Exploring Options to Assess And Improve The Resilience Of Organic Farming Systems

– A Case Study For The Droevendaal Farm –

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Abstract

Resilience thinking is important for the survival and achieving sustainable of farming systems in a dynamic background. The definition and management of the resilience of farming systems are researched in this thesis. One organic farm which is located in the Netherlands is used as a case study in this report. Computer model FarmDesign is used to evaluate the resilience of this case study farm and explore scenarios for it in order to achieve good whole farm performance and high resilience simultaneously. A clear definition of resilience specified for farming systems, descriptions of the targeted system, state variables and disturbances are prerequisites for researching resilience of farming systems. The results of this thesis show that although there are some limitations, it is feasible to use the FarmDesign model to quantify resilience of farming systems. Improving resilience can be used as a way to improve the whole farm performance and achieve sustainability. Good farm management plays very important role in building up resilience of farming systems.

Key words: resilience, farming systems, FarmDesign, quantitative, assess and manage, redesign, scenario

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List of abbreviations and relevant concepts

This list provides the interpretations of abbreviations used in this thesis

EDM	Effective dry matter intake by animal.
VEM	Feed unit for milk. VEM is the contribution of feed to animal energy requirement, used for maintenance, milk production and growth (VEM/animal/day). Availability in feed expressed in VEM/kg dry matter.
DVE	Protein digested in the intestines. Used for maintenance, milk production and growth (g/animal/day). Availability in feed expressed in g/kg dry matter.
STR	Structure. Contribution to fibrous material requirement.
SOM	Soil organic matter. Expressed in kg/ha
FYM	Farm yard manure. Animal manure produced in farm yard, contains plant material (often straw) which has been used as bedding for animals and has absorbed the feces and urine.
SWh	Spring wheat
SBa	Spring barley
FBe	Fodder beet
FRy	Forage rye
Bea	French bean
N	Nitrogen
P	Phosphorus
K	Potassium

1. Introduction

Agriculture is a fundamental human activity, and is crucial for survival of human beings on the Earth. Farming systems can be considered as linked social-ecological systems since on one hand people manage natural resources for their own purposes and on the other hand, respond to feedback from the ecosystem. As social and ecological systems are interdependent and both of them are dynamic and complex (Holling, 2001), it is vital for humans to understand these dynamism and complexity in order to better manage farming systems for their own purposes, i.e. producing food (Milestad, 2003). The concept of resilience is very powerful in providing insight into the dynamism and complexity of natural resource management in social-ecological systems. Its most salient application has been in the metaphoric sense, to illustrate the dynamics of systems development cycles (adaptive cycles), to show interrelations among scales within coupled dynamic systems, and to indicate the necessity of preparedness for change and adaptation at all hierarchical level (Gunderson and Holling, 1999). Therefore, understanding and building resilience of farming systems is important and necessary (Berkes and Folke, 1998; Folke and Colding, 2003). As a fast developing branch of agricultural production, only when the organic sectior can produce enough food and build resilience at the same time, will it be a totally viable alternative to conventional agriculture (Milestad, 2003).

In this part of report, the background information of research on resilience of farming systems is elaborated, in terms of the definition of system, the theoretical foundation, research necessity and importance, and research prerequisites.

1.1 Systems and their states

System, no matter in ecological, social, physics or computer fields, can be defined as a set of interacting or interdependent components forming an integrated whole with certain boundary (Anonymous, 2011). Systems can be divided into stable systems and dynamic systems. Stable systems always exist without any changes. In other words, stable systems either exist in the single equilibrium or destroyed at all. However, for dynamic systems, their states change continually with time, and the systems can stay stably in different equilibriums. What worth mention here is that, the multi-equilibriums of dynamic systems are not necessarily certain points with all fixed characteristics. In contrary, there can be some degree of variation while the overall characteristics of the systems remain largely the same. As a consequence, “stable states” doesn’t imply complete lack of change, and the term “regime” sometimes is used to replace “equilibrium”. A regime is the set of states that defined a domain of certain characteristic of a system. In a regime the system has the same essential structure, function, feedback and, therefore, identity. A regime shift occurs when a system crosses a threshold into an alternate domain (Resilience Alliance, 2007).

1.2 Resilience

The first introduced of the term “resilience” into the ecological literature can be traced back to about three decades ago (Holling, 1973). Since that time, multiple definitions of this term have appeared (Grimm and Wissel, 1997; Gunderson and Holling, 2001; Neubert and Caswell, 1997; Pimm, 1984; Tilman and Downing, 1994). Generally, resilience of ecosystems has been defined in two different ways: engineering resilience and ecological resilience. Engineering resilience concentrates on stability at a presumed point of equilibrium (Ives, 1995; Mittelbach et.al, 1995; Neubert and Caswell, 1997; Pimm, 1991; Tilman and Downing, 1994). In other words, engineering resilience is quantified as the speed of return to this global equilibrium (Pimm, 1984; O'Neill et al., 1986; Tilman and Downing, 1994). The faster a system can move back to the equilibrium after disturbances, the higher resilience it has. On the other hand, ecological resilience emphasizes conditions far from any certain equilibrium state, where disturbances can flip a system into another regime of behaviour and stay in that stability domain (Holling, 1973). In this definition, the measurement of resilience is the amount of changes or disturbances that are required to transform a system from being maintained by one set of mutually reinforcing processes and structures to a different set of processes and structures (Holling, 1996; Gunderson, 2000). The system which can absorb more disturbances has higher resilience.

The key distinction between these two definitions is the assumption regards to the existence of multiple stability domains. The definition of engineering resilience assumes that a system exists near a single or global equilibrium condition,. However, ecological resilience indicates that stability domains are dynamic and variable. Holling and his colleagues in the Resilience Alliance suggest that the latter definition is more useful to assess the response of a system to disturbances based on numerous studies on ecosystem functioning (Holling, 1973, 1986, 2001; Gunderson et al., 1995; Peterson et al., 1998; Gunderson, 2001; Carpenter et al., 2001). Therefore, the definition of ecological resilience is used as a point of foundation in the following report for researching the resilience of farming systems.

What is worth noting here is that, if we analyse a system and its resilience under a long time span background, since the system and its environment are subject to adjustments, for instance in bio-physical environment, or due to technological and socio-institutional innovations, etc. (Groot & Rossing, 2011), as a consequence, the resilience of this system changes continuously and should be considered as a dynamic property. However, when we take a screenshot at any time in the timeline, or focalize to a short time span, although the environment and disturbances of a system is dynamic and changing all the time, with certain components and interactions among them, a system has certain resilience. In this case resilience is a static property of a defined system at certain time. This provides the possibility to quantify resilience of farming systems.

1.3 Resilience of farming systems

A farming system is an assemblage of components which are united by some form of interaction and interdependence and which operate within a prescribed boundary to achieve a specified agricultural objective on behalf of the beneficiaries of the system (MacConnell and Dillon, 1997).

Many papers about farming systems (e.g. Conway, 1985; Carroll, Vandermeer and Rosset, 1990; Dent and McGregor, 1994; Gliessman, 1998; Pretty, 1998; Roling and Wagemakers, 1998; Cerf et al., 2000; Ellis, 2000) have mentioned that farming systems are dynamic systems suffering changes and disturbances all the time. On the one hand, farming systems themselves are active. The components which consist of the systems are alive, as a consequence, the life cycles of the components and the interactions among them make the farming systems perform dynamically. On the other hand, the surrounding dynamic environment always brings pressures to farming systems. Under this background, farms can be considered as dynamic systems in constant co-evolution with their environment (Milestad, 2003). Therefore, coping with changes, uncertainties and surprises, as well as maintaining development options in face of changes are crucial for farming systems. The concept of resilience focuses explicitly on the capacity of systems to changes and disturbances. Therefore, management of resilience is necessary for the survival of both farming systems as well as individual farms (Pretty, 1997; Hinterberger et al., 2000; Holling, 2001).

Over the last 50 years, agricultural production has been boosted by the use of fossil fuels, artificial fertilizers, pesticides and machinery (Conway & Barbier, 1990; Björklund, Limburg & Rydberg, 1999). However, when we look back, the development in agricultural industry in fact has been achieved at the cost of a long-term degradation of biophysical environments (Soule & Piper, 1992; Tilman et al., 2002). Therefore, being able to survive is not enough for farming systems, concerning the environmental effects of the intensive farming methods, the demands for sustainable agricultural production systems have been increasing rapidly. Ikerd (1993) defines a sustainable agriculture as "capable of maintaining its productivity and usefulness to society over the long run... it must be environmentally-sound, resource-conserving, economically viable and socially supportive, commercially competitive, and environmentally sound". Under a dynamic background as mentioned above, sustainability here does not mean fossilization, and sustainable agriculture should be able to keep it's good performance in a long term by coping with changes in both external and internal conditions, rather than repeat a set of practices to be fixed in time and space (Pretty, 1997; Hinterberger et al., 2000). The concept of sustainability is too general to operate in practice, and this leads to a switch to focus on the resilience of farming systems rather than on their sustainability. This is based on the insight that resilience and sustainability are two complementary concepts because resilience is a prerequisite for sustainability. In other words, resilience, and the resulting capacity to adapt to change, is a key property of sustainability (Folke et al., 2002).

To date, most of the research has been conducted on resilience are for ecological systems. However, from the concept of farming system, it can be seen that the most significant distinction between farming systems and natural ecological systems is the role human beings play. The objectives of farming systems are mainly decided by the demands of people rather than totally natural behaviours of the system components themselves. Humans, in farming systems, are unique in having the capacity for foresight and deliberate action. Their actions influence resilience, either intentionally or unintentionally. Their capacity to manage resilience with intent determines whether they can successfully avoid crossing into an undesirable system regime or succeed in crossing into a desirable one (Berkes et al., 2003). Therefore, resilience in farming systems is somewhat different from that in natural ecological systems. In this case, the research results of resilience in ecological system cannot be borrowed directly to analyse the resilience of farming systems. New concepts and criteria of resilience specified for farming systems are required.

1.4 Resilience of what to what

A dynamic system consists of collection of components and has infinite different states. In general, the state of a dynamic system at any one time can be defined by the values of the variables that constitute the system. However, when comparing two states of one system, some features of the system are changed while some others remain the same. In other words, the descriptions of a system's dynamic changes might be different when focusing on different state variables. Therefore, the first prerequisite for research on resilience of farming systems is to specify what state variables of the system should be kept stable under disturbances, i.e. resilience of what. Normally, these state variables are the main objectives of the system.

All the factors that exert pressures to a system and push it to change can be considered as disturbance. The factors which have influences on one system are infinite, therefore, it is impossible to take all the disturbances into account in one research at one time. This requires clearing what disturbances will be focus on and which others will not be taken into account in one research. This depends on the type emphasis of research, and disturbances which are important and can cause significant effects on one system should always be taken into account while others might not in order to avoid causing complication.

Finally, although sustainable development and resilience are undoubtedly related, not all definitions of sustainable development capture the meaning of resilience (van der Leeuw and Aschan, 2000). An important, fundamental distinction between these two definitions is that, sustainable development is always a desirable outcome while, in contrast, resilience can be desirable or undesirable (Carpenter et al., 2001). It is not necessary that systems which are preferred by people are always more resilient than those which people don't like. For example, system states that decrease social welfare, such as polluted water supplies or dictatorships, can be highly resilient. Since agricultural researches always aim to improve systems, clarification of which system configuration is desirable is necessary and important. Specified to this thesis, better resilience capacity and whole farm performance should be achieved simultaneously in the redesign process, in order to make sure that the redesigned system is desired and this system can keep its good performance under dynamic environment.

Although many researchers have worked hard to find out methods to assess and manage resilience, no completed theory or methodology has been established, especially for the resilience of farming systems. Some researchers even argued that although it is possible to assess resilience quantitatively in theory, it is unpractical in reality at all (Harrington, 1991; Carpenter et al., 2005).This thesis is an exploratory research, which is concerned with resilience of farming systems and the feasibility to use computer model FarmDesign to assess and manage resilience on organic farms. Conception of farm resilience and the characteristics of resilient farming systems are generated based on literatures, and an exploratory case study approach has been employed in order to investigate this topic. The report begins with the objectives of the thesis, and in the following methodology chapter, background of the case study farm and the computer models used in this thesis, as well as the methods of research and analysis are introduced. Subsequently, the results are presented and discussed corresponding to the objectives. Finally, conclusions are drawn and related to practice.

2. Research objectives

This thesis attempts to develop a concept of resilience of farming systems, and utilize the computer model FarmDesign for assessing resilience of farming systems and redesigning the targeted farm in order to build resilience to achieve sustainability. The concept "ecological resilience" is used in this thesis as a theoretical foundation since it enables an exploration of the research objectives and understanding of the system in focus. One case study in the Netherlands is researched in this thesis. The case study organic farm provides a telling example for other organic farming systems, and the conclusions and recommendations derived can be used for all the organic farming systems in the world with necessary adjustments based on local situations. Therefore, there are five research objectives of this thesis:

- To define the concept of resilience of farming systems, and the characteristics of resilient farming systems.
- To find out the feasibility of using FarmDesign model to evaluate resilience of farming systems quantitatively;
- To redesign the case study farm Droevendaal, aiming at improving the whole farm performance, in terms of soil quality, nutrient cycling, weed control, pest suppression, crop productivity, labor management and profits, as well as the farm resilience.
- To provide suggestions for future research on resilience of farming systems, as well as on model adjustment in order to make FarmDesign model more suitable for assessing resilience.
- To provide recommendations for other organic farms, especially strategies to improve resilience.

3. Methodology

The task of this thesis can be divided into two parts, i.e. theoretical research and practical application. In the theoretical research part, the definition of resilience of farming system is defined, and characteristics which resilient systems should have are found out. These characteristics are concrete and practical, which can easily be used to manage the resilience of farming systems. The method used in the practical application part is a case study. Four steps are included in this part: data collection, modeling, scenario(s) generation and trade-off analysis. The current resilience of the case study organic farm and its resilience after being redesigned are evaluated quantitatively by using the FarmDesign model. Besides, the farm is redesigned in order to improve its performance in terms of both resilience and whole farm performance (Figure 1).

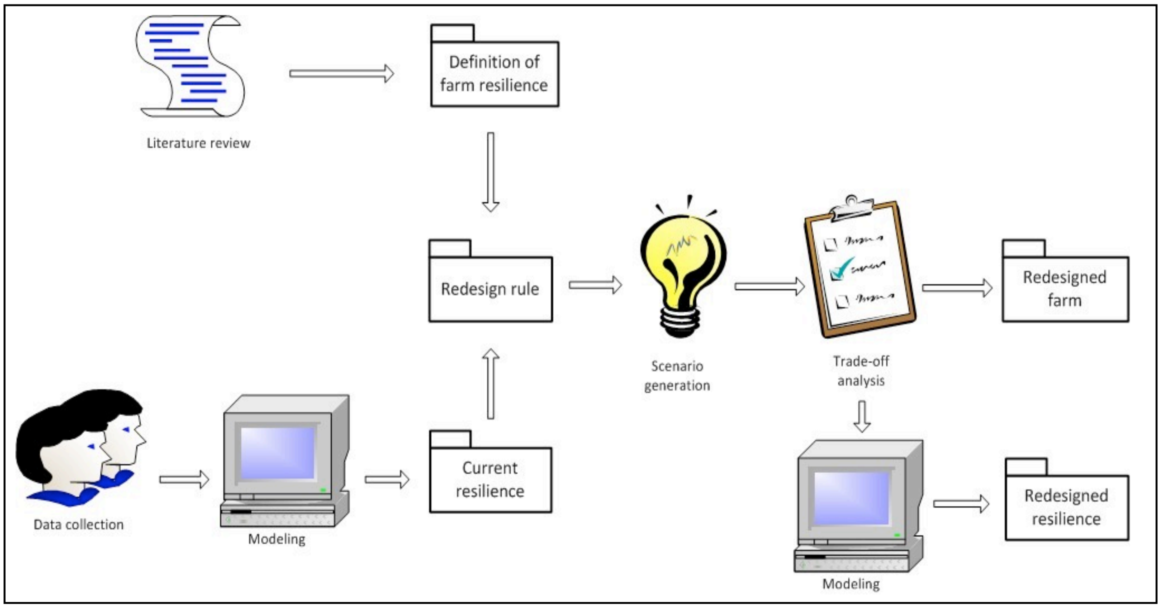


Fig 1. The methodology used in the research

3.1 Theoretical research

Literature review, definition and characteristics generation

The first introduction of the term "resilience" was in ecological literature, and the research about resilience focused more on the ecological systems rather than on farming systems. Therefore, parts of the objectives of this thesis can be defined as exploratory research. In order to assess and manage resilience of organic farming systems, clear definition of farm resilience and the characteristics of resilient farming systems are needed to. This paper combines the literature on resilience of ecological system and on farming systems to generate the definition, and factors that contribute to farm resilience are listed based on literature review and the analysis of the current situation and resilience of the case study farm, which will be introduced below. The first research objective is achieved in this step.

3.2 Practical application

Case study

Organic experimental and training farm Droevendaal is used as a case study farm in this thesis. Droevendaal farm is located in Wageningen, the Netherlands. It is a 50 ha mixed farm with crops and livestock (from 2010 it stopped keeping animals in winter time). The soil on the farm has about 3% soil organic matter, pH 5.5. The soil texture is shown in table 1. The soil of the western field consists of wind-borne sand deposits. The eastern fields consist of a combination of wind-born sand deposits and Pleistocene sand soil. There are 24 fields in total, of which the fields numbered from 1 to 16 are used for arable crop farming (Figure 2). The rotations used on Droevendaal farm are always 1: 8 rotation since it was conversed into an organic farm, however, the crops included in rotation have been changed a bit in different years based on their performances and the experiments of students and researchers.

Table 1 Soil texture of Droevendaal

Particle size	>50µm	<50 µm	<16 µm	<2 µm
%	85	10	5	3

USDA texture class: Loamy Sand

Fig 2. Field map of Droevendaal farm in Wageningen, the Netherlands. Field number 1 to 16: arable fields; 17 to 22: permanent grassland; 23: Nature field and 24: orchard.

Before 2002 when Droevendaal farm was changed into organic, the farming system was well balanced because of the timely application of artificial fertilizer, pesticide and herbicide. However, after the conversion to organic farm until now, problems such as heavy weed infestations, low and unstable yields, high nitrate leaching losses, and etc. have been emerged (personal conversation with Dr. Egbert and farm manager Andries, 2011). By redesigning the farm, these problems are expected to be solved directly or indirectly. And the better farm performance will be enhanced by improving the farm resilience.

Data collection

Two computer models, FarmDesign and NDICEA (see below) are used in this thesis. Relevant data of Droevendaal farm, which is required by the computer models, are collected from different sources. The information about environment/climate is got by consulting Dr. Jeroen Groot, Dr. Egbert Lantinga and students who have worked with Droevendaal farm before, as well as by downloading from internet. The data about crops and animals is collected from the farm manager Andries Siepel, Dr. Egbert Lantinga and Dr. Gerard Oomen. The economical information is gathered by comparing the relevant data of similar farms. As mentioned above, Droevendaal farm did not follow the original crop rotation plan exactly. However, in the FarmDesign model only one crop rotation which represents the whole farm can be implemented at one time, therefore, it is not possible to follow the reality accurately. A crop rotation which consists by potato (1 year), winter triticale (0.5 year), grass clover (2.5 years), spring wheat (1 year), maize (1 year), French bean (1 year), and spring barley (1 year) is used for analysis in this thesis. This rotation was used on Droevendaal farm two year ago, and can represent the farm performance in the last eight years best when compared with the other rotations that have been used on the farm.

Modeling

Two computer models, namely FarmDesign and NDICEA, are used in this thesis as tools to assess resilience of organic farming system and to redesign the case study farm.

FarmDesign

FarmDesign is a static farm balance model, created by Dr. Jeroen Groot and Dr. Gerard Oomen in Wageningen University, which can be used to calculate flows of nitrogen, phosphorus and potassium to, through and from a farm, the feed balance, the amount and composition of manure, labor distribution and economic results on an annual basis. Input data of FarmDesign describes information of the case study farm in terms of rotations and crops (area, yield, and destination), farm animals (species, number, weight, growth, production, and activities), feed rations, additional fertilizers, labor, equipment and buildings. By setting decision variables (e.g. the areas of cultivated crops, the number of animals kept on the farm, and the destination of crop products) and objectives (e.g. maximize operating profit to generate sufficient income, minimize the labor balance to optimize allocation of labor resources, and maximize the organic matter balance to improve soil structure), alternative management options can be generated and evaluated in terms of Pareto optimality within the Model Explorer environment (Groot et al., 2009).

FarmDesign model is created and normally used for planning or redesigning mixed farms. In this thesis, it is used for two purposes: Firstly, it is used as a tool to evaluate the resilience of farming systems quantitatively. This process explores a new way to use this model. The current and redesigned resilience of the case study farm Droevendaal is checked, separately (For detailed methodology see chapter 4.4, 4.5 and 4.7). Secondly, FarmDesign model is used to redesign the case study farm and to find out the best farm redesign scenario by assessing the alternative management options (For detailed information see chapter 4.6).

NDICEA

NDICEA is a two layer (topsoil and subsoil) model, developed by Louis Bolk Instituut, which can be used to study the availability of nitrogen in a crop rotation with a timestep of one day (version 6.0.16). Soil organic matter mineralization is calculated according to Janssen's formula (Janssen, 1984) and corrected for soil temperature, moisture, texture and pH. N mineralization from initial organic matter, crop residues and manure is calculated and integrated into the N balance that includes deposition, irrigation, matrix flow, bypass flow and fixation as inputs and plant uptake, denitrification and matrix flow as outputs (Van der Burgt et al., 2006).

In this report, NDICEA model is used for an integrated assessment on the nitrogen availability for the current and redesigned rotation on Droevendaal farm.

Scenario(s) generating

Farm redesign is an important step in this thesis with two meanings:

On the one hand, farm redesign aims to improve the whole farm performance in terms of soil quality, nutrient cycling, weed control, pest suppression, crop productivity, labor management and profits. As mentioned in the previous part, both preferred and disliked systems can be resilient. Since people always want to improve the resilience of a desired system to keep its good performance under disturbances, rather than to enhance the resilience of an undesired system and make it more difficult to be changed, redesigning the current system to improve the whole farm performance to an desired level is always necessary if the current situation is not quite satisfying.

On the other hand, the farm is redesigned, based on the characteristics of resilient farming system generated in the literature review step, to improve its resilience ability in order to make sure the farm can keep the good performance in a dynamic environment.

Trade-off Analysis

At a particular level of economic objective (operating profit) many alternative management options are often impossible unless environmental performance of the farm, e.g. nutrient losses and organic matter balance are strongly contrasting. Labor balance and operating profit have the similar relationship (Groot et al., 2009). Moreover, the two aims of farm redesign, namely improving the whole farm performance and increasing the farm resilience must be achieved simultaneously. Therefore, trade-off analysis is necessary for choosing the optimal scenario(s) within a multi-objective solution space. Finally, the final scenario must be practical, and take the farmer's preference into account.

4. Results

The results of this thesis, including the definition of resilience of farming systems, characteristics of resilient farming systems, farm redesign scenarios, current and redesigned farm resilience assessment are described in this part.

4.1 Definition of resilience of farming systems

Ecological resilience has been discussed briefly above and is defined as the capacity of a system to absorb disturbances while maintaining the key functions and controls (Holling, 1973; Gunderson, 2000). Ecological resilience is measured by the magnitude of disturbances a system can tolerate and still persist (Holling, 1996). Based on this conception, the definition of resilience specified for farming systems is generated. The resilience of farming systems is the ability of a farming system to absorb disturbances, and its flexibility in the dynamic environment, in order to avoid crossing a threshold into an alternative regime. In this definition, regime is a set of states that define a domain of attraction. In a regime the system has the same essential structure, function and identity. A regime shift occurs when a system crosses a threshold into an alternative domain of attraction. Similarly as mentioned above, from resilience point of view, “stable” doesn’t mean none change at all (see chapter 1.1). On the contrary, as long as the system doesn’t cross the threshold, it can be considered as “stable”.

4.2 System of Droevendaal farm

Resilience of a farming system strongly depends on the components of the system, and the interactions among the components and with the external influences. The resilience capacity of one certain farm might be very different with different defined boundaries and components. Therefore, it is necessary and important to define the system and its boundary clearly before analysis. Figure 3 illustrates the system of Droevendaal farm defined in this thesis.

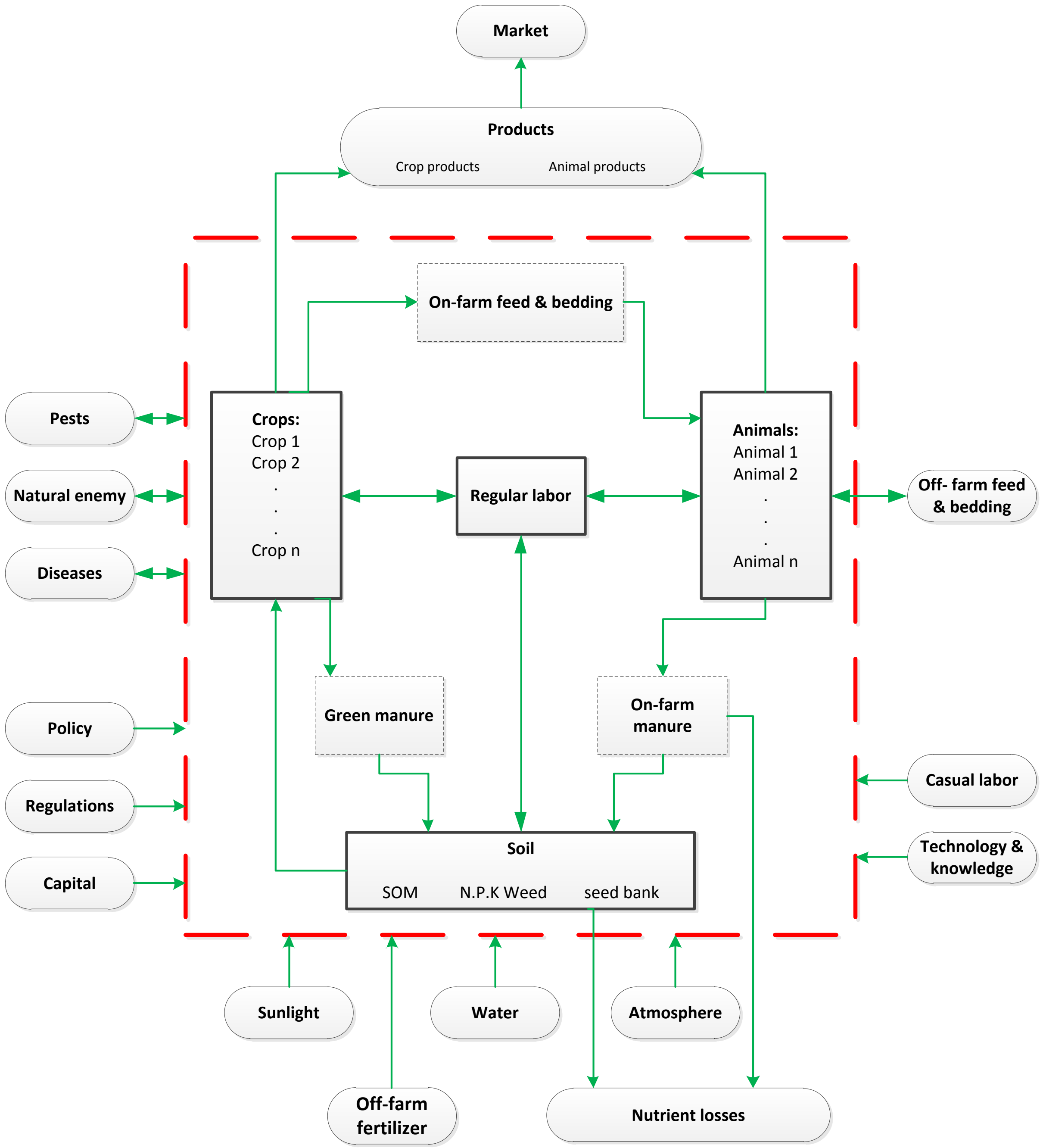


Fig. 3 System of Droevendaal farm. Red dotted line represents the boundary of the system. Rectangles represent the components in the system. Ovals represent the external inputs and influences. Green arrows represent the interactions among the items.

Four main components are included in the system of Droevendaal farm, namely crops (include different types of crops), animals (include different types of animals), soil (include SOM, nutrients such as N, P and K, weed seed bank) and regular labor (include the farm manager and 3 regular farmers). These components are connected among each other, and interact with many external inputs and influence. Certain amount of products and nutrient losses are exported from the system as outputs.

Table 2 and 3 describe the current crop and animal situation on Droevendaal farm. Seven crops species from four categories are grown and one animal species is kept on the farm currently. Within the crops, potato, French bean and grass/clover silage are sold as cash crops, while the others are used as animal feed, except the by-product French bean residue that is used as green manure. The young bulls on the farm are kept for meat production.

Table 2. Current crops on Droevendaal farm

Crop on Droevendaal Farm				
Species	7 crops species			
Categories	**Name**	**Product**	**Yield (kg/ha)**	**Destination**
Cereal	Winter triticale	WT silage	4500	Feeding
	Spring wheat	SW grain SW straw	3750 2500	Feeding Bedding
	Maize	Maize silage	11500	Feeding
	Spring barley	SB grain SB straw	3300 2500	Feeding Bedding
Legume	French bean	French bean FB residue	4600 2500	Selling Green manure
Root crop	Potato	Potato	18000	Selling
Ley	Grass/clover	GC meadow GC silage	3000 7000	Feeding Selling

Table 3. Current animals on Droevendaal farm

Animals on Droevendaal Farm		
Species	1 animal species: cattle	
Varieties	**Name**	**Product**
Croossbred between HF (Holstein Friesian) and MRIJ (Maas-Rijn-IJsselvee). HF blood dominating	65 Young bulls	Meat

The current feed balance of Droevendaal farm is shown in Table 4, the numbers are simulated by FarmDesign model. Feed balance influences animal production and animal welfare on the farm, therefore, it is important to be well managed, especially for organic farms. The general assessment criteria of feed balance on organic farms are: EDM values should be lower than 0; VEM values in the range between -5 to 5; DVE values in the range between 0 to 30; and STR values are higher than 0 (Rossing et al., 2010). Therefore, from Table 4 it can be seen that, all the feed balance values during stable period are fine. However, the VEM value during grazing period is a litter bit higher than the upper limit, and the DVE value during grazing period is significantly higher than the upper limit. The reason of this might be that during grazing period, fresh grass and clover which contain a relevant lower energy vs. protein ratio compared to the other animal feeds (CVB, 2008). The feed balance should be improved by the redesign process.

Table 4. Animal feed balance of Droevendaal farm (See P.6 for abbreviations)

Animal feed balance Droevendaal		
	Grazing period *[(available-requirement)/requirement, %]*	*Stable period* *[(available-requirement)/requirement, %]*
EDM	-35	-10
VEM	-6	3
DVE	66	25
STR	63	158

Other key farm performance values of the current Droevendaal farm are shown in Table 5. From the table it can be seen that although a lot of efforts have been done to build up the soil on Droevendaal farm, still the soil organic matter is decreased. This simulated value by FarmDesign model on organic matter balance is very close to the value measured in the fields (See Figure 4). The current value of total nutrient losses (sum up of N,P and K losses) is fine, and many regular labor are left unused in the current situation and should be better reorganized. The operating profit of Droevendaal farm is negative currently, this is caused probably by the characteristic of Droevendaal farm as an experimental farm of the university, i.e. the whole plan and management options of the farm are designed for research rather than making profit.

Table 5. Key values of whole farm performance of Droevendaal farm

Key values of farm performance Droevendaal	
Organic matter balance (kg/ha/yr)	-41
Nutrient losses N+P+K (kg/ha/yr)	35
Regular labor balance (hour/yr)	-541
Operating profit (currency)	-34319

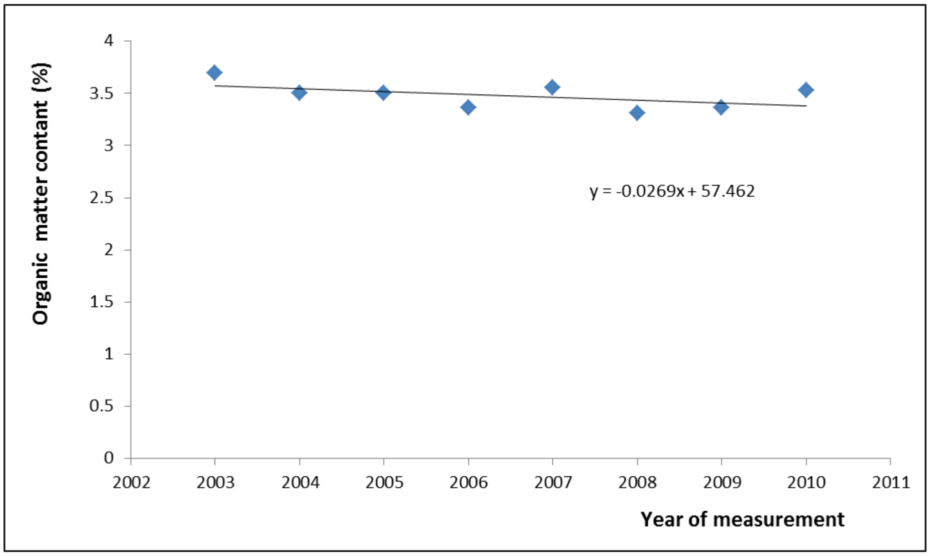


Figure 4. Yearly field measurement result of organic matter balance on Droevendaal farm.

The blue dots are the field measurement results, and the straight line shows the average trend line which indicates the change of organic matter balance on Droevendaal farm as time passes by. From the figure it can be seen that, in average, with the time passes the soil organic matter decreases 0.0269% every year.

Figure 5, which is part of the results of NDICEA model, illustrates the nitrogen balance of the current crop rotation used on Droevendaal farm. Based on the figure, it can be seen that in the past eight years the nutrient requirements of all the crops were fulfilled.

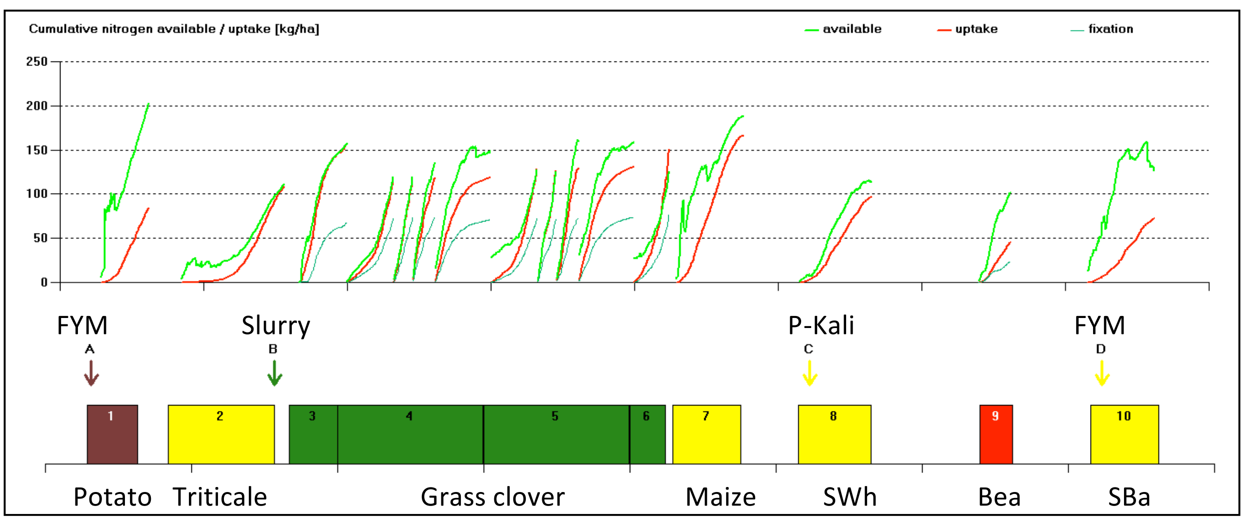


Fig 5. Nitrogen balance of current crop rotation on Droevendaal farm

4.3 Resilience of what to what for Droevendaal farm

"Resilience of what" describes the state variables of a system which are preferred to be kept without changing under disturbances. Specified to Droevendaal farm, productivity and environmental performance are set as "resilience of what", because high productivity and good environmental performance are always preferred by agricultural production. What should be mentioned is that productivity here means the general productivity of the whole farm rather than the productivity of individual crop or animal. When disturbances come, the possibility of a reduction of individual productivity is quite high, and people always focus more on keeping the whole productivity of the farm through alternative management options. However, it is not logic to sum up the productivities of different crops and animals simply, therefore, in this thesis operating profit is used to replace whole farm productivity as one of the “resilience of what” stable variables. In this case, economic parameters such as market price and currency exchange rate should be taken into account. Since this thesis focuses on ecological aspect rather than social aspect, as well as the timestep of the FarmDesign model which is used to assess resilience quantitatively is only one year, the related economic parameters are assumed as stable. About the environmental performance, since there is no one parameter expresses environmental performance of the farm directly in FarmDesign model, total losses of N,P and K through soil processes and volatilisation is used as another “resilience of what” state variable in this research. Environmental performance of the farm equals to the minus of total nutrient losses. Generally, in this report, under the influences of disturbances, resilience helps the farm to keep operating profit not lower than the current level, and the total losses of N, P and K not more than the current amount.

Same as all the other farms, Droevendaal farm is influenced by many external factors as illustrated in Figure 4. Some of the influences are more related to ecological aspect while others are more about social aspect. This thesis focuses on the ecological influences, and pests, diseases, weeds, less or no off-farm resources and climate change are set as “resilience to what” here.

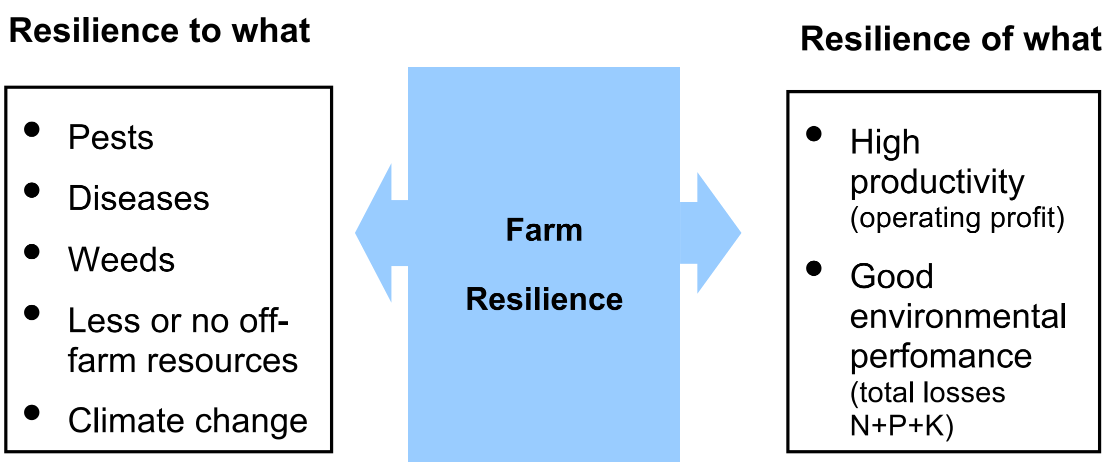


Fig 6. Resilience of what to what for Droevendaal farm

4.4 Resilience assessment method

The current and redesigned resilience of the case study farm Droevendaal are assessed quantitatively by imitating the disturbances with the FarmDesign model. In order to do this, it is necessary to estimate the potential influences of the disturbances accurately. Disturbances can cause various impacts, such as reducing product yields, decreasing product quality, and etc. However, for the crops, no matter what kinds of effects are caused by the disturbances, their influences on the redefined “resilience of what”, i.e. operating profit and total losses of N, P and K, are same. Therefore, in order to simplify the imitation process, this thesis assumes that the only impact caused by disturbances on crops is the decrease of product yield. The effects of disturbances for animals are more complicated because of the calculation method of FarmDesign model, and will be analysed in detail in the following part of the report (See 5.5.5).

Since different pests, diseases and weeds disturbances may influence different categories of crops and animals, as well as climate change and less or no external resources disturb the whole farm, in this thesis the potential disturbances which have the highest probability of happening in the future on Droevendaal farm are divided into six types: four types of disturbances which reduce the yields of cereals, legume, root crop and ley, separately; one type of disturbances which reduce the yield of animals; and the last type of disturbance which reduces the yields of all the crops on the farm at the same time. These six types of disturbances are imitated separately in the resilience assessment process by reducing the yields of products. The destinations of products are set as decision variables, and several constrains and objectives, which are important assessment factors of the performance of farming systems, are set based on literatures (See Table 5, 6 and 7; Walter et al., 2010). The model explores to check whether there are any alternative management options which can keep the predefined state variables, i.e. "resilience of what", perform equal or even better than the current values. Increases the influence of disturbances, in other words reduces the yields of products gradually, until no useful alternative management option exists, the resilience of the farming system is found out. Mathematically, the more grades of yield reduction are divided in the imitation process, the more precise the resilience assessment result is. However, because of the time and labor limitation, only 10 grades are set in this thesis, which means the yield of certain crop or animal is reduced by 0, 10%, 20% until 100%.The more disturbances one system can absorb without being changed, the higher resilience ability this system has.

Table 5. Decision variable of resilience assessment

Description	Minimum	Maximum
Destination of products	0	The maximum yield

Table 6. Constrains of resilience assessment

Description	Minimum	Maximum
GrazingPeriod.Deviation Saturation EDM (unit)	-100	0
GrazingPeriod.Deviation Energy TDN (unit)	-5	5
GrazingPeriod.Deviation Protein CP (unit)	0	30
GrazingPeriod.Deviation STR (unit)	0	10000
NonGrazingPeriod.Deviation Saturation EDM (unit)	-100	0
NonGrazingPeriod.Deviation Energy TDN (unit)	-5	5
NonGrazingPeriod.Deviation Protein CP (unit)	0	30
NonGrazingPeriod.Deviation STR (unit)	0	10000
Bedding.Deviation (unit)	-5	5
Soil losses	0	50
Volatilization	0	19

Table 7. Objectives of resilience assessment

Description	Direction
Organic matter balance (kg/ha/yr)	Maximize
Regular labor balance (hour/yr)	Minimize
Operating profit (Euro)	Maximize
Losses N+P+K (kg/ha/yr)	Minimize

4.5 Current resilience of Droevendaal farm

4.5.1 Resilience to cereal disturbances

The first type of disturbance to Droevendaal farm, which is imitated with FarmDesign model, is the one disturbs the yields of cereals. From Figure 7 it can be seen that with the yields decrease of cereals, no useful alternative management option can be found after the yields are reduced by 40% or more. Therefore, the current resilience of Droevendaal farm to the cereal disturbances is 30% of the yield reduction.

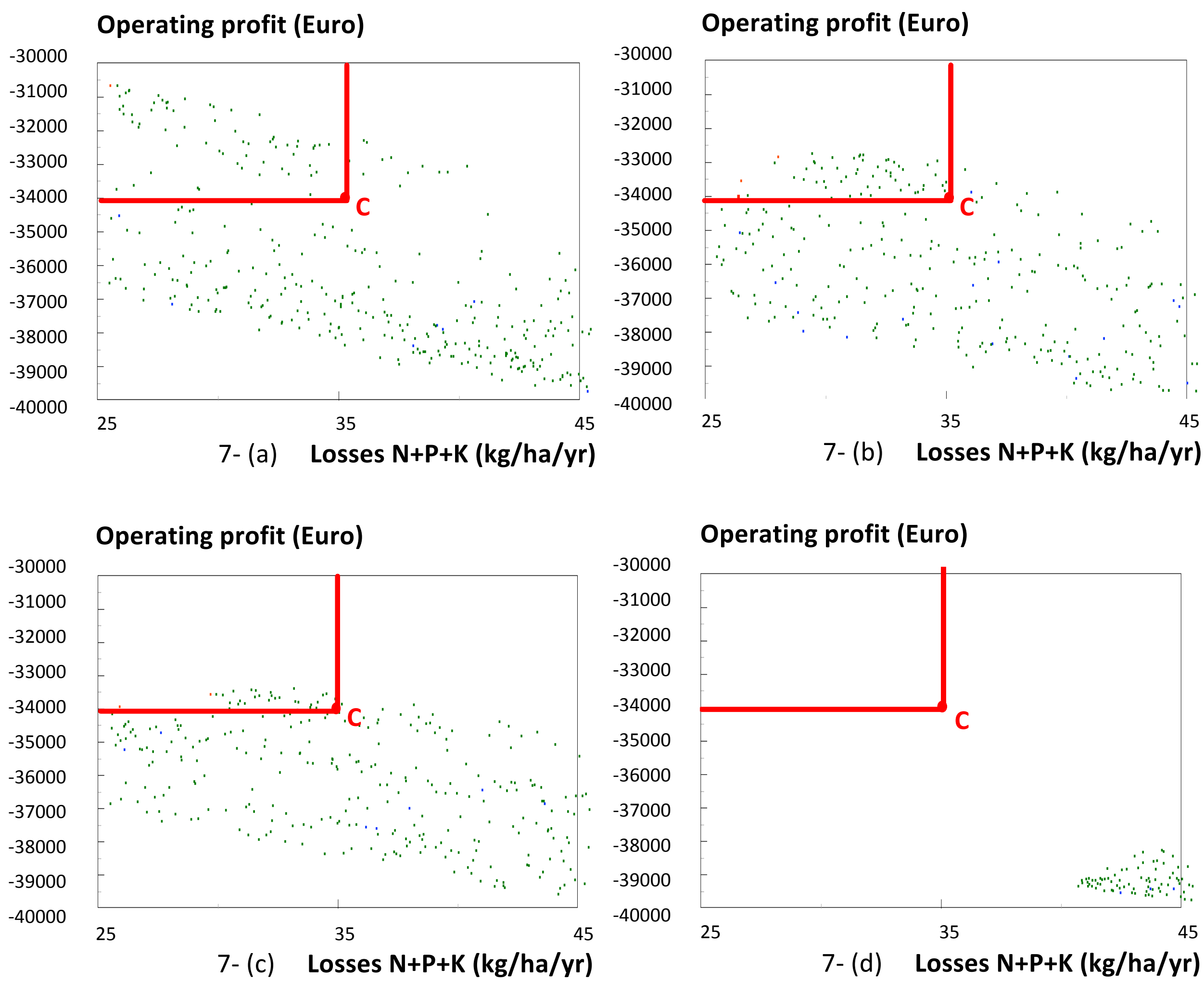


Fig 7. Result of current resilience to cereal disturbances. Point C is the current performance of Droevendaal farm in terms of operating profit and total nutrient losses. Alternative management options are represented by the green dots. Only the ones with improvements in both two system states (profit and total nutrient losses) relative to the current situation are considered as useful

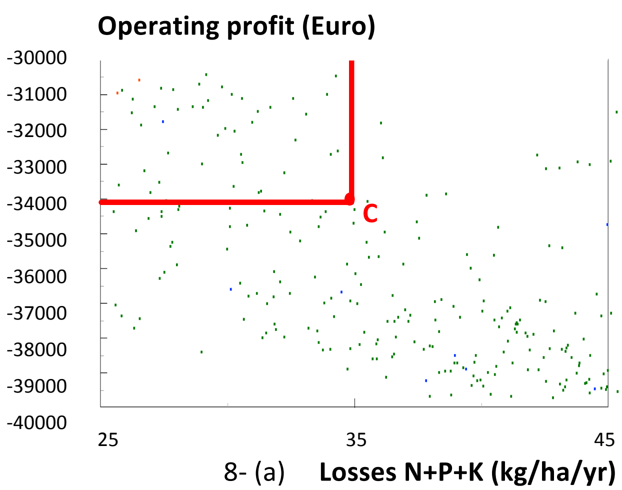
options (the ones in the left-up corner of the graph). Graph 7-(a), 7-(b), 7-(c) and 7-(d) show the results of cereal yields decrease by 10%, 20%, 30% and 40%, seperately.

Cereal products produced on Droevendaal farm are all used for feeding and bedding material, therefore, the yield reduction of cereals causes insufficient feed and bedding for the animals. To the selected state variables- operating profit and total nutrient losses- not enough feed directly reduces operating profit while a shortage of bedding material has no effect on operating profit; both insufficient feed and bedding don't have direct relationship with total nutrient losses, although they might influence it unintentionally.

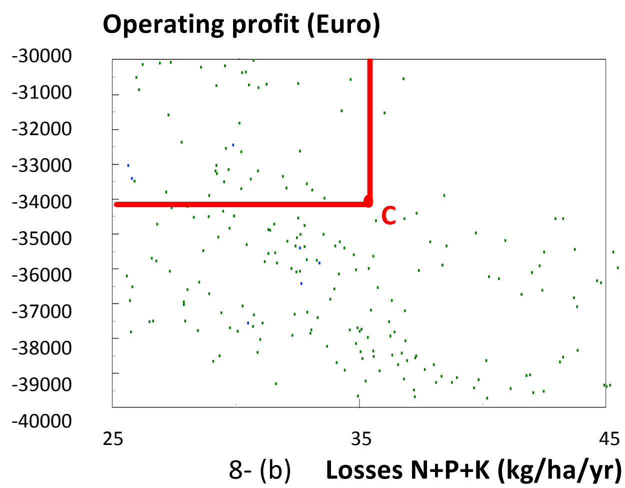
From checking the management details of the alternative solutions which perform equal or even better than the current one, the strategy used to overcome cereal disturbances is to reorganize the destinations of components on the farm. However, what should be mentioned here is that, besides helping the selected state variables keep on preferred levels, this kind of reorganizations may influence the other features of the farming system negatively. For example, French bean residue, which is currently used as green manure, is used for feeding animals in some alternative options. In this case the soil organic matter balance is reduced, and this strategy actually uses the soil fertility to compensate the reduction of operating profit. Another example is that no remedial measure is used in some alternative options to solve the problem of bedding insufficient, because not enough bedding doesn't show significantly influence on both operating profit and total nutrient losses. This is in fact using animal welfare to compensate the reduction of operating profit. However, the situations mentioned above are not what organic farming prefers. Therefore, although there are alternative management options which can help the farm to keep the current performance under disturbance, farmers need to use their own knowledge and philosophy to choose which alternative strategy they prefer and would like to implement on their own farms.

4.5.2 Resilience to legume disturbances

The legume crop grown on Droevendaal farm is French bean, and the second type of disturbance imitated with FarmDesign model is legume disturbances. It is necessary to notice that, the amount of nitrogen fixed by legume should also be reduced accordingly with the reduction of legume yield. Figure 8 shows that the current resilience of Droevendaal farm to legume disturbances is 50% of the yield reduction. Only when the yield of legume is reduced by 60% of the current yield, no useful alternative management option can be found.



8- (a)



8- (b)

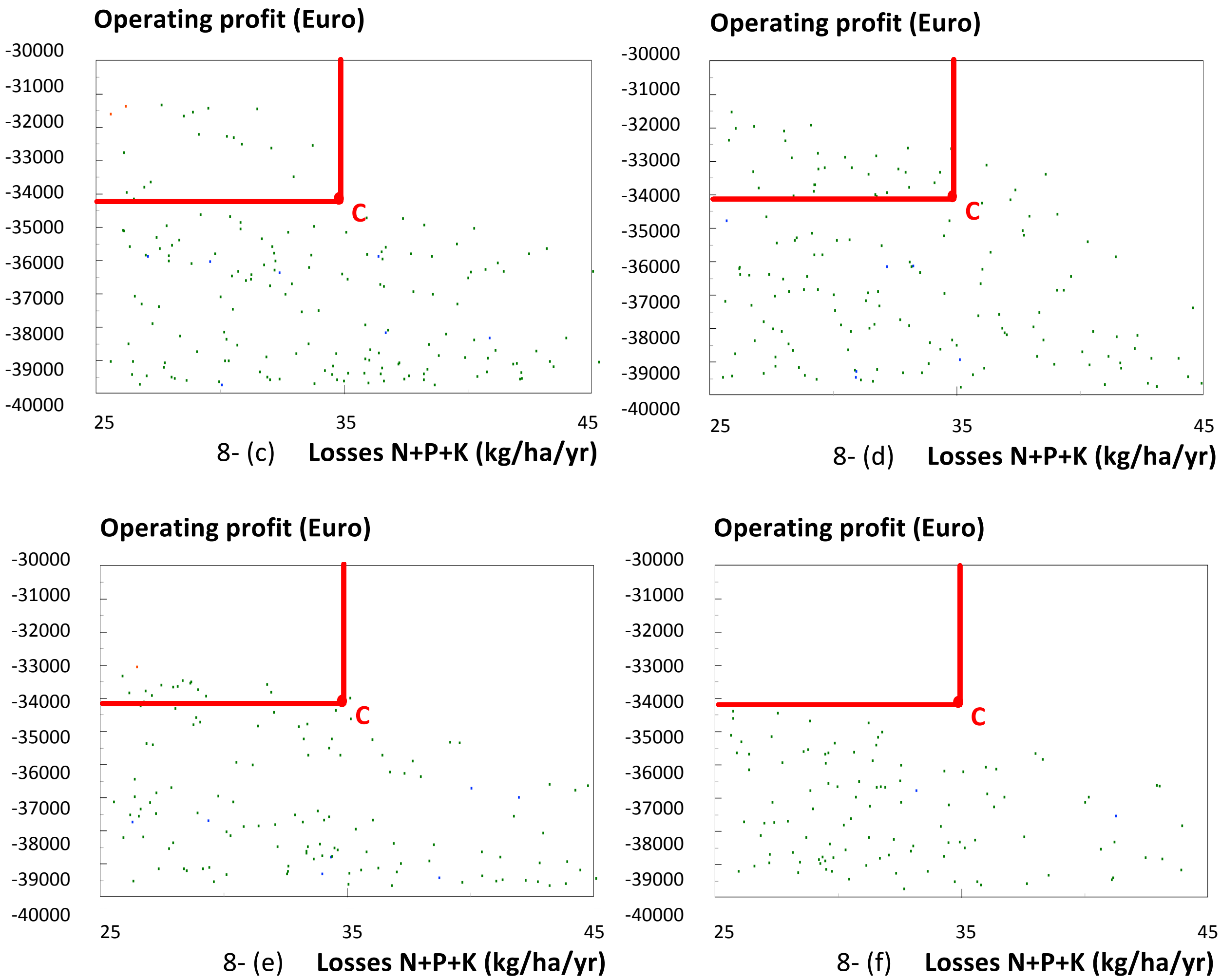


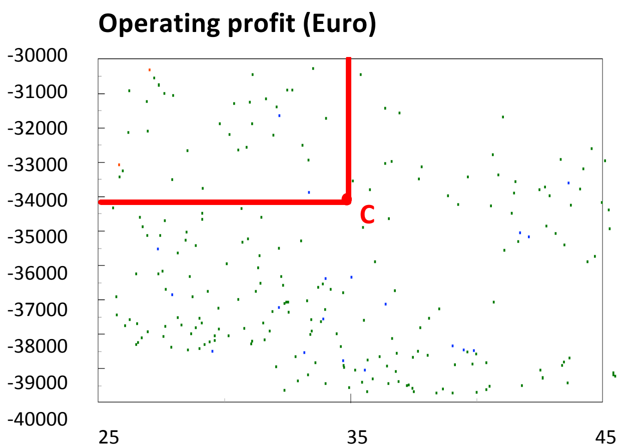
Fig 8. Result of current resilience to legume disturbances. Point C is the current performance of Droevendaal farm in terms of operating profit and total nutrient losses. Alternative management options are represented by the green dots. Only the ones with improvements in both two system states (profit and total nutrient losses) relative to the current situation are considered as useful options (the ones in the left-up corner of the graph). Graph 8-(a), 8-(b), 8-(c), 8-(d), 8-(e) and 8-(f) show the results of legume yields decrease by 10%, 20%, 30%, 40%, 50% and 60%, seperately.

On Droevendaal farm, French bean is sold as cash crop and French bean residue is used as green manure currently, and as legume crop French bean plays an important role on the farm to fix nitrogen. Reducing the yield of French bean results to the decrease of operating profit and the reduction of soil organic matter which is not the selected state variable. No direct influence on total nutrient losses is caused by the reduction of legume yield.

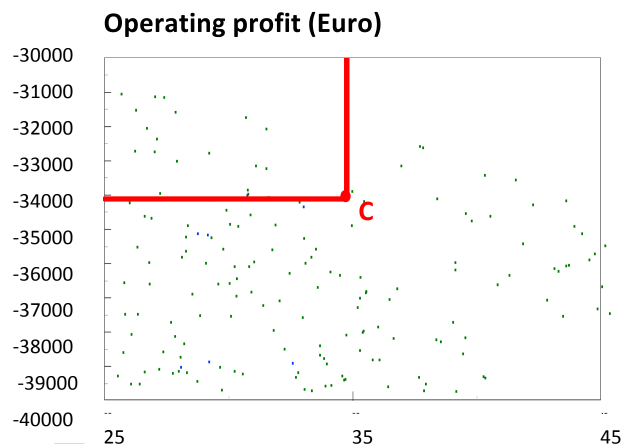
To compensate the reduction of operating profit, useful alternative management options reorganize the destinations of products on the farm. Grass clover silage, which is used for selling currently, is used for feeding animals. In this case more other crops which are used for feeding, e.g. spring wheat grain and spring barley grain, can be sold for profit. By changing the destinations of components, products produced on the farm are used in a more efficient and profitable way. This is how the farm can achieve the same, or even more profit with reduction of cash crop yield. Since the change on the amount of green manure, the reduction of N-fixation value, and their consequences on soil organic matter decrease don't have direct relationship with the selected state variables, most of the useful alternative management options don't make any effort to solve this problem. Similary as mentioned in the result of resilience to cereal disturbances, in a long term point of view, soil organic matter decrease might cause even more seriouse result to the farm. Therefore, although in this thesis it is not selected as a research item, many attentions should be paid on this point.

4.5.3 Resilience to root crop disturbances

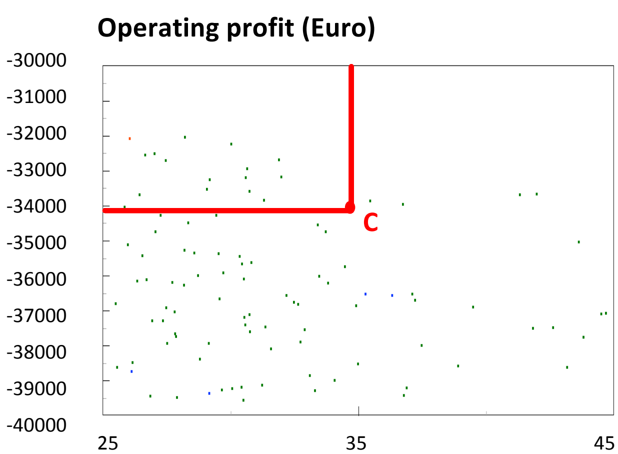
The result of root crop disturbances imitation shows that the current resilience of Droevendaal farm to root crop disturbances is 30% of the yield production (Figure 9). From the result it can be seen that when the influence of disturbances is increased into 40% yield reduction, there are still a few useful alternative management options. However, in realistic, the possibility that the farm cannot achieve the current or better performance on the selected state variables is already quite high. Therefore, although theoretically resilience is decided by the amount of disturbances when no useful alternative management options can be found, the current resilience to root crop disturbances is considered as 30% of the yield reduction.



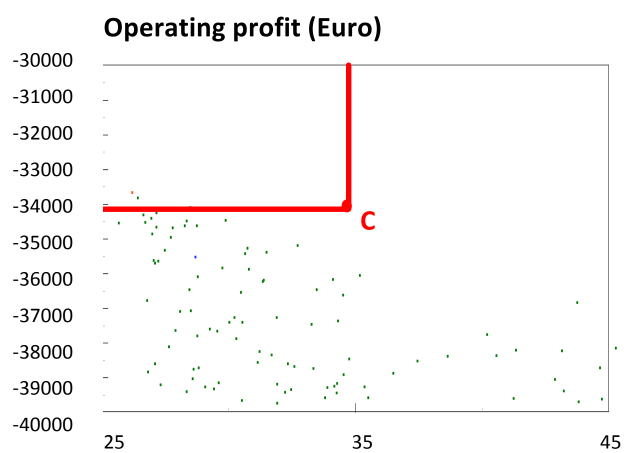
9- (a) **Losses N+P+K (kg/ha/yr)**



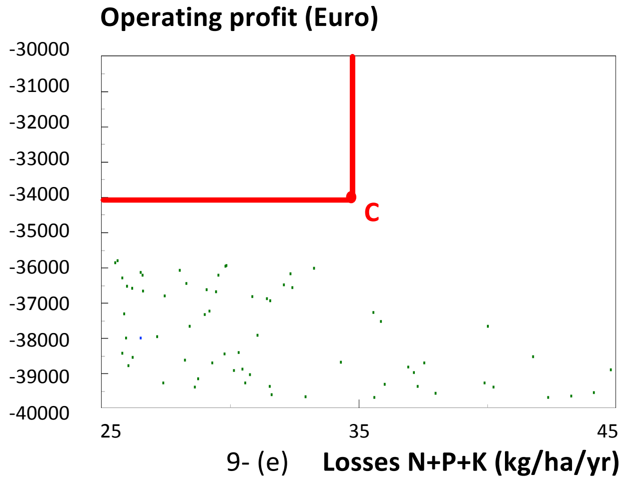
9- (b) **Losses N+P+K (kg/ha/yr)**



9- (c) **Losses N+P+K (kg/ha/yr)**



9- (d) **Losses N+P+K (kg/ha/yr)**



9- (e)

Fig 9. Result of current resilience to root crop disturbances. Point C is the current performance of Droevendaal farm in terms of operating profit and total nutrient losses. Alternative management options are represented by the green dots. Only the ones with improvements in both two system states (profit and total nutrient losses) relative to the current situation are considered as useful options (the ones in the left-up corner of the graph). Graph 9-(a), 9-(b), 9-(c), 9-(d) and 9-(e) show the results of root crop yields decrease by 10%, 20%, 30%, 40% and 50%, seperately.

The only root crop grown on Droevendaal farm is potato, and it is sold as the most important cash crop. Therefore, the influence of reduce the yield of root crop is related with operating profit directly. However, for the total nutrient losses, the influence is indirectly and not quite significant (from figure 9 it can be seen that the alternative management options which have equal or lower nutrient losses are still many even when the yield of potato is reduced by 50% of the current yield).

Similarly as the strategies used to compensant the yield reduction of legume under disturbances, the method of the useful alternative management options to keep the current or even better performance of the selected state variables is reorganizing the destinations of production on the farm in a more efficient and profitable way. Changing the use of grass clover silage from selling to feeding animals is also used here. Both French bean (legume) and potato (root crop) are used as cash crops on Droevendaal farm, compared to the resilience to legume disturbances, the current resilience to root crop disturbances is less. From the result of the FarmDesign model, it can be seen that potato contributes much more than French bean to the operating profit. This explains why the farm operating profit is more sensitive to the changes of potato yield, and the resilience to root crop is less.

4.5.4 Resilience to ley disturbances

The last type of disturbances which disturb individual crop category is ley disturbances. Grass clover is the only ley grown on Droevendaal farm. Similarly as the process of legume disturbances imitation, when the yield of ley crop is reduced, the relevant N-fixation value should also be decreased accordingly. From Figure 10 is can ben seen that the current resilience to ley disturbances is 30% of the yield reduction.

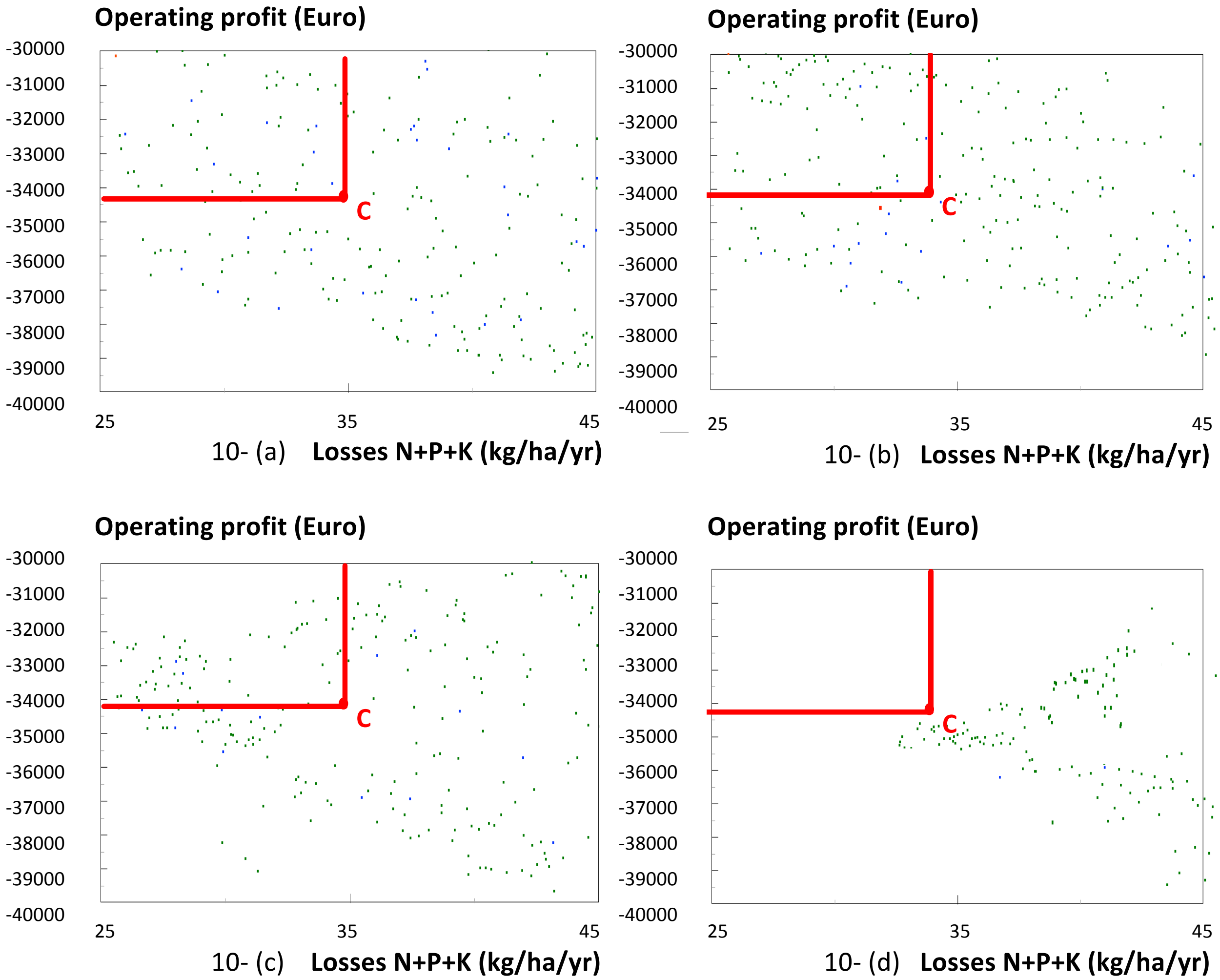


Fig 10. Result of current resilience to ley disturbances. Point C is the current performance of Droevendaal farm in terms of operating profit and total nutrient losses. Alternative management options are represented by the green dots. Only the ones with improvements in both two system states (profit and total nutrient losses) relative to the current situation are considered as useful options (the ones in the left-up corner of the graph). Graph 10-(a), 10-(b), 10-(c) and 10-(d) show the results of ley yields decrease by 10%, 20%, 30% and 40%, seperately.

The grass clover field on Droevendaal farm is divided into two uses: grass clover meadow for feeding animals during grazing period and grass clover silage for selling. Therefore, reducing the yield of grass clover results in insufficient animal feed and less operating profit. Besides, by taking up readily-available plant nutrient- in particular, nitrate- grass clover effectively sequesters them within its tissues and so minimises nutrient losses on the farm (Woodward and Burge, 1982), therefore, the total nutrient losses of the farm will be increased significantly if the grass clover field is destroyed.

To deal with the problem of insufficient feed to animals, the useful alternative management options use French bean (which is currently used as green manure) and grass clover silage (which is for selling in current) to feed the animals. It seems a helpful choice to use green manure to feed animals in this research, because not enough feed to the soil shows no change on the selected state variables here. However, as mentioned in the previous part, soil organic matter will be decreased in this case, and the farmers should be very carefully when doing this. Furthermore, together with the imitation results of all types of disturbances, it can be concluded that using grass clover silage for feeding animals is more profitable than using it for selling. This is also why the reduction of operating profit resulting from the decease of grass clover yield can be compensated by reorganizing the destinations of all the components on the farm. It is interesting to see that, with the increase of yield reduction, to all the other types of disturbances which influence individual crop categories, the crucial state variable which decides the resilience capacity is always profit, but to ley disturbance the crucial state variable is total nutrient losses. From Figuer 10 (d) it can be seen that when the yield is reduced by 40% of the current value, many alternative options can still achieve the current or even better profit but with much higher nutrient losses. This proves the effect of grass clover on reducing soil losses in a round-about way.

4.5.5 Resilience to animal disturbances

Another type of disturbances should be imitated with FarmDesign model is the disturbances to animals. Generally, the animal disturbances cause two consequences: the most possible one is that animals require the same amount of feed as without suffering disturbances, and produce same amount of products (milk or meat) but with much lower quality; Another possibility is that the animals require the same amount of feed but produce less amount than current (Personal communication with organic farmer, 2011). However, none of these two situations can be imitated with FarmDesign model, because all the relevant values are connected and used as calculation foundation for each other. On the one hand, it is impossible to estimate the change-directions of the nutrient composition in animal products under disturbances; and on the other hand, if the animal growth rate and milk production value are changed in FarmDesign model, the requirements from animals will also recalculated automatically based on the factors mentioned above. Therefore, with FarmDesign model, it is impossible to imitate animal disturbances, and for this reason FarmDesign model cannot be used to assess animal disturbances quantitatively.

4.5.6 Resilience to whole farm disturbances

Some disturbances, such as climate change, can influence the performance of all the components on the farm. The influences of this kind of disturbances are normally serious, and based on the imitation result the current resilience to whole farm disturbances is 10% of yield reduction for all crops(Figure 11).

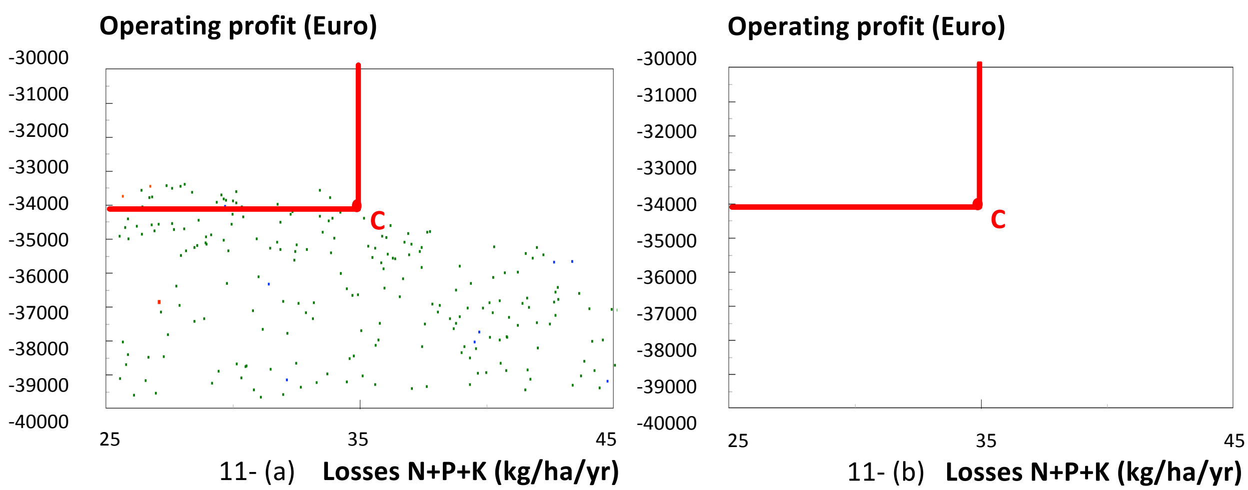


Fig 11. Result of current resilience to whole farm disturbances. Point C is the current performance of Droevendaal farm in terms of operating profit and total nutrient losses. Alternative management

options are represented by the green dots. Only the ones with improvements in both two system states (profit and total nutrient losses) relative to the current situation are considered as useful options (the ones in the left-up corner of the graph). Graph 11-(a) and 11-(b) show the results of whole farm crop yields decrease by 10% and 20%, seperately.

It is very difficult to keep current performance under the influence of whole farm disturbances because, if only parts of the system components are disturbed, there are still some alternatives to compensate, but if all the components on the farm are disturbed, no or only less efficient alternative exists. From Figure 11-(a) it can be seen that the useful alternative management options are already a few with only 10% whole farm yield reduction. And from Figure 11-(b), when the whole farm yield is decreased by 20% even no alternative management options can be found within the range chosen for the two selected state variables.

4.6 Farm redesign for Droevendaal farm

Case study farm Droevendaal is redesigned, and the results are shown in this part. Through farm redesign, the whole farm performance and farm resilience are improved simultaneously.

4.6.1 Characteristics of resilient farming systems – resilience redesign rule

Carpenter et al. (2001) listed three distinctive features resilient systems should have, which are 1) buffer capacity, 2) self-organization capacity, and 3) the ability to build the capacity for learning and adaptation. Some researchers suggested to use these criteria to assess and manage resilience of farming system (Milestad, 2003; Milestad and Darnhofer, 2003). However, this statement is metaphorical, albeit based in empirical studies and difficult to implement in the field. Moreover, after careful consideration it can be seen that there is some overlap between these three items, e.g. self-organization capacity actually contributes to buffer capacity and is not necessary to be listed separately.

The aim to manage resilience is to increase the resilience of a farming system to keep its good performances under disturbances. Several approaches can help farming systems to improve their resilience. The following report will explain these approaches in detail:

Approach one: using high resistant varieties in farming systems

Using the quality of the components in a system to keep the influences of disturbances to zero or minimize the influence is a very direct and understandable way. This approach rephrases the resistant ability of different crop cultivars and animal breeds.

For crops, when pests, diseases, weeds, atrocious weather, lack of nutrient input and other disturbances happen, they can use their properties of antixenosis, antibiosis, tolerance and competitiveness to cope with disturbances. Similarly, animals can use their immunity and tolerance to resist diseases, lack of feed and bedding, atrocious weather and etc. (REFERENCE, BOOKS IN LIBRARY, ADD LATER). Different crop cultivars and animal breeds have different resistant ability, therefore, their responses to certain disturbances might be different. Some researches show that certain crop cultivars and animal breeds perform better than the others in terms of disturbance resistance. For example, Elba potato is more resistant to the serious potato diseases late blight, wilt and viruses disease; Impala French bean is resistant to thrips; Residence winter wheat performs better than other cultivars under nutrient shortage; and MRIJ cow is hardy and more adaptive than other breeds (REFERENCE, BOOKS IN LIBRARY, ADD LATER). Therefore, to different selected “resilience of what” state variables, using the varieties which have higher resistance helps to improve the resilience of farming systems.

What worth noting here is that, the varieties which have higher resistant ability do not necessarily perform better on the other features such as productivity, environmental protection, etc. Therefore, integrated consideration is required when deciding the crop cultivars and animal breeds which will be used on the farm. Furthermore, when design/redesign a farming system, farmers always make decision for the rotation, layout and other general plans of the farm first, and then choose the suitable crop varieties and animal breeds in the second step. Therefore, in this thesis we focus on the general redesign of the case study farm, and won’t research the characteristics of different crop varieties and animal breeds in detail. However, when the farmer starts to implement the redesign scenario, he should remember approach one in mind and make good decision based on it.

Approach two: using interactions between system components

Farming systems are always very complicated and full of interactions and reflections, in which a small change might result to a huge consequence later on. Therefore, using the interactions between system components, i.e. reorganization and coherence of system components, is a very effective way to minimize the influence of disturbances.

The results of current resilience assessment of Droevendaal farm show several examples about how to use interactions among system components to overcome disturbances. For example, when the yield of feed crops is reduced by a disturbance, in order to keep the current profit and total nutrient losses, green manure, bedding material and crop residues are used to feed animals. Besides, even some current cash crops are changed to feed animals. Another example is that, when the yield of cash crops are reduced under disturbances, it is still possible to keep the current profit and total nutrient losses by changing the destinations of products on the farms into a more efficient and profitable way, e.g. use grass clover silage, which is currently used for selling, as animal feed.

Some other examples which are not shown in the results of current resilience assessment of Droevendaal farm include, e.g. when disturbance, such as pests, diseases, weeds and atrocious weather come to the farm and destroy the N-fixation crops on the farm, the nitrogen supply to the other crops will be influenced. In order to keep high productivity, there should be enough nitrogen in the soil for crop absorbing to compensate the shortage. And the last example, which often happens in organic farming systems, is that when the farmer reduces the supplement of external fertilizer to the crops, the nutrients stored in soil should be enough to compensate the gap between requirements and supplements.

Two conclusions, which are also the resilience redesign rules in this thesis, can be summarized from the analysis and examples mentioned above.

Resilience redesign rule No 1: building up diversity in farming systems

In farming systems, two types of diversity are useful to be organized to improve the resilience capacity: functional and response diversity (Walker et al., 2006).

Functional diversity means the number of functionally different groups. Refering to Table 2, functional diversity is represented by the different destinations of crops products, as well as the products produced by animals on the farm in Table 3. In systems that are characterized by high functional diversity the probability of the presence of redundant components and links is high, which supports the resilience (Walker et al., 2006), because links and flows can be redirected to support crucial system processes without compromising other vital functions.

Response diversity is the diversity of responses to disturbance among species and actors contributing to the same function in systems. In Table 2, the crops which have the same destination may come from different categories, for on destination, the more crop categories are included, the higher response diversity it has. Similarly for the animals, different varieties can be used to produce the same animal product, the more varieties are included for producing the same product, the higher response diversity the farm has. However, from Table 3 it can be seen that on the current Droevendaal farm there is only one animal variety, therefore, the current response diversity of animals is very low. Except the disturbances which influence the performance of all the components on the farm, e.g. climate change, most of the disturbances only disturb certain category of crops and animals. Therefore, increasing response diversity helps to spread the risks cause by disturbances.

Besides the reason mentioned above, building up diversity in farming systems helps to attract natural enemies of pest, diseases and weeds, which also contributes to resilience. Moreover, besides increasing the diversity of crops and animals on farms, introducing semi-natural elements such as hedges into farming systems could help to improve resilience.

Resilience redesign rule No 2: building up soil fertility in farming systems

From the examples of how to use interactions among system components to overcome disturbances, it can be seen that the soil plays a very important role in the process to overcome disturbances. Soil is like a huge nutrient and energy storage and helps to compensate the gap between requirements and supplements. Therefore, soil depletion happens in most of the strategies used by resilience to keep the current performance of farming systems. Together with that soil depletion is usually not easy to be noticed but can be very dangerous which might result fatal catastrophe in a long term, building up soil fertility in farming systems is important for both improving farm resilience and for protecting farming systems themselves from a long term point of view.

A sound crop rotation and good farm management help to increase soil fertility. Besides, they help to deplete the soil seed bank, pathogen and pest eggs from the previous year, and therefore are useful to prevent pests, diseases and weeds outbreaks after the year with the disturbances.

Specified to the crops grown on Droevendaal farm, because all the possible functions of crops, i.e. feeding, bedding, selling and green manure are all included in the current system already, on farm level there is not much room to improve the functional diversity. However, on the individual crop level it can be improved still. The destinations of the crop products are set as decision variables in the redesign process to find the optimal scenario (see Table 11). Based on the results of current resilience assessment of Droevendaal farm, it is more efficient and profitable to harvest the grass clover for making silage and feeding animals. Therefore, in the farm redesign grass clover is not used for grazing at all but all harvested for making silage. About the response diversity of crops, first, almost all the feeding crops come from cereal category, therefore, it's better to replace some cereal feedings by crops from the other category. Secondly, only one root crop on the farm that is the most important cash crop results in sensitivity to root crop disturbances, so increasing another root crop is a wise choice. Although introducing more root crop may cause some problems such as soil structure damage, the general advantage of it on improving both the resilience and the whole farm performance is bigger than its disadvantage, therefore, after an integrated consideration fodder beet is used to replace winter triticale in crop rotation in the redesign process. Finally, introducing more green manure on Droevendaal farm helps to reduce nutrient losses and provide higher probability of the presence of redundant components and links. The criteria to choose green manure variety is, on one hand whether the green manure variety is suitable to be succeeding crop follows the main crops, and on the other hand whether the variety is possible to be used as animal feed.

For the animals kept on Droevendaal farm, since there are only young bulls which are used for meat production, functional diversity can be increased by introducing animals for producing milk. Other types of animals, e.g. sheep (for milk production) and lamb (for meat production), horse, pig and etc. are options to be introduced into Droevendaal farm to improve the response diversity. However, it's not practical to add pigs on the farm because pigs require definitely another keeping system which is not owned by Droevendaal farm. Horses are not helpful choice either, because they are usually kept for landscape and horse riding rather than production. The cost for keeping sheep and lamb is very low but the profit is sound, therefore, keeping sheep and lamb is good choice to increase response diversity. Besides, sheep and lamb eat the lower part of the crops which can help the farmer to increase the feed efficiency. However, compared with sheep, lamb are more suitable for Droevendaal farm because meat production doesn't require extra milk equipment.

4.6.2 Whole farm performance redesign rule

The aim of farm redesign process in this thesis is not only to increase farm resilience, but also to improve the whole farm performance. Generally, we aim to achieve the objectives and constraints listed below through the redesign step.

- Farm resilience > current farm resilience
- SOM balance > current SOM balance
- No shortage of nitrogen to attain target crop yield levels
- Nitrogen loss from manure by volatilisation < 19 kg N/ ha
- Nitrogen loss by leaching plus denitrification < 50 kg N/ha
- No major deficits of P and K
- Operating profit > current operating profit
- Regular labour requirement <= Current regular labour available

Furthermore, the principles and dreams of the farmers are taken into account. As an experimental organic farm of WUR, Droevendaal farm is regulated by organic certification and principles. Besides a positive profit, the most import function of Droevendaal farm is to achieve a positive balance with nature and social integration, and provided as a place for students and researchers to implement their experiments.

4.6.2.1 Soil and crop redesign rule

Grown area of each crop is set as decision variables of soil and crops here (Table 8). Winter triticale which is grown on Droevendaal farm currently is excluded in the redesigned crop rotation, and fodder beet is used to replace it.

Table 8. Decision variables of soil and crops

Description	Minimum	Maximum
Potato+ Forage Rye ... Area	0	5
Grass Clover ... Area	0	10
Spring Wheat + Forage Rye ... Area	0	5
Spring Barley + Fodder radish ... Area	0	5
French Bean + Fodder radish ... Area	0	5
Maize + Forage Rye ... Area	0	5
Fodder beet ... Area	0	5

The importance of soil fertility for the resilience of farming systems is demonstrated in the previous part of the report (see chapter 5.6.1 resilience redesign rule No 2). Therefore it is set as an additional objective in the farm redesign step. Total nutrient losses is a very important value as "resilience of what" in this thesis, so it is another objective (Table 9). Besides objectives, several constraints are set based on the aim of farm redesign (Table 10).

Table 9. Objectives soil and crops

Description	Direction
Nutrient Losses N+P+K (kg/ha/yr)	Minimize
Organic matter balance (kg/ha/yr)	Maximize

Table 10. Constraints soil and crops

Description	Minimum	Maximum
Volatilization N (kg/ha/yr)	0	19
SoilLosses N (kg/ha/yr)	0	51
Maize + FRa.Maize silage SelfSupplyRate (%)	1	100
Grass Clover.GC silage SelfSupplyRate (%)	1	100
SW + FRy.SW grain SelfSupplyRate (%)	1	100
SB + FRa.SB grain SelfSupplyRate (%)	1	100
Fodder beet.Fodder beet SelfSupplyRate (%)	1	100

4.6.2.2 Livestock and animal feeding redesign rule

Several decision variables about animals are set in order to reorganize the interactions among the components on the farm in a more efficient way, and achieve the optimal performance (Table 11). In the table the maximum values of the decision variables are calculated as the yield multiple the maximum potential area of each crop, separately.

Table 11. Decision variables of animals and feeding

Description	Minimum	Maximum
Maize silage ... ToAnimals (kg)	0	46000
Maize silage ... FractionNonGrazPeriod	0	1
Grass Clover silage... ToAnimals (kg)	0	80000
Grass Clover silage ... FractionNonGrazPeriod	0	1
Spring Wheat grain ... ToAnimals (kg)	0	12750
Spring Wheat grain ... FractionNonGrazPeriod	0	1
PermPasture pasture ... ToAnimals (kg)	0	90000
PermPasture hay ... ToAnimals (kg)	0	90000
PermPasture hay ... FractionNonGrazPeriod	0	1
Spring Barley grain... ToAnimals (kg)	0	11220
Spring Barley grain ... FractionNonGrazPeriod	0	1
Fodder beet ... ToAnimals (kg)	0	32448
Fodder beet... FractionNonGrazPeriod	0	1
External straw... ToBedding (kg)	0	18000
Young bull ... Number	0	40
Milk cow ... Number	0	40
Milk cow ... ReplacementRate	0	1
Lamb ... Number	0	70

Table 12 shows the constraints set for livestock in the farm redesign process. These constraints are all about the feed and bedding balance because fulfil the requirements of animals to protect animal welfare is a very important point need to be considered by organic farmers. The minimum and maximum values are decided based on reference (Walter et al., 2010).

Table 12. Constraints livestock

Description	Minimum	Maximum
GrazingPeriod.Deviation Saturation EDM	-100	0
GrazingPeriod.Deviation Energy TDN	-5	5
GrazingPeriod.Deviation Protein CP	0	30
GrazingPeriod.Deviation STR	0	10000
NonGrazingPeriod.Deviation Saturation EDM	-100	0
NonGrazingPeriod.Deviation Energy TDN	-5	5
NonGrazingPeriod.Deviation Protein CP	0	30
NonGrazingPeriod.Deviation STR	0	10000
Bedding.Deviation	-5	5

4.6.2.3 Farm level redesign rule

There are two objectives at the farm level (Table 13): to maximize the operating profit and to minimize the labour balance. Table 14 shows that the farm area can be varied by the FarmDesign model, in order to get more solutions.

Table 13. Objectives farm level

Description	Direction
EconomicResults OperatingProfit (Euro)	Maximize
LabourBalance.Balance Regular (hour)	Minimize

Table 14. Constraints farm level

Description	Minimum	Maximum
Farm Area (ha)	48	50

4.6.2.4 General redesign rule

Some general redesign rules, such as on mixed farm the proportion of legumes, cereals, root crops and cover crops should be about 25-40%, 40-60%, 10-20% and 20-50%, separately, as well as the favourable and unfavourable rotational pairs and interval of crops due to incompatibilities or biotic factors must be taken into account (Annex 1).

4.6.3 Farm redesign results

The Pareto optimization in farmDesign model was run according to the variables, constraints, and objectives mentioned above. The results are depicted in Figure 12-14.

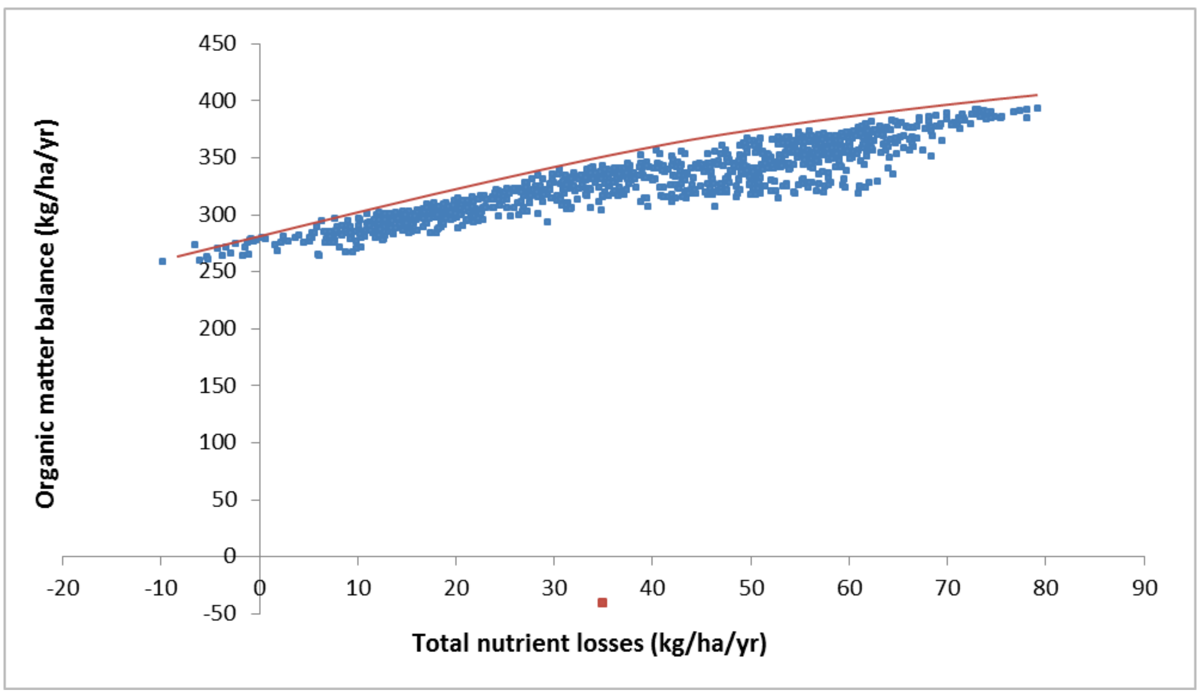


Fig 12. Organic Matter Balance vs. Total Nutrient Losses

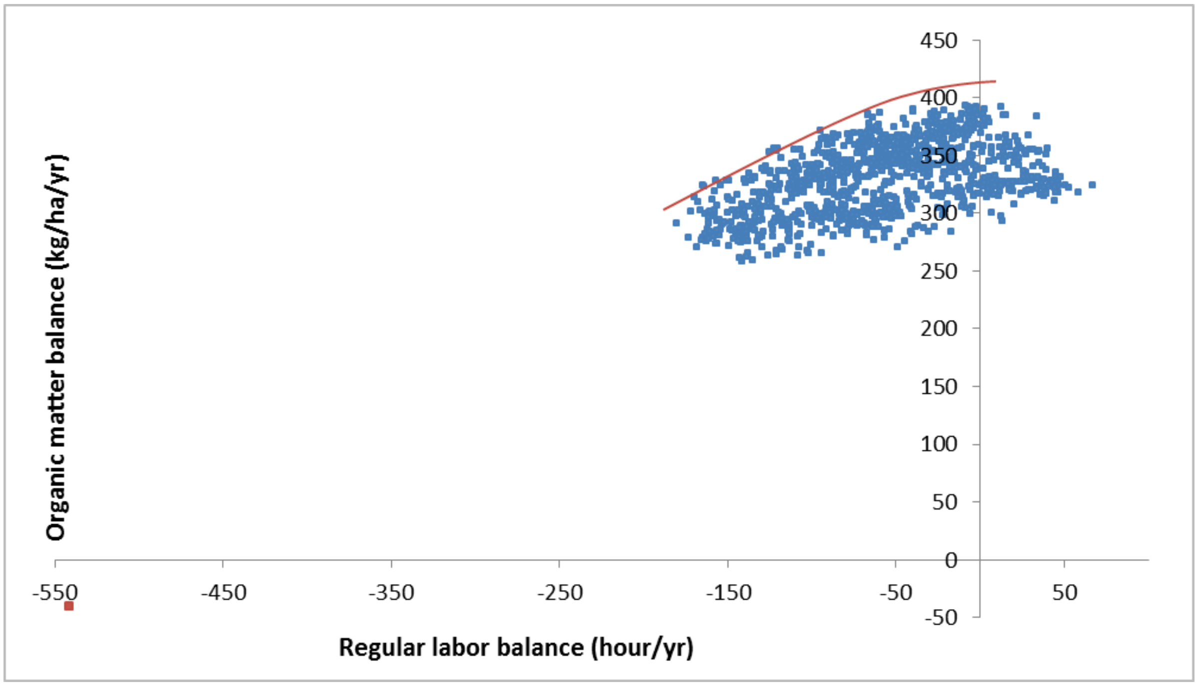


Fig 13. Organic Matter Balance vs. Regular Labor Balance

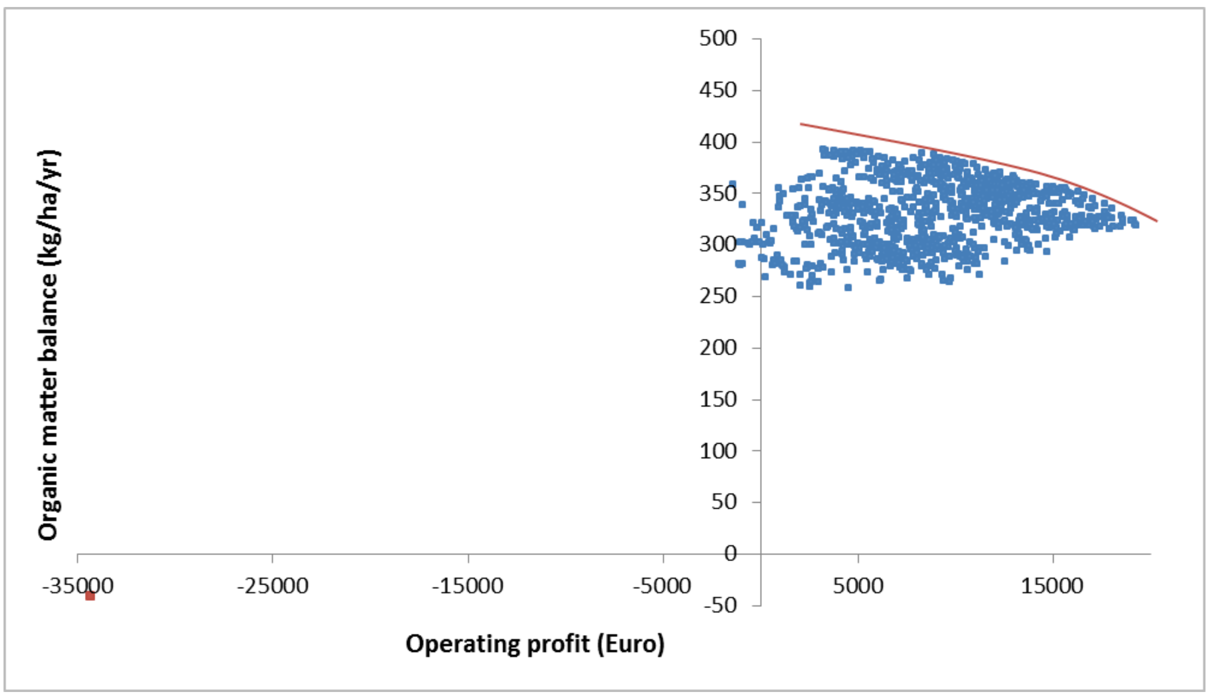


Fig 14. Organic Matter Balance vs. Operating Profit

Blue dots are the alternative solutions generated by FarmDesign model, and the red dot represents the current situation of Droevendaal farm in terms of the two objectives selected as X and Y axis. The red line in each graph shows the trade-off between the two objectives represented by X and Y axis and indicates the approximate Pareto optimal points for the two trade-offs in each graph.

From Figure 12, 13 and 14 it can be seen that for every increase of 100 kg/ha of organic matter balance, the total nutrient losses will increase approximately by 70.7 kg/ha/yr, the regular labor balance will increase around 175 hr/yr, and the operating profit will decrease about 3000 euro.

For Droevendaal farm, although minimization of regular labor balance is set as an objective, it is not a crucial criteria because as an experimental farm large part of jobs are done by students who do experiments on the farm. Soil organic matter balance is considered as the most important criteria in the scenario selection process because soil fertility plays such important role in resilience management as mentioned above. Therefore, in the new scenario, as long as the total nutrient losses is expected to be not more than the current value, and the operating profit is higher than zero, soil organic matter balance should always be the priority in trade-off analysis.

After an integrated consideration and comparison (Annex 2) of the solutions present in the Pareto optimal line of the graph depicting the trade-offs among soil organic matter balance, operating profit, total nutrient losses and regular labor balance, solution 711 is chosen as the optimal scenario because it has high organic matter balance while all the values of the other objectives fulfil the criteria. Table 15 and 16 shows the comparison between solution 711 and the current farm.

Table 15. Comparasion of input variables between solution 711 and current farm

Description	Current	Solution 711
Maize silage ... ToAnimals (kg)	46000	45250.28
maize silage ... FractionNonGrazPeriod	1	0.5
Grass Clover meadow ... ToAnimals (kg)	24000	0
Grass Clover silage... ToAnimals (kg)	0	62769.01
Grass Clover silage ... FractionNonGrazPeriod	0	0.84
Spring Wheat grain ... ToAnimals (kg)	12750	10904.15
Spring Wheat grain ... FractionNonGrazPeriod	0.55	0.95
PermPasture Pasture ... ToAnimals (kg)	63000	78341.13
PermPasture hay ... ToAnimals (kg)	63000	89869.58
PermPasture hay ... FractionNonGrazPeriod	1	0.8
Spring Barley grain... ToAnimals (kg)	11220	10547.09
Spring Barley grain ... FractionNonGrazPeriod	0.55	0.92
Fodder beet ... ToAnimals (kg)	0	25691.41
Fodder beet... FractionNonGrazPeriod	0	0.45
External straw... ToBedding (kg)	18000	17983
Young bull ... Number	65	28
Milk cow ... Number	0	28
Milk cow … ReplacementRate	0	0.14
Lamb ... Number	0	68
Potato ... Area (ha)	4	2.95
Forage Rye follows Potato ... Area (ha)	0	2.95
Grass Clover ... Area (ha)	8	9.12
Spring Wheat ... Area (ha)	4	4.08
Forage Rye follows Spring Wheat ... Area (ha)	0	4.08

Spring Barley ... Area (ha)	4	4.06
Fodder Radish follows Spring Barley ... Area (ha)	0	4.06
French Bean ... Area (ha)	0	2.76
Fodder Radish follows French Bean ... Area (ha)	0	1.62
Maize ... Area (ha)	4	4.05
Forage Rye follows Maize ... Area (ha)	0	4.05
Fodder beet ... Area (ha)	0	3.37
Winter Triticale ... Area (ha)	4	0

Table 16. Comparison of results between solution 711 and current farm

Description	Current	Solution 711
GrazingPeriod.Deviation Saturation EDM	-35	-5.89
GrazingPeriod.Deviation Energy TDN	-6	-3.76
GrazingPeriod.Deviation Protein CP	66	24.36
GrazingPeriod.Deviation STR	63	145.65
NonGrazingPeriod.Deviation Saturation EDM	-10	-5.01
NonGrazingPeriod.Deviation Energy TDN	3	-3.76
NonGrazingPeriod.Deviation Protein CP	25	12.66
NonGrazingPeriod.Deviation STR	158	174.17
Bedding.Deviation	3.969	1.67
Nutrient Losses N+P+K (kg/ha/yr)	35	34.04
Organic matter balance Balance (kg/ha/yr)	-41	341.61
Volatilization N (kg/ha/yr)	12	33.7
SoilLosses N (kg/ha/yr)	40	14.65
EconomicResults OperatingProfit (Euro)	-34319	4470.18
LabourBalance.Balance Regular (hour)	-541	-15.3
Farm Area (ha)	50	48.39
Maize + FRa.Maize silage SelfSupplyRate	1	1.03
Grass Clover.GC silage SelfSupplyRate	1	1.45
SW+ FRy.SW grain SelfSupplyRate	1	1.19
SB+FRa.SB grain SelfSupplyRate	1	1.08
Fodder beet.Fodder beet SelfSupplyRate	1	1.07

NDICEA model is used to check the nitrogen balance of the redesigned crop rotation (Figure 15). Certain amount (values generated by FarmDesign model) of FYM, slurry and P-Kali is applied on fodder beet, grass clover and spring wheat, separately. From the Figure 15 it can be seen that the requirements for nitrogen of all the crops are fulfilled in the redesigned crop rotation.

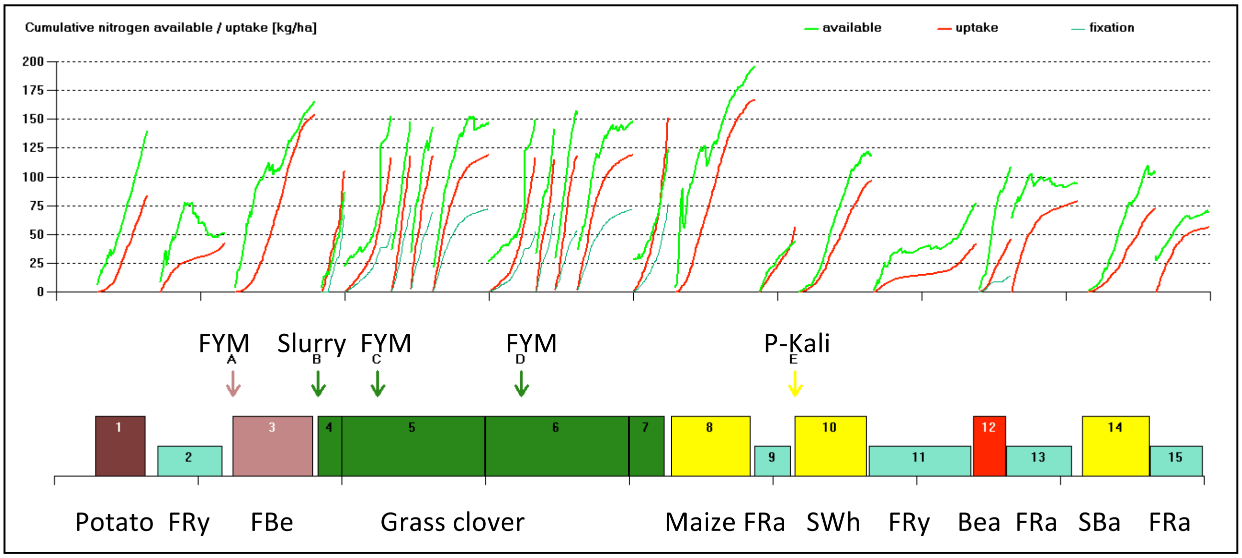


Figure 15. Nitrogen balance of redesigned crop rotation on Droevendaal farm

Table 17 and 18 descript the redesigned crop and animal situation on Droevendaal farm. Although the total crop species on the farm are still seven, the complication and interactions are increased and it is supposed to be helpful for improving resilience as explained in chapter 5.6.1, and the quantified resilience improvement results will be shown in chapter 5.7 below. The species, categories and functions of animals on Droevendaal farm are all increased.

Table 17. Redesigned crops on Droevendaal farm

Crop on Droevendaal Farm				
Species	7 crops species			
Categories	**Name**	**Product**	**Yield (kg/ha)**	**Destination**
Cereals	Spring wheat + Forage rye	SW grain SW straw Forage rye	3750 2500 1200	Feeding&Selling Bedding&Selling Green manure
	Maize + Fodder radish	Maize silage Fodder radish	11500 2200	Feeding&Selling Green manure
	Spring barley + Fodder radish	SB grain SB straw Fodder radish	3300 2500 2200	Feeding&Selling Bedding&Selling Green manure
Legume	French bean + Fodder radish	French bean FB residue Fodder radish	4600 2500 2200	Selling Green manure Green manure
Root crop	Potato + Forage rye	Potato Forage rye	18000 1200	Selling Green manure

	Fodder beet	Fodder beet	48000	Feeding&Selling
Ley	Grass/clover	GC silage	10000	Feeding&Selling

Table 18. Redesigned animals on Droevendaal farm

Animals on Droevendaal Farm			
Species	2 animal species: cattle and lamb		
Varieties	**Name**	**Product**	**Description**
Blaarkoop	28 Young bulls	Meat	Good meat price and nature variety.
Holstein Friesian	28 Milk cows	Milk	High roughage intake and ingestion capacity with high milk production (1). High adaptibility level, acclimate to every kind of environment (even extreme) and every kind of feeds (2).
Holstein Friesian	4 Heifers	Replacement	
Holstein Frieslan	4 Calves	Replacement	
Unknown	68 Lambs	Meat	

4.7 Redesigned resilience of Droevendaal farm

After being redesigned, the resilience capacity of Droevendaal farm is expected to be increased. The results of redesigned resilience assessment are shown and analysed in this part of report.

On the current farm, the functions of only two products, French bean residue and grass clover silage, can be changed from green manure and cash crop to feeding animals. For the other products, their functions are not changed and only the amount used for the current function might be adjusted in the alternative management options. However, on the redesigned farm, the interactions and reflections among system components are much more complex than the current system, and when disturbances come to the redesigned farm, there are many possible alternative management options which help the farm to overcome disturbances and keep the current performance by changing the functions of system components. Therefore, it is impossible to assess the resilience capacity of the redesigned farm in the same way as used for assessing current resilience capacity. Otherwise, the FarmDesign model will choose the scenarios which use as much green manure as possible to feed animals and leave the other main crops for sale to achieve higher profit and less nutrient losses, but these scenarios are not practical solutions. For this reason, the resilience capacity is assessed in another way round, which from 100% yield reduction, and allow all the green manures to be used for feeding. If no useful alternative management options can be found, then decrease the yield reduction gradually until the farm can keep the current performance under disturbances. The decision variables, constrains and objectives set here to quantify the redesigned resilience are same as those when quantifying the current resilience of Droevendaal farm (see Table 5, 6 and 7)

4.7.1 Redesigned resilience to cereal disturbances

When the yields of cereals on the redesigned farm are reduced by 100%, 90% and 80%, it is impossible to make the feed balance in the constraint range, and therefore unable to explore the model at all. And when the cereal yields are reduced by 70%, 60% and 50%, even all the green manures are allowed to be used as animal feeds, no useful alternative management options can be got by exploring FarmDesign model because of high total nutrient losses. This is because in FarmDesign model, the nutrient uptake by crops will also be reduced when the yields are decreased. More nutrients are left in soil causes higher leaching. Useful alternative management options are found till the yield reduction is 40%. Figure 16 shows the explore window of FarmDesign model when the yields of cereals on the redesigned farm are reduced by 40%. The strategy used by the useful alternative management options is to use green manures as animal feeds to compensate the feed insufficiency. Compared with the current situation, the resilience to cereal disturbances of the redesigned farm increases 10%.

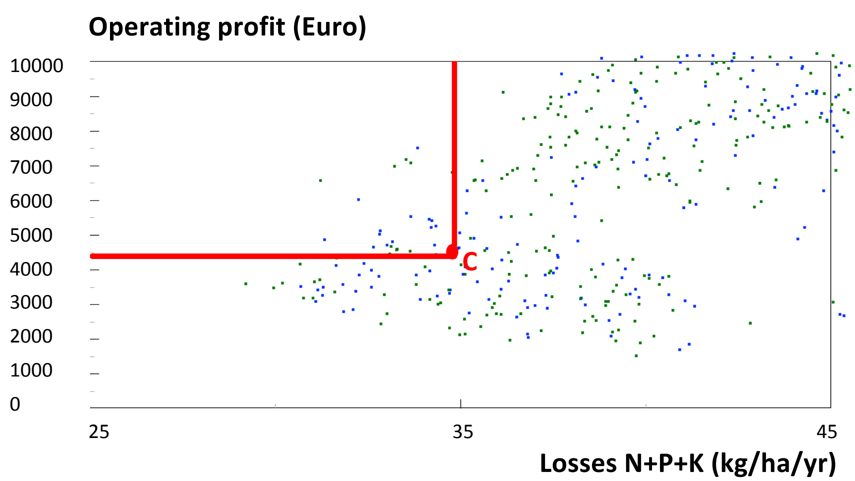


Fig 16. Alternative management solutions when the cereal yields are reduced by 40%

4.7.2 Redesigned resilience to legume disturbances

Based on the results of disturbance imitation, the redesigned farm can keep its performance even when the yield of legume is decreased by 100% (Figure 17). This is because, on the one hand, in the redesigned farm, the area for grown legume, i.e. French bean, is reduced from 4 ha to 2.76 ha, and therefore the influence of legume on the farm performance is smaller than before; and on the other hand, there are much more redundant components and links present on the redesigned farm compared to the current one. The resilience to legume disturbances of the redesigned farm increases 40% when compared with the current resilience.

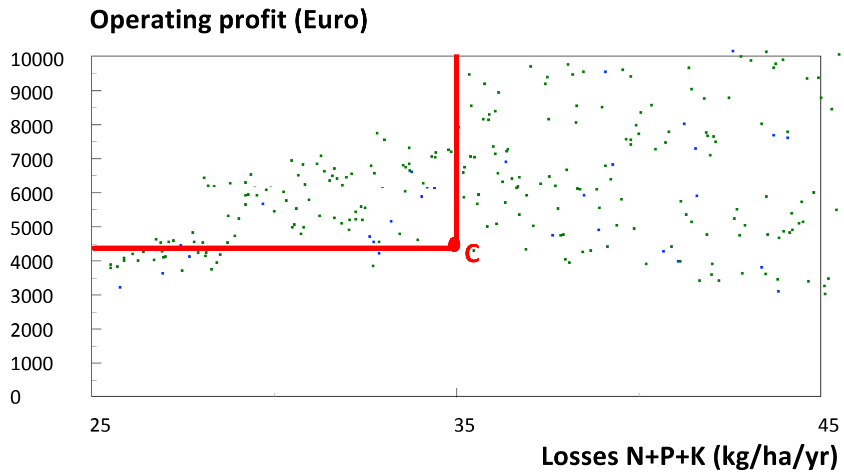


Fig 17. Alternative management solutions when the legume yield is reduced by 100%

4.7.3 Redesigned resilience to root crop disturbances

The third type of disturbances imitated with FarmDesign model is root crop disturbances. From the results it can be seen that, when the yield of root crops on the redesigned farm, i.e. the yield of potato and fodder beet, is reduced by 100% and 90%, although all the green manures are used to compensate the feed insufficient, it is still impossible to make the feed balance within the constraint range, and therefore impossible to explore the FarmDesign model. And when the root crop yield is reduced by 80% and 70%, it is able to explore the model but cannot achieve the same operating profit level. The redesigned resilience to root crop is 60% when useful alternative management options can be got (Figure 18). The redesigned resilience to root crop is 30% higher than the current resilience.

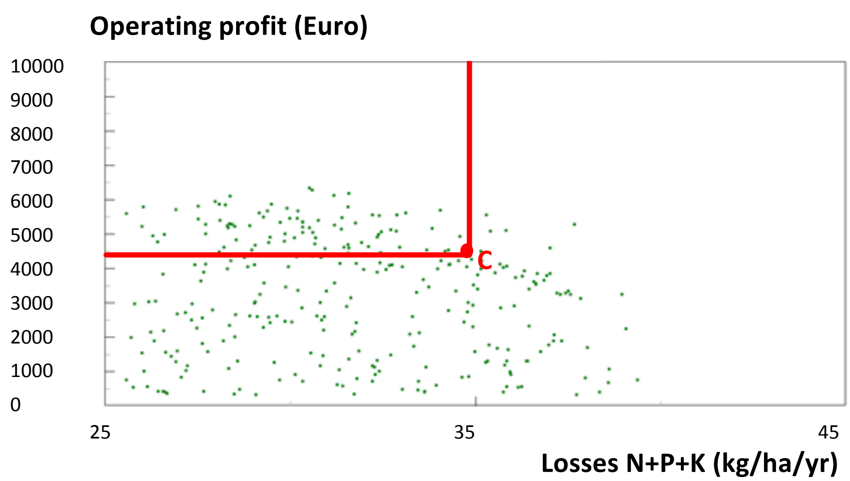


Fig 18. Alternative management solutions when the root crop yield is reduced by 60%

4.7.4 Redesigned resilience to ley disturbances

When reduce the yield of grass clover by 100%, 90% and 80%, the value of soil losses is out of the constraint range and therefore unable to explore the model. This result is consist with the result of the current resilience assessment and proves the effect of grass clover on reducing nutrient losses from soil again. Both the operating profit and total nutrient losses cannot achieve the current level when the grass clover yield is decreased by 70%, 60% and 50%. Figure 19 shows that when the yield is reduced by 40%, useful alternative management options can be found and therefore the redesigned resilience to ley disturbances is 40%. Compared with the current value, the resilience to ley disturbances of the redesigned farm increases 10%.

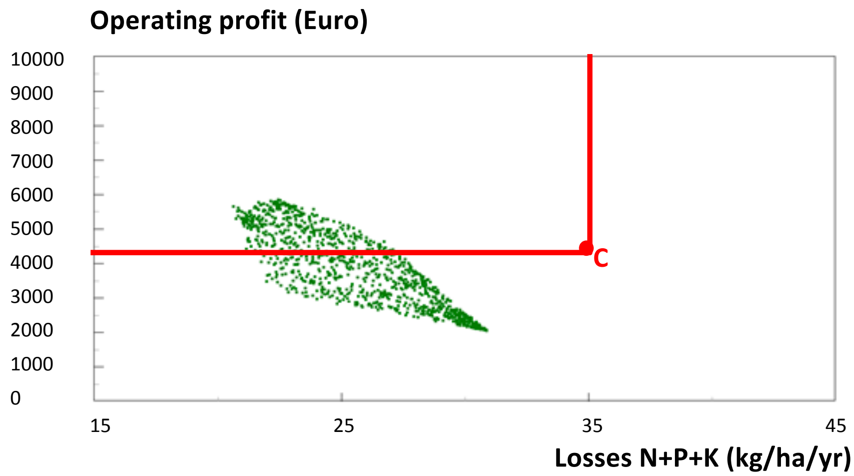


Fig 19. Alternative management solutions when the ley yields are reduced by 40%

4.7.5 Redesigned resilience to animal disturbances

As mentioned in the previous part of the report (see chapter 5.5.5), it is infeasible to assess animal disturbances quantitatively with FarmDesign model. Therefore, no graph can be generated to prove the improvement of resilience to animal disturbances on the redesigned farm directly. However, based on the analysis, it can be seen that the redesigned resilience to animal disturbances must be more or less increased, because both the functional and response diversity of animals are improved on the redesigned farm. In order to show the changes quantitatively, either FarmDesign model need to be adjusted or new methods should be discovered.

4.7.6 Redesigned resilience to whole farm disturbances

The results of whole farm disturbances imitation show that when the yields of all the crops on the redesigned farm are reduced from 100% to 20%, either it is unable to explore the model because it is impossible to make all the constrains in the decided range or no useful alternative management options can be found. Only when the yield is reduced by 10%, useful solutions can be got by exploring the model (Figure 20). Therefore, the redesigned resilience to whole farm disturbances is 10% yield reduction. When compared with the result of current resilience to whole farm disturbances, there is no improvement on this point. This is probably because the whole farm disturbance is quite serious. Even though, the useful alternative management options are much more than those found when the whole farm crop yields are reduced by 10% on the current farm.

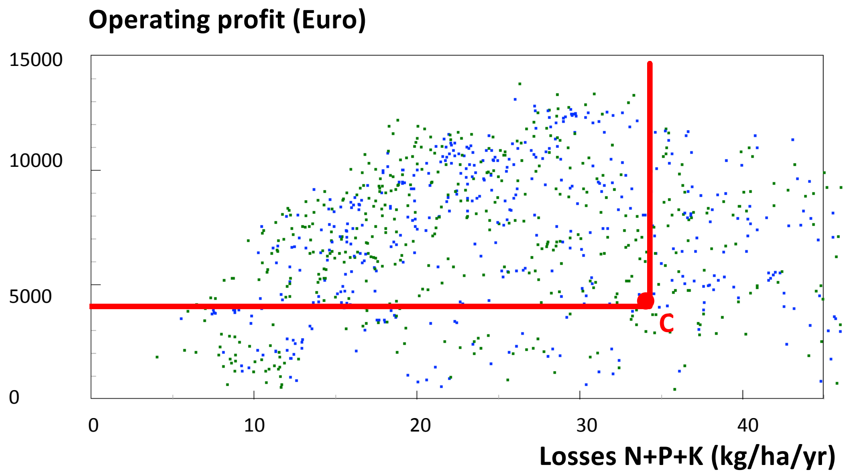


Fig 20. Alternative management solutions when the whole farm crop yields are reduced by 10%

5. Discussion and conclusion

Several research prerequisites need to be done before starting the research on resilience of farming systems. Firstly, compared with ecological systems, farming systems are more influenced by the non-natural disturbances. Therefore, new definition of resilience specified for farming systems is required. The concept of ecological resilience is a suitable theoretical foundation to develop this definition. Secondly, because the interactions among system components contribute and influence the resilience of farming systems directly, clear description of the targeted system and its components is necessary. Finally, what state variables of a farming system are expected to be kept stable under what kinds of disturbances, i.e. resilience of what to what, must be defined carefully beforehand, since they decide the focus of the research and with different focuses the results of the research might be significant different.

By using the methodology in this system, it is feasible to use the FarmDesign model, which was invested for planning or redesigning mixed farms originally, to evaluate resilience of farming systems quantitatively. However, there are several limitations:

- It is infeasible to use the FarmDesign model to assess the disturbances to animal because of the calculation methods of this model. In order to quantify animal disturbances with the FarmDesign model, the calculation methods about animals used in this model need to be adjusted. Relevant values should be more independent rather than all connected and used as calculation foundation for each other. Or more parameters such as producing efficiency, which means how much percent of animal products the animals can produce under disturbances when compared with the optimal situation, should be added into the model.
- When imitate disturbances with the FarmDesign model, users have to change the values of all the relevant parameters manually every time. If the users want to imitate the disturbances very precisely with small grade gap such as increasing the influence of disturbance by 1% each time, the huge amount of workload can easily cause errors in the process. Otherwise, the big grade gaps causes inaccuracy.

Furthermore, this thesis focused on the ecological disturbances. However, there are many other types of disturbances, which are much more complicated than the ones chosen as “resilience to what” in this report or more about social aspect such as regulations and economical changes. For these disturbances, it is not able to be assessed with the FarmDesign model. Therefore, designing a computer model which is created specified for evaluating resilience of farming systems quantitatively would be an interesting research topic for the future.

The results of the redesign process show that it is possible to run farming systems with good whole farm performance and high resilience capacity simultaneously, and by increasing the resilience of farming systems, the whole farm performance can also be improved under a dynamic environment - “building resilience to achieve sustainability”.

Good farm management is very important for building up resilience. In order to improve the resilience of farming systems, organic farmers should pay attention to increase both functional and response diversity of the components on their farms, improve soil fertility and soil organic matter content, and use highly resistant crop cultivars and animal breeds. When disturbances come, there are different useful alternative management options available. Every alternative management option has its advantages and disadvantages, some of them may work well to keep the selected state variables on the required level under disturbances but negatively influence the other features of farming systems which are not chosen as state variables. However, farmers should focus on the selected “resilience of what” but always remember the integrated consideration in mind, in order to make the best trade-off analysis and select the optimal scenario to achieve good whole farm performance and high resilience at the same time. All the management practices and decision making process mentioned above require a wealth of knowledge and experience. Therefore, improving the learning and feedback capacity is very important for organic farmer.

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7. Annex

Annex 1. General farm redesign rule

Table 1 Examples for proportions (%) of typical crop groups (Freyer, 2003)

Farm structure	Legumes	Cereals	Root crops	Cover crops
Mixed farm (milk cows)	30–50[A]	30–50	5–15	20–50
Mixed farm (various animals)	25–40[B]	40–60	10–20	20–50
Mixed farm (pigs)	20–35[C]	50–60	15–25	40–60
Arable farm	25–30[D]	40–60	20–30	40–60

[A] Mainly forage legumes; [B] forage legumes (>50%), grain legumes; [C] grain legumes, forage legumes, propagation of cover seeds, set-aside; [D] grain legumes, forage legumes, propagation of cover seeds, set-aside.

Table 2 Favourable and unfavourable rotational pairs (Baeumer, 1992)

1, very unfavourable; 2, unfavourable; 3, possible; 4, favourable; 5, very favourable.

	Succeeding crops												
Preceding crops	Grass-clover (perennial)	Winter rape	Sugar beet	Potatoes	Sunflower	Faba beans	Field peas	Maize (grain & silage)	Winter wheat	Winter barley	Winter rye	Spring barley	Oats
Grass–clover (perennial)	1	5	1	4	1	1	1	5	5	4	4	2	2
Winter rape	3	1	1	4	2	3	3	4	5	4	4	1	1
Sugar beet	3	1	1	4	2	2	2	5	5	1	1	4	3
Potatoes	3	5	5	2	2	2	2	5	5	5	5	4	3
Sunflower	3	1	4	4	1	4	4	4	5	5	5	4	4
Faba beans	2	1	2	5	1	1	1	5	5	4	4	3	3
Field peas	2	4	4	4	1	1	1	4	5	5	5	3	3
Maize (grain & silage)	3	1	5	5	5	5	5	3	4	2	2	4	4
Winter wheat	4	2	5	5	5	5	5	5	1	3	3	3	4
Winter barley	5	5	5	5	5	4	4	4	1	2	2	2	3
Winter rye	5	5	5	5	5	4	4	4	1	1	2	2	3
Spring barley	5	4	4	4	4	4	4	4	3	1	2	2	1
Oats	5	4	5	4	4	4	4	4	4	4	4	2	1

Table 3 Interval of crops due to incompatibilities or biotic factors (Muller, 1988)

Crop	Year	Incompatibility	Viruses	Fungi	Nematodes	Insects
Winter wheat	2			✓	✓	
Winter barley	1–2			✓		✓
Spring barley	0–1				✓	
Oats	3–5				✓	
Winter rye	0–1			✓		
Potatoes	3–4				✓	
Sugar beet	4			✓	✓	
Rape	3			✓	✓	
Field peas	4	✓		✓		
Flax	6	✓		✓		
Faba beans, lupins	3	✓	✓	✓		
Lucerne	4–5	✓		✓		
Red clover	6	✓		✓		
White or yellow clover	2–3	✓		✓		
Grass-clover	3–4	✓		✓		
Cabbage spec.	3–4			✓	✓	
Celeriac	3			✓		
Leek	2–3			(✓)	✓	
Carrots	3–4			(✓)	✓	
Onions	4–5			✓	✓	

Annex 2 Farm redesign scenarios comparison

Description	185	146	123	517	378	711	608	514	736	148	192
Farm Area (unit)	48.62	48.09	48.14	48.15	48.36	48.39	48.32	48.52	48.65	48.61	48.14
GrazingPeriod.Deviation EDM (unit)	-2.41	-4.63	-4.39	-5.95	-5	-5.94	-4.81	-6.88	-3.66	-4.71	-2.14
GrazingPeriod.Deviation CP (unit)	25.99	26.29	26.43	24.45	24.62	23.69	24.56	22.37	26.23	19.85	29.83
GrazingPeriod.Deviation STR (unit)	152.51	147.03	147.75	140.34	149.16	145.65	149.81	139.84	151.03	142.48	149.38
NonGrazingPeriod.Deviation EDM (unit)	-3.65	-1.67	-1.48	-6.13	-3.57	-5.05	-3.45	-4.77	-4.42	-2.41	-7.18
NonGrazingPeriod.Deviation TDN (unit)	-2.48	-1.32	-1.31	-4.02	-2.23	-4.09	-2.16	-4.51	-3.45	-1.89	-1.78

NonGrazingPeriod.Deviation CP (unit)	13.5	16.33	16.53	11.42	14.77	12.19	14.86	10.2	13.22	12.63	14.91
NonGrazingPeriod.Deviation STR (unit)	173.7	181.24	181.77	165.71	179.02	174.17	179.16	171.67	175.74	171.33	159.39
Organic matter balance Balance (unit)	360.91	356.41	352.49	344.76	342.64	341.61	339.75	339.16	334.58	330.65	328.31
LabourBalance.Balance Regular (unit)	-47.91	-120.21	-125.33	-37.99	-26.77	-15.3	-33.47	-58.45	-30.45	-96.01	-139.25
EconomicResults OperatingProfit (unit)	8873.53	3224.77	3881.79	5591.07	3320.01	4820.18	3600.8	4245.29	3911.49	8140.21	1811.84
NutrientFlow.TotalNutrientLosses (unit)	47.17	40.42	38.83	37.48	34.95	34.04	33.42	30.52	28.44	27.75	27.06
NutrientFlow.SoilLosses N (unit)	41.88	39.37	38.79	34.41	34.26	33.7	33.4	33.18	32.36	34.04	33.35
NutrientFlow.Volatilization N (unit)	14.94	14.92	14.9	14.77	14.77	14.65	14.76	13.83	14.41	13.86	14.3
GrazingPeriod.Deviation TDN (unit)	-1.71	-2.62	-2.59	-1.83	-3	-3.55	-3.11	-3.81	-1.31	-4.72	0.86
BeddingBalance Balance (unit)	-1.84	-0.85	-0.86	-3.97	4.44	1.67	4.39	0.19	4.39	-2.77	3.16
Maize + FRa.Maize silage SelfSupplyRate (unit)	1.03	1.06	1.06	1.03	1.03	1.03	1.03	1.02	1.01	1.04	1.04
Grass Clover.GC silage SelfSupplyRate (unit)	1.49	1.52	1.52	1.56	1.45	1.45	1.44	1.61	1.55	1.63	1.54
SW+ FRy.SW grain SelfSupplyRate (unit)	1.03	1.08	1.09	1.06	1.2	1.19	1.21	1.49	1.09	1.02	1.07
SB+FRa.SB grain SelfSupplyRate (unit)	1.09	1.17	1.12	1.03	1.11	1.08	1.11	1.41	1.16	1.2	1.04
Fodder beet.Fodder beet SelfSupplyRate (unit)	1.46	1.4	1.56	1.06	1.09	1.07	1.13	1.01	1.07	1.31	1.47