RE-DESIGN AND 'EX-ANTE' EVALUATION OF CROPPING SYSTEMS: A MODEL-AIDED PROCEDURE TO IMPROVE PLANNING AT THE FARM LEVEL

C. Abedala[1], S. Dogliotti[1], K. Monvoisin[2], J. Groot[2] and W. Rossing[2]
[1] Departamento de Producción Vegetal, Facultad de Agronomía, Uruguay; [2] Biological Farming Systems Group, Wageningen University, the Netherlands
sandog@fagro.edu.uy

INTRODUCTION

Most vegetable farms in Uruguay are family farms producing for the internal market, which had to deal with 20 years of continuously decreasing products prices and increasing inputs and energy costs. Most farmers tried to maintain their income by intensifying and specializing their production systems, putting more pressure on already deteriorated soils and on limited farm resources. One of the causes of this downward spiral is that the adaptation of farmers to changing conditions is mostly incremental, short-term oriented and only rarely involves strategic re-design of their rural livelihood strategies as a whole. To farmers and other resource users inventing and experimenting is part of their way of life. However, small farmers are increasingly confronted with situations for which their experience provides little guidance. Here, technical advisers or extension agents can play a role in supporting the resource users' own learning capabilities so that they can make better-informed decisions to adaptively manage their land. Systems models are one of the tools with potential to contribute to better decision making by improving stakeholders understanding of their systems functioning and possibilities (Carberry et al., 2002; Sterk et al., 2006).

A bio-economic whole farm model (FarmIMAGES) was developed to explore options for sustainable development of small-holder farms in South Uruguay. This model proved useful to design alternative production systems taking into account different farm development paths and resource endowment. The results showed that for most farms significant increases in family income were possible, combined with reduction of soil erosion by a factor 2-4 and reversing soil organic matter decline. Main adaptations in farming systems concerned reducing the area of vegetable crops, implementing crop rotations including green manure, pastures, and forage crops, and integrating animal production (Dogliotti et al. 2005). These results inspired a project (EULACIAS[22]) with the aim of testing this hypothesis in a participatory context applying a model-aided procedure to diagnose, re-design, implement and evaluate innovative farm systems on 16 farms in South Uruguay.

The theoretical prototypes suggested by the explorative bio-economic model appeared too far from most farmers' current situation. In our work with them and with extension agents we experienced the need of a planning instrument more aligned with the farmers' needs and their crop-by-crop way of changing their farm systems. The inherent uncertainty in the dynamics of a farm and about the effects of management interventions makes relevant the readiness to adjust part of the planning activity and FarmIMAGES does not provide such flexibility.

In this article we present a model-aided procedure to design and evaluate cropping plans able to use the results of the diagnosis phase, the current crop plan and the field history as starting point for improvement.

METHODOLOGY

The re-design procedure is divided in three steps (Figure 1): in the first step a selection of crops and animal production activities currently implemented on the farm or new promising ones is optimized in terms of area of each crop and number of animals of each type, using linear

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programming. Constraints are based on availability of resources (land, labor, machinery and water for irrigation). Agronomic criteria and farmers' preferences are used to group the fields of the farm according to their suitability for different crops and to define minimum crop areas and maximum crop frequencies for certain crops. This module includes a subroutine to calculate and plot the resource use along the year and the economic performance of the plan. This step can also be carried out in a 'trial and error' mode by entering the crop selection and crop areas, and using the module to estimate economic results and resource use along the year. In this way the best guess of the farmer and/or extension agent can be tested. The optimal combination of crops and crop areas (defined as a range for each crop) resulting from the LP model are used as input for the second step where all feasible cropping plans are generated using the FarmSTEPS model. This model is based on the ROTAT model (Dogliotti et al., 2003). It generates crop sequences and allocates crops to fields in a farm during a user-defined planning horizon and using user-defined agronomic rules, and taking into account the history of each field of the farm. Finally, in the third step the inter-crop activities are designed and the cropping plans are evaluated using simple indicators of economic and environmental performance, inspired by the work of Vereijken (1997). These indicators are still under development.

The first and third steps of the procedure were programmed in Microsoft Excel using VBA. The FarmSTEPS model was programmed in C# .NET.

To demonstrate the model-aided procedure we selected one of the farms participating in the EULACIAS project and designed a cropping plan for three years. We compared the result with the plan designed by the research team using expert knowledge and interacting with the farmer. The latter plan is currently implemented and under evaluation on the farm.

The farm is specialized in open-field vegetable production and does animal production only for self-consumption. It has 3.06 ha of land for crops. Water availability is around 600 m^3 for summer crops, but not all the fields have access to irrigation. For this reason the fields were classified in two groups: irrigated area and rain-fed area. Labor is contributed by two full-time family workers (4800 h yr^{-1}) and temporary hired labor (600 h yr^{-1}) for harvest and planting. The farm has a small tractor with basic implements for tillage and spraying. Main current crops are table tomato, onion, garlic and butternut. Summer and winter green manure crops are grown when the inter-crop period is long enough.

Candidate crops for the irrigated and rain-fed area were selected based on farmers' experience and resources, suitability of the soil type of the farm, market possibilities, and ensuring variability in botanical families and growth period seasonality. Candidate crops were: table tomato, melon, garlic, onion, pea, butternut, sweet potato and maize for the irrigated area and the same crops except table tomato and melon for the rain-fed area. Maize was included as a crop for on-farm use only, to feed farm animals.

RESULTS AND DISCUSSION

From the 8 candidate crops, 6 entered the optimal economic selection in the first step (Table 1). The main difference with the current plan, designed by the research team interacting with the farmer, was that onion was eliminated, pea and melon entered the solution, and the area of garlic was increased. This was a consequence of the emphasis given to singular economic performance in step one. Using as input the field areas and their cropping history, and target ranges for optimal crop areas, FarmSTEPS generated 12 cropping plans for each group of fields (irrigated and rain-fed). Target ranges were defined around the optimal areas listed in Table 1 taking into account the actual field areas, to make the cropping plan feasible. The results of each plan are listed in Table 2. Despite limited variation in crop areas and successions between plans, there is still some variation in economic results and environmental impact among cropping plans. The best generated cropping plans had a theoretically better performance than the current one (Table 3). The main reasons for the improvement were that the replacement of onion by pea and increasing the area of garlic allowed a better gross margin and more opportunities for growing green manure in the inter-crop periods. However, there was a concern of the farmer about the high variability in yield and prices of fresh peas between years, together with a high concentration of labor demand during the few days of harvest.

The model-aided procedure allowed us to re-design the cropping plan for the following year adjusting yields, prices and labor demand of each crop according to previous year experience and/or market trends and new opportunities. The main lines of future improvement of this procedure is first, to increase the number of objective functions in the first step to address aims others than economic performance and to explore trade-offs between objectives, second, to improve sustainability indicators used in the evaluation phase, and third, to integrate the three steps in one computer program.

The ability of this model-aided procedure to support the users (extension agents and farmers) during the farm planning process by combining and sharing knowledge from different sources will need to be tested.

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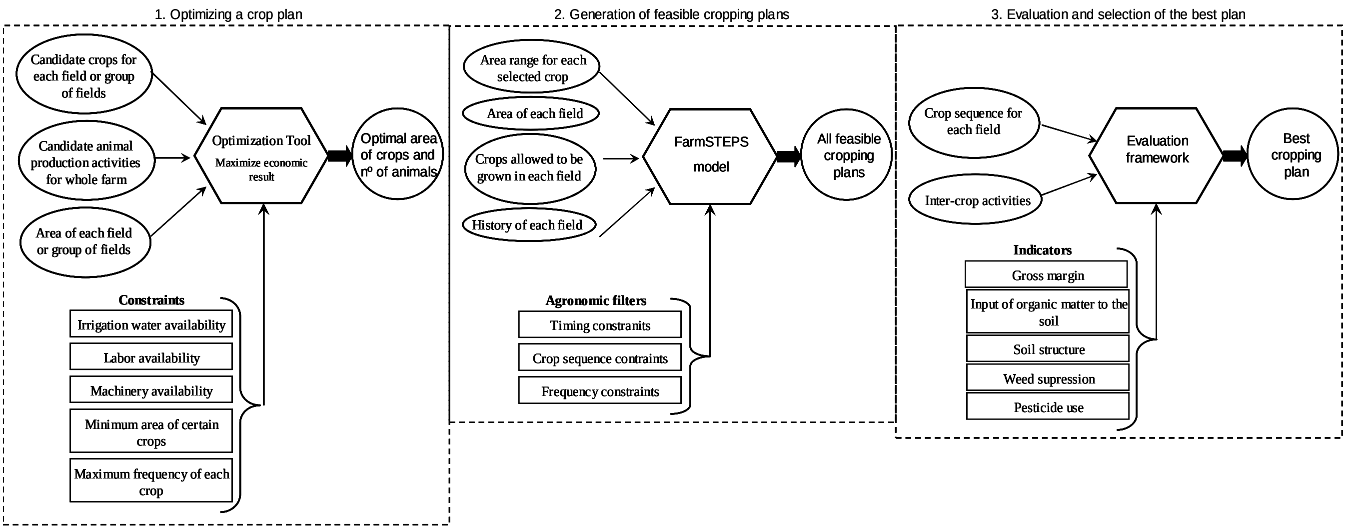

Figure 1. Overview of the model-aided design and evaluation procedure to generate a cropping plan

Table 1. Candidate crops and optimal crop areas resulting from model-aided design, and crop areas of the current cropping plan.

	New plan		Current plan	
Candidate crops	**Irrigated (ha)**	**Rain-fed (ha)**	**Irrigated (ha)**	**Rain-fed (ha)**
Butternut	0.44	0.60	0.33	0.44
Garlic	0.45	0.60	0.33	0.39
Maize	0	0.25	0	0.44
Melon	0.1	0	0	0
Onion	0	0	0.33	0.43
Pea	0	0.25	0	0
Sweet potato	0	0	0	0
Table tomato	0.35	0	0.35	0
Total	1.34	1.70	1.34	1.70

Table 2. Results of the cropping plans generated for the irrigated and rain-fed fields of the farm.

Cropping plan n°	Gross margin ($u yr^{-1})	OM input (kg ha^{-1} yr^{-1})	Soil structure	Weed supresiveness	Pesticides use
Irrigated 12	170746	5842	2.4	2.2	3.3
Irrigated 10	162606	5947	2.4	2.2	2.9
Irrigated 8	156206	5724	2.3	2.0	2.7
Irrigated 4	164346	5619	2.3	2.0	3.0
Irrigated 6	163668	5619	2.3	2.0	3.0
Irrigated 9	163764	5610	2.3	2.0	3.0
Irrigated 2	171807	5514	2.4	2.1	3.3
Irrigated 11	171904	5505	2.4	2.1	3.3
Irrigated 7	157365	5387	2.2	1.9	2.7
Irrigated 3	165505	5282	2.3	1.9	3.1
Irrigated 5	164826	5282	2.3	1.9	3.1
Irrigated 1	172965	5177	2.3	2.0	3.4
Rainfed 7	108665	5592	2.3	1.8	1.7
Rainfed 4	107085	5617	2.3	1.8	1.6
Rainfed 2	100096	5568	2.3	1.8	1.6
Rainfed 11	107423	5568	2.3	1.8	1.6
Rainfed 8	107085	5568	2.3	1.8	1.6
Rainfed 6	107308	5348	2.2	1.7	1.7
Rainfed 12	105843	5545	2.2	1.7	1.5
Rainfed 5	105843	5288	2.2	1.7	1.5
Rainfed 1	95921	5413	2.4	1.8	1.6
Rainfed 9	99201	5568	2.3	1.8	1.6
Rainfed 10	106067	5325	2.2	1.6	1.6
Rainfed 3	106019	5325	2.2	1.6	1.6

- OM input is the average amount of above ground dry matter left by crops and green manures
- Soil structure (1 to 4) indicator takes into account the soil cover, rooting, and compaction by tillage
- Weed supressiveness (0 to 4) takes into account competitive ability and control measures in crops and green manures
- Pesticide use (1 to 7) ranks the average amount of active ingredient applied per ha per year

Table 3. Results of the current plan and the best cropping plans (12 and 7) aggregated at the farm level.

	Gross margin ($u yr^{-1})	**OM input** (kg ha^{-1} yr^{-1})	**Soil structure**	**Weed supresiveness**	**Pesticides use**
Current	229203	4517	2.1	1.5	2.5
New plan	279411	5717	2.3	2.0	2.5