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A dynamic product flow model for a mixed ecological farm – an ICT application for ecological agriculture

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Abstract

Specialised farming systems, which focus on producing one or few products, are characterised by high productivity but also by high amounts of detrimental emissions and low quality residual products that makes them unsustainable. Mixed ecological farming systems, which focus on several products, are characterised by processes with cyclic product flows and low levels of detrimental emissions that makes them more sustainable. In this article, a model is introduced that provides a tool for developing and managing sustainability at mixed ecological farms. This will be done from a quality assurance perspective. The core of the model is the process informatics layer that connects business control and process control. This approach structures and generates data from business processes and physical processes and in this way acts as a decision-making platform or learning environment. The model can form a basis for an operational or tactical decision-support system.

Keywords: mixed farming; product flow management; process informatics; sustainability management; quality assurance

1. Introduction

In the last few decades, Dutch agriculture became highly specialised with its extremes in factory farming. This specialisation developed alongside the introduction and application of external (artificial) inputs, mainly concentrates, artificial fertilisers and pesticides. This resulted in high-specialised knowledge levels and also high yields. However this type of agriculture turned out to be unsustainable, because all kind of detrimental emissions to the environment occurred. Recently social concerns about food safety, animal welfare, genetic manipulation and attractiveness of the landscape were added to that. A more sustainable type of agriculture is needed.

1.1. A renaissance of mixed farming?

A *renaissance* of mixed farming seems to be a reasonable pathway to come to a more sustainable agriculture (Lantinga and Rabbinge, 1996; Lantinga and Van Laar, 1997). The *a priori* advantages of mixed farming systems can be summarised as:

1) reduction of external inputs and increase of efficiency
2) a more evenly spread labour input
3) spreading of income risks

This has led to the start of mixed farming research at the APMinderhoudhoeve, an experimental farm of Wageningen Agricultural University. At this farm two mixed systems, an integrated (135 ha) and ecological (90 ha) variant, were set up. A more detailed description of these farming systems can be found in Lantinga and Oomen (1998).

1.2. Problem statement and objective of this research project

The two mixed farms were designed according to different sustainability goals. This gives rise to two questions (see Beulens, 1996):

1) Do the designed farm configurations (crop rotation, herd composition, etc.) have the potential to become sustainable or do they have to be changed? This requires a strategic modelling approach, which Bos (1998) is currently working on.
2) With the given farm configuration, how can sustainability be put into practice in terms of farm management?

In this communication a project will be described that deals with the latter question, where in the first place only the mixed ecological variant is taken into account. A modelling approach is introduced which aims to support operational and tactical farm management. The resulting model must provide a tool for evaluating and developing sustainability. Thus it will act as a kind of learning environment for those involved in developing this farm. The model could form a basis for a complete operational and tactical decision support system, although this is outside the scope of the project.

2. Mixed Ecological Management

Compared with specialised, conventional agriculture, mixed ecological farming (that is, *organic farming*) implies the following differences:

1. *mixed* – the farming system can be characterised as a network of processes with cyclic product flows between them. This means that a residual product from one process can be a valuable input for other processes (e.g. manure). While the main objective in specialised agriculture was optimising external inputs per unit product, in mixed farming optimisation of the whole process network becomes important.

2. *ecological* – ecological farm management is characterised by management of resilient natural resources, which have self-regulating and self-buffering properties, without use of external inputs (Lampkin, 1990; Van Mansvelt and Mulder, 1993;). To achieve sustainable production, it is important that the natural resources are not irreversibly exhausted or destroyed. Management of ecological farming systems is based on control of complex ecological, dynamic processes. In contrast to conventional farming, an ecological farmer does not have quick-acting instruments like chemical fertilisers, pesticides, etc., to his disposal, but has to rely on more complex ones. For example, chemical fertiliser is substituted by a multi-functional crop rotation in time and space with sufficient legumes, stimulation of soil life to make nutrients available, etc. As well as these ecological aspects of ecological farming, animal welfare and an attractive landscape are of major importance.

In the Netherlands, several farm management models already exist. However, they were developed for conventional, specialised farming. They do not account for the features described that are specific for mixed ecological farming. This calls for another approach for management support. The concept of *product flow management*, as proposed by Udink ten Cate *et al.* (1994), seemed to be a good starting point for this. This concept will be described and applied to our specific context in the next section.

3. The Process Informatics architecture

Product Flow Management is based on a system science view on the farming system: the Process Informatics (PI) architecture. This architecture is borrowed from process industry, but the application for agriculture is new. In Fig. 1 this architecture is shown from a decision-making viewpoint. The core part is the PI layer that links *business control* with *process control*. Business control refers to control of the enterprise as a whole. It deals with planning, regulatory processes and supporting functions of the enterprise. In farm management context this refers to processes like setting up a crop configuration, nutrient management, pest and disease management, human resource allocation, marketing and sales and maintenance of machines. In business control the physical production process is usually visible only at a highly abstracted level (the farm is growing potatoes, producing milk, etc.) Process control covers the actual control of this physical production process. In the farm management context it refers to processes like animal feeding, land tillage, sowing, etc.

At the bottom of Fig. 1, the physical production process is shown as a collection of processes that transform materials, life phenomena and energy into products and services. Data from this entity are modelled in a *product flow model* that provides information to the PI. The same holds for business processes, except that these are not physical processes. Hence these are represented by just one component, namely the *business information model.* This component provides general farm data (e.g. farm goals, total land area, land division in plots, financial data) and also links external data (e.g. market prices, financial information, regulations and weather data). Retrieval of external data can be automated by using Electronic Data Interchange (EDI) formats.

In the PI layer information that is generated by the product flow model and the business information model must be coupled correctly, so that decisions on actual processes can be made to meet business goals. This will finally result in actions that change the state of physical production process or the business information model and so the loop can start again. Business goals are also farmer-specific so that this approach leaves room for specific styles of farming (Van der Ploeg, 1994).

In addition to structured information, a manager would often like to compare several scenarios by doing *what-if analyses*. That could be a second goal of the product flow model: generating information. This will be much harder to model, because all variety of relationships of the physical production process need to be defined in terms of mathematical equations.
Finally the PI is also a place where qualitative information about products, and how they are produced, is gathered. This information can be used for certification, which means that a production process fulfils several rules. This certification process can be automated by formulating Product Data Interchange (PDI) formats.

4. Dynamic Product Flow Model for a mixed ecological farm

In this project a model will be developed based on the PI architecture in order to manage sustainability. The complete model is called the *Dynamic Product Flow Model*. Two main steps can be taken one after another:

1. *Try to identify and structure process data that are important for the set of sustainability goals (critical success factors)*
   This will be done from a Quality Assurance (QA) perspective (see). Quality Assurance are all those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy specified requirements for quality (Paretec, 1994). This will result in a quality handbook that contains several quality cycles. Quality cycles are recurrent acts, connected with several processes to ensure end product quality. Product quality concerns product properties (composition, colour, etc.) and how the product is produced (environmental load, working conditions, etc.) This quality handbook will be set up in an electronic format using hyperlink techniques that help to gain insight into and give an overview of the whole production process.

2. *Try to create a simulation model that generates data in order to facilitate what-if analyses*
   Here, it is important to keep in mind that optimisation of the whole process network is the main objective. The same product flow model that is used in the first step to structure process data is now used for simulation. This means that input-output(I/O) functions of several processes have to be defined. Management is not primarily interested in the contents of the processes, but rather their behaviour of transforming input to output. This means that every process can (in principle) be represented by a black box with input and output. This is called the ‘minimal model approach’ (Beers *et al.*, 1994). I/O functions can be derived by correlation and regression techniques. This approach leaves room for farm-specific functions.
   A general I/O function can be formulated as:

   $$f(I) = O$$

   From experience, a manager knows the bandwidth of several properties of an input flow that results in desired quality of an output flow. So in practice an I/O function is:

   $$f(I \pm \Delta I) = O \pm \Delta O$$

What the manager needs to know (or to learn) is what measures have to be taken to keep the input flow properties within the bandwidth? In mixed farming, this can also depend on preceding flows in the production line.
Input not lonely defines output, but input can also change the function itself:

$$f \rightarrow f'$$

Beside the bandwidth, this is a second important management instrument.

4.1. Business information model and product flow model

Two submodels can be distinguished: the *business information model* and the *product flow model*. The business information model will comprise information about the sustainability goals of the mixed ecological farm at the APMinderhoudhoeve experimental farm. Fig. 2 illustrates how sustainability can be split up and described in quantifiable goals. The goals must be split up until they can be matched in the PI layer with a manageable physical production process.
Much attention will be paid to developing the product flow model. The collection of processes at a mixed ecological farm is rather heterogeneous. To obtain a flexible, multi-purpose model, the mentioned minimal model approach was used. This approach was extended with the so-called *multi-input, multi-output process (MIMOP)* approach (Jansen, 1998), which means that input and output are further split up. This resulted in a conceptual product flow model as shown in Fig. 3.

4.2. Model instantiation – a practical illustration

The conceptual product flow model was instantiated for this specific case, the mixed ecological farm at the APMinderhoudhoeve. Part of this result in shown in Fig. 4. For simplicity's sake only the 'product flow view' is shown; internal resource flows, emission flows and by-product flows are drawn, but not visible. Natural resources are shown at the top. From there, several internal resource flows flow, mainly to the growing process units. An example of an emission flow, is NH_3-emission from the 'milk production (cows)' process unit to the natural resource 'air'. Product flows from several process units converge finally into the 'milk production (cows)' process unit that produces milk and meat as end products, finally leaving the farm. 'Concentrate factory' is an external resource that provides concentrates. To balance this nutrient import, home-grown wheat and oat is sold to the concentrate factory so that, in fact, nutrients are exchanged. Another interesting details is the 'waste potatoes' flow to the 'milk production (cows)' process unit. This is an intermediate flow from the potato production line (which is not shown here) to the milk production line. Waste potatoes are a residual product of potato production, but forms an energy-rich feed source for the cows. Manure is split up into solid and liquid manure and is separately stored. During storage, manure's composition is changed and this can be influenced by management measures (e.g. reversal of the solid manure heap). Stored manure is applied to several growing processes that (sometimes indirectly) deliver animal feed (cyclic product flows!). Some of these growing processes also deliver valuable residual products like straw. Straw is important for animal welfare and health. Straw for bedding results in a higher amenity value of 'natural' production. Straw for feed adds structure to the cow's diet, which positively influences health.

The next step is to attach relevant data to these specific components of the product flow model, in particular to the various flows. This process of knowledge acquisition should be carried out in interaction with the farm manager and, in this specific research setting, with several other experts.
If we suppose that the milk produced is used for cheese making, an important quality parameter (critical success factor) is the absence of butyric acid bacteria spores in the milk. For the farmer, this is an important parameter that needs to be watched and guaranteed. Fig. 5 shows what a quality cycle for this business control process might look like. This figure shows that quality assurance for this parameter involves several process units and connecting flows. For these flows, several property bandwidths can be set and by experimenting the farmer can try to get grip on the I/O functions.
Other business control processes will also involve the same process units. In this way a list of measures per process unit can be constructed. Each process unit gets a list of measures that can be connected with several sustainability goals. The other way around, a sustainability goal gets a list of connected process units and accompanying measures.

5. Conclusions

In this paper a dynamic product flow model was outlined as a tool for developing sustainability in mixed ecological farming systems. Sustainability goals are defined in terms of business processes that must be connected with the actual production process. As long as a goal cannot be connected with a manageable process, it remains purely hypothetical.
Using this modelling approach, sustainability is not being imposed from above, but develops in proportion to the grip on quality improvement the farmer can get. The farmer does not talk about products per unit, but qualities that need to be watched, guaranteed and controlled during the complete production process.

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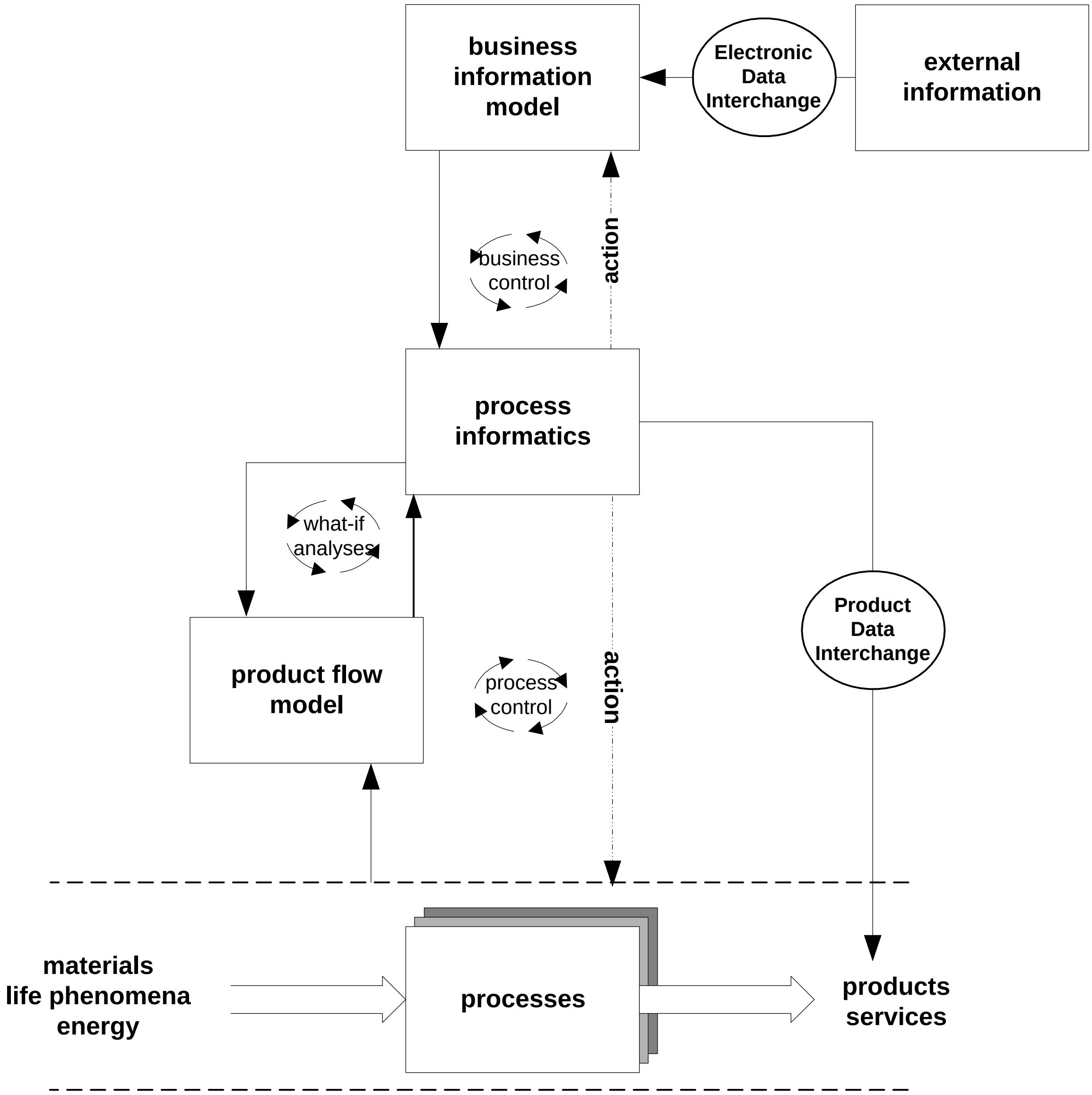


Fig. 1. Process Informatics as a decision-making platform.

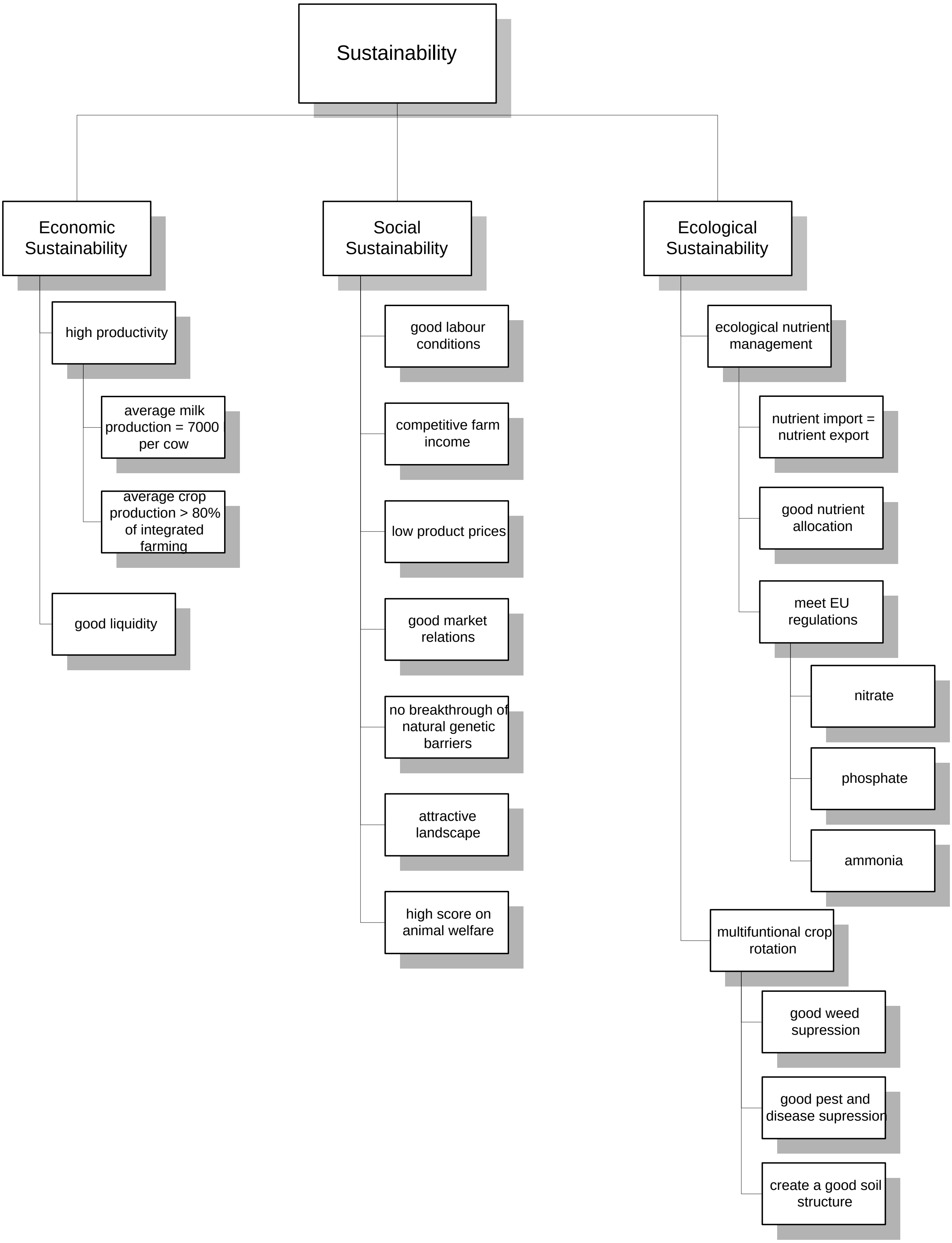
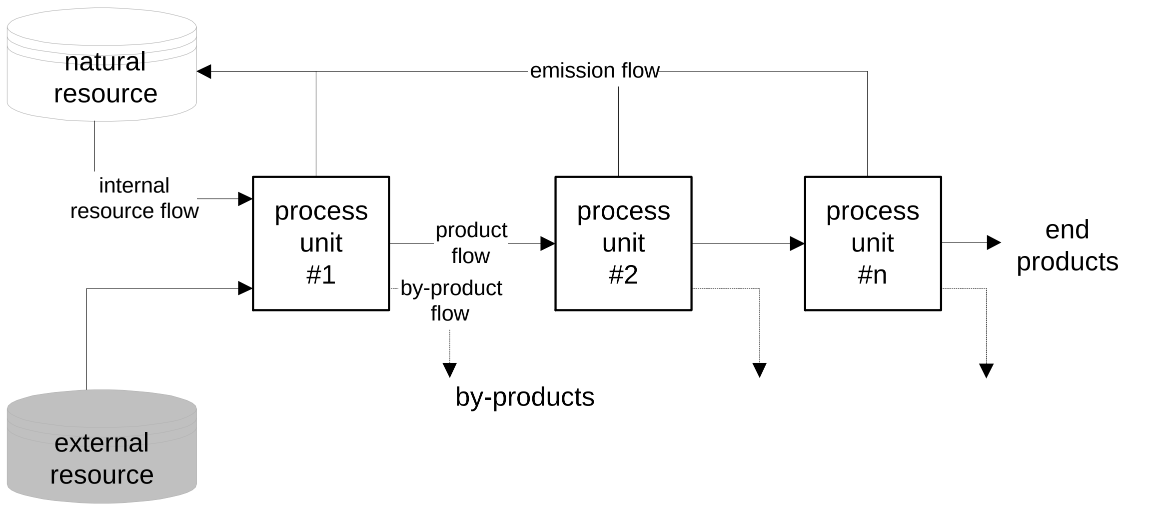


Fig. 2. Detailing sustainability goals. This diagram is not an exhaustive list. Several goals must be further split up before they can be matched with a specific process.



Definitions:

natural resources	these are internal resources that naturally exist in the farming system (e.g. soil nutrients, soil water, air)
internal resource flow	material flow from a natural resource to a process unit (e.g. nutrient uptake, water uptake, carbon assimilation)
external resources	these are resources outside the farming system (e.g. concentrates factory, fuel company, seed company)
process unit	represents a process (e.g. potato growing, ensilaging, straw storage)
product flow	material flow between two process units or between an external resource and a process unit (e.g. wheat, mown grass, concentrates)
emission flow	material flow between a process unit and a natural resource (e.g. NH_3-emission, N-leaching, biological nitrogen fixation)
by-products	qualitative, immaterial products (e.g. soil structure, animal welfare, amenity values)
by-product flow	qualitative effect on by-products
end products	products that are sold (e.g. milk, cabbage, potatoes)

Fig. 3. Conceptual product flow model with its basic components

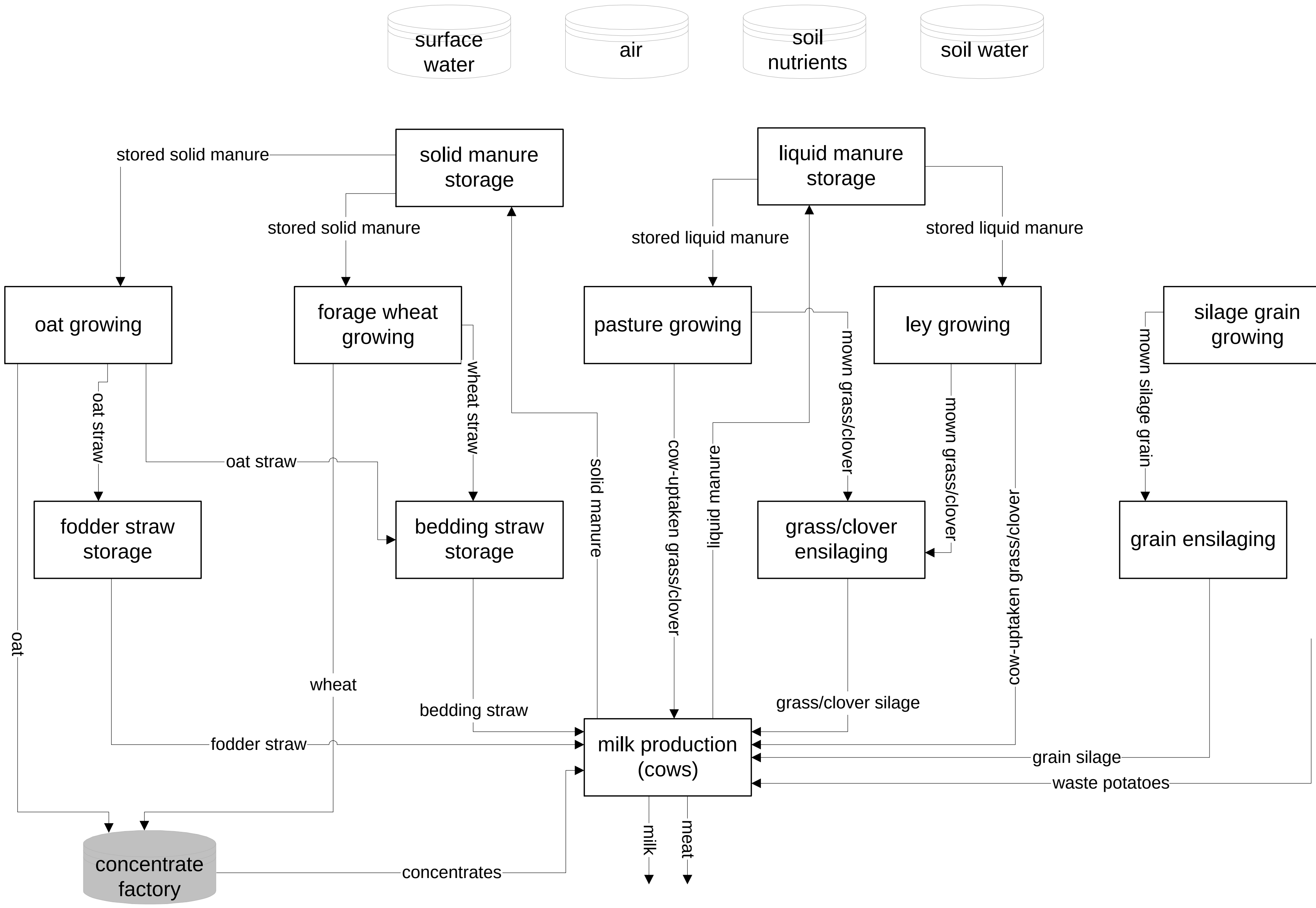


Fig. 4. Product flow model of the milk production line (product flow view). Further explanation in text.

Quality cycle

Name: *butyric acid bacteria spores*

Goal: Milk produced by the milk production (cows) unit may not contain butyric acid bacteria spores

Reason: Cheese production will fail if milk contains butyric acid bacteria spores.

Measures to take	Involved process units
• prevent mole hills	ley growing; pasture growing
• adjust mowing machines	ley growing; pasture growing; silage grain growing
• clean mowing equipment (wagons)	ley growing; pasture growing; silage grain growing
• mow at a dry matter content of > 40%	ley growing; pasture growing; silage grain growing
• clean trench silo before ensilaging	grass/clover ensilaging; grain ensilaging
• take care of clean cows	milk production (cows)
• clean udder before milking	milk production (cows)
• …	

Fig. 5. An example of a quality cycle.