FARMING IN A LANDSCAPE CONTEXT: A FRAMEWORK FOR THINKING ABOUT ECOSYSTEM SERVICES IN AGRICULTURAL LANDSCAPES

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INTRODUCTION

The deplorable state of natural resources in many parts of the World has prompted a renewed interest in farming systems designed to maximize sustainable use of natural processes, thus minimizing the reliance on external inputs. This has been an important topic in the EULACIAS project. In addition to farm-internal ecological processes, farms may benefit from natural processes operating at scales beyond the single farm. For example pest suppression by natural enemies is higher in small-scale landscapes where agricultural fields are intermixed with semi-natural elements than in large-scale landscapes (Bianchi et al., 2006). Shading of cattle (West, 2003) is an example that supports cattle production and also contributes to animal welfare, timber production, general biodiversity and landscape quality. These 'multiple roles of agriculture' (Bresciani et al., 2004) cover environmental services as well as contributions of agriculture to development challenges like food security, poverty alleviation, social welfare and cultural heritage.

In an influential paper De Groot (2006) defined ecosystem functions as 'the capacity of natural processes and components to provide goods and services that satisfy human needs directly or indirectly'. He distinguished five primary categories of ecosystem functions: regulation (with services such as water regulation, pest control), habitat (e.g. refugium), production (e.g. food, medicinal resources), information (e.g. esthetics, education) and carrier (e.g. habitation). A substantial number of these functions rely on spatial relations in the landscape. For instance, water regulation depends on the relations between locations in a watershed; pest suppression is a function of the spatial pattern of susceptible cultivars; and landscape perception depends on the pattern of landscape elements. Improving ecosystem functions requires considering multiple levels of organization: field, farm, and landscape. At each level, different indicators may describe the performance of the ecosystem, some spatially explicit, others spatially implicit or non-spatial.

Scientific efforts to improve agro-ecosystem functioning thus need to rely on methodology that deals with multiple objectives and multiple scales. In addition, various categories of stakeholders are usually involved and negotiate about solutions. Kröger and Knickel (2005; www.multagri.net) reported to the European Commission on an inventory of concepts, tools and approaches for assessing the multifunctionality of agriculture. They conclude that more holistic analytical frameworks are needed to address ecosystem functions, along with more integrative research tools, as well as more attention for education and training in inter- or transdisciplinary work.

In this paper, we present a spatially explicit, GIS-based land-use exploration methodology named Landscape IMAGES (Interactive Multi-goal Agricultural Landscape Generation and Evaluation System). The approach combines agronomic, economic and environmental indicators with biodiversity and landscape quality indicators operating at different scales, ranging from the field to the landscape. The framework has been applied in different studies in a region in the Netherlands, one of which was executed in close interaction with stakeholders. Here, we present an illustration based on Groot et al. (2007) to demonstrate analyses at the production – environment - landscape interface. Other applications addressed economy – landscape ecology – landscape quality aspects (Groot et al., 2010) and the relation between supply and citizen’s demand for ecosystem functions (Parra-Lopez et al., 2009).

CASE STUDY

The case study was located in the north of the Netherlands, in an area of in total several thousand hectares of small-scale hedgerow and pasture landscape. The hedgerows and field shapes reflect the historical development pattern and are cherished by farmers, inhabitants and tourists as a unique cultural-historical landscape. Field sizes of 2 ha on average often lined by hedgerows conflict with large-scale production-oriented dairy husbandry. Maintenance of landscape and nature values was achieved through institutional arrangements, especially so-called environmental cooperatives and subsidies to compensate for production loss, and through adapted management at field scale. An integrated assessment would allow putting the current situation into perspective and would enable exploration of alternatives in terms of agronomic, economic and environmental objectives. The integrated assessment was carried out in a subarea of 232 ha, comprising 3 farms. For the purpose of developing the assessment framework location specific data were replaced by data estimated from a range of studies carried out in the area.

DESCRIPTION OF THE Landscape IMAGES FRAMEWORK

A goal-oriented explorative modeling approach was adopted, in which goals or objectives of ecosystem management drive the way the model is developed. Four objectives were formulated: 1) maximize gross margin; 2) minimize loss of nitrogen to the environment; 3) maximize nature value of fields and borders; 4) maximize variation in the landscape. These objectives were translated into quantifiable indicators. Objective 1 was calculated as the sum of returns and subsidies minus variable costs per field. Subsidies are related to loss of grass production for nature conservation, and are linked to specific management packages. Returns were calculated in terms of milk production per ha by converting grass production to milk, based on energy content. Nitrogen loss (objective 2) was calculated as the sum over all fields of the difference between N application and uptake by grass (Fig. 1b). Nature value (objective 3) was interpreted as species abundance in the grass swards and was calculated from an empirical relation describing the relation between N availability in the soil and maximum number of species (Oomes, 1992; Fig. 1c). These relations were assumed to apply both to fields and field borders. Finally, landscape quality (objective 4) was equated to variation in the number of species between fields and to variation in the occupation of field boundaries by hedgerows, which according to local sources is typical for the area.

The system was described in a spatially explicit manner. On a map, individual fields, field borders, farm houses and roads were distinguished. A range of ‘production activities’ was defined for the fields, defined as the cultivation of grass in a particular environment, completely defined by its inputs and outputs (Van Ittersum and Rabbinge, 1997). The field borders could contain hedgerows or not. Farm houses and roads were assumed to be fixed. A constraint was set on minimum proportion of grazed herbage per farm to avoid full reliance on zero grazing with is not common in the area at the moment. A soil nutrient gradient was assumed across the region, reflected in 5 levels of soil-N mineralization ranging from 140 to 180 kg N ha^{-1}.

An agro-ecological engineering approach was used to describe the set of possible production activities per field. Fertilizer rate and harvesting regime were taken as ‘design criteria’ since they impact strongly on gross margin, N-losses and nature value. In total 11 levels of fertilizer input were defined, together with agronomically feasible combinations of 0 to 5 mowing cuts, each with 0 to 5 grazing periods and 3 dates of first harvest (earlier dates resulting in higher yearly dry matter yields). This resulted in a total of 98 to 114 feasible production activities per field, depending on soil fertility.

Outputs of the field-based production activities were described in terms of kg milk ha^{-1}, nature value and nitrogen loss.

Finding optimal combinations of the around 100 possible production activities per field and the 2 activities per field border (yes or no hedgerow) constitutes a large combinatorial optimization problem. We solved this using a heuristic optimization method called an evolutionary algorithm. This approach generates a population of solutions, in this case landscapes with specific land use per field and field border, and improves this population by changing the solutions according to rules inspired on genetic evolution. The optimization criterion was the Pareto rank of a landscape. A Pareto rank 1 indicates that in the population no landscapes exist which are better in at least one of the objectives and not worse in any of the others. Subsequent Pareto ranking of all solutions allows combination of the four objectives into one criterion, without any subjective a priori weighting. For details see Groot et al. (2007).

RESULTS AND DISCUSSION

In Fig. 2 Pareto-optimal solutions are shown after 12,000 iterations of the algorithm in terms of the objectives and an example landscape. The relations between the objectives can be seen as trade-offs, showing how much has to be sacrificed in one objective to achieve more in the other. Landscapes I and II in Fig. 2a represent extremes in the trade-off between gross margin and nature value. Landscape I (low gross margin, high nature value) is dominated by fields with production activities characterized by high species numbers and low nutrient losses as a consequence of low fertilizer inputs. Landscape II (high gross margin, low nature value) comprises more production activities where low species numbers occur. However, it also contains 14 low-input fields with production activities characterized by high species numbers where subsidies are earned. In this landscape, nutrient loss levels per field varied strongly. The strategy is to use lesser quality fields for nature conservation. From an ecological perspective, the question is whether the resulting network is effective for species conservation. This aspect was addressed in a follow-up study (Groot et al., 2010).

The effect of scale of observation is shown in Fig. 3 for nature value. Fig. 3a shows the large variation in nature value for the field level production activities. At the level of farms, averaging over fields removes extremes (Fig. 3b). Clear differences between farms were found (Fig 3b). Farm B exhibited a much larger range of species – gross margin combinations than farms A and C. The reason was that the minimum proportion of grazed herbage on farm B was smaller, leading to more solutions with mowing regimes which increased gross margin. The solution set for farm A appears shifted ‘to the left’ compared to those for B and C (Fig. 3b), most likely due to the lower overall soil fertility of farm A compared to farms B and C. This result emphasizes that development options of farms may be highly context-specific, requiring tailor-made solutions when negotiating change with farmers.

Landscape IMAGES provided the research team and the participating stakeholders with a framework for thinking about different objectives across different scales, taking into account where activities take place. The stakeholders were particularly interested in the degree of conflict between objectives to obtain more insight in their ‘negotiation space’. Another useful feature that was developed with the stakeholder was the link between solutions and the map showing the spatial consequences.

We propose the Landscape IMAGES framework as a way to link agronomic knowledge to other knowledge domains and to stakeholder needs, in order to progress towards farming systems that are able to combine internal and landscape-scale ecosystem services as part of sustainable development.

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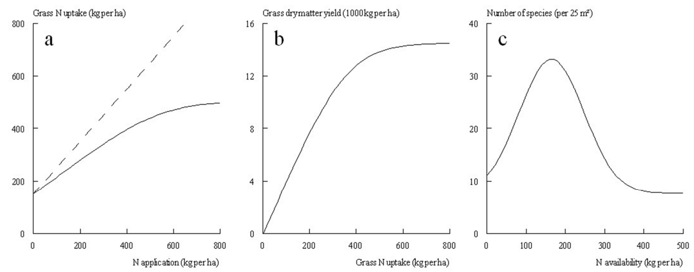

Fig. 1. Main agroecological relations used in the study.

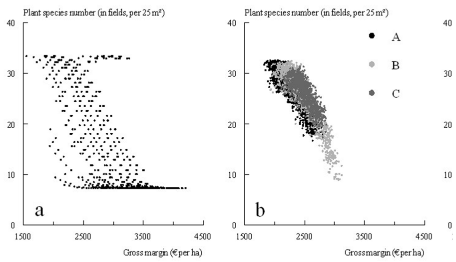

Fig. 3. Gross margin – nature relations at the field (a) and farm (b) level. A, B and C refer to 3 different farms (see map in Fig. 2).

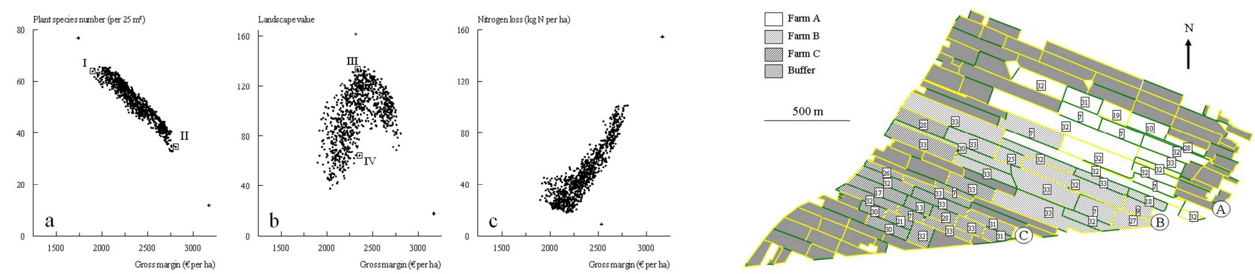

Fig. 2. Landscape scale trade-off curves between gross margin (€ per ha) and nature value (a), gross margin and landscape value (b) and gross margin and nitrogen losses (kg N per ha, c) after 12,000 generations of optimization (●). Four selected landscapes are numbered I-IV; the landscape associated with solution III is shown on the right. Extreme solutions obtained by single-objective optimization are indicated (+).