# The conceptualisation of robust production systems

*Eindrapportage Scientific Project (WP-084)*

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a) ***doelstellingen en opzet—hierbij dienen zowel de maatschappelijke aanleiding als de daarvan afgeleide wetenschappelijke aanleiding te worden beschreven, en de manier waar de wetenschappelijke operationalisering en opzet zijn afgeleid van de maatschappelijke aanleiding (vertaalslag maatschappelijke observatie—wetenschappelijk concept);***

After the Second World War agriculture in Europe has changed dramatically from a countryside with many small mixed farms to a few big specialized farms. This not only led to a huge increase in production, also agriculture has become much more vulnerable to disturbances. From a systems approach these may be interpreted as unwanted fluctuations.

Ten Napel, Bianchi & Bestman (2006) discuss two approaches for dealing with unwanted fluctuations, the so called Control Model and the Adaptation Model. The Control Model uses protection and intervention to keep balance and is the prevailing model. It has been successful in improving productivity enormously in a relatively short period by controlling external disturbances. In order to control these external disturbances strict controlling measures (preventive drug use, repellents, high hygiene etc) are necessary. However, a number of problems concerning efficiency and negative side-effects became apparent (Ten Napel, p.3). For example freak accidents may have dramatic consequences, but also chronic stress and overburdening of animals, soil degradation, an emerging pest, weed and disease problems. Most of these side-effects have unwanted societal, environmental, economic and animal welfare consequences.

Under the Adaptation Model the design of production systems and processes is optimised for stable performance in the normal bandwidth of sources of variation. The Adaptation Model tries to reduce the consequences of sources of variation by returning to the original position after a disturbance. Rather than eliminating the sources of variation, the management of these sources is important. This is done by designing a robust production system "The concept of robust design is to use robust components and set control parameters in such a way that deviations from the ideal function caused by the present disturbances are minimal." (Ten Napel, p. 7) The concept of 'robustness' has been transferred to agriculture from the manufacture of cars and microchips.

The basic idea behind the introduction of the concept of robustness is that not only production systems but also (traditional) breeding of life stock and crop plants used in these production systems needs to change its focus. Traditional breeding with a dominant focus on efficiency and production has resulted in varieties and life stock adapted to sensitive production systems that, although highly efficient and productive, are vulnerable for external disturbances. The idea is that by adding robustness as a goal to production systems helps to solve these problems. With robustness as a goal for research we might be able to create animal and plant varieties that fit in sustainable and social acceptable production systems. In three TAG WP's **(animal production systems, pip**

**fruit and greenhouse** plants) robustness is an important research goal. During this project, this concept was further elaborated, drawing on literature which discusses similar notions, such as Bos *et al.* (2003).

The process of the introduction of the concept of robustness in research projects is open for improvement, because of at least five reasons:

- Firstly, Ten Napel does not define robustness, but connects it loosely to the Adaptation Model. In common language the word 'robust' has connotations like 'is able to resist' or 'will not move under pressure.' Ten Napel suggests a kind of flexibility: 'returning to the original position after a disturbance.' It remains unclear why the existing systems are non-robust. What are suitable indicators to conclude that they are not? Also, the social aspects and implications of robustness are not discussed in the project proposals. These conceptual problems need to be clarified.
- Secondly, the WP's are about different systems such as open field cultivation/production system (apple), protected cultivation/production system (green house) and (semi-)protected laying hen production systems. From a systems-theory perspective different production systems could give rise to different translations of robustness. It is to be expected that these systems will have different specific robustness factors. The link between different systems and robustness must be explored, with a focus on social factors.
- Thirdly, a production chain like the pip fruit industry has to translate the general idea of robustness into specific elaborations. Such elaborations will require the co-operation of a variety of actors. Therefore, these elaborations typically are being designed in interaction between the different stakeholders in a production chain. Their values and choices have influenced the translation of the production chain problems into the concept of robustness. The social background of the WP's needs to be made explicit. Theoretically, this can be framed as forms of learning between different kinds of actors (Grin and Van de Graaf, 1996)). More specifically, as we know from earlier analyses of similar projects (Roep et al., 2003; Grin et al., 2004; Bos and Grin, 2008) and from the area of spatial planning (Healy et al., 2003) they have repercussions for institutionalized rules, resources and actor configurations within and between the market, knowledge infrastructure, government and society. The ways in which thus feeds back in project needs to be better understood.
- Fourthly, the specific translation of robustness in a certain production chain like the laying hen industry has been translated in scientific problems in a WP. The way in which such transdisciplinarity is being given shape deserves further attention. This may be looked into from the growing body of literature on transdisciplinarity (Gibbons et al., 1994).
- Fifthly, the interaction between the scientific work in the WP's and the production chains is focused on technical solutions to problems in production systems. Robust solutions aim at sustainable and social acceptable production systems. Involvement of stakeholders and consumers has to be arranged and managed in order to use the scientific results in the different production systems. This

prescriptive interest will be met on basis of a reflection on the analysis in terms of the previous four points, in joint sessions of our team and the WP project leaders.

This project focuses at the social aspects of the scientific development of robust agricultural production systems as a step in the transition to a more sustainable and social acceptable agriculture.

**Detailed problem definition and research objectives**

In setting the research agenda for agriculture, especially in plant- and animal sciences robustness is rapidly becoming a key concept. The concept is introduced to criticise the existing scientific practice and to stimulate the transfer of agricultural production towards a sustainable and social acceptable production system. The general aim of the research is to contribute to the social implementation of robustness in the interaction between different agricultural production systems and scientific research.

This social research project has the following aims:

1. to clarify the content and use (scientific translations) of the concept of 'robustness' by discussing its justification vis-à-vis the transitions towards a more sustainable and social acceptable agriculture.
2. to investigate the relation between different kinds of systems and different translations of robustness and to describe specific (social) robustness factors in a general manner;
3. to analyse and assess the dynamics of the interaction between the different societal stakeholders (including agricultural users) and animal and plant sciences using the three WP's as examples
4. to develop instruments to improve the quality of this interaction

**Key problem**

Ten Napel et al. (2006) argue that developing robustness as a characteristic for production systems is a way to achieve both sustainable and social acceptable agriculture. However, a uniform definition of robustness is missing. As a consequence, for different kinds of problems both societal stakeholders and scientists may use varying conceptualizations (or production chain specific translations) of robustness. Unclear is in what way societal concepts of robustness are being translated into scientific research questions. To justify robustness as a research goal for sustainable and social acceptable agriculture its relation with sustainability and social acceptability, as well as its content and its power to steer to solutions needs to be developed.

A better understanding of the dynamics of the process society-science-society translations, especially the normative background in which they take place, is needed to ensure that scientific results are directed at the identified problems and are translatable into applications.

**Hypotheses:**

In the project several hypotheses play a role.

1. With regard to the strategies toward robustness we expect that:
    - There are different concepts of robustness

- Different stakeholders hold implicitly different values and choices about robustness
- Different concepts of robustness could lead to different translations of robustness into research questions

2. With regard to the case studies we expect that:
   - There is a difference between animal- and plant sciences in the way robustness is conceptualized,
   - There is a difference between protected and open cultivation in the way robustness is conceptualized;
   - Value judgements play a key role in the translation of robustness;
   - There are different normative backgrounds in the three case studies;
   - There are different social aspects in the three case-studies;
   - In the three case-studies there are different arrangements used to stimulate involvement of relevant stakeholders.

**Specification of the general questions:**

*1. What is the meaning of robustness?*

- What is the meaning of robustness in general? How is it related to sustainability? What does it mean that robustness is a (stakeholder) interpretation of sustainability?
- What are the different conceptualisations of robustness in animal- and plant sciences?
- For which problems are these conceptualisations a solution?
- How does robustness lead to more sustainability?
- How does robustness lead to social acceptability?

*2. What are the relations between different kinds of cultivation/production systems and different translations of robustness in the three case-studies?*

- What are the relevant systems in the three case-studies?
- How is robustness translated in the different systems? Which normative frameworks are used in these translations?
- Are there specific (social) robustness factors involved in the different systems?
- What is the responsibility of the scientists regarding these translations of robustness?
- Does robustness as a ‘scientific goal’ change research in a practical way?

*3. What is the dynamics of the interaction between the different stakeholders (including agricultural users) and the animal and plant sciences in the three case-studies?*

- How autonomous are scientists in this process?
- What are the similarities and dissimilarities between plant and animal with regard to the role of robustness and of stakeholders?
- What are the similarities and dissimilarities between natural- and artificial production systems with regard to the role of robustness and of stakeholders?
- What are the different arrangements around plant and animal robustness that are created to stimulate involvement of relevant stakeholders? How do they function?

*4 Can we develop arrangements (instruments) to improve the quality of the interaction between science and stakeholders of the different production systems in the three case-studies?*

- What can we learn from the current practice? (Based upon the answers under 1,2 and 3)
- Can we translate the answers (under 1 & 2) into new practical arrangements?

**Methodological design**

This PhD project was set up as an interdisciplinary project, with four steps to answer the abovementioned research questions:

1. An analysis of the role that robustness and robust production systems might play in a transformation towards a more sustainable and social acceptable agriculture. This has been done by a desk-study into literature on robustness with a focus on the social aspects.

2. An analysis of three case-studies, with a specific emphasis on the systems involved and the role of social aspects. In a qualitative stakeholder analysis the perspective of the stakeholders of the three cases has been analysed. Techniques used in this method include desk research and semi-structured interviews.

3. Based upon the description of the three case studies we will scrutinize current practice in order to identify the needs and possibilities for improvement. Specific emphasis will be given to system management and the role of stakeholders analysed in the first part of the project.

In this social science project it was the intention to closely co-operate with three bio-scientific WP's which have been used as case-studies:

- Stacking functionally expressed apple genes for durable resistance to apple scab. This is a WP of Transforum Agro & Groen which is closely linked to the Integrated Project (IP) 'Healthy pip fruit chain' that focuses on regulatory aspects, communication and acceptance of cisgenic scab resistant apples. The aim of the project is to improve fungicide resistance by developing apple varieties that have a durable resistance to apple scab.
- Robustness of animal production systems: concept and application. This is also a WP of Transforum Agro & Groen which aims to develop new market concepts for the laying hen in husbandry system, pig meat production chain and dairy farming, new chains around these concepts, and innovative keeping systems in these chains. This project tried to reach a breakthrough in animal welfare and to gain societal acceptance by establishing new alliances.
- Green house plants The SynErgie WP aims at the development of energy-poor or even energy-producing greenhouses. The SynErgie project has identified a number of barriers that obstruct the development of energy-producing greenhouses. Removal of these barriers will lead to an Agro Innovation System which reduces the energy use by the greenhouse industry spectacularly while an optimal production of vegetables, cut flowers and pot plants is achieved. In addition the produced energy by the greenhouse system will be marketed and add to the financial outcome of this activity.

These 3 WP's provide material for case-studies. The PhD students (together with their supervisors)of the 4 projects have met several times to discuss robustness in general and robustness of each project in more detail.

**Aimed project deliverable(s)**
We expect results on three levels:

- An inventory of strategies for robustness from a sustainability perspective (done)
- scientific improvement of the science- society relation and the role that societal values, and contested scientific developments play in this interaction (in progress)
- improvement of stakeholder involvement (in progress)

**Content of thesis (concept)**

Introduction

Chapter 1. The concept of Robustness

Chapter 2. Robustness and Agriculture

Chapter 3. Robust Animals

Chapter 4. Comparison of robust open and closed systems in agriculture

Chapter 5. Social Robustness

Discussion and conclusions

**Planned promotion date**: June 2012

***b) samenvatting van de verkregen (wetenschappelijke) resultaten en aanbevelingen, zoals verwoord in de (wetenschappelijke) publicaties / het proefschrift (toolbeschrijvingen, cases, rapporten, ervaringen, lessen, inzichten);***

This PhD project was set up as an interdisciplinary project. During the first period, research was in the first place focused on the conceptual analysis of robustness in general and in the second place focused on an analysis of the role that robustness and robust production systems might play in a transition towards a more sustainable and social acceptable agriculture.

**The result of the first study** is a classification of conceptualizations of robustness. It is based on an extensive literature review and consists of three organizing principles: 1.

system stability; 2. system behaviour; and 3. system environment. We discuss these principles below:

System stability

Our first organizing principle relates to different aspects of stability. We distinguish two ways of looking at system stability (see also (Holling and Gunderson, 2002; Jen, 2005; Kitano, 2007). The first assumes that systems have one steady state or equilibrium and relates stability to system performance in the neighbourhood of this steady state. In this view, robustness refers to the capacity of a system to withstand perturbations and to stabilize an optimized efficiency steady state. We will refer to this view as 'efficiency of function' perceptions of robustness. Efficiency of function perceptions of robustness are typically found in engineered systems where system functions are related to qualitative or quantitative output levels and robustness is measured in terms of sensitivity, resistance or rate of return. In agricultural contexts, efficiency of function perceptions of robustness include for instance water use efficiency aspects of drought tolerance, disease resistance and ability to recover from disturbances.

The second way of looking at system stability assumes that systems have multiple steady states and are mainly found in descriptions of socio-ecological systems (Walker *et al.*, 2005; Levin and Lubchenco, 2008). Rather than defining robustness as ability to keep the system in an optimized efficiency steady state, robustness as persistence refers to the capacity to maintain a particular state of balance, i.e. to persist in one configuration, rather than another. We will call this view the 'persistence of functionality' conceptualization of robustness.

Persistence of functionality is expressed as a magnitude of disturbance that a system can withstand before it moves to an alternative steady state. Consider for instance food webs, the robustness of which can gradually decline due to biodiversity loss, thereby reducing equilibrium stability and increasing the chances of transitions to alternative steady states (Gilbert, 2009). Examples also include settings with moral hazard, such as the evolutionary robustness of altruism against invasions of selfishness (Alger and Weibull, 2006) or the robustness of high sellers effort in online trading environments against cheating incidents that could lead to an alternative equilibrium, in which "sellers will always cheat and buyers will expect them to do so" (Dellarocas, 2003).

System behaviour

A second organizing principle concerns the behaviour of systems, i.e. the ability of a system to cope with disturbances. We distinguish two different system views and corresponding premises concerning system behaviour. The first view pictures systems steady states as essentially unstable and presumes a necessity of continuous supervision and regulation. We will refer to this way of coping with disturbances as 'control'.

The second view assumes that systems have one or more stable steady states, or equilibriums, towards which systems will return after disturbances. We will refer to this system behaviour as 'adaptation'. Ten Napel *et al.* (2006) make a similar distinction between a traditional control model and a presumed more robust adaptation model. However, the difference between the two models lies in the ability of systems to cope with disturbances independently and the changeability incorporated in the systems design. The control model suggests that the system needs human support to maintain function. Control models characteristically picture system steady states as unstable, for instance as a sphere on the top of a hill or as a pen balancing on its top. One can image that when the control fails, the system risks a fatal collapse. In a control model, robustness may therefore refer to insensitivity towards changes, or the lacking need for external implementation of changes to create such insensitivity (Fricke and Schulz, 2005). Adaptability, on the other hand, refers to a system's capacity to adapt successfully towards changing environments. Under the adaptation model, the system steady state is typically being pictured as an equilibrium, for instance as a sphere at the bottom of a cup or valley. Not only does this suggest that it is hard to disturb the system, it also suggests that the system will easily and naturally return to its stable position at the bottom of the cup. However, robustness in an adaptation model can also describe a system's ability to maintain functionality through changing itself under a wide range of environments. These differences in perception of system behaviour suggest that system behaviour is a second organizing principle in a robustness taxonomy.

System environment

A third, and final organizing principle of robustness relates to the underlying forces that shape disturbances. We distinguish perceptions of systems in static environments (Pimm, 1984; Clausing and Frey, 2005; Frey *et al.*, 2007) and systems in dynamic environments (Walker *et al.*, 2005; Webb and Levin, 2005; Carpenter and Brock, 2008; Levin and Lubchenco, 2008). The contours of static environments are fixed over time, while the contours of dynamic environments constantly change. A static environment assumes either one equilibrium or steady state, or cycles of change that move a system though alternative, but predictable and successive steady states. The static view suggests that both disturbances and system responses are predictable. A dynamic view on the contrary presumes that reality is full of unpredictable dynamics that can alter the environment. Robustness has a likely different meaning in static and dynamic environments, as system stability in dynamic environments becomes increasingly related to unpredictable changes in system variables and environmental dynamics.

Based on these principles, we suggest a conceptual framework of robustness, comparable to Jordan's (1968) dimensional systems taxonomy. The organizing principles described above relate to bipolar dimensions of system robustness. Indeed, system stability is either related to efficiency of function, or to persistence of functionality. Likewise, system behaviour is either control or adaptation and the system environment is either static or dynamic. We believe that different conceptualizations of robustness can be reduced to different combinations of dimensional descriptions, for instance Efficiency – Control – Static (ESC).

The three organizing principles, or robustness dimensions thus generate a frame of reference consisting of eight dimensional descriptions that represent what we believe are eight different robustness conceptualizations. To underline differences we use synonyms of robustness meanings (robustness as…) to refer to these conceptualizations (see table 1).

**Table 1: a taxonomy of robustness in dimensional descriptions**

| *Dimensional description* | *Robustness as …* |
|---|---|
| 1. Efficiency, Static, Control (ESC) | Reliability; |
| 2. Efficiency, Static, Adaptation (ESA) | Resilience (Elasticity); |
| 3. Efficiency, Dynamic, Control (EDC) | Insensitivity; |
| 4. Efficiency, Dynamic, Adaptation (EDA) | Invariability; |
| 5. Persistence, Static, Control (PSC) | Continuity; |
| 6. Persistence, Static, Adaptation (PSA) | Resilience (Amplitude); |
| 7. Persistence, Dynamic, Control (PDC) | Applicability; |
| 8. Persistence, Dynamic, Adaptation (PDA) | Evolvability |

Although the content of robustness may still be unclear, the first study has described eight meanings frequently given to robustness in relation to different system views. The second study will specify which of the conceptualizations discussed here are applicable to agricultural systems.

**The result of the second study** suggests that robust systems are neither vulnerable, nor stable, and that robustness is not a clear cut system feature. Rather, robustness relates to an intermediate sphere, in which aspects of vulnerability and stability are mutually exchanged to optimize a system's capacity to cope with both ordinary and occasional perturbations. **Robustness is thus a strategy to cope with specific aspects of vulnerability in the absence of specific stability properties.**

We distinguish three aspects of vulnerability, namely a system's exposure to a particular perturbation, a system's resistance to withstand this exposure, and its resilience to recover after being exposed to this perturbation. Exposure measures the vulnerability of a system as a relational property of system and environment together, while resistance and resilience are system features irrespective of the environment in which the system operates. This is why exposure is regarded the external side of vulnerability. For a designed system it is important to understand whether the vulnerability of a system is experienced as a system feature or as a relational property. Indeed, as opposed to the internal lack of capacity to cope with perturbations, the external side of vulnerbility can be controlled with preventive control measures. Table 1 summarizes possible relations of a system (S) in relation to a specific perturbation (P). Column 1 lists the three aspects of vulnerability. For each of these aspects extreme vulnerable situations (column 2) and their contrastive stability images (column 4) are defined.
Three robustness states (column 3) exist on imaginary continuums with tail ends representing vulnerability aspects on the one side and their contrastive stability images on the other side.

| **Vulnerability aspect** | **Extreme vulnerable situation** | **State of robustness** | **Stability image** | **Robustness strategy** | **Related terms** |
|---|---|---|---|---|---|
| Exposure | S is never released from | S is released from exposure to P in | S is always released from | Avoid | constant, constancy, |

| | | | | | |
|---|---|---|---|---|---|
| | exposure to P (relational) | specifically designed and controlled environments | exposure to P (relational) | | reliability, control, avoidance, invariance, (non-)exposure |
| Resistance | S never has sufficient resistance to resist any exposure to P without loss of structure and/or functionality. | S has sufficient resistance to resist any exposure to P without loss of structure and/or functionality within normal bandwidth. | S always has sufficient resistance to resist any exposure to P without loss of structure and/or functionality. | Resist | resistant, resistance, tolerant, tolerance, susceptible, susceptibility, (in)sensitive, sensitivity, fragile, remain |
| Resilience | S never has enough resilience to recover from loss of structure and/or function caused by exposure to P. | S has enough resilience to recover from temporary loss of structure and/or function caused by exposure to P within normal bandwidth. | S always has enough resilience to recover from temporary loss of structure and/or function caused by exposure to P. | Recover | (non-)resilience, recovery, return, recurrence, restoration, adaptation, balance, equilibrium, regain |

**Table 1. States of robustness between vulnerability at worst and idealized images of stability.**

***States of robustness***

Robustness is a state of relative system stability in relation to a specific perturbation. States of robustness are relevant with regard to systems that persist, despite the presence of perturbations that could potentially harm the system structurally or functionally. In other words, robustness is a feature of systems that are neither in a completely vulnerable, nor in a completely stable situation, but always somewhere in between. We term these situations states of robustness (column 3).

Robustness strategies are management strategies that aim to strengthen a particular state of robustness. We term the robustness strategies: avoid, resist and recover.

Robustness strategies refer to a defined system, a specific perturbation, and primarily relate to one of the states of robustness. Consider attempts to improve the vertical robustness of tall buildings against earthquakes

***Use of robustness in animal husbandry***

In our **third paper** we concentrate on one of the TransForum Scientific Projects, namely: Robustness of animal production systems: concept and application. This project aims to develop new market concepts for the laying hen and husbandry system, pig meat production chain and dairy farming, new chains around these concepts, and innovative keeping systems in these chains. The project tries to reach a breakthrough in animal welfare and to gain societal acceptance by establishing new alliances.
We will argue that Robustness is required to protect systems against perturbations that could possibly harm (change) the system structurally or functionally. Hence, the perturbations against which systems develop robustness are sustainability problems (fig 1).

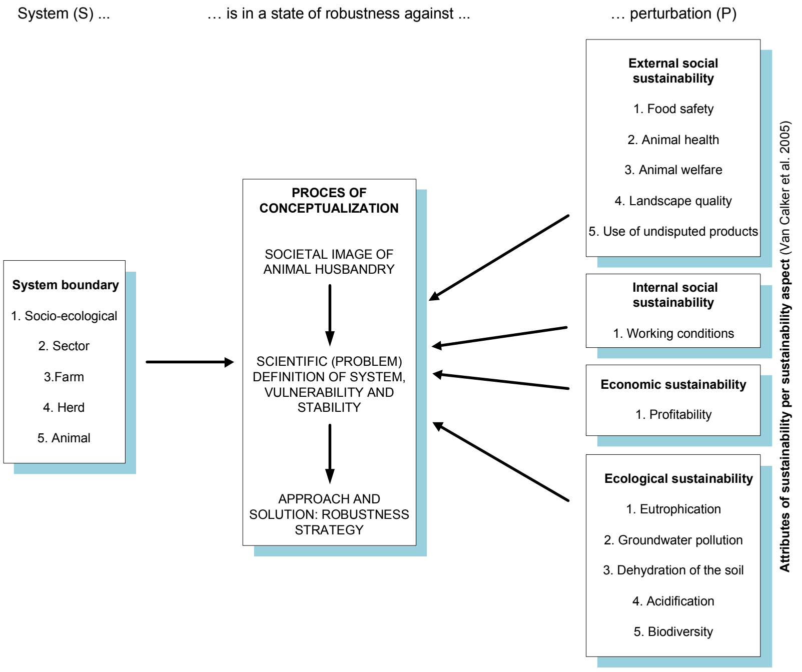


Figure 1. Conceptualization process of Robust animal husbansdry. Figure 1 shows that robustness has relevance only in relation to specified systems and specified perturbations. Rather than being robust or not robust, systems can be in different states of robustness, depending on their strategy to cope with perturbations. Perturbations against which systems develop robustness are sustainability problems.

Scientific literature about robustness in animal husbandry systems is limited to physiological, behavioral and immunological qualities. Robustness is mainly associated with vigorous animals, and reducing the negative effects of constant selection on production. Both research papers and policy documents show a clear relationship between robustness ansd animal welfare and animal health (LNV, 2007a, b; Van der Weijden, 2007). Robustness is, in other words, especially conceptualized at animal level, where it refers to the inherent self-regulation in a range of environments on the one hand, and the capacity to adapt to changing management and health conditions of the other hand(Kanis et al., 2004; Kanis et al., 2005; Ten Napel et al., 2006; LNV, 2007b; Star et al., 2008; Klopčič et al., 2009). This suggests that, in the livestock sector, robustness is regarded a system property.

Robustness strategies in the livestock sector aim to strengthen the capacity to cope with disruptions, both in terms of resistance as in terms of recovering capacity. This interpretation is typical of what has become known as 'engineering resilience' (Holling and Meffe, 1996), i.e. the amount of time a system needs after a disruption to regain a functional efficiency level that is considered normal.

Breeding programs that focus on such recovery qualities select, for example, on the rate of return to positive energy balance after energy balance nadir (lowest energy balance) during early lactation, which was found to affect a cow‟s luteal activity and day of first heat(Berry et al., 2009; Pollott and Coffey, 2009; Wall et al., 2009). Selection for high milk production may have reduced the capacity of lactating cows to regain positive energy balances. System properties that are now being seen as robustness qualities, have received little attention in breeding programmes for decades. As a result, these qualities were slowly eliminated in favor of quality preferences of consumers and processing industries. Consider genetic correlations between milk production and sensitivity to mastitis (Simianer et al., 1991) and between food efficiency and environmental sensitivity(Knap, 2005). Similar trade-offs occur in non-agricultural systems, such as the internet(Carlson and Doyle, 2002; Csete and Doyle, 2002; Willinger and Doyle, 2005).

Although it is generally assumed that breeding criteria need to be adjusted, the solutions to these trade-offs are not straightforward, particularly concerning the question whether breeding criteria should lead to specialists for specific environments or rather focus on ability to adapt to changing conditions. Kanis et al. (2004) argue that animal welfare relates to the maintenance requirements in a specific environment and conclude that animal welfare should be improved by selection on low needs and high functional efficiency. On moral grounds, Star et al. (2008) recently advocated implementing robustness as a breeding goal for both animal health and animal welfare reasons, each related to the ability to function optimally in a range of conventional production systems. The EFSA described robustness in 2009 as "the extent of the possibility for a population of animals to have the capacity in its gene pool to deal with a wide range of circumstances", and called on to reduce the loss thereof by thoroughly revising the prioritisation of breeding criteria(EFSA, 2009). Recent research, however, also shows that the ability to adjust to changing conditions is not only genetically determined. Early life experiences can increase adaptability at later age (Walstra et al., 2010).

**Robustness of animal production systems: a TransForum scientific project**

The starting point for the scientific project '*Robustness of animal production systems: concept and application* was the TransForum working paper called utilizing intrinsic robustness in agricultural production systems (Ten Napel et al., 2006). Their paper discusses two approaches for dealing with unwanted fluctuations, the so called Control

Model and the Adaptation Model. The prevailing Control Model uses protection and intervention to keep balance. It has been successful in improving productivity enormously in a relatively short period by controlling external disturbances. In order to control these external disturbances strict controlling measures (preventive drug use, repellents, high hygiene etc) are necessary. However, a number of problems concerning efficiency and negative side-effects became apparent. For example freak accidents, but also chronic stress and overburdening of animals, soil degradation, an emerging pest, weed and disease problems may have dramatic consequences. Most of these side-effects have unwanted societal, environmental, economic and animal welfare consequences.

Under the Adaptation Model production systems and processes are designed for stable performance in the normal bandwidth of sources of variation. The Adaptation Model tries to reduce the consequences by returning to the original position after a disturbance. Rather than eliminating the sources of variation, the management of these sources is important. This is done by designing a robust production system. Ten Napel et al. (2006) use a broad definition of robustness: minimal variation of target features following disturbance. In the research proposal, the methodology of Robust Design is mentioned as "a promising methodology to utilise robust components and design the production process for minimal variation". For crops and livestock this methodology would involve "utilising and supporting their intrinsic ability to deal with disturbances by adaptation. In the research proposal, robustness is defined narrowly as an 'ability to switch between underlying processes to maintain the balance'. Related to controlled livestock systems, it is argued that a controlled system is robustly stable if it remains stable if the system is slightly changed, and has a robust performance when its performance stays more or less the same if the system is changed a little.

### Recursive control approach

Bram Bos, Peter Groot Koerkamp and Karin Groenestein (Bos et al., 2003) outlined and discussed a novel design approach for livestock housing based on recursive control. This approach considers the natural behaviour of animals as an integral part of the functioning of livestock systems. Rather than suggesting that animal behaviour is a societal requirement that is at odds with economic and ecological conditions, the recursive control approach favors an increased contribution of animals to the functional order of the system as a means to attain different sustainability goals simultaneously. As Bos et al. argue, this implies *'that we adopt a perspective in which animals are seen as participants and co-creators of the system, rather than as elements to be contained and manipulated by the system'*. Two features are essential to make recursive control possible. First, the animal must have adaptive responses, i.e. must be able to adapt and respond to changing circumstances, such as heat, food shortage and stress. Second, the (genetic) variability of animals is respected and promoted.

This novel design approach was deemed necessary because the traditional way of dealing with problems in technological systems, the so-called unidirectional control approach, typically increased the amount of external measures to control unwanted consequences of the systems themselves. The unidirectional control approach suffered, in other words, from a process of spiraling complexity to battle fragility that is caused by robustness trade-offs. Processes of spiraling complexity have been described in relation to different kinds of systems, including biological systems (Csete and Doyle, 2002), technological systems (Willinger and Doyle, 2005), and social systems.

From a robustness perspective the recursive control approach is interesting because:

- The system depends on the capacity of animals to adapt and respond to fluctuations in environmental circumstances, such as temperature and food availability. The system requires, in other words, robust animals;
- The recursive control approach is introduced as an alternative to the unidirectional control approach, which, as described above, suffered from spiraling complexity caused by robustness trade-offs. As an alternative, the recursive control approach aims to break out of this spiral, while maintaining system robustness. This implies an approach that deals with existing fragilities without adding complexity to the system as a whole. Rather than to a robust, yet fragile 'Highly Optimized Tolerance' system, the suggested design approach should lead to an especially resilient and adaptive system.

The unidirectional control approach leads to complex 'robust, yet fragile' systems, where vulnerability and robustness are increasingly being seen as relational properties of the system and its environment together. The recursive control approach aims to break out of this process of spiralling complexity, with a robustness strategy moving back to system resistance or even resilience. This implies an increased influence of the environment on system functioning. Rondeel

We will use the Rondeel case as an example of an attempt to break out of the robustness/complexity spiral in egg production. The complexity of the supply chain of egg production and consumption has gradually grown. Rather than efficiently organizing a supply chain of egg production and retail activities, the current ambitions and challenges concern questions like: "What do civilians want from an egg?", What does the chicken want?"and "What does the poultry farmer want?". These questions were, at least, the guiding questions of the Rondeel case (van Someren and Nijhof, 2010; p47).

Rondeel resulted from an instigation of the Dutch minister for Agriculture, Nature and Food Quality in 2003 to rethink hen housing, after confrontations with Avian Flu showed the high contamination risks of both free range eggs and intensive hen farming (van Someren and Nijhof, 2010; p45). Contrary to gradual introductions of incremental improvements of production methods, the Rondeel case aimed to radically improve the production of sustainable eggs by rethinking the entire supply chain, taking into account the whole range of sustainability issues related to the production and consumption of eggs. According to representatives of all interest groups, the values that had to be taken into account for the production of sustainable eggs were:

- Hen welfare;
- Ecological sustainability;
- Transparency of supply chain;
- Fit the landscape;
- Higher returns for the farmer;
- Innovation and exemplary function;
- Optimal coherence between all parts of the value chain

The Rondeel case is, like the recursive control approach, an example of adaptive system thinking. Klerkx et al. (2010) note that adaptive management is essential for succesful innovation. This is, because innovating actors constantly have to react to changes in their environment, while at the same time actively trying to modify this environment in their favour. Adaptive capacities can be increased by extensive networking, and, for instance, the (re)formulation of visions to sell the story to a wider public. In the Rondeel case, TransForum has operated as an innovation broker, assisting in vision formulation and reformulation, network formation and adaptation, facilitating multi-stakeholder interaction, applying monitoring and evaluation methods aimed at learning. As an example of reformulating visions, note that the Rondeel case started with a focus on rethinking hen housing, but ended up rethinking the whole supply chain after Kwetters en Zn BV, one of the largest parties involved, withdraw from the project.

**Conclusion**

We distinguish three strategies that have found applications in current agricultural systems, in which resistance is representing robustness in a narrow sense and avoidance and resilience in a more broad sense:

1. Resistance: is based on reducing a system’s sensitivity to disturbance by increasing the inherent resistance of systems. Recognizing that exposure to some disturbances cannot be avoided this strategy aims to develop systems that can resist exposure to these disturbances without structural damage. It is particularly relevant with respect to disturbances that cause unacceptable and irreparable damage, such as apple scab. The WP “Stacking functionally expressed apple genes for durable resistance to apple scab” is an example of this robustness strategy;
2. Avoid exposure: is based on precautionary measures or system integration in a larger whole that provides shelter or reduces largely the likelihood of being exposed to particular disturbances. Focusing on the relationship between system and perturbation this strategy has led to highly protective, constant and intensively controlled production environments, such as closed-greenhouse farming. The WP “SynErgie” is an example of this robustness strategy for an optimized plant growth in such a system;
3. Resilience: is based on increasing a system’s capacity to respond and recover after being disturbed. This strategy does not aim to avoid or resist disturbances, but uses the capacity of systems to respond and recover to cope with disturbances instead. It is relevant with respect to disturbances that cause temporary, repairable and acceptable damage, such as temperature fluctuations or changing feed quality. The WP “Robustness of animal production systems” is an example of this robustness strategy.

***c) maatschappelijke relevantie van de resultaten, aan de hand van de maatschappelijke aanleiding, met expliciete aandacht voor die ervaringen/lessen/inzichten die generiek zijn en bijdragen aan TransForum doelstellingen en gevolgtrekkingen;***

In its recent policy documents (e.g. nota dierenwelzijn, nationale agenda diergezondheid) the Dutch Ministry of Agriculture, Nature and Food Quality (MINLNV) increasingly uses the concept of robustness with respect to political spearheads such as animal welfare, animal health and sustainability. In its policy document “nota dierenwelzijn” MINLNV has decided to stimulate research into robust animals to increase both animal welfare and sustainability of technological cattle breeding systems. Animal welfare is politically seen as an integral part of sustaining of cattle breeding on all aspects of social acceptability. It is likely that stimulating research on ‘robustness’ implicates a need for development or societal regulation of current agricultural practices. Robustness entails a value aspect and the implications of the values and ethical issues involved need to be discussed. This research contributes to that discussion.

Robustness is also an important issue for transition to all kind of durable Metropolitan Agriculture (MA) production systems. Starting point is social acceptance of these agricultural activities which has to be balanced with the needs in urban areas. For example,1. robust organic agriculture combined with all kind of other services, such as care farming, could best be organised near urban areas; 2. energy producing greenhouses have to be improved and properly positioned in our landscape, and 3. durable resistance of apple and potato to important diseases can bring back apple into and near the cities and keep potato as main cash crop in our metropole.

Robust and social accepted agricultural transitions have to be the base for bringing added value to the farmer in many production systems. Behaviour of more and more consumers is not only focused on prices nowadays, so that more attention can be paid to other aspects of agricultural (fresh) products and the way they are produced. New added values of such products are: honestly produced, healthy, animal friendly and durable. Many more farmers have to be convinced to listen to consumers and even sometimes to allow consumers to participate in determining circumstances of production. The Rondeel egg is a recent example of combining animal friendly circumstances with the higher price of eggs.

***d) Een lijst van alle (wetenschappelijke) publicaties (tijdschriften, congresbijdragen, boekhoofdstukken, vakbladen etc.) die uit dit project zijn voortgekomen— rapporteer ook publicaties die nog niet verschenen maar wel gepland zijn (in preparation, submitted, in press);***

**(Scientific) Papers**

Goede, D. de, Gremmen, B., Blom-Zandstra, M., Grin, J., 'Classifying various meanings of robustness: towards a frame of reference,' (submitted)

Goede, D. de, Blom-Zandstra, Gremmen, B., 'Vulnerability aspects, stability images and the urge for robustness in agricultural systems,' (submitted)

Goede, D. de, 2010, 'Van robuust vee naar zorgvuldige veehouderij', *Zorgvuldige veehouderij. Mogelijke oplossingsrichtingen vanuit Wageningen UR*, ISBN 978-90-8585-895-9 (in press)

Goede, D. de, Gremmen, B., Blom-Zandstra, M., Grin, J, 'Robust animals,' (in preparation)

**Presentations**

- The various meanings of robustness: towards a taxonomy. Presentation at lunchseminar Plant Sciences Group, Centre for crop systems analysis (22-01-2009);
- The meaning of robustness. Presentation at Robustness meeting I (14-09-2009)
- Robustness, follow-up. Presentation at robustness meeting II (8-10-2009)
- Robust Production Systems. Meta colloquium 17-11-2009

**Posters**

- The social aspects of robust production systems. Poster presentation at WTMC summerschool 'A critical Theory of Technology' (25-08 – 29-08 2008);
- The social aspects of robust production systems. Poster presentation at TransForum PhD day, 21-01-2009;
- The various meanings of robustness: towards a frame of reference. Poster presentation at the 12th PhD workshop of the Dutch-Flemish Network for Philosophy of Science and technology. Soeterbeeck, 9-04 – 10-04-2009;

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