conventional	Supply chain
Number of selected production activities	1	1	3
Rotation length (yr)	8	6	6
Number of crops on the farm	6	4	5
Area used (ha)	2.2	3.0	3.2
Irrigated area (ha)	1.4	1.5	1.1
Gross margin ($\$U.yr^{-1}$)	340,620	233,914	553,007
Family income ($\$U.yr^{-1}$)	307,425	208,634	519,812
Capital requirements ($\$U.yr^{-1}$)	233,898	171,850	261,169
Farm production costs ($\$U.yr^{-1}$)	211,703	149,655	238,974
Return to assets ($\$U.yr^{-1}$)[1]	198,166	114,913	397,193
Family labor use (-)	0.7	0.6	0.7
Labor productivity ($\$U.hr^{-1}$)	101	75	158
EEP soil ($kg\text{-}day.yr^{-1}$)[2]	801	468	354
EEP water ($ppm.yr^{-1}$)[2]	0.0	13.2	0.0
EEP air ($kgAI.ha^{-1}.yr^{-1}$)[2]	0.3	1.3	2.4
N surplus ($kg.ha^{-1}.yr^{-1}$)	64	23	85
Erosion ($Mg.ha^{-1}.yr^{-1}$)	5.3	6.3	4.7
SOM ($kg.ha^{-1}.yr^{-1}$)	859	516	358

[1] Return to assets (land, own capital and management of farm) is defined as the gross margin minus the costs of hired and own labor

[2] Environmental exposure to pesticides for soil, water and air refers to the indicators of Wijnands (1997)

Environmental performances of selected production activities

Compared to the 'conventional' scenario, the 'organic' and 'supply chain' scenarios are less harmful to the environment with regard to EEP soil and erosion (Tab. 3.). Nevertheless, exposure to pesticides for 'organic' scenario is not null because of the use of mineral products such as sulfur. N surplus is lower in the case of the ‘conventional’ scenario (Tab. 2.). N inputs were designed a priori per crop and intercrop, without taking into account N mineralized from SOM. This explains the higher values of N surplus observed for ‘organic’ and ‘supply chain’ scenarios. SOM balance is much higher in case of ‘organic’ scenario mainly because of manure application instead of chemical fertilizers but values for ‘conventional’ and supply chain’ scenarios are also acceptable as all are positive (Table 3).

Strengths and weaknesses of the approach

Results obtained in this study were strongly linked to the local conditions, making them soundly relevant for local farmers and stakeholders. Indeed, data used for defining yields and practices were based on local data, assuming best means and practices. Moreover, sub-models for calculation of evolution of soil organic matter and erosion were also parameterized for local conditions (Dogliotti et al., 2004). Finally, evaluation indicators and objective functions were defined with regards to local economic and environmental problems. The modeling toolkit was thus adapted to local conditions, and in turn it could not be used directly in other conditions. Nevertheless, the approach and the framework are usable for other regions, as long as relevant issues would be identified, objectives and indicators would be defined and model parameterized for those conditions.

So far, the modeling toolkit was not meant to be used by farmers or by other stakeholders because it was designed by and for researchers to be used to inform discussions with stakeholders. Addressing the right questions before using the modeling toolkit with scenarios is thus crucial for the researchers. Nevertheless, adapting scenarios and criteria of the model runs could always be redefined when discussing results with farmers and/or stakeholders to better fit their expectations.

This modeling toolkit offered the opportunity to combine economic and environmental aspects while contributing to design of innovative farming systems. The project started at the smallest scale, i.e. field level, and scaled up to farm level and, in this latest phase, to region level, integrating, through an iterative process, knowledge and participation of local farmers, experts, advisors and stakeholders to achieve higher impact of research on regional development.

Conclusion

In terms of economic results, the ‘supply chain’ scenario seems to present the most desirable window of opportunity for the studied farm. However, this scenario requires high capital and depends on contracts with industry. Moreover, the environmental impact of this scenario is relatively high. The ‘organic’ scenario provides good economic results while minimizing the environmental impact of the farm. Conversion from conventional farms to organic farms would require technical and financial help which depends on institutional settings. Market opportunities for organic products should also be studied in more detail in Uruguay before recommending conversion to organic farming. There is room for improvement of N management to reduce N surplus in all scenarios by adjusting N inputs depending on expected SOM surplus. Application of mineral products in organic farming should be reduced in order to decrease the environmental impact of the ‘organic’ scenario.

The model-based explorative study, illustrated here for one farm, will be applied to all farm types, for both optimistic and pessimistic trends, in order to get a regional picture of the possible futures. Those results would have to be discussed with the stakeholders to help developing local and national policy. The close interactions between research and stakeholders as part of the co-innovation approach in the EULACIAS project enable such discussions, and are planned for later this year.

References

Contini C., Gabbai M., Omodei Zorini L. and B. Pugh (2010) *Involving stakeholders in the exploration of sustainability perspectives and innovations of farming systems: a case study from Latin America.* Presentation held at the 9th European Symposium of the International Farming Systems Association in Vienna, Austria, 4-7 July 2010.

Dogliotti, S., Rossing, W.A.H. and M.K. Van Ittersum (2003) ROTAT, a tool for systematically generating crop rotations. *European Journal of Agronomy* 19: 239-250.

Dogliotti, S., Rossing, W.A.H. and M.K. Van Ittersum (2004) Systematic design and evaluation of crop rotations enhancing soil conservation, soil fertility and farm income: a case study for vegetable farms. *Agricultural Systems* 80: 277-302.

Dogliotti, S., Van Ittersum, M.K. and W.A.H. Rossing (2005) A method for exploring sustainable development options at farm scale: a case study for vegetable farms. *Agricultural Systems* 86: 29-51.

Righi, E., Pacini G.C., Dogliotti S., Aguerre V. and W.A.H. Rossing (2009) *Farm typology identification by multi-variate analysis as a method to scale-up results of integrated impact assessment.* Presentation held at the AgSAP Conference in Egmond aan Zee, The Netherlands, 10-12 March 2009.

Van Ittersum M.K. and R. Rabbinge (1997) Concepts in production ecology for analysis and quantification of agricultural input-output combinations. *Field Crops Research* 52: 197-208.

Vereijken P. (1997) A methodical way of prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms. *European Journal of Agronomy* 7: 235-250

Wijnands F.G. (1997) Integrated crop protection and environmental exposure to pesticides: methods to reduce use and impact of pesticides in arable farming. *European Journal of Agronomy* 7: 251-260.