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Abstract
A concept and method are developed and applied to improve robustness in animal production

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Robustness of animal production systems: concept and application to practical cases

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December 2010

Samenvatting

Dierlijke productiesystemen functioneren in dynamische en diverse omgevingen. Verstoringen in deze milieus beïnvloeden het functioneren van het systeem en veroorzaken verlies van efficiëntie, toename van vervuiling, meer verspilling van grondstoffen en extra kosten voor aanpassing en reparatie met management. De huidige trends van schaalvergroting en toenemende eisen aan duurzaamheid van dierlijke productie vergroten juist de impact van verstoringen op het systeem.

Het doel van dit project was daarom om op een gestructureerde manier uit te zoeken hoe systemen in dierlijke productie de gevolgen van algemene verstoringen kunnen beperken met het ontwerp van het systeem in plaats van met management.

Er bestaan twee theorieën op dit gebied. De Resilience theorie is een beschrijvende methodiek die vooral van toepassing is op ecosystemen en complexe sociale systemen. Robustness theorie is juist ontwikkeld voor technische en biologische systemen. Voor industriële productie is deze theorie uitgewerkt in een praktische methode, met de naam Robust Design.

In dit project is deze methodiek geschikt gemaakt voor praktijkdata om ook de robuustheid van bestaande systemen in dierlijke productie te vergroten. De kern van deze methodiek is het gebruik van SN ratio's. De SN ratio die hoort bij optimalisatie van de variatie gegeven het niveau is bruikbaar om instellingen te vinden die variatie in het functioneren van het systeem verminderen, maar kan ook gebruikt worden voor het vinden van manieren van werken die de adaptatiecapaciteit van dieren vergroten.

Summary

Animal production systems operate in dynamic and diverse environments. Disturbances in these environments influence system performance and cause undesired loss of efficiency, increased pollution, a higher waste of resources and extra costs for adaptive management. Current trends of scale enlargement and demands for more sustainable production increase the impact of disturbances.

The aim of the project was to evaluate in a structured manner how systems in animal production can reduce the impact of common disturbances by design instead of management.

Two theories exist on this issue. Resilience theory has been developed for ecosystems and systems in the social domain. It is mainly a qualitative and descriptive approach. Robustness theory has been developed for systems in the technical and biological domain. In engineering, robustness theory has been developed into a practical approach, called Robust Design.

In this project, the methodology of Robust Design was extended to field data analysis in order to make existing systems in animal production more robust to common disturbances. The core of this methodology is the use of Signal-to-Noise ratios. The SN ratio that applies to nominal-the-best optimisation can be used to identify settings that minimise variation in performance, but also to identify management routines that build up adaptation capacity of animals.

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1 Objectives and scientific approach

1.1 Introduction

Livestock production systems changed dramatically during the last five decades in western societies like Europe by incorporating new knowledge and technology. The driving force behind these changes were food security policies focussing 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. The intensification and optimization in livestock production systems, and the global organization and trade of feedstock and 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 crises such as outbreaks of (highly) infectious diseases, and contamination of large volumes of feed. This has fuelled the demand for more sustainable Livestock production systems 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 Livestock production systems by means of sustainability indicators that cover aspects of the whole range of economic, ecological and social demands. Little attention has been given to variation in time and space of the sustainability indicators of livestock production systems, particularly when faced with disturbances inside and outside the system. The predominant strategy in livestock production systems to maintain sustainability and avoid unwanted variation is to control conditions and keep out disturbances. Robustness of a system is the ability to maintain sustainability in the presence of disturbances.

1.2 Objective

The objective of the project was to transfer and develop the theoretical concept of robustness to livestock production systems and apply the concept in various practical cases for different hierarchical system levels.

1.3 Scientific approach

The objective was further divided into four research questions and each one was addressed in a work package. The focus of the first work package was on an analysis of current strategies in animal production systems for achieving stability. The aim was to develop a coherent conceptual framework for interpreting animal production systems in practice. The second work package focussed on potential new strategies for designing livestock production systems for robustness, based on existing concepts and control models in other scientific and practical fields.

During the process it became clear that it was more efficient to combine the first two work packages, as there was a great deal of overlap between the two questions. The main activities were a review of literature and an structured application of these models to livestock production chains from individual animal to global production. Pig production chains were used as an example.

The third work package focussed on quantifying robustness. Robust engineering design appeared to be a promising approach to measure and quantify robustness and compare concepts and configurations. The main activities were to extend the Robust Engineering Design theory to field data and apply the new method to field data of a commercial hatchery for identifying whether certain genetic lines or feed suppliers of the breeder herds induced variation in first-week mortality and 7-d broiler weight.

The fourth work package focussed on design for robustness. The objective was to demonstrate the process of designing for robustness using Robust Design. Two studies were carried out. The first study involved an experiment into hatching and early rearing of layer chicks. The second study focussed on the design of a robust panel to evaluate the presence of boar taint in pork of uncastrated boars.

2 Summary of results and recommendations

2.1 Work packages 1 and 2: Current and new approaches to achieve stability in livestock production systems

Livestock production systems are complex systems consisting of subsystems from the biological, ecological, technical and social domain. Approaches in literature to dealing with disturbances and dynamic environments exist for each of these domains. These approaches can be divided into the resilience approach for the ecological and social domain and the robustness approach for the biological and technical domain.

Resilience theory is the model for maintaining system features in the presence of disturbances in ecosystems and systems of the social domain. It is merely a descriptive and qualitative approach, due to the low level of design and human control in systems of these domains. Key features of resilient systems are (1) sustained individuality and diversity of components, (2) localised interactions between components and (3) an autonomous process that favours the most favourable interactions in a given context, such as natural selection.

Robustness theory is an equivalent model to describe and understand the maintenance of system features in systems of the biological and technical domain. This theory presupposes a form of (central) control, such as the brain in an animal, a control feedback loop in electrical equipment or a stockman in an animal production unit. Key features of robustness across the biological and technical domain are (1) system control, to perceive and monitor disturbances (2) diversity, to have alternative pathways available, should one fail, (3) redundancy, to have sufficient extra capacity for an adaptive response, (4) modularity, to keep any damage local, and (5) decoupling, to remove low-level variation from high-level function.

Livestock production systems are also hierarchical structures of nested systems. Lower system levels are from the biological and ecological domain (animals and micro-organisms), intermediate levels are predominantly from the technical domain (pen, barn and herd) and higher levels are increasingly from the social domain (production chain, livestock production sector). To enhance robustness of livestock production systems for sustainability, a specific approach is needed for each system level and these approaches should be integrated and balanced.

Robust Design theory is particularly applicable to systems that mainly belong to the technical domain. It distinguishes *concept design* (choice of concept, components, relations and materials), *parameter design* (optimal configuration of control factors given the concept design) and *tolerance design* (eliminating causes of variation). System levels of current livestock production systems in the technical domain are heavily based on tolerance design, but an interesting opportunity for new concept designs is to utilise the animal's intrinsic adaptation capacity and incorporate concept design and parameter design for over-all robustness. Other 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. In work package 3 and 4, the focus is on developing the parameter design for existing and new animal production systems.

The robustness theory can be applied both to design production systems and breeding of animals. Genetic selection is also a form of design and can be used to increase the likelihood of successful adaptation. Breeding for robustness is possible through avoiding inbreeding depression, utilising heterosis, using multi-trait selection, reducing environmental sensitivity in the target range of production systems and through breeding for group performance. Environmental sensitivity may be reduced through natural selection, using genetic correlations between environments, using reaction norms or through selection for a lower residual variance within progeny groups of sires.

2.2 Work package 3: Quantification of robustness in livestock production systems

In Robust Design theory, robustness is quantified with signal-to-noise ratio's (SN ratio). A SN ratio is a measurement of the extent to which the intended or expected system performance is corrupted by the dynamics and diversity of the system environment. The definition of the SN ratio depends on the optimisation objective of the level of the variable of interest (lower-the-better, nominal-the-best, higher-the-better, most-linear, least-variable, etc).

An essential aspect of Robust Design experiments is inclusion of uncontrollable factors that contribute to the dynamics and diversity of the target environment. This is counter-intuitive to most researchers who aim to standardise the experimental conditions. Such factors which cannot be controlled or are not controlled voluntarily (for example because it is too expensive) are included in the design as noise factors. Factors that can be adjusted to change the performance of the system are included as control factors.

The existing approach in Robust Design is based on efficient experimentation. It relies heavily on equal numbers of observations per factor level and is generally unsuitable for analysis of field data. The challenge is to replace the terms in the formulas of the SN ratio with terms that can be estimated in an analysis of field data. The SN ratio for nominal-the-best optimisation contains sample size, sample mean and sample variance. The squared residual approach was found to be an alternative method to estimate the sample variance of a control factor level across levels of other factors in unbalanced and dependent designs.

The first step of this approach is to analyse a trait of interest with the proper statistical model. This yields estimates of the sample means for each level of each control factor. The second step is to retrieve the residual of each observation and take the square. The squared residual is then analysed with the same statistical model, except for covariates and random effects, as if it were an observed trait. The average squared residual of a control factor level is an estimator of the sample variance. A signal-to-noise ratio can then be calculated for each factor level using the estimated sample means from the first analysis and the estimated sample variances from the second analysis.

It was shown with a simulation study that this method was successful in identifying the least variable levels of control factors in a sample in the presence of noise factors and that it is highly robust to deviations from a balanced and independent design. Analysis of the data from a hatchery showed that there is substantial variation among genetic strains and among feed suppliers of breeder herds in robustness of 7-d broiler weight, but not in robustness of first-week mortality.

The simulation study also highlighted the need for a sufficiently large sample size. With small sample sizes, there is a substantial risk that the least variable level in the sample is not the least variable level in the population. To keep the probability of a sample with an incorrect least-variable level below 10%, a sample size of 375 is needed if the difference between the two least variable levels is 10%, 100 if the difference is 20% and 21 if the difference is 50%.

2.3 Work package 4: Design for robust animal production systems

The initial objective was to design and implement a Robust Design experiment. Robust design experiments differ from research experiments to develop generic knowledge (1) by using an experimental design based on orthogonal arrays for efficient experimentation, (2) by inclusion of common disturbances as noise factors in the experimental design and the statistical model and (3) by analysis of a signal-to-noise ratio of the trait of interest instead of the trait itself.

The aim was to collaborate with a commercial hatchery for configuring the incubating and hatching settings for minimal variation in chick quality. The incubating and hatching process would be a suitable case to demonstrate the project, because the conditions are controlled or monitored and the variation between individuals is still limited. We, however, could not find a party that was interested in carrying out such an experiment. So instead we extended a running experiment into hatching and early rearing that had a disturbance in the experimental design to demonstrate the statistical analysis for designing for robustness. It means that we did not demonstrate the Robust Design characteristic of efficient experimentation using orthogonal arrays.

Our hypothesis of the first study was that longitudinal analysis of the nominal-the-best SN ratio (NTB-SN ratio) of a trait may provide information on the robustness of groups of animals that are exposed to a disturbance. Groups with a decreasing NTB-SN ratio following a disturbance may be less robust than groups with a stable NTB-SN ratio. Identifying treatments and practices that develop the robustness of animals requires a method to test the significance of differences in NTB-SN ratio.

It was shown in a simulation study that the standard error of the NTB-SN ratio due to sampling is largely independent of the sample mean and sample variance and is a function of the sample size. With a sample size of 40 or higher, the NTB-SN ratio is approximately normally distributed. It means that the meaning of a certain difference in NTB-SN ratio in terms of the variance is always the same, regardless of the trait studied, and its significance is only dependent on the sample size.

Data analysis of the early-rearing experiment with layer chicks showed that there were large differences in SN ratio of body weight and average daily gain due to early feeding and antibiotics treatment. The group with access to feed from 6 h post-hatch onwards and receiving colistin in drinking water until d 21 post-hatch showed a marked decrease in SN ratio, following a challenge with coccidiosis on d 27.

The second study into a robust design of a boar-taint panel was initially carried out with a relatively limited number of observations (N=1,021 boars, each sampled by three out of ten panellists). Analysis of this data showed that the most variable panellists had an average squared deviation from the mean of the three panellists within boars that was 3.2 times higher than the least variable panellists. More-variable panellists assess pork with different scores than the majority of panellists. Removing the most variable panellists will improve the consistency of the panel, but it needs to be established whether the most variable panellists perhaps are able to perceive compounds of boar taint, to which the majority is insensitive.

In December 2010, a much larger set of data became available (N=5,019 boars). The above analysis is being repeated and will be reported as part of a scientific article on olfactory assessment of pork of uncastrated boars.

2.4 Recommendations

- Using the key features of resilience and robustness, system levels of animal production chains should be evaluated in a structured manner for sensitivity to small and large disturbances.
- Companies at all levels of the production chains of animal products should quantify the losses due to unintended variation. As we are generally unaware which practices contribute to unintended variation, there is a large scope for improvement. Field data analysis can be a useful first step.
- To develop the approach of design for minimal variation further, additional research is required in the following areas
    - Develop for animal production the concept of loss functions for the quantification of losses due to deviations from a target
    - Extend the use of other types of SN ratios to unbalanced data and dependent designs
    - Develop the approach into a practical tool that can be used for context-specific optimisation, given the local limitations and opportunities.
    - Evaluate what this approach means for the current practice of developing generic knowledge from standardised and controlled experiments and applying it to less standardised and controlled environments in practice.

3 Societal relevance of results

When evaluating new designs of livestock production systems from a robustness and resilience perspective, it appeared that the current focus still is on designing for the potential of efficient production. Within the current developments the impact of dynamics, diversity and disturbances is dealt with by protection and repair. With the current trends of scale enlargements and increased requirements on the number and level of aspects of sustainability, this may be a dead end.

This project elaborated on a change of perspective when designing more sustainable livestock production systems. The different perspective is to design for minimal variation in the dynamics and diversity of the real world.

The project has yielded a generic approach to design for robustness through concept design, parameter design, tolerance design and hierarchical design. Parameter design using field data provides an opportunity to make existing systems less sensitive to day-to-day variation under varying conditions.

Applied to animal welfare and microbial resistance to medication: new designs should seek to utilise the intrinsic adaptive capacity of animals and prepare animals for inevitable changes that they otherwise needless perceive as stressful. This is the basis of livestock production with minimal clinical symptoms of disease and minimal use of medication in the presence of ubiquitous pathogens.

Experience with Robust Design in engineering yields a promise of using this methodology in animal production: it allows the use of lower grade material and components, it reduces labour and material cost for rework and recovering, it improves reliability and reduces operating costs and it improves the efficiency of the design process itself.

We showed that the theory is applicable to practical cases from the real world of animal production systems and chains. This offers a new basis to broaden and deepen the concept for similar complex systems as plant production systems, food and production chains, biobased production chains, etc.

The concept and the developed tools allow us to embark on context-specific optimisation. Many of the persistent problems in animal production are related to *variation* in performance and less to the *average* performance. Our current approach of applying generic knowledge developed in standardised experimental conditions may need re-consideration, as conditions in practice are dynamic and diverse. This would require a major shift in the current socio-technical regime in animal production.

4 Description and evaluation of process approach

One of the original objectives of the project was to raise the awareness of the possibility of designing systems in livestock production for minimal impact of disturbances. From an early stage onwards we have tried to involve people in animal production in the process.

The first company collected eggs and sorted them for consumption and processing. They found the subject interesting, but too premature to invest any time in at this stage. The second company was an egg-trader. They were initially interested, but when it came to data analysis, they changed their priorities and no longer wanted to share their data. The third company was a large egg producer with several farms. They were interested and agreed to cooperate, but lost all their data in a farm fire. A fourth company was a hatchery of layers. They had other research priorities. Only the fifth company (a broiler hatchery) showed interest, but preferred that we analysed their field data first to demonstrate the concept for animal production.

Hence, although the issue and the concept to design for robustness was initially appealing to all of the people, most of them did not want to be involved in the first stages. We observed something similar in the academic realm, where people appeared to find it difficult to think in terms of effects on variation in addition to effects on the average. People understand the issue, but find it difficult to visualise how that would lead to different solutions. Apparently, some kind of paradigm shift is necessary.

5 List of publications

Ten Napel, J., Calus, M.P.L., Mulder, H.A., Veerkamp, R.F., 2009. Genetic concepts to improve robustness of dairy cows. In: Klopcic, M., Reents, R., Philipsson, J., Kuipers, A. (Eds.), Breeding for robustness in cattle. Wageningen Academic Publishers, Wageningen, pp. 33-42.

Ten Napel, J., Van der Veen, A.A., Oosting, S.J., Groot Koerkamp, P.W.G., 2011a. A conceptual approach to design livestock production systems for robustness to enhance sustainability. Livestock Science (in press).

Ten Napel, J., Velthuis, A.G.J., Groot Koerkamp, P.W.G., 2011b. Design for robustness: identifying the least variable levels of control factors with heterogeneous residual variances. (in preparation).

Ten Napel, J., Walstra, I., Bohte-Wilhelmus, D., Van den Brand, H., Groot Koerkamp, P.W.G., 2011c. A method for quantifying the impact of management routines on robustness of layer chicks in hatching and early rearing experiments. (in preparation).

Van der Veen, A.A., Ten Napel, J., Oosting, S.J., Bontsema, J., van der Zijpp, A.J., Groot Koerkamp, P.W.G., 2009. Robust performance: principles and potential application in livestock production systems. Joint International Agricultural Conference, 6-8 July 2009 (JIAC2009). Wageningen Academic Publishers, Wageningen, The Netherlands

The study into a robust boar-taint panel will be reported as part of a scientific article on olfactory evaluation of boar taint, which will appear in 2011.

6 Participants

Organisation	People
Wageningen Livestock Research	Jan ten Napel
	Aldert van der Veen
Wageningen University, Farm Technology Group	Peter Groot Koerkamp
Wageningen University, Animal Production Systems Group	Akke van der Zijpp
	Simon Oosting
Wageningen UR Greenhouse Horticulture	Jan Bontsema

As indicated in Chapter 4, several companies were approached to participate. Their names are not listed in the public report, either because they did not contribute or for reasons of confidentiality.

7 Conclusions

- Robustness and resilience theory are two complementary approaches to minimise the impact of disturbances on the performance of a system
- Resilience theory can be used to evaluate complex systems with a low level of control over the system, such as ecosystems or social systems
- Systems with a high level of control can be designed for insensitivity to disturbances with a Robust Design approach, which consists of concept design, parameter design and tolerance design
- Parameter design can also be used to make existing systems more robust
- A signal-to-noise ratio is a measurement of the extent of corruption of the intended performance through unintended variation
- The squared residual approach is useful for calculating nominal-the-best signal-to-noise ratios from field data and is highly robust for deviations from balanced designs with independent factors. It can be applied to field data to improve existing systems
- The interpretation of a difference in nominal-the-best signal-to-noise ratio is independent of the trait studied, so a difference of 1 dB corresponds with a 26% higher variance and a difference of 2 dB with a 59% higher variance
- The significance of a difference in nominal-the-best signal-to-noise ratio depends on the sample size and the square of the coefficient of variation
- Longitudinal analysis of signal-to-noise ratios can be used to identify groups of animals that are more sensitive to a certain disturbance than other groups
- The concept of robustness offers a new basis to quantify and improve the robustness of complex agricultural production systems and chains (where technological and natural / biological elements interact) in a structured and science based way
- The developed concept and methodology are a challenge to reconsider the way in which new knowledge is generated and applied in animal production.

8 Press statement

Het is mogelijk om bestaande en nieuwe systemen in de veehouderij te ontwerpen en aan te passen voor minimale gevoeligheid voor verstoringen. Een bestaande industriële ontwerpmethode is geschikt gemaakt voor gebruik in de veehouderij. Hierdoor is er een grotere kans dat bedrijven hun potentie realiseren in de praktijk zonder ongewenste bijeffecten en een kleinere kans op verstoringen met grote gevolgen.

Dierlijke productiesystemen functioneren in dynamische en diverse omgevingen. Verstoringen in deze milieus beïnvloeden het functioneren van het systeem en veroorzaken verlies van efficiëntie, toename van vervuiling, meer verspilling van grondstoffen en extra kosten voor aanpassing en reparatie met management. De huidige trends van schaalvergroting en toenemende eisen aan duurzaamheid van dierlijke productie vergroten juist de impact van verstoringen op het systeem.

De Robust Design methodiek is geschikt gemaakt voor praktijkdata om ook de robuustheid van bestaande systemen in de veehouderijsector te vergroten. De kern van deze methodiek is het gebruik van SN ratio’s. De SN ratio die bij hoort bij optimalisatie van de variatie gegeven het niveau is bruikbaar om instellingen te vinden die variatie in het functioneren van het systeem verminderen, maar kan ook gebruikt worden voor het vinden van manieren van werken die de adaptatiecapaciteit van dieren vergroten. Toepassing op praktijkdata van vleeskuikenbedrijven liet grote verschillen zien tussen fokproducten en tussen voerleveranciers van de vleeskuikenmoederbedrijven in de invloed op variatie in 7-dagen gewicht van de kuikens.