Livestock Science 139 (2011) 150–160

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

A conceptual approach to design livestock production systems for robustness to enhance sustainability[☆]

J. ten Napel[b,*], A.A. van der Veen[a,b], S.J. Oosting[c], P.W.G. Groot Koerkamp[a,b,c]

[a] Wageningen University, Farm Technology Group, P.O. BOX 17, 6700 AA Wageningen, The Netherlands
[b] Wageningen UR Livestock Research, P.O. Box 65, 8200 AB Lelystad, The Netherlands
[c] Wageningen University, Animal Production Systems Group, P.O. Box 338, 6700 AH Wageningen, The Netherlands

ARTICLE INFO

Keywords:
Robustness
Resilience
Livestock production
Systems theory
Perturbation
System design

ABSTRACT

Existing approaches to enhance sustainability of livestock production systems focus on the level of sustainability indicators. Maintaining the level of sustainability in the face of perturbations, which is robustness of sustainability, is relatively unexplored. Perturbations can be classed as noise (common in a specific system environment), shock (uncommon, either in occurrence, magnitude or duration), cycle or trend. Livestock production systems are hierarchical structures of nested systems. Lower system levels are from the biological and ecological domains (animals and micro-organisms), intermediate levels are predominantly from the technical domain (pen, barn and herd) and higher levels are from the social domain (production chain, livestock production sector). Resilience theory is the model for maintaining system features in the presence of perturbations in ecosystems and social systems. It is merely a descriptive approach, due to the low level of design and human control in these systems. Robustness theory is an equivalent model to describe and understand the maintenance of system features in biological and technical systems under perturbations. Additionally, robust design theory distinguishes concept design (choice of concept, components and materials), parameter design (optimal configuration of control factors given the concept design) and tolerance design (eliminating causes of variation) to deal with perturbations and their effect on the system. Technical systems of current livestock production systems are heavily based on tolerance design, but an interesting opportunity for new designs is to utilise the animal's intrinsic adaptation capacity and incorporate concept design and parameter design for over-all robustness. Concept design strategies for robustness include diversity and heterogeneity of components, functional redundancy and modularity. A fourth level of design, called hierarchy design, is needed to ensure that higher system levels support lower system levels of livestock production systems for optimal robustness. To enhance over-all robustness of livestock production systems for sustainability, a specific approach is needed for each system level and these approaches should be integrated and balanced.

1. Introduction

Livestock production systems (LPS) changed substantially during the last 5 decades in western societies like Europe by incorporating new knowledge and technology, after food security policies focused on higher agricultural production quantities, low food prices and high food quality (EU policy framework). As a result, agricultural systems were able to improve production quantity and quality significantly, backed by governance measures and enhanced knowledge and technology. Negative side-effects of the success of this agricultural system, however, are becoming more and more visible. The intensification and optimization in livestock production systems, and the global trade of feedstock and

☆ This paper is part of the special issue entitled: Assessment for Sustainable Development of Animal Production Systems, Guest Edited by Akke van der Zijpp.

* Corresponding author at: Wageningen Livestock Reseach, P.O. Box 65, 8200 AB Lelystad, The Netherlands. Tel.: +31 320 238 222; fax: +31 321 238 050.
E-mail address: jan.tennapel@wur.nl (J. ten Napel).

1871-1413/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.livsci.2011.03.007

animals, have put a major pressure on animal welfare and the environment. Social acceptance of intensive livestock production systems is therefore decreasing. The currently common way of keeping and managing livestock has also proved to be vulnerable to outbreaks of infectious diseases, like the classical swine fever outbreak in the Netherlands in 1997 (Bos, 2004). This has fuelled the demand for more sustainable LPS that provide the farmer with a reasonable and stable income and consumers with products of the desired quality and safety, without detrimental effects on the well-being of animals, human health or the environment, and that are acceptable to society. Various approaches exist for quantifying the level of sustainability of LPS by means of sustainability indicators that cover the ecological, economical and social aspects of sustainability (Boogaard et al., 2008; Mollenhorst et al., 2006).

Little attention has been given to variation in time and space of the sustainability indicators of LPS, particularly when faced with perturbations inside and outside the LPS. For arable production, Fresco and Kroonenberg (1992) considered stability and resilience to be integral components of sustainability. Stability and resilience refer to maintaining the function in changing conditions. In LPS, the predominant strategy to maintain its function is to control variation by controlling conditions and keeping out perturbations. Although this has proven to be a successful approach, the drawbacks of completely relying on this approach are accumulating (Ten Napel et al., 2006).

We aim to reconsider the way in which animal production systems are designed, configured and implemented given the omnipresence of perturbations and the need for stable performance in terms of sustainability indicators. The objective of this paper is therefore to identify and discuss current and new strategies for LPS to maintain sustainability in the face of perturbations. We start with defining our terminology, with examples of LPS in systems-theoretical terms. We review the concepts in literature on maintaining system features of interest in the face of perturbations, apply these concepts on pig production and draw lessons for LPS in general.

2. Background on systems theory

2.1. Systems terminology

2.1.1. System definitions

A system is a collection of elements, that can be distinguished from the universe (total reality), with relationships among elements in the collection and possibly also with elements in the universe. Elements of a system can be either dead, referred to as objects, or alive, referred to as subjects. Elements have certain characteristics, named attributes, and these attributes have quantitative values. Elements of a system can have a single or double-directional relationship, whereby 1) the attribute of one element affects the attribute of another and possibly vice versa, 2) a change in the value of an attribute affects the value of the attribute of another element, or 3) elements influence each other's spatial location. A relationship refers generally to transport, transfer or accumulation of mass, energy or information (Pahl et al., 2007).

The choice of the system border heavily depends on the goal of research or problem studied. By defining a system and its borders we implicitly make a simplified model of the real world and create a so-called ‘model system’. The environment of the system consists of the collection of elements of the universe that influence the elements within the system, without being part of it. The interaction between the environment and the system, being either mass, energy or information, is defined by the input, which is the effect of the environment on the system, and output, which is the effect of the system on the environment of the system. A subsystem is a subset of the elements within the system, with unchanged relations.

The state of a system at a certain moment in time is determined by 1) the complete collection of elements at that moment, 2) their internal and external relations, and 3) the elements' attributes and their values. Both attributes and their values can change in time, but relations can, too. We call such a system dynamic or time varying. Time-varying input and output are referred to as signals (In 't Veld J., 1975). Two cases of systems in pig production are described in terms of the above definitions in Table 1.

2.1.2. Function, requirements and performance

The function of a system is its contribution to a higher system level. A function is qualitative in its description. A system can deliberately be designed to perform a predefined function, or just perform an evolved function. The functions of a pig farm are to supply pigs to a slaughterhouse and generate income and work pleasure for the farmer (Table 2).

Just performing the function is not sufficient in most cases. The income generated by a pig farm needs to be reasonable and stable. The production of pigs must not cause irreversible damage to the environment. These are requirements on the system function. Requirements are precise descriptions and preferably measurable in quantitative units.

The performance of a system is a quantitative reference to a system feature that is related to the execution of a system function and in an evaluation compared with the requirements on the system function. Requirements and performance generally relate to quantitative aspects of

- the output (e.g. amount, rate or quality of output),
- the input,
- the combination of input and output (e.g. efficiency),
- the values of attributes of elements within the system (e.g. state of welfare of animals),
- a relationship between elements (e.g. milk yield of a sow for piglets).

The function and performance indicators for the two cases of systems in pig production are described in Table 2. Sustainability is increasingly becoming part of the requirements on the function of livestock production systems and has ecological, economic and social aspects.

2.1.3. Hierarchy, spatial scales and time scales

Most systems are part of a hierarchical structure of systems with many interactions between finer and coarser system levels (Holling, 2001; Kitano, 2004). Systems at a fine system level are large in number, take up little physical space and have a short time cycle. Systems at a coarser system level are smaller in number and have relatively large spatial and time scales. Table 3 describes system levels that can be distinguished in pig production, as well as their approximate spatial and time scales.