A LEARNING TOOL FOR SUSTAINABILITY AT A MIXED ECOLOGICAL FARM

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ABSTRACT

This paper presents a management control (MC-)model that supports the process of translating the complex and dynamic concept of sustainability to the operational management of a mixed ecological farm. Sustainable farm development is defined as maintaining the ability to continue in an ever-changing economic, ecological and social environment. Mixed ecological farm management focuses on effective nutrient cycles and preventive management. The primary production process is modeled in a product flow model. A negotiation process of the farmer with his environment sets a hierarchy of sustainability goals. These goals are further deployed, resulting in a farm-specific electronic handbook containing procedures and instructions in order to achieve and assure sustainability-related goals.

INTRODUCTION

This paper describes a management control (MC) model that supports decision-making of the farmer from the perspective of sustainability. It is related to a research project on mixed ecological farming (see www.agro.wau.nl/apm/efs.htm). ‘Mixed’ refers to the integration of arable and animal farming; ‘ecological’ is equivalent to organic farming. First we define our working definitions of sustainability and of mixed ecological farming. Then we describe the MC-model architecture. Finally, we provide a concrete example of how this model should be used in practice.

SUSTAINABILITY AND MIXED ECOLOGICAL FARMING

Sustainable development is maintaining the ability to continue. Hence, a farm must be simultaneously economically viable, ecologically sound and accepted by society. As the environment, constituted by these three dimensions, is constantly changing, sustainable farm management is characterized by a continuous process of resetting goals and searching for appropriate means to reach these goals. The farmer himself must set his goals by a negotiation process with his environment (Röling, 1994). This will result in a diversity of local-specific sustainable farms and management styles.

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Mixed ecological farming is widespread regarded as a promising variant for sustainability. Nevertheless it can still be further developed. Lampkin (1993) provides some key characteristics for ecological farm management. In summary, it is based on self-regulating properties that keep the effect of disturbances within acceptable boundaries. Hence, management should focus on establishment and maintenance of 1) *effective nutrient cycles* in time and space and 2) *preventive mechanisms* for pests, diseases and quality.
In conclusion, sustainable and mixed ecological farm management is complex, dynamic and knowledge-intensive. There is not a singular static goal where the system can be optimized for. In that case management is characterized by a heuristic problem solving process (Simon, 1997). The challenge for agricultural research is how this can be improved and supported.

MANAGEMENT CONTROL

The farm is viewed from a regulatory perspective. The farmer controls the production system consisting of primary processes. Control takes place based on information from an information system. The information system aggregates data derived from the production system and the environment. The environment is defined as the economic, social and ecological environment of the farm. The farmer makes decisions based on actual and historical data. Historical data allows the farmer to reflect on his own behavior so that he can obtain suggestions to improve his management.
Control can be seen as a form of problem solving. A problem can be defined as a discrepancy between a desired and actual state of the production system. If information to solve a problem is incomplete and no clear-cut method is at hand, we speak of *semi-structured problems*. In the opposite case, *structured problems* can be distinguished. These are connected with structured tasks. Structured tasks concern routine actions at the operational management level and can be typically included in handbooks. Decision support aims at conversion of semi-structured tasks into structured tasks (Keen and Scott Morton, 1987).
A perceived problem can be solved by identifying goals and accompanying means that help to achieve this goal. However, these means in their turn can be regarded as goals and so on. In this way, a whole hierarchy of goals and means can be established. It depends on the context whether a mean is a goal or a goal is a mean. In semi-structured problem situations, identifying goals and means is related with values. For example, a dairy farmer sets a certain target on his economic return. An obvious mean is milk production of the cowherd that in its turn can be set as a goal. This goal can be reached by a combination of several means. One farmer will focus on the production per cow, another on fodder production and a third one on efficient use of machinery. Thus, several styles of farming can be distinguished, which are determined by the normative behavior of the farmer.
Based on these prerequisites, the MC-model must be generic, accounting for different farms and styles. Besides, it must be flexible because goals and means will be regularly reset.

THE MC-MODEL ARCHITECTURE

The MC-model consists of three subcomponents: 1) a model of the production system: the product flow model, 2) the sustainability goal hierarchy and 3) the information system that connects the first two components and performs the translation to the operational management. All three components are combined in a relational database. Several graphical user interfaces were developed to manipulate the database. The model components will be described in the succeeding subsections, while the next section provides an illustrative example of how the model should be implemented.

The product flow model

A product flow model of the production system was made for the mixed ecological farm. Fig. 1 gives a simplified, but illustrative example. The product flow model consists of *production*

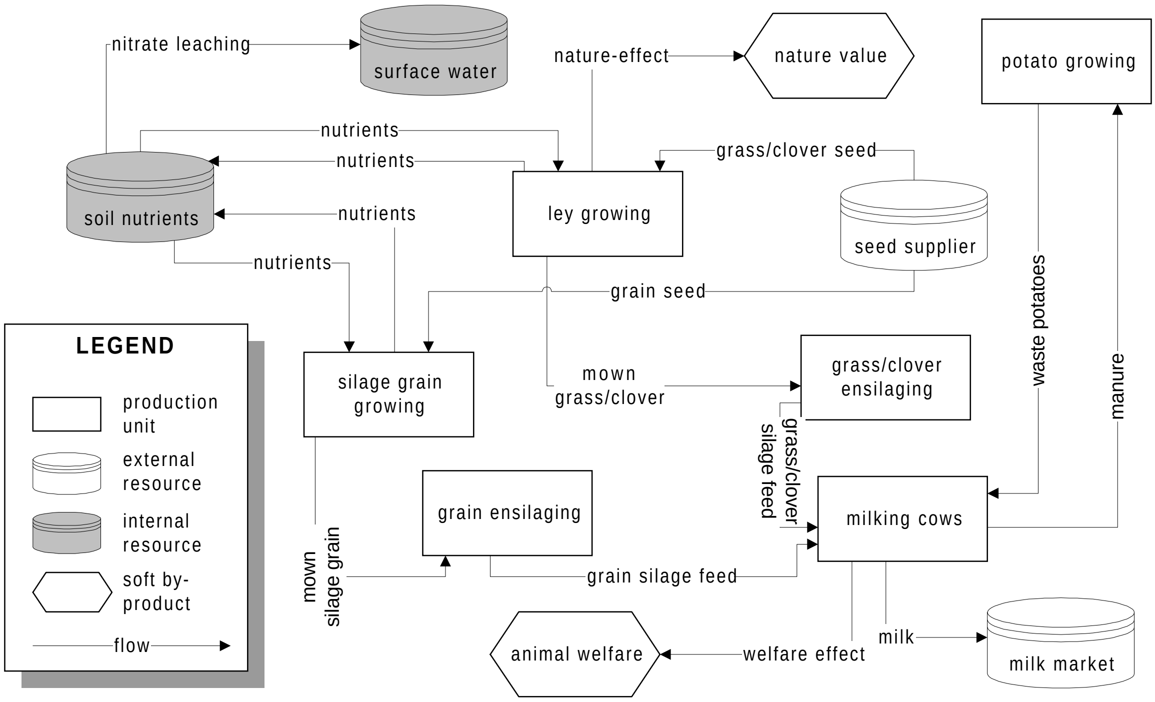

FIGURE 1. An illustrative example of a product flow model.

units between which physical products flow, such as feed and potatoes, but also by-products like manure and straw. *Internal resources* are distinguished as their (changing) states are important in relation with sustainability. The flows that are connected with internal resources are less concrete (e.g. nutrients are part of the soil or ground water), but way they are connected with managed production units that make them controllable. *External resources* are included to evaluate economic goals and material balances at the farm level. The product flow model also includes qualitative products, so-called *soft by-products*. 'Soft' indicates that the value of this product is much related with human perceptions. They are also connected with production units so that they become manageable. Various *properties* can be attached to flows. For example properties like *nitrogen content*, *dry matter content* or *smell* can be assigned to the flow manure.

The product flow model thus provides a network representation of the production system. Cyclic product flows are distinguished and inherently flows are preceded by other flows, linked by managed production units. This provides points of application for preventive management. These features link up with the ecological farming concept. Relevant resources are included, which provides points of application for managing sustainability variables.

The sustainability goal hierarchy

Sustainability as such is too complex a goal to be directly applied in practice. It must be translated or decomposed into more concrete goals that can be linked up with entities that have a meaning in practice and that can be monitored (Simon, 1997). In the context of this model, it means that a relation with the product flow model should be made. A hierarchy takes care of consistency and cohesion between goals. To obtain a well-balanced decomposition, a multifaceted-structured-entity (MSE) approach was applied (Rozenblit and Zeigler, 1986). In this approach a *root entity* is decomposed into one or more *aspects*; each aspect into one ore more *entities* and so on. The end leaves of the hierarchical tree always have to be entities. Additionally, *specialization entities* can be distinguished. For example an entity 'nutrients' could be specialized for 'nitrogen' and 'phosphorus'. The approach is applied to the mixed ecological farm and an illustrative part is shown in Fig. 2.

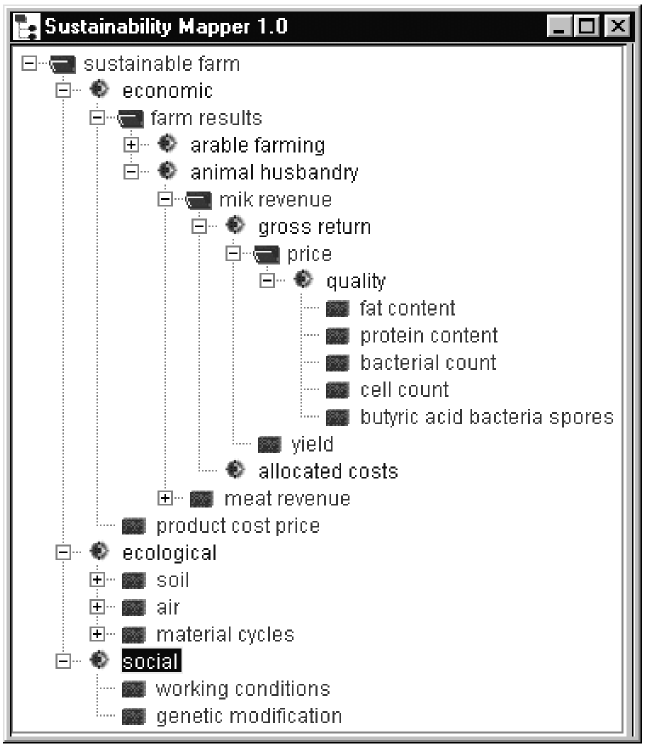

FIGURE 2. A multi-faceted structured entity hierarchical tree starting with the goal entity 'sustainable farm'. The rectangular node icons represent an *entity*; the round ones an *aspect*

Each entity-node of the tree has several attributes. A text-attribute *definition* urges the farmer to be clear. A text-attribute *comments* leaves room for arguments why the farmer has chosen this goal and why he distinguishes the underlying aspects. The attribute *goal* has a text part that formulates the goal in words and an optional value part that quantifies the goal. If a goal cannot be quantified, it means that it still has to be further decomposed. Finally a value-attribute *weight* is attached to prioritize between sibling branches. Aspect-nodes only have the text-attributes *definition* and *comments*.

The graphical user interface is a Java-application, called *Sustainability Mapper*. It is connected with the shared database, which facilitates establishing a connection with the product flow model. In a dialog window product flows can be chosen from a list that should be connected with a goal, according to the farmer's judgement. These connections are further elaborated in the third component, the information system.

In conclusion, the goal hierarchy is a flexible model component that leaves much room for subjective perceptions, and gently guides a farmer into a direction that makes sustainability more explicit and quantifiable for his specific context.

The information system

The established connections between a sustainability goal from the goal hierarchy and product flows from the product flow model must be further translated to the operational management. For that purpose a method was developed called *sustainability function deployment* (SFD). It has been taken from industry where it is called quality function deployment. The main vehicle for this method is an association matrix as presented in Fig. 3. The horizontal rows list *property goals* of a particular flow that are chosen as means (according to the farmer's judgement) for a goal somewhere higher in the hierarchy. The vertical columns list *operations* of the production unit of which the particular flow is an output. The numbers in the cells (1, 3

or 9) indicate the relationship and its strength between an operation and a property goal of a flow. Again these are also assigned according to the farmer's judgement. An *importance factor* indicates the relative importance of a property. The accumulated multiplication of the importance and relationship factors results in a value that can be used to indicate the most critical operations.
The information in the sustainability function deployment matrix is translated into an *electronic handbook.* This handbook describes the actions that must be done in order to manage the property goals that serve one or more goals, higher up in the sustainability goal hierarchy. Two sections are distinguished. First a section for monitoring the property goals, containing standardized instructions (e.g. about when and how samples should be taken). Monitoring results are entered in the database, so that evaluation can take place. A second section describes preventive measures that act as means for achieving property goals. This results in procedures per operation that must be followed when they are carried out. Procedures can consist of several detailed instructions about how to carry out certain subtasks. Procedures and instructions must not be understood as inflexible structures; they may contain for example *if-then* rules.

		operations[ley growing]					
property goals [mown grass/clover]	**importance factor**	seed purchase	soil tillage	sowing	growing	mowing	loading
sand content	**4**		3		3	9	9
grass/clover ratio	**3**			9	3		
dry matter content	**5**	3				9	
structure value	**2**	3				9	
critical operations		**21**	**12**	**27**	**21**	**99**	**36**

FIGURE 3. An example of a sustainability function deployment matrix.

AN ILLUSTRATIVE EXAMPLE

This section describes a concrete example of the methodology that is also contained by Figs. 1, 2 and 3. Three steps must be taken in order to implement the model for a specific situation. Although these steps are described in a sequential order, it is actually an iterative procedure.
First, product flow modeling takes place by mapping the primary production process of a farm. Some formal rules guide this process, although modeling leaves room for creativity. It is important that the farmer recognizes his farm in the model.
Secondly the sustainability goal hierarchy is defined, using the Sustainability Mapper application. The higher level goals will be a result of the combination of a negotiation process with the environment and the farmer's personal values. Lower level goals are a result of logical translation to the particular farm system. Fig. 2 illustrates how the economic aspect is worked out. It is related with the entity *farm results* on which a certain goal can be set. Farm results depend on revenues in the arable and animal subsystem. *Milk revenue* has a *return* and *cost* aspect. The return will depend on *price* and *yield*. An aspect of the price is *quality*. Quality can be translated into several properties of milk. Now a stage is arrived at which quantitative goals can be set and related with the product flow model. For example *butyric acid bacteria spores* are related with the flow milk that goes from *milking cows* to the *milk market* (see Fig. 1). Practical knowledge learns that these spores are produced by butyric acid bacteria during the ensilaging process. These bacteria are mainly attached to sand particles. Butyric acid bacteria spores in the silage feed are taken up by the cows and excreted in the milk. Especially for cheese making, milk must not contain any butyric acid bacteria spores.

This practical theory shows that several preceding flows are involved in this goal. An example is the flow *mown grass/clover* that goes from the production unit *ley growing* to *grass/clover ensilaging*.
In the third step, sustainability function deployment, the goal is translated into goals for particular properties of the flow (see Fig. 3). In this case *sand content* of the mown grass/clover will be important. (Fig. 3 shows that other property goals were also derived depending on other goals in the hierarchy.) Monitoring instructions must be added to the handbook to assure that sand content is correctly measured. For example, a sample can be taken from each fifth wagon that is transported from the ley to the silo. Fig. 3 shows that sand content is mostly associated with the operations *mowing* and *loading* and less with *soil tillage*. Procedures and instructions can be added like 'mowing equipment adjustment', 'use of clean wagons' and 'norms for soil tillaging to obtain a smooth ley surface'.
After initial model implementation, the handbook can be further extended with new or customized procedures and instructions in order to improve the production system. These adjustments can be derived from on-farm experiments with different modes of operations. Initial ideas for these experiments can be inspired by scientific knowledge and own observations. This illustrates that improvement concerns a heuristic problem solving process.

CONCLUSIONS

An MC-model was presented that supports the process of transforming sustainability as a very unstructured task into more structured tasks. The model links up with ecological farm management that focuses on effective nutrient cycles and preventive management. Abstract sustainability goals are set by a negotiation process with the environment. After normative, personal assessment, several goals are derived that are translated to the operational management level. This is not achieved via a strict mechanistic way, but a rather loose and flexible connection is made with the farm operations. The emphasis lays on control of product properties that in an aggregated way serve higher sustainability goals. Further achievement of goals is characterized by heuristic improvement based on learning from on-farm experimentation. It is difficult to prove to what extent the model contributes to better management. Hence, evaluation should take place by expert validation. Sustainability must emerge with the grip a farmer can get on product properties by monitoring and assurance throughout the complete production process.

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