MODEL-BASED ON FARM DESIGN OF MIXED FARMING SYSTEMS

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INTRODUCTION

The planning of mixed farming systems with cropping and animals is complicated, since it involves many management decisions. These choices and their resulting outcomes are subject to a large range of constraints and objectives. For instance, bio-physical conditions can restrict the possibilities for allocating crops and rotations, the requirements of animals should be balanced with feed supply and the farmer will aim to optimize operating profit while also improving the sustainability of the system. Recently, various tools have been developed and applied for exploration of strategic improvements in farming systems (e.g. Dogliotti et al. 2005; Groot et al. 2007). However, tools that enable tactical planning, which can provide rapid insight into the consequences of large ranges of options would be very helpful to inform the planning process of farmers and farm advisors. In this paper we present the Farm DESIGN tool, which supports evaluation and design of mixed farming systems.

DESCRIPTION OF MODEL

A static farm balance model was used to calculate flows and balances of carbon, nitrogen, phosphorus and potassium to, through and from a farm, the feed balance, the amount and composition of manure, labor balance and economic results on an annual basis. Input data representing management options described rotations, crop groups and crops (area, yield, and destination), farm animals (species, number, weight, growth, production, and activities), feed rations, additional fertilizers, labor, equipment and buildings. Economic calculations allowed determination of crop and animal margins, fixed costs, operating profit and return to labor.

The model was applied to a 100 ha mixed organic farm named ‘Ter Linde’, located in Oostkapelle, The Netherlands. The cultivated area is divided into two rotations that are laid down in almost concentric circles around a core consisting of the farm buildings and an adjacent area for extensively used meadows, green manures, and small vegetable crops. Candidate crops for the 45.5 ha exterior rotation include potatoes, black beans, chicory, celeriac, pumpkin, red beet and sugar beet, whereas for the 35 ha interior rotation whole crop silage, celeriac, turnip, parsnip, maize for silage, sugar beet and fodder beet can be grown. In both rotations grass clover pastures are can be included. The animal herd consists of 80 Holstein Frisian dairy cows and 15 calves. During the 200 days grazing season the animals are outdoors for day grazing only.

The trade-offs between socio-economic and environmental objectives were explored by linking the farm balance model to a multi-objective Pareto-based Differential Evolution (DE; Storn and Price 1997) algorithm. With this modeling approach, alternative management options are generated and evaluated in terms of Pareto optimality. The objectives were to maximize operating profit to generate sufficient income, to minimize the labor balance to optimize allocation of labor resources, to maximize the organic matter balance to improve soil structure, and to minimize nitrogen soil losses (i.e. leaching and denitrification). The decision variables concerned the areas of cultivated crops (including feed crops), the number of milk cows kept and the destination of crop products, which could be either sold or used on-farm as feed or green manure. Constraints were set on crop areas in the rotations on the farm, the energy and protein balances of animals, the self-supply rate of feeds, and acceptable nutrient balances (N, P and K; no excessive losses and no mining). The optimization algorithm was run for

10,000 iterations on a set of 1,500 solutions, with a total processing time of two hours on a laptop with an Intel® 2.0 GHz Dual Core processor.

RESULTS AND DISCUSSION

The large result set of feasible farming systems at the end of the optimization demonstrated the relations between the objectives for this farm (Fig. 1). At a particular level of operating profit often many alternative options were possible with strongly contrasting environmental impact in terms of nutrient losses and organic matter balance. Compared to the existing situation, the operating profit and the organic matter balance can be improved considerably, labor balance can be reduced, and nitrogen soil losses can be reduced.

The various objectives were strongly conflicting. This could be explained based on the management options the model could use from (Table 1). Higher values for the organic matter balance could be obtained by growing more mixed green manure and importing more straw for bedding and feeds (high and positive correlation in Table 1). This could compensate for the increased areas of crops that have a negative impact on soil organic matter balance, such as celeriac, chicory, pumpkin and red beet. These crops were positively correlated to operating profit and contributed to lower nitrogen losses. It should be noted that the correlations in Table 1 are not always direct causal relationships; for example, the positive effect of purchased grass silage on operating profit could be attributed to the larger animal stock and consequent animal product sales that it supports.

Considering the conflicts between the objectives it would be imperative to find good compromises that address the various objectives in a balanced way. As an initial assessment of compromises we selected a set of ten solutions that showed the best aggregate performance when three of the objectives were considered equally important, and therefore received the same weight of one, and only operating profit received a weighing of 1.5. In Fig. 1 it is demonstrated that compared to the current farm configuration, the selected solutions showed some increase in operating profit at the expense of a higher labor balance, but nitrogen losses could be considerably reduced and the organic matter balance was increased in the compromise solutions. Clearly, the strong conflict between increasing operating profit and reducing labor balance (Fig. 1d) played an important role. Important consistent changes in the ten selected solutions compared to the current system included the larger number of milk cows, and higher areas of celeriac and chicory, crops that combine a positive effect on operating profit with a negative correlation with nitrogen losses. The straw purchase for bedding purchased grass silage for animal feeding was also increased in the selection, which resulted in higher organic matter balance.

The results and their interpretation showed the complexity of on-farm decision making when a large array of possible combinations of management options are available and multiple conflicting objectives are involved. Explorative approaches such as Farm DESIGN can help to understand interactions among farm components and allows what-if analyses of changes in farm organization and structure. This provides a basis for further discussion of the farm design with the farmer.

REFERENCES

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Table 1. A comparison of the values of the main decision variables for the current farm and the average of the ten selected compromise solutions, with their coefficient of variation (CV). Correlations between the values of the decision variables in the whole result set (1500 solutions) and the objectives operating profit (OP), organic matter balance (OM), nitrogen losses (NL) and labor balance (LB). Correlations of >0.50 are indicated in bold.

Decision variable	Comparison of current farm with ten selected solutions			Correlations			
	Current	Selected	CV	OP	OM	NL	LB
Imported animal feeds (kg)							
Beet pulp	70000	74673	0.05	0.41	**0.80**	**0.72**	**0.91**
Concentrate	65000	52546	0.35	0.03	**0.80**	**0.70**	**0.67**
Purchased grass silage	40000	95048	0.06	**0.59**	**0.58**	**0.58**	**0.89**
Bedding material (kg)							
Purchased straw	120000	154484	0.11	**-0.56**	**0.66**	**0.51**	-0.04
Crop areas in interior rotation (ha)							
Whole crop silage	5	5	0.08	0.31	**0.81**	**0.71**	**0.81**
Celeriac	5	6	0.02	0.27	-0.44	-0.46	-0.18
Maize silage	0	0	1.00	-0.12	0.01	0.00	-0.08
Sugar beet	3	4	0.05	0.19	-0.40	**-0.52**	-0.25
Fodder beet	1	0	0.54	0.27	-0.09	-0.18	0.10
Grass clover meadow	20	18	0.02	**0.57**	**0.75**	**0.65**	**0.97**
Crop areas in exterior rotation (ha)							
Potatoes	7	7	0.04	**0.68**	0.05	-0.22	**0.54**
Black beans	7	1	0.60	**-0.56**	-0.15	0.14	**-0.55**
Chicory	3	7	0.03	0.44	**-0.52**	**-0.70**	-0.20
Celeriac	7	7	0.01	0.05	0.02	0.01	0.03
Pumpkin	7	7	0.07	0.43	**-0.64**	**-0.68**	-0.24
Red beet	2	3	0.92	0.00	**-0.55**	**-0.64**	-0.40
Sugar beet	2	0	0.57	-0.05	0.28	0.10	0.15
Grass clover (mown)	13	13	0.14	0.27	**0.81**	**0.71**	**0.76**
Other crop areas (ha)							
Extensive grassland	3	3	0.01	0.11	0.05	0.02	0.10
Grass clover	3	5	0.00	0.07	0.21	0.19	0.17
Mixed green manures	20	16	0.04	-0.04	**0.72**	0.46	**0.53**
Number of milk cows	80	87	0.01	**0.52**	**0.80**	**0.71**	**0.97**

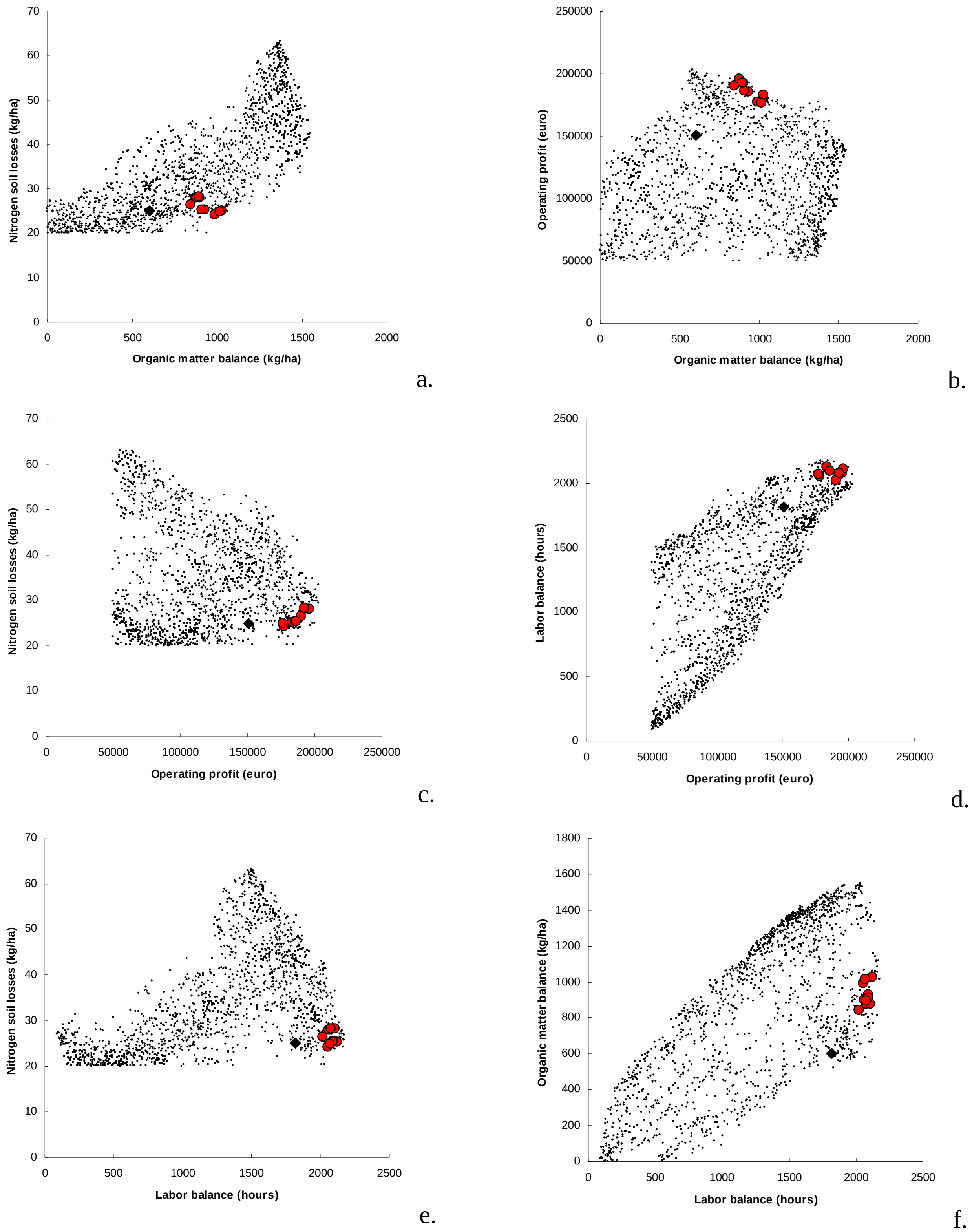

Fig. 1. Result set of multi-objective optimization, representing farm configurations (•), differing in operating profit, OM balance, N losses and labor balance. Selected ten solutions (red circles) are best when objective weights of 1.5-1-1-1 are applied. Original farm performance is indicated (♦).