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FoPIA-Surefarm 2 Case Study Report The Netherlands

Work Performed by P1, Wageningen University

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Supplementary Materials H. FoPIA-SURE-Farm 2 Case Study Report The Netherlands

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Supplementary Materials H. FoPIA-SURE-Farm 2 Case Study Report The Netherlands

1 Introduction

1.1 Main indicators, resilience attributes and challenges

The farming system in the Veenkoloniën in the Netherlands is characterized by starch potato cultivation in a rotation with cereals and sugar beets. The presence of a starch processing cooperative in the area results in stable farm gate prices, which influences the stability of supply and demand. The main functions of the farming system are providing affordable and healthy food, providing economic viability and maintaining natural resources (soil, water, air). Indicators that are most representative for these main functions (function indicators) are presented in Table 1. In general, function indicators have a low to moderate performance (Table 1).

General resilience in the area is mostly realized by the resilience attributes as presented in Table 2. Presence of these attributes is low to moderate. A fifth attribute bringing resilience to the Veenkoloniën is the heterogeneity of farm types, but this was not considered in the workshop.

Table 1. Main indicators and their performance and development. Source: Paas et al. 2019

Main indicators	Current level (score 1:5)	Current level (explanation)	Current development
Starch potato production (t/ha ; area in the region)	**3.3**	Full potential not reached, but plateau seems to be reached; new nematodes that broke through the resistance; sensitive to drought	Stable, although less so during the two previous seasons.
Profit (Euro/ha)	**3.0**	Avebe innovates, which leads to higher prices for starch potatoes, the most important crop. Prices for cereals are good, but prices for sugar beets are low after abolishment of the quota.	Prices for potato rise, but in the last two years, low yields caused lower profitability.
Soil quality	**2.4**	Presence of nematodes limit production; starch potatoes growing in a very narrow rotation; root and tuber crops disturb the soil at harvest; not all soils in the region have good water holding capacity.	Slowly declining (soil structure, active organic matter, nematodes)
Regional water availability	**3.0**	Region dependent on water from elsewhere.	In dry years, water availability is limited.

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Table 2. Main resilience attributes and their presence in the farming system. Source: Paas et al. 2019

Main resilience attributes	Current level (score 1:5)	Current level (explanation)	Current development
Reasonably profitable	**2.0**	Even though profit per hectare is moderately high, dependence on subsidy stays.	With two years below average, it is hard to say, but it might be that a plateau is reached.
Coupled with local and natural capital (production)	**2.9**	Farmers in the region use locally available manure and use nature friendly techniques (leaving straw in the field; cover crops, flower strips); with regard to nutrient use efficiency and pesticide use, improvements can be made.	Goal is to reduce crop protection products in the future. Research on cover crops will support tailoring of more nature friendly agriculture. Increased collaboration with dairy farmers can help to better use locally available nutrients.
Socially self-organized	**2.9**	Starch potato growers are organized in a cooperative which improves the stability of income, however, it limits the choice for cultivating different crops. Collaboration with dairy farmers could still improve. Shared experimentation and data sharing could still be improved.	The relationship between farmers and the cooperative seem stable, there is reciprocal loyalty. Implementation of precision agriculture provides opportunities to further share experiences.
Infrastructure for innovation	**3.0**	The cooperative has created an innovation center near a university; POP3-projects provide funds for technological innovation in the field; limited profitability impedes experimentation on farm level.	Actors in the system actively look for expanding the infrastructure for innovation; for instance the cooperative provides a cultivation registration tool to farmers.

Main challenges for the farming systems are (Paas et al. 2019):

- Plant parasitic nematodes in the soil
- Extreme weather events (drought, wet conditions etc.)
- High production costs in comparison to farm gate prices
- Continuous change in laws and regulations

1.2 Participation in the workshop

22 persons participated in the workshop, of which 8 were farmers. Other participants belonged to the processing industry (2), water authorities (2), banks (1), breeding (1), insurance company (1), students (2; BSc management of the living environment, both coming from a farm in the

region), provincial authorities (1), agricultural nature organization (1), agricultural innovation organization (1), regional agricultural researchers (2).

Participants agreed with the proposed main indicators, resilience attributes and challenges as presented in Section 1.1. However, some participants indicated that the performance of indicators and attributes was higher than previously assessed.

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2 Results

2.1 Maintaining the status-quo

2.1.1 Introduction

In order to keep the current system as it is, participants provided minimum or maximum levels of indicators, resilience attributes and challenges. These maximum or minimum levels can be considered as tipping points.

2.1.2 Indicators

Starch potato production

Starch potato production was mainly discussed with regard to area and tons per hectare. Estimates for the minimum area with starch potato were 35,000 and 40,000 hectares. Another participants noted down that the area should stay stable. The current area is roughly 40,000 ha with a rotation of roughly 1:2.5 at regional level. One participant noted down that the minimum rotation would be around 1:3, implying an area of around 33,000 ha.

Estimates noted down by other participants indicated a minimum production per hectare ranging from 38, 40 (3x), 45 to 50 t/ha. Current average production of starch potato is 42.6 t/ha (KWIN-AGV, 2018; average over period 2016-2018). It should be noted that in the case of starch potatoes, the amount of starch is also important. One participant noted down an estimated threshold for starch production of 7 t/ha for several years in a row. On average 19% starch (KWIN-AGV, 2018) per 42.6 t/ha starch potatoes is a current yield of roughly 8 t starch/ha (average over period 2016-2018). However, the percentage provided by KWIN-AGV (2018) might be an underestimation. Supply figures of AVEBE show a starch content of around 20% (J. Klok; Personal communication), resulting in a yield of around 8.5 ton per hectare.

One post-it indicated the area reduction for starch potato would only start when gross margin is smaller than alternative crops. Another post-it mentioned that the tipping point is related to nematodes in the soil and other plant diseases.

Profitability (Euro/ha)

Regarding profitability, there was confusion whether we were talking about revenue minus variable costs (gross margin) or revenue minus variable and fixed costs (net profit). Moreover, participants filled in numbers for starch potato alone, or for the whole rotation. In a plenary discussion, participants also argued that these numbers should not be treated as hard facts and should be compared with real data. Also, participants indicated that the threshold level differs per

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individual farmer. Still, quite a few participants felt comfortable enough to quantify the threshold. One participant noted down that profitability is the most important steering element.

One participant estimated the revenue for starch potatoes to be at least 2,700 Euro/ha. Another estimated 3,000 Euro/ha as the revenue for the whole rotation. Another participant also mentioned a revenue of 3,000 Euro/ha, but didn't specify whether this was for starch potatoes or the whole rotation. During the discussion, one farmer indicated that to compensate for all costs and to have a good living, 3,000 Euro per hectare for starch potatoes was indeed a minimum. Currently, average revenue from the whole crop rotation is around 2,800 Euro per hectare (Reindsen, 2018; Vos, 2018) and in the period 2016-2018 around 3,200 Euro per hectare for starch potato (KWIN-AGV, 2018). A suggested revenue of 5,000 Euro/ha was also noted down, but this was laughed away as impossible during the discussion. However, it is possible that this is an upper limit beyond which other types of changes can occur.

Further suggestions for minimum levels that were noted down ranged from 1,000 to 1,500 (3x), 1,800 (for starch potato) and 2,000 Euro/ha. It is likely that these values are for gross margin per hectare, but without further comparison with real data, it is hard to guess whether this is for the whole rotation or only for starch potato. A participating farmer mentioned that some farmers can survive with quite low gross margins, but that much more was needed than the mentioned minimums to be able to innovate.

Soil quality

Participants agreed that current soil quality should be improved (noted down 5 times) or at least maintained (noted down 2 times) to avoid a tipping point. One participant noted down an organic matter content of 3% as a tipping point, while another mentioned 8%. 3% could refer to active organic matter and 8% could refer to total organic matter. One participant noted down that a tipping point would be reached when soil would further disintegrate in sand and organic matter. Active organic matter is important for the integration of soil particles. One participant noted down that the tipping point was reached years in the past. This was mentioned again during the plenary discussion.

Many participants did not define a tipping point, but indicated that the tipping point was related to soil mining through a tight rotation, too much sealing, soil life (2x), good balance of oxygen, water and soil particles, disturbing layers, organic matter at a good level, presence of nematodes. Also, one participant noted down that CO_2 fixation in the soil and compensation for that, could be related to a tipping point. Further, there was a participant mentioning that instead of symptom treating, underlying causes of low soil quality should be found.

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In the plenary discussion, no definitive conclusion was reached on the minimum level of organic matter. However, participants agreed that active organic matter was important for building soil structure and water holding and draining capacities. In general, participants agreed that soil quality was declining. As an example, one participating farmer mentioned waterlogging in lower laying fields in wet autumns. These fields apparently have not enough soil structure to adequately drain water away. This is related to peat oxidation in the region, which lowers the soils. There is no financial compensation for this phenomenon. Another participating farmer concluded that keeping the current soil quality was almost the highest achievable goal, given the current circumstance.

Water availability

Most participants indicated that availability of water in the region is currently good and should stay the same (3x) or should improve (3x). One participant indicated that a reduction of up to 20% is still possible, before things start to change. Two participants linked the tipping point to the water supply from the lake IJsselmeer: when water in this lake cannot be adequately replenished and water supply from this lake is not obvious anymore, they expect a tipping point. Four participants linked the tipping point to irrigation possibilities: water should be unlimited available and a reduction of or (total) ban on irrigation would imply a tipping point. One participant noted down that a tipping point will be reached when the difference between water levels between higher and lower parts of the region is becoming too big.

During the plenary discussion, a participant of the local water authorities mentioned that water supply from lake IJsselmeer is not guaranteed in the future. So far, the water authorities have done the best they could, which was good enough for the current situation. In the future, water availability will not only be dependent on supply from lake IJsselmeer, but will also depend on water retention in the soil. Improving soil quality, especially structure, is therefore key to avoid a tipping point in the future. One farmer also indicated to be willing to invest in a water reservoir on his own field -- others reflected though that this is likely not allowed.

2.1.3 Resilience attributes

Participants had much less ideas on defining tipping points for resilience attributes. Because of the extended discussion on tipping points for main indicators, the tipping points for resilience attributes were not discussed in a plenary session.

Reasonably profitable

One participant indicated a threshold of at least 1000 Euro/ha for the whole farm, another participant noted down that net profit should stay higher than the average of the last 5 years, another participant noted down that a threshold is reached when spending income is lower than

20,000 Euro/year and another participant noted down a threshold when solvency (own capital/total capital * 100%) is lower than 30%.

Another participant indicated that a threshold would be reached when bills cannot be paid anymore and shocks cannot be absorbed. Yet another participant perceived the threshold already at the point where there was no room for experimentation and innovation. A clear sign for a threshold being reached, according to one participant is when the crop rotation needs to be changed.

Socially self-organized

For this attribute few, but diverse ideas were posed. One participant noted down that social self-organization would reach a tipping point when farmers are forced to deliver (by the starch processing cooperative). This expresses the need for the region to keep high starch potato yields in the current setting. Another participant mentioned a reduction of 20% in the farmer or rural population. Another participant noted down that openness with regard to crop protection was important. One participant mentioned that cooperation should be better and can be an important factor for innovation, e.g. interaction between arable and livestock farmers is also socially important. Another participant stated that if by 2025 no more regional cooperation is realized, a tipping point is reached.

Infrastructure for innovation

Participants indicated that infrastructure for innovation should improve and become more than just good and should go faster (mentioned by two participants). One participant indicated that innovation should focus on content rather than mass (of starch potato production). Another participant mentioned that a critical mass is needed in terms of area cultivated and in terms of income to allow for sufficient infrastructure for innovation. Finally, one participant mentioned that by 2025 there should be a cooperative investment in precision agriculture.

Production coupled with local and natural capital

No clear thresholds were defined for this resilience attribute. However, participants related the tipping point water drainage and availability in the region. One participant mentioned that improvement for this resilience attribute was only possible when this reduces production costs and when support from the market or government is present (new business model).

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2.1.4 Challenges

High costs relative to farm gate prices

According to one participant, a tipping point is passed when costs are higher than benefits. To avoid a threshold being passed, one participant indicated that by 2025, profitable protein-rich crops should be developed. Other participants noted down that other profitable crops and cheap precision agriculture technology should become available. Also new, shorter value chains (Veenkoloniën as food shed of surrounding cities), were noted down by participants.

In the plenary discussion it was mentioned that precision agriculture can reduce costs and improve yields, for example of protein crops. Local producing and selling was also mentioned to better valorize products.

Plant parasitic nematodes in the soil

Based on participant's notes, the nematode issue is getting out of control and really needs to be solved. One participant noted down that the tipping point is where the pressure is so high that a 1:2 rotation of starch potatoes is no longer feasible. This was mentioned again in the plenary discussion.

Most participants thought in terms of solutions that could help to reduce the problem: more measurements, enforcement of nematode reducing practices, boosting natural enemies through developing biodiverse soil life, search for the actual causes, control through good choice of varieties, soil resistance, resistant varieties, new breeding techniques. Resistant varieties were also mentioned again in the plenary discussion.

Extreme weather events

A few clear thresholds were mentioned: maximum three times in ten year, 3-4 years in a row with extreme weather events. These were also mentioned in the plenary discussions, where it was added that such extreme years would also limit options for irrigation. Most participants noted down ideas for avoiding tipping points in terms of the availability of (new) solutions: possibility of irrigation (with ground water) , having good soil structure and drainage, possibilities for control with regard to availability of water and drainage, no-till resulting in keeping the soil surface green. (No-till also increases soil organic carbon and water holding capacity.) One participant mentioned also the years when solutions should be available: by 2025 innovation in new crops, and by 2030 innovation in water supply at field level.

One participant mentioned that awareness was needed that water availability is not a matter of just opening a tap. Yearly millions of cubic meters of water are supplied to the Veenkoloniën from lake IJsselmeer. IJsselmeer is the biggest sweet water reserve in the Netherlands, which makes

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that water supply to the Veenkoloniën is part of a national distribution issue. A participant from the water authorities mentioned that also regionally they need to decide whether to provide water to the Veenkoloniën for example for irrigation possibilities, or that they should provide more water to the region north of the Veenkoloniën that has issues with salinization of soils.

Continuous change in laws and regulations

Participants noted down few general thresholds for this challenge. Some participants mentioned that laws and regulations should be more consistent and predictable, i.e. giving more certainty. Another participant defined a threshold when confidence between farmer and government is broken. In the plenary discussion, participants indicated that there is continuous change, which causes uncertainty among actors in the farming system. To become more consistent and predictable, it was suggested that laws and regulations should be maintained for at least 10 years. In addition it was mentioned that laws and regulations should be coherent with the available innovations.

Currently, based on what participants noted down, actors in the region are specifically challenged by laws and regulations related to crop protection products and sustainability issues in general. In the plenary discussion, the importance of tipping points related to crop protection products was emphasized. Specific thresholds related to crop protection products stated that a threshold is reached when crop protection products are no longer available (chemical or biological), or when prohibition of crop protection products is going faster than innovation and breeding better varieties. This last point was also repeated in the plenary discussion. With regard to nematodes, one participant noted down that laws and regulations need to be aligned with what is needed in the field. With regard to sustainability issues in general, one participant mentioned the societal/political pressure to increase biodiversity and reduce nitrogen surpluses. Other participants noted down the role of the Common Agricultural Policy (CAP) to avoid a critical threshold: new CAP should serve increased sustainability, by 2022, extra funds should become available in general and opportunities should be grasped for nature-inclusive agriculture. Another participant noted down that services to water and nature should become part of the business model. It was not clear whether this should be realized through higher consumer prices and/or increased subsidies. Another participant noted down that laws and legislations should increase the room to invest in soil improvement (crops) in order to avoid passing a critical threshold.

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2.2 System decline

2.2.1 Introduction

In small groups, participants discussed one challenge and its impact on main indicators and resilience attributes, in case thresholds would be exceeded.

2.2.2 Performance of indicators and resilience attributes

High costs in relation to farm gate prices

Participants argued that the threshold for costs becoming too high is there when other crops become more profitable. Or when costs are simply not covered anymore. The precise threshold will vary widely among farmers, depending on amongst others the share of own capital in the farm and farm management. A participant from a bank indicated that the bank expected many farmers to get in trouble in the difficult years of 2018 and 2019 and ask for financial support from the bank. In the end, this was not the case, which showed adaptability of farmers according to the participant. However, another participant indicated that there were also delay in payments from farmers to suppliers, thus using suppliers as a bank. When the threshold for costs versus income is exceeded, eventually a reduction in most system indicators is expected. Farmers will start looking for other crops, thus reducing the supply of starch potato. However, participants expected that farmers will mainly look for other crops in the part of the rotation without starch potatoes. The relation between high costs and profitability was considered to be directly negative, indicating that there is no mechanism that can charge consumers down the line of the value chain to compensate for higher costs. To compensate for higher costs, one of the first things farmers will do is to reduce investments on soil quality; as an example, one participant mentioned that farmers in Zeeland (another region in the Netherlands) were selling straw in financial hard times, rather than keeping it in the field for maintaining or improving soil structure. Participants noted that the effect of high costs on soil quality investments depends on whether a farmer has just started or not and, related to that, whether there is a loan to be paid back. When a loan has to be paid back, farmers might be more inclined to look at the short-term and invest less in the long-term processes related to soil quality. On the other hand, participants indicated that low soil quality also could lead to higher costs. Water availability was not discussed, but via decreased soil quality, lower water holding capacity could lead to lower regional water availability.

With regard to resilience attributes, high costs put pressure on the social self-organization in the system. Two participants indicated for instance that interactions between the cooperative and farmers were more tense and less obvious in financial difficult times that were experienced in 2005/2006. Participants also mentioned that farmers are not willing to be open about their financial situation in difficult times and that they tend to isolate themselves more on their individual farms. And for some farmers, financial hard times in the region could provide opportunities for expansion when neighboring farms are exiting. High costs also have a direct negative effect on the infrastructure for innovation with regard to testing entire new things and with regard to experimenting within the current system configuration. One participant mentioned that the starch producing cooperative needs to balance between innovation and paying good prices to farmers, the latter being the main aim of the cooperative. One participant that is involved with a group of farmers that experiment for the sake of experimenting mentioned that the farmers in this group indicate that after two consequent years with lower yields than average, there is less room for experimenting. Innovation was perceived as going step-wise, making it challenging expressing the relationship between high costs and innovation. Related to soil quality, also coupling of production to natural and local resources is negatively affected by high prices, as a result of decision making for the short-term rather than the long-term. Participants perceived the long-term as 50-100 years.

Participants further mentioned that a change in legislation with respect to a possible ban on crop protection products could imply an increase in costs (e.g. mechanical killing of aboveground biomass of potatoes is more expensive) and possibly a reduction in quality which would further distort the balance between costs and farm gate prices.

Nematodes in the soil

An increase of nematodes in the soil beyond the critical threshold will have the strongest effects on the production of starch potato and the profitability. Although impact of nematodes can be reduced with resistant varieties and green manures, increasing the crop rotation and thus reducing the area with starch potatoes is an obvious measure in reducing the impact of nematodes. However, participants perceived that this was a last resort. Participants indicated that nematodes have less impact when soils have a good quality in terms of the fungi/bacteria balance and water retention and drainage capacities.

In the case of nematodes, farmers and other actors in the farming system are perceived to further build their social self-organization by making contact with each other, exchanging information and joining forces. An example is the increased investment in the network for cultivation protection measures of starch potatoes (Dutch: Teeltbeschermingsmaatregelen Zetmeelaardappelen; TBM).

The presence of nematodes in the soil stimulates research for finding appropriate measures, for instance breeding for nematode resistant starch potatoes and nematode killing green manures. However, participants indicated that currently, law and legislation are impeding the timely development of innovative techniques. The connection between nematodes and production being coupled with natural and local resources was not perceived by participants. However, for

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improving soil quality, biomass from nature areas is applied to fields, thus increasing the coupling of production with the natural and local resources.

Extreme weather events

In the Veenkoloniën, most occurring extreme events are wet conditions in spring or autumn, drought and heatwaves. Different extremes require different solutions. Wet conditions limit the cultivation and harvesting of crops. Plants in the current crop rotation are most sensitive to heat (at least, according to a farmer who manages his soil well), but participants decided to focus in the workshop on drought, which occurred in the last two cultivations (2018; 2019). They used the threshold mentioned during the previous session as a basis: three droughts every ten years. In such a situation, the cultivation plan with starch potatoes every two years can remain economically viable, but management should be more extensive. In 2018, production of starch potatoes reduced with up to 50%, which also affected profitability. Participants indicated that a yield reduction was not necessary and that the system can be more robust, for instance by having higher soil quality. One of the farmers changed his management by applying less chemicals, improving soil structure, keeping his fields green all year, and taking into account dryer conditions; and on his farm, droughts had little impact. In 2019, when the impact of heat was small, droughts rarely affected his yields. In 2018, yields were lower due to heat impact. On average, yields are higher than on other farms. The improved soil structure reduced nematode problems, less fertilizer reduced plant growth but increased robustness to extreme events, including second growth due to heat waves, i.e. potatoes, the harvestable product, start to sprout during the season.

Droughts negatively affect the regional water availability in the region. Water availability issues should and can be solved in the region, for instance by stimulating local water storage on the lower and wetter grounds in the region, possibly in combination with re-organization of land ownership. Water supply from the Ijsselmeer lake of 50-70 million cubic meter per year should stay, but should be complemented with water supply from the region.

The presence of droughts in the region could stimulate cooperation with regard to local water storage. Further measures to increase regional water availability could imply innovative water management, for which the sacrifice of production land to water storage is necessary, which implies that crops need to be grown somewhere else. As concrete first step, an experimental farm that is partly under water is an option. Inundating less productive land and growing crops on more productive parts of land is also an example of better coupling production with local and natural resources. Also improving soil structure and greening of the landscape are options to improve water retention and drainage capacities that are better aligned with local and natural resources and conditions.

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Continuous change in laws and regulations

In the area, important changes in laws and regulations are related to use of water and crop protection products. Both reduce adaptability in the cultivation with regard to weather conditions and presence of pest and diseases, respectively. Especially for crop protection products there are currently no good alternatives. For water use, participants see more space for improvement, for instance by improving soil structure for water retention and drainage, or maybe even having a water quota, as is in practice in Germany currently, or for making own water reservoirs (if allowed). On the other hand, the presence of the potato brown rot disease (*Ralstonia solanacearum*), will limit the options for irrigation. Also the option of water buffers in the region was perceived as limited, because it requires too much investment in terms of finance and organization. As a result of changing laws while limited options are available, participants expected moderate to negative influence on the production of starch potatoes and profitability. However, participants assessed that the influence would be much less when more robust varieties would become available. Participants expected that soil quality will increase slightly. Water availability in the region was also perceived to be moderately positive influenced by changes in laws and regulations. Also, participants perceived an advantage in becoming less dependent on chemical products. For becoming less dependent, changes in legislation need to be realistic (set realistic time paths with realistic goals), i.e. time for adaptation is required and alternatives should be available before older crop protection products are banned. As concrete goals, a reduction of 20% in five years, and a reduction of 50% in ten years of crop protection products was mentioned, provided that consumers will pay more for their products.

Continuous change in laws and legislation were perceived to positively stimulate social self-organization. However, participants see the room for more collaboration between arable and livestock farmers as limited, because of the relative low number of livestock farmers in the region. On the other hand, also new possibilities were mentioned, such as nature-inclusive agricultural fields with a rotation of 2:5, supported by subsidies from the second pillar (POP3) of the Common Agricultural Policy (CAP). Infrastructure for innovation was perceived to be stimulated moderately, for instance with regard to finding more robust varieties and substitute products and practices for banned crop protection products. Participants indicated that innovation (a.o. in precision agriculture) is a parallel process that should be present before further changes in law and legislation are realized. The influence of changing laws and legislation was perceived to moderately stimulate the coupling of the production with local and natural resources, especially when it comes to limitation of water use and more stricter regulations for applying manure.

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2.2.3 System collapse?

The impact of different challenges differs, but overall crossing tipping points leads to a collapse in starch production, a decrease in farm income, a decline in soil quality, and decreased water availability (Table 3). It can be anticipated that the delivery of other private and public goods will also be affected, including the attractiveness of the area. As it is difficult to visualize how a collapsed system looks like, and stakeholders always attempt to prevent a collapse. This was also noticeable during the workshop: in all groups stakeholders mainly focused on strategies to cope with increasing challenges. This relates to the idea that if tipping points are reached, actions need to be taken to adapt. Some of these are adaptations which relate to moving towards alternative systems are discussed in the next section.

2.3 Alternative systems

2.3.1 Introduction

The collection of post-its with ideas for alternative future farming systems yielded four different alternative systems: nature-inclusive agriculture, precision agriculture, alternative crops, collaboration & alternative water management. Some participants indicated that all alternative systems could be part of the future system and that there was hence no need to split them up. Overall results suggest that alternative systems can moderately improve main functions and resilience attributes of the farming system (Table 3). Boundary conditions that are relevant for maintaining the status quo are also likely to be relevant in alternative systems. Shared boundary conditions among multiple alternative systems are the presence of a good business model, ongoing innovation and the presence of more livestock farmers in the region. In all proposed alternative systems, starch potato remains as the most profitable crop, and therefore a low presence of nematodes is also a boundary condition. It is difficult for stakeholders to foresee completely transformed systems without starch potato, and therefore alternative systems are mainly adaptations of the current farming system. However, in some groups it was argued that more extreme changes in for instance nature inclusive agriculture could lead to transformed systems without starch potato.

Table 3. Current perceived performance of main functions and presence of resilience attributes (FoPIA-SURE-Farm 1) and their expected change in future systems.→ implies no change, ↗ implies moderate positive change, ↑ implies strong positive change, ↘ implies moderate negative change, ↓ implies strong negative change, V implies that a boundary condition is relevant for a future system. Arrows and tick marks in bold font are results obtained in the workshop. Arrows and tick marks in normal font are deductions from what has been said in the workshop.

<table>
<tr><th></th><th></th><th></th><th></th><th colspan="5">Future systems</th></tr>
<tr><th>Indicator</th><th>Current level</th><th>Status quo</th><th>System decline</th><th>Alternative crops</th><th>Precision agriculture</th><th>Nature inclusive</th><th>Collaboration & water</th></tr>
<tr><td>Starch potato production</td><td>Moderate</td><td>→</td><td>↘|↓</td><td>→</td><td>↗</td><td>↗</td><td>→|↗</td></tr>
<tr><td>Profitability</td><td>Moderate</td><td>↗</td><td>↘|↓</td><td>↗</td><td>↗</td><td>↗</td><td>↗</td></tr>
<tr><td>Soil quality</td><td>Low</td><td>↗</td><td>↘|↓</td><td>↗|↘</td><td>↗</td><td>↑</td><td>↗</td></tr>
<tr><td>Water availability</td><td>Moderate</td><td>↗</td><td>↘|↓</td><td>→|↘</td><td>↗</td><td>→/↗</td><td>↗</td></tr>
<tr><td>Reasonable profitable</td><td>Low</td><td>→</td><td>↘|↓</td><td>↗</td><td>↗</td><td>↗</td><td>↗</td></tr>
<tr><td>Social self-organization</td><td>Moderate</td><td>→</td><td>↘|↓</td><td>↗|→|↘</td><td>→</td><td>↗</td><td>↑</td></tr>
<tr><td>Infrastructure for innovation</td><td>Moderate</td><td>→</td><td>↘|↓</td><td>→/↗</td><td>↑</td><td>↗</td><td>↗</td></tr>
<tr><td>Production coupled with local and natural resources</td><td>Moderate</td><td>→</td><td>↘|↓</td><td>↗</td><td>↗</td><td>↑</td><td>↗</td></tr>
<tr><td>Functional diversity</td><td>Low</td><td>→</td><td>↗</td><td>↗</td><td>→</td><td>↗</td><td>↗</td></tr>
<tr><td>Exposed to disturbance</td><td>Moderate</td><td>→</td><td>→</td><td>→|↘</td><td>↗</td><td>→|↘</td><td>→|↘</td></tr>
<tr><td>Boundary conditions</td><td>Domain</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Higher presence of livestock farmers in the region</td><td>Agronomic</td><td>V</td><td></td><td></td><td></td><td>V</td><td>V</td></tr>
<tr><td>Lower presence of livestock farmers in the region</td><td>Agronomic</td><td></td><td></td><td>V</td><td></td><td></td><td></td></tr>
<tr><td>Less root and tuber crops</td><td>Agronomic</td><td></td><td></td><td></td><td></td><td>V</td><td></td></tr>
<tr><td>Starch potato as most profitable crop</td><td>Economic</td><td>V</td><td></td><td>V</td><td>V</td><td>V</td><td>V</td></tr>
<tr><td>Good business model</td><td>Economic</td><td></td><td></td><td>V</td><td>V</td><td>V</td><td></td></tr>
<tr><td>More local economy</td><td>Economic</td><td></td><td></td><td>V</td><td></td><td></td><td></td></tr>
<tr><td>Lower cultivation costs</td><td>Economic</td><td></td><td></td><td></td><td>V</td><td></td><td></td></tr>
<tr><td>Financial rewards for services to nature and society</td><td>Economic</td><td></td><td></td><td></td><td></td><td>V</td><td></td></tr>
<tr><td>Low presence of nematodes</td><td>Environmental</td><td>V</td><td></td><td>V</td><td>V</td><td>V</td><td>V</td></tr>
<tr><td>Limited number of extreme weather events</td><td>Environmental</td><td>V</td><td></td><td></td><td>V</td><td>V</td><td></td></tr>
<tr><td>Maintain or improve soil quality</td><td>Environmental</td><td>V</td><td></td><td>V</td><td></td><td></td><td>V</td></tr>
<tr><td>Consistent policies for greening and water retention</td><td>Institutional</td><td></td><td></td><td></td><td></td><td>V</td><td></td></tr>
<tr><td>Changes in norms for water management</td><td>Institutional</td><td></td><td></td><td></td><td></td><td></td><td>V</td></tr>
<tr><td>Better laws and regulations for collaboration</td><td>Institutional</td><td></td><td></td><td></td><td></td><td></td><td>V</td></tr>
<tr><td>Technological innovation</td><td>Social</td><td>V</td><td></td><td></td><td>V</td><td>V</td><td>V</td></tr>
<tr><td>Awareness of water management issues</td><td>Social</td><td>V</td><td></td><td></td><td></td><td></td><td>V</td></tr>
<tr><td>Good infrastructure</td><td></td><td>V</td><td></td><td>V</td><td>V</td><td></td><td>V</td></tr>
</table>

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2.3.2 Nature-inclusive agriculture

This alternative state can have different levels, from small adaptations at field level to changing the crop rotation and increased collaboration between farms. In general, in this alternative state, participants expect that soil quality will increase out of necessity. An important aspect in this alternative system is the collaboration between arable and livestock farmers. This alternative state improves circularity, where manure is seen as a valuable product and where rest products are processed. Downside of this alternative state, as perceived by participants, is that this system is more labor intensive. Apart from improving circularity, this alternative system also increases the interaction between nature and agriculture. The soil is seen as very important in this interaction. Production of starch potato was expected to increase moderately: on the one hand there are increased risks for contamination of fields with nematodes, on the other hand, increased soil fertility will lead to increased yields. With subsidies for nature-inclusive agriculture, participants expected that profitability will increase moderately. The influence of this alternative system on regional water availability was not discussed.

Combining options in smart ways can make a nature-inclusive system sufficiently profitable, but subsidies are also needed, especially at the start. Social self-organization was perceived to be positively affected in this alternative system, because of increased collaboration between arable and livestock farmers. Infrastructure for innovation was more seen as a boundary condition for realizing this system. For instance, new technology is needed to keep waters clear from pollutants through improved spraying techniques. Options like strip cropping also require alternative technology, like smaller machines and robots. The coupling of production with local and natural resources, was not specifically discussed, but the focus on soil quality and circularity suggests a positive impact.

Boundary conditions for this alternative system were mainly related to policies & legislation and having a successful business model. With regard to policies & legislation, participants indicated that the rewarding of services of agriculture towards nature and water management should become more consistent. Participants mentioned that the current reward for nature in fields is rewarding enough, but effects should be better quantified, which could help to adjust in time when effects are different than anticipated for. In general, participants would like to see more clarity in policies at national level, e.g. with regard to import of products. When aiming for circularity, this has implications for farmers in the Netherlands, and this should be considered when importing products. There was no agreement however whether this was possible, also because Dutch farmers export a lot. With regard to a good business model, participants indicated again that innovation is important to become more interesting for the international market. Another boundary condition that was mentioned is the presence of livestock farmers in the area.

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Currently, roughly 25% of the farms in the area are livestock farms; according to participants, this should go up in order to improve exchange between arable and livestock farmers.

Concrete strategies for this alternative system were diverse and sometimes resembled the boundary conditions mentioned in the previous paragraph. A big role was perceived for the policy makers behind the CAP, who should work on more consistency and clarity. Using the CAP as a basis, national and local stakeholders should develop a consistent vision (as an overarching strategy), including strategies at the level of economics, technology and collaboration. Developing a good business model would help to realize the nature-inclusive farming system. Concretely, participants perceived that the quickest wins would lie in the maintenance of current crop protection products in combination with cultivation free zones that could serve as buffers, e.g. a strip with natural vegetation. Another suggestion was to look at field level at the tightness of rotation. In some cases a rotation with starch potatoes of 1:2 is possible, in other case 1:4 might be necessary. In general, participants indicated that less root or tuber crops would be good to contribute to the goals of a nature-inclusive system. Other suggestions were strip cropping, flower mixtures around fields, growing green manures rather than cereals as "resting" crop and herbage-rich grasslands (which is already profitable for livestock farmers). Collaboration with livestock farmers was also mentioned again to make practices profitable. Innovation and precision agriculture were also mentioned again as strategies. Participants perceived that innovation would go faster with higher yields. New technologies are also required for strip cropping.

2.3.3 Precision agriculture

For this alternative system, participants expected less production risks which would lead to a higher and more steady supply of starch potatoes in the region. For instance by early detection of mycotoxins by drones. Drones could also be helpful in assessing damage, thus improving insurance of crops and thus improving incomes in lesser years. Profitability and soil quality were assessed to improve through reduced application of crop protection products. Furthermore, application of light robots could reduce soil compaction. Reduced application of nitrogen is currently not assessed to improve profitability. The level of regional availability of water in the region was not assessed. The resilience attributes were assessed to be positively influenced in this system. Moreover, participants indicated that this alternative system was also contributing to the other proposed alternative systems. They state that precision agriculture will be "conventional" in the next generation.

A boundary condition for this alternative state is the creation of a good business model for agricultural products. In this business model there should be a higher price for improved products, e.g. food for babies, high quality animal feed and good rest products. Another part of the business model should be the reduction of costs and the reduction of variation in crop yields. Another boundary condition is the further evolution of precision agriculture, which depends on the availability of time, better interpretation of data and the availability of finance. Furthermore, participants indicated that the facilitation of precision agriculture should also be supplied by the industry that processes agricultural products, rather than being dependent on farmers alone. On the other hand, participants indicated that not all farmers might be ready for adopting precision agriculture and that in this alternative state some farmers may not have the possibilities to follow and consequently will exit the farming system. As a last boundary condition, which can also be interpreted as a concrete option for realizing this alternative state, participants indicated that allowing Crispr-Cas for improving varieties should be allowed in the regulations of the European Union.

2.3.4 Alternative crops

In the current situation, agriculture in the Veenkoloniën produces a lot of bulk products. Participants perceive that there are opportunities to increase value of products, for instance by filling niches in the provision of animal and protein suitable for human consumption. These niches require also alternative processing facilities.

Participants indicated that the area for livestock farming will decrease in this alternative system, thus guaranteeing that the current level of starch potato production can be maintained. Through increased value of products, profitability is expected to increase. The soil quality was expected to change because of a different fertilizer need of the alternative crops. Participants could not assess whether this change would be negative or positive. With regard to water availability in the region, participants indicated that a lower water supply could be a possibility. They argued that lower water supply will stimulate farmers to learn to grow with less, thus increasing the water use efficiency. Furthermore, participants saw opportunities for more local water retention.

Social self-organization can be maintained, can increase or can be reduced in this alternative state, according to participants. Increased self-organization can be realized by the conscious way of living in society, where there is more attention for other farming sectors and a more contact between producers and consumers. Decreased self-organization could be the result of another trend in society related to increased individualism. Participants perceived a decrease in social self-organization as more likely than an increase. Infrastructure for innovation was perceived to stay the same or be improved, because it would help to go faster in the transition. This implies that this is also a kind of boundary condition for this alternative state. Production was assessed to become more coupled with local and natural capital, because participants perceived that this alternative state would go parallel with increased circularity, with less dependencies on resources from abroad.

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Boundary conditions for this alternative state to be realized are the increased value of agricultural products, i.e. that citizens will de facto buy the products. Participants perceived a good marketing strategy as key for this. With regard to the ideas, finances and organization of the cultivation and processing of other crops, participants noted that these should be closely linked to the region, which implies the need for ownership. Finally, participants indicated, as boundary condition, that soil quality should not further decrease. They also indicated that for some new crops, there might be adaptations needed to the soil.

2.3.5 Collaboration & alternative water management

This system is focused on collaboration between actors within the farming system. There is the collaboration between arable and livestock farmers to exchange land and improve circularity. In addition, participants mentioned collaboration with regard to alternative water management. Central in the alternative water management is the idea of taking the 5-10% of lowest laying fields with low productivity out of production and improving water levels in the remaining areas. Participants expected that the improved water levels would result in higher yields per hectare and at least compensate for the loss in area. Participants expected higher profitability in this alternative system as collaboration will reduce the need for investment, e.g. through sharing costly equipment. Improved water tables would increase soil quality, provided that also machines in the future would exert less pressure on the soil. In this system, the share of land that is taken out of production will be dedicated to nature and water retention, thus increasing water availability, but also making a better connection between production and local and natural resources. Social self-organization is a result as well as a precondition for this alternative system. Participants estimated that the extension of social networks would lead to better exchange of information and more joint ventures in terms of investments, thus improving the infrastructure for innovation.

For this alternative system, more livestock farmers are welcome in the region, under the precondition that output of ammonia, fine particles and unwelcome odors are staying under the governmental standards. Another boundary condition is that standard norms for water management should be abandoned. Currently, water authorities have to deal with two important norms: 1) only 5-10% of agricultural fields may become too wet, 2) also the difference between the maximum and minimum water levels in the region need to be below a certain standard. Abandoning these standards would allow for more freedom to maintain a variety of water levels in the region which respond to specific needs. Apart from being a boundary condition, participants indicated that this alternative water management was also a concrete strategy to realize this alternative system. For the alternative water management to work there should be improvements in the soil with regard to structure that allows for water retention and restoring levels of water

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aquifers (also mentioned as concrete strategy). Participants also mentioned that, as boundary condition and as concrete strategy, laws and regulations should improve to stimulate collaboration, for instance to support collaborative financing initiatives as Ecolana (http://ecolana.nl/). As a concrete strategy, participants perceived that financial/fiscal stimuli would also work to improve collaboration. One participant mentioned that collaboration between arable and livestock farmers would only work when they are in three km radius of one another. Another important boundary condition for this alternative system is the continuous innovation of technology.

A first step to realize alternative water management could be to have a show case of an experimental farm for which 5-10% of land is taken out of production and the rest of the land has a different water management. As further concrete strategies, participants mentioned collaborative efforts of farmers and municipalities to retain water in existing water ways. Raising awareness about water management, preserving nature and biodiversity was seen as another strategy, which could help to make actors in the farming system realize that change is necessary. Finally, the option of land consolidation was mentioned to compensate for land loss when less productive land would be taken out of production.

2.4 Strategies towards the future

Participants in the workshop mentioned that all proposed alternative systems could be merged in the future, i.e. they were all to a certain degree desired and likely. Therefore, participants argued that before talking about strategies, a shared vision on the future farming system should be discussed. In general, participants agreed that strategies that were used to improve sustainability and resilience in the past (D5.2) are compatible with the alternative future farming systems. This can indeed be concluded for several strategies, including 'extend knowledge on soils and varieties', 'better varieties', 'increase value of starch products', and 'improve soil quality' (Table 4). However, 'scaling' and 'reduce costs' were important strategies in the past, while they may not be compatible with a nature-inclusive system.

Strategies to realize alternative systems seem to be compatible, implying that all strategies are no-regret options. One participant indicated that to know whether a strategy would be a no-regret requires to look ahead for several decades. On the other hand, all alternative systems and the proposed strategies to realize them showed positive effects on main indicators and resilience attributes, especially on profitability and soil quality. Profitability and soil quality were also often mentioned as boundary conditions, implying that stimulating these two indicators would be good for all alternative systems. So basically, all past and future strategies could help to realize alternative farming systems. However, resource availability might force actors in the farming system to choose for a limited set of strategy options to start with. In that case, a good business model to valorize sustainability improvements is essential, for instance by being able to ask a higher price for products or farmers being rewarded for services to society and nature.

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Table 4. Current strategies and future strategies for different future systems. Current strategies are based on FoPIA-SURE-Farm 1. Bold font indicates that these strategies were mentioned during the workshop for a specific system. Normal font indicates that, based on the discussions during the workshop, it seems likely that strategies will be applied in certain systems. This table is continuing unto the next page.

		Current system	Future systems				
Strategy	**Domain**		**Status quo**	**Alternative crops**	**Precision agriculture**	**Nature inclusive**	**Collaboration & water**
Extend knowledge on soil & varieties	Agronomic	V	V	V	V	V	V
Better varieties (starch content, nematode resistance)	Agronomic	V	V	V	V	V	V
Precision agriculture	Agronomic	V	V		**V**	**V**	V
Exchange land with dairy farms	Agronomic	V	V		**V**	**V**	V
Changing crop rotation	Agronomic		**V**	**V**		**V**	
Protein crops for animal and human consumption	Agronomic			**V**			
Different way of fertilizing (alternative) crops	Agronomic			**V**			
Increasing water use efficiency	Agronomic			**V**			V
Applying drones (for early risk detection and damage assessment)	Agronomic				**V**		
Improve circularity	Agronomic		V	**V**	V	V	
Scaling up	Economic	V	V		V		
Increase value of starch products	Economic	V	V	V	V	V	V
Reduce costs (in general)	Economic	V	V				
Reduce crop inputs	Economic	V			**V**	**V**	
Have land available outside contract farming	Economic	V	V				
Developing new business models	Economic			V	V	**V**	
Introduction of new value chains	Economic			**V**			
Having a good marketing strategy	Economic			**V**			
High value products	Economic			V	**V**		
Improve soil quality	Environmental	V	V	**V**	V	**V**	V
Maintain water locally in canals	Environmental						**V**

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Take lower laying lands out of production	Environmental						**V**
Actively replenishing ground water levels	Environmental						**V**
		Current system			**Future systems**		
Strategy	**Domain**		**Status quo**	**Alternative crops**	**Precision agriculture**	**Nature inclusive**	**Collaboration & water**
Land consolidation / redesign of the landscape	Environmental					**V**	**V**
Nature friendly interventions at field level (buffer strips, strip cropping, green manures etc.)	Environmental					**V**	
Customized water levels	Institutional						**V**
Relax constraining regulations (water management, collaboration, taxes)	Institutional						**V**
Rewarding services with regard to nature	Institutional			V		**V**	**V**
Adapting trading policies	Institutional					**V**	
Allowing genetic improvement techniques (Crispr-Cas)	Institutional				**V**		
Raising awareness about soil quality	Social	V	V	V	V	V	V
Raising awareness about water availability	Social	V	**V**				**V**
More contact between consumers and producers	Social			V			
Precision agriculture as shared responsibility of processors and farmers	Social				**V**		
Collective action	Social			V			**V**

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The strategies proposed for the alternative systems allow in most cases for experimentation, e.g. having test cases and field/farm experiments. However, the eventual investment in complete strategies for some alternative systems will be very high, e.g. value chains in the alternative system “Alternative crops” and alternative water management and land consolidation in “Collaboration & water”. High investments will likely lead to sunk costs and possibly path dependency, reducing transformability of the farming system. The improvement of soil quality in all alternative systems could improve robustness with regard to weather extremes. Furthermore, improved soil structure could improve water buffering in ground and surface waters, increasing room for adaptation, such as adapting water levels and irrigating crops.

Presence of resilience attributes was perceived to be maintained or improve in all alternative systems. Social self-organization seems most present in the alternative system “Collaboration & water”. This alternative system is expected to improve the infrastructure for innovation via social self-organization, where other alternative systems are more likely to be dependent on general developments in society with regard to innovation. All proposed systems have potential to improve profitability and couple production with local and natural resources, which can help to make the system more robust and adaptable.

3 Interpretation

3.1 Tipping points

The farming system seems to be close to tipping points of all main indicators, attributes and challenges. In the case of soil quality, the system was perceived to be beyond a critical threshold. Participants did not admit that the situation is very dire. Their general feeling is that it is going well, e.g. profitability is increasing and technology advances. Moreover, participants trust on the capacities of the farming system to adapt to challenging conditions. For instance by breeding nematode resistant varieties and varieties that have more starch content. Genetic progress in starch potato is about 110 kg starch per hectare per year (under average conditions), where farmer yields increase with roughly 90 kg starch per hectare per year (Rijk *et al.*, 2019). With a relative stable number of starch potato farms (Schutz, 2020), the yearly progress in yield in should indeed be enough to stay away from a critical point regarding starch potato production (at farm and farming system level). However, Rijk et al., (2019) also observed that low starch yields in 2013 could level off the trends in genetic progress in the last decades. With regard to profitability, average revenue per hectare for starch potato was roughly 3,200 euro and gross margin per hectare was roughly 1000 Euro (KWIN-AGV, 2018; average over 2016-2018). The value of gross margin is lower than the minimum for starch potatoes that was mentioned by most farmers. Gross margins for sugar beets and cereals were roughly 2,500 and 1,000 euro per hectare over the period 2016-2018 (KWIN-AGV, 2018). For a rotation of potatoes, sugar beets and cereals of 2:1:1, this would imply a gross margin for all crops of roughly 1,375 euro per hectare, which is still below most of the indicated minimum levels. Water supply from the lake IJsselmeer is expected to decrease in the future (Jansen, Kwakernaak and Querner, 2011), which will most likely have implications for irrigation possibilities. Being able or not able to irrigate was mentioned as a critical threshold. Moreover, increased occurrence of warm and wet conditions, intensive rainfall and droughts towards 2050 are expected to render part of the agricultural land in the Veenkoloniën unviable for cultivation from an economic perspective (Diogo *et al.*, 2017). The lower laying parts , that mostly suffer from intensive rains and wet conditions, could be converted into water retention areas. This would decrease the dependence of the Veenkoloniën on water from the lake IJsselmeer considerable and improve water availability in the region (Jansen, Kwakernaak and Querner, 2011).

The resilience attributes "reasonably profitable" and "infrastructure for innovation" stay important in the future not only for robustness, but also as precondition for realizing alternative systems (adaptability and/or transformability). From the perspectives of participants, it can therefore be deducted that it is necessary that current trends in profitability and technological innovation are not slowed down. The key objectives of the new Common Agricultural Policy (CAP)

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of improving income and competitiveness (amongst others through technology) are in line with these requirements (European Commission, 2020). Market demands for innovative starch potato derivatives are currently not saturated. Also, there is high potential for further innovation in starch potato products (Engwerda, 2019). This would imply that increasing profitability can be realized. This is also suggested by the increased farm gate prices paid for starch potatoes (Engwerda, 2019, using data provided by Avebe), which increased with roughly on average 3.8% per year relative to 2011 (own elaboration of data from Engwerda, 2019 using data provided by Avebe). The index of agricultural input prices for the Netherlands increased with roughly on average 0.8% per year relative to 2011 (own elaboration of data from Eurostat of the European Commission, 2020). Locally, agricultural input prices may deviate from national averages. Although on average, increasing costs relative to revenue does not seem a concern, price spikes in individual years (e.g. 2012-2014, related to high oil prices) may still be a challenge for farm management and impact the farming system (see section 1.2.2.)

3.2 What-if thresholds are exceeded?

Starch potato production is an important indicator for the farming system. Throughout the workshop, participants indicated that starch potato supply at regional level cannot be reduced too much, otherwise the farming system will change. Extreme weather events, especially droughts, were perceived to impact starch potato production of up to 50% and lowering regional water availability. However, participants perceived that this was not necessary and that the system could be more robust.

Diogo et al. (2017) also assessed that adaptation to droughts was a possibility to keep agriculture economically viable in most parts of the Veenkolonien. Similar to the perceptions of the participants, Diogo et al. (2017) also expect bigger challenges to cope with heat waves. According to projections of Diogo et al. (2017), it will be difficult to remain economically viable when the frequency of heat waves increase. They however did not take into account the innovations of Avebe leading to higher prices for starch potatoes. A higher potato price has ensured robustness of starch potato production and economic viability in the past. As higher potato prices reduce the reserves of Avebe, whether these higher prices can be maintained depends on the capacity to adopt innovation strategies in the future (Schuetz, 2020)

High costs were perceived to moderately affect starch potato production, but profitability was perceived to be affected strongly. Loyalty of farmers towards Avebe and thus to other farmers could explain the moderate effect on starch potato production. Also the presence of production obligations in the share system of the starch processing cooperative can partly explain starch potato production in the region: the starch potato processing cooperative for instance charged a few producers with 125 Euro per ton starch that was not delivered in 2014 (Tholhuijsen, 2019). According to Schuetz (2020), using a systems dynamic model, high costs indeed have a negative impact on economic viability in the short-term, but Avebe has more capacity to increase starch potato prices when input prices are high than when potato yields reduce, and in the long-term impacts on economic viability may therefore be mitigated.

Continuous change in law and legislation was expected to negatively impact production through the ban on crop protection products before good alternatives are available. With more robust starch potato varieties, participants expected that the lack of adequate crop protection products could be compensated. Nematodes in the soil were perceived as a big risk for affecting starch potato production per hectare and thus regional supply of starch potatoes. Lower production per hectare results in lower profitability for farmers and the cooperative. Lower profitability will likely negatively affect farm management choices with regard to maintaining soil quality.

Overall, exceedance of thresholds will lead primarily to a moderately to strongly undesired farming system performance with lower starch potato supply, lower profitability and lower soil quality, which also reinforce one another. On the other hand, exceedance of these thresholds might provide room for other crops entering the farming system, provided soil quality has not too much deteriorated. The introduction of new crops could actually also improve the soil quality.

With regard to resilience attributes, exceedance of thresholds is also mostly perceived to have a negative impact. Lower profitability will lower financial reserves that can serve as a buffer in extreme years, or be used for experimentation. Social self-organization was expected to increase with higher nematode pressure and extreme weather events, where it was expected to decrease with rising costs and financial problems. Possibly, it is easier for farmers to be united around what is primarily perceived as a technical problem (nematodes; drought) than around what is primarily perceived as a financial problem. However, in the end, all challenges affect profitability negatively, which has consequences for the resources available for the infrastructure for innovation. At the other hand, social self-organization around a challenge could provide the network for innovations to spread among actors in the region. Lower profitability could on the one hand lead to a more extensive farming system, thus connecting agricultural production with local and natural resources better. On the other hand, it can be expected that lower profitability will make farmers neglect the maintenance of natural and local resource in a race to the bottom. However, the perceived feedback of soil quality on regional water availability and nematode pressure could provide solutions, eventually leading to a better coupling of agricultural production with local and natural resources.

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Overall, dependent on which threshold is exceeded, resilience of the farming system could improve with regard to social-self organization, infrastructure for innovation and production being coupled with local and natural resources. However, this possibility is only likely to be realized when the negative impact on profitability is somehow compensated.

Based on the workshop, other SURE-Farm activities and literature (Kinzig *et al.*, 2006; de Bont *et al.*, 2007), some interacting thresholds could be defined (Figure 1). Firstly, a narrow crop rotation which is essential for the profitability of the starch processing cooperative, increases nematode pressure. When pressure becomes higher, yields will reduce. Without further interventions, yields can go below the critical threshold of around 40 ton per hectare. This will reduce the revenue of farmers directly (less tons), and indirectly via a lower price when profitability of the cooperative goes down. When economic viability goes below a certain threshold (e.g. expressed in net profit per ha), farmers will grow less starch potatoes, provided there are good alternatives, thus further reducing the supply of starch potatoes to the cooperative. In case there are no good alternative crops, availability of successors will decline and more farmers will exit the farming system. At the farming system level this leads to a smaller rural population. When profitability is going down, the starch potato processing cooperative will have to re-organize and reduce in size at some point. This was also indicated as a possible option by de Bont et al. (2007) after the changing CAP legislation in 2013, provided that remaining starch products would be sold for a higher price. Kinzig et al. (2006) found a similar interaction for one out of three dairy processing plants in a region in Australia that closed when volume at regional level went below a critical threshold. The re-organization of the starch processing cooperative would reduce the need for the large share of starch potato area in the region, which would widen the rotation. Reducing the starch potato processing facilities would reduce the number of jobs in the region, leading to a further decline of the already shrinking rural population (Kuhlman *et al.*, 2012). Smit, working for Wageningen Economic Research and over the past involved in multiple studies in the Veenkolonien and Avebe, (2019; personal communication) estimated that re-organization of the cooperative would be necessary when the area with starch potatoes becomes less than 30,000 ha, implying a rotation of around 1:3 and a supply reduction of 25% compared to the current level. This level corresponds more or less with the thresholds mentioned in this workshop. It should be noted that the interaction of thresholds as sketched above is one example of how the system could decline, related to a combination of nematode pressure, yield decline and possibly increased production costs. Figure 2 presents a causal loop diagram that shows how different challenges and system indicators can interact with positive or negative results, i.e. negative effects as presented in Figure 1 could also be reversed. A yield increase for instance, would provide space in the crop rotation, thus potentially reducing nematode pressure. In this positive example, no interactions with thresholds at regional level are expected (Figure 1, Figure 2).

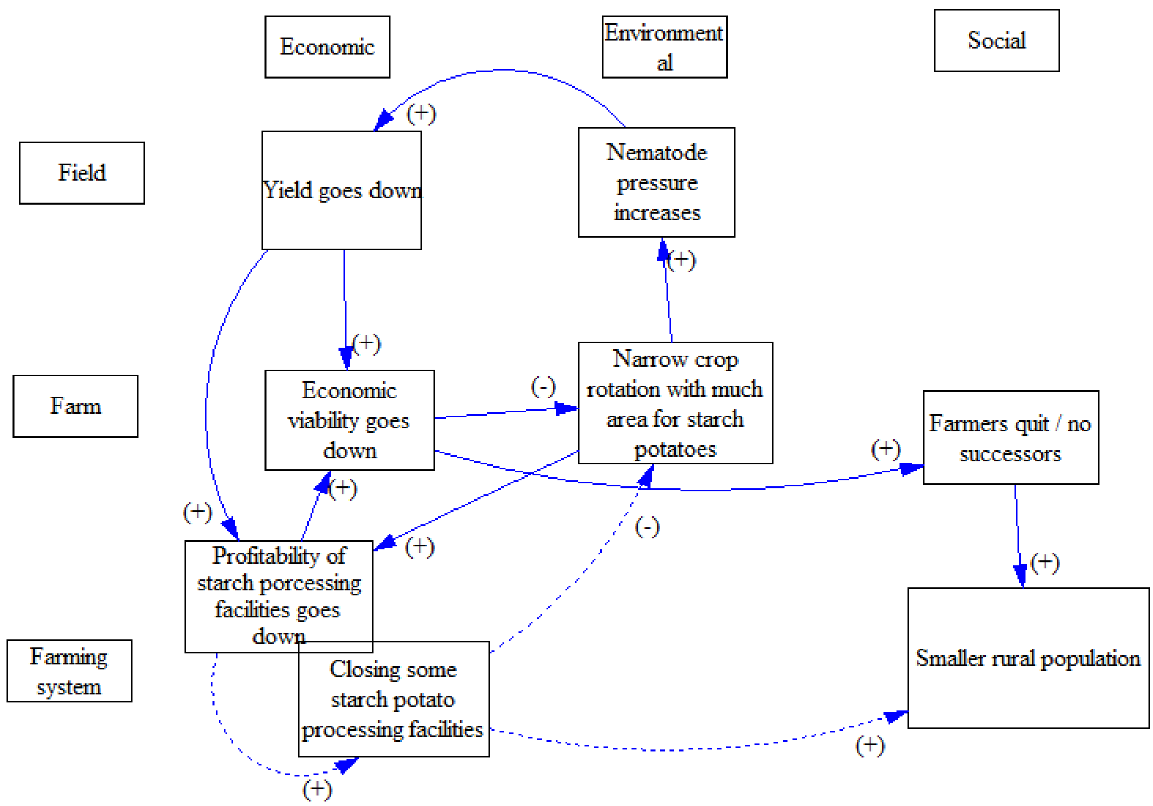

Figure 1. Interacting thresholds in the farming system, using "nematode pressure", the main challenge as example. Based on framework of Kinzig et al. 2006. Dashed lines indicate relationships that were not discussed during the workshop.

3.3 Alternative systems

Performance of main indicators is expected to be maintained or moderately improved in all alternative systems, except for "Alternative crops", where soil quality and regional water availability could also decline (Table 1). In "Precision Agriculture" improvement of gross margins is perceived to be realized through increased yields and reduced costs. Based on data of Kempenaar (2019), precision agricultural techniques for ware potatoes in its current stage are improving gross margins only through reduction in inputs (Table 5), which is in several cases not enough to compensate for the investment costs (Kempenaar, 2020; personal communication; Kempenaar is working for Wageningen Plant Research and is coordinator of "Nationale Proeftuin Precisie Landbouw", a Dutch national experiment with precision farming). This implies that techniques and decision support for precision agriculture need to be further developed in order to also improve yields, which is also foreseen by Kempenaar (2019) through more preciseness, science based decision support and sharing of data.

Table 5. Gross margin estimations for starch potato cultivation for the period 2016-2018 and for a situation with precision agriculture for that same period. Source: [1] KWIN-AGV (2018), [2] Kempenaar, (2019; *results of the "Nationale Proeftuin Precisie*

Landbouw" for ware potato cultivation in 2018). It should be noted that technologies for precision agriculture are expensive: current positive difference in gross margin will not cover investments costs (Kempenaar, 2020; personal communication).

	Gross margin (2016-2018)[1] Euro/ha	Changes through precision agriculture[2]	Gross margin (precision agriculture) Euro
Revenue main product (a)	3234	0%	3234
Starting material	*600*	*0%*	*600*
Fertilizer application	*364*	*-10%*	*328*
Crop Protection Products	*763*	*-23%*	*588*
Energy	*429*	*0%*	*429*
Other costs	*53*	*0%*	*53*
Total cultivation costs (b)	2208	-10%	1997
Gross margin (a – b)	1026	+21%	1237

Presence of main resilience attributes is expected to increase in all alternative systems (Table 1), generally suggesting improved robustness and to a lesser extent adaptability and transformability (based on findings from FoPIA-SURE-Farm 1; Paas et al., 2019). An exception to this is "Alternative crops" where social self-organization could also stay the same or decrease and where infrastructure for innovation could stay the same. Based on findings from the previous workshop, this could imply that adaptability based on infrastructure for innovation is less well developed in "Alternative crops" compared to other alternatives. Infrastructure for innovation is expected to strongly increase in a system that is geared towards precision agriculture, suggesting higher adaptability and transformability levels in this system. However, it should be noted that increased infrastructure for innovation could also be a pre-condition for "Precision agriculture". Social self-organization is expected to increase strongly in a system geared towards collaborative water management, suggesting an larger increase in adaptability through this resilience attribute, compared to other alternative systems.

The proposed alternative systems arguably have also an effect on functions and resilience attributes that were not discussed in the workshop. The system "Alternative crops" could contribute to more functional diversity, because other crops will be included in the rotation. However, this really depends on which crops will be introduced, e.g. very "exotic" crops might not fulfill any important niche in the agricultural ecosystem. Investments that are needed in all proposed alternative scenarios might require economies of scales, thus favoring the current trend of farms growing bigger. That would reduce farm type heterogeneity in the region, which was perceived to have a relative high contribution to robustness and transformability (Paas et al., 2019). Increased social-self organization in the system "Collaboration & water" and "Nature-inclusive" could lead to more interactions with citizens in the region, which could foster the

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support of agriculture by rural life. “Collaboration & water” also clearly shows that response diversity can improve with regard to dealing with drought. The role of innovation and technology in all alternative systems is dependent on the openness of the system. At the same time, starch potato, sugar beet and cereals, the conventional crops that stay in all proposed systems, are largely grown for export, which also requires an open system. Therefore, exposure to disturbances stemming from international markets could increase towards the future. In the system “Alternative crops”, the openness and exposure for disturbance of the system can be reduced, provided alternative crops are grown for relatively short value chains that aim at nearby markets.

In all proposed alternative systems, starch potato production stays important, while other main indicators are expected to improve mostly moderately. Therefore it seems that alternative systems are mainly adaptations to the current system. At actor level it is however possible that transformations are necessary. For instance, in “Collaboration & water”, actors need to work in a fundamentally different way to realize alternative water management. In “Alternative crops”, niches can be filled by individual farms, where most farms will maintain their current way of producing. For each of the systems, it however depends how much change is realized. A system that is much more nature-inclusive, relying on precision agriculture, producing more alternative crops, and depending more on collaboration among different types of farmers and other farming system actors, may be considered as a transformation. It is however clear that most stakeholders aim at maintaining starch potato production in the farming system.

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3.4 Causal loop diagram

In the farming system in the Veenkoloniën there are multiple closed feedback loops (Figure 2). In this section we discuss the most important ones. An important **reinforcing feedback (R1: "increasing production")** loop is that higher yields lead to more supply, which lead to higher profits for Avebe, that can consequently spend more on improving starch potato varieties and innovative products. This reinforcing feedback loop has turned out effective around 2000, when nematode resistant varieties reduced nematodes in the soil and when also varieties with higher starch contents were made available. Another example is the creation of innovative protein derivatives around 2009 that currently serve as ingredients of for instance cheese substitutes. As a participant mentioned in the workshop, a large enough volume of starch potatoes produced in the region is essential for having funds available for innovation. This note on the importance of volume is also found for the industry of sugar beet processing (Verlouw, 2018).

An important **balancing feedback (B1: "Natural limits to production")** loop is characterized by on the one hand the economic supply and demand mechanism which stimulates production in the current setting, and on the other hand the biophysical boundaries of starch potato production that are reached, or even exceeded. Current tight crop rotations stimulate nematodes and cause soil disturbance, are leading to yield reductions in the long term. The negative effects in this balancing feedback loop are counterbalanced by strategies implemented in the farming system: genetic improvement with regard to yield and nematode tolerance and resistance. Also efforts on increasing soil management and fertility are getting higher on the agenda nowadays. This is also in relation to drought, an important challenge in the region, which can be better handled when water retention in the field through better soil structure is improved. During the workshop, participants were worried that soil quality is still decreasing and that it is already a challenge to keep what is currently there.

Overall, in case implemented strategies do not have the desired effect on the previously mentioned feedback loop, growing starch potatoes might become less lucrative. As a result, farmers are likely to be less inclined to grow starch potatoes. This **reinforcing feedback loop (R1: "Crop choice")** is counteracted by two other feedback loops: one **balancing feedback loop (B2: "Innovation")** that works at a relatively slow pace (> 1 year), and another **balancing feedback loop (B3: "Extra profit sharing")** that works on a relative short pace (< 1 year). **B2** increases the role of innovation (a relatively slow process), when farm income is low, this leads to higher prices, which makes growing starch potatoes more attractive again. **B2** became very visible after the loss of production-based subsidies: through innovation Avebe could realize higher product prices, which compensated the loss of subsidy. Until now, **B2** is important as gross margin from starch potato production is relatively low. **B3** increases the share of profit with shareholders at the cost of

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reserves for innovation, when gross margin is low in particular years, this increases the attractiveness of growing starch potatoes. By sharing more profit than normal in extreme years, a **reinforcing feedback loop (R2: "Building loyalty")** is introduced: loyalty of farmers is kept high by providing high starch potato prices to farmers, especially in financial hard times, which happened for instance in 2018 and 2019. In these years, the cooperative decides to keep less of the profit for their own reserves. In return, the cooperative expects loyalty from farmers to keep on growing starch potatoes in the years to come. The downside of sharing extra profit (**B3, R2**) is that, when happening too often, too little funds are available for innovation and genetic improvement, thus reducing **B2**. Finally, the share system that is in place obliges farmers to deliver a certain volume of starch potatoes, thus counteracting **R1**. When the obligations are not met, a fine applies. Moreover, to get rid of shares, a farmer needs to pay a considerable sum of money.

The challenge "Changing rules & regulations" is not part of feedback loops, but influences feedback loop **B1** by limiting adaptation options to water shortage (Limitations on water use) and pests and diseases (Ban on (certain) crop protection products). This challenge further stimulated **R1** by making starch potato production less profitable after the subsidy change in 2013. In that specific case, mainly **B2** was stimulated to counteract **R1**. Social self-organization is positively impacted by the nematode pressure and negatively impacted by lower farm income. It is however not evident how social self-organization could provide a feedback to the farming system. Possibly, innovation could be influenced, as a social self-organization can create a network to diffuse and tailor new technologies. Cabell and Oelofse (2012) mention that social self-organization is mainly important in the re-organization phase of a system, which could explain why it is difficult to find feedbacks to the current system. Production being coupled with local and natural resources is difficult to place in the CLD. One could argue that this resilience attribute is represented by the feedback loop B1 "Natural limits to production".

All reinforcing feedback loops in the system are linked or contributing in different (indirect) ways to the price for starch potatoes, and thus stimulates the production of starch potatoes. It should be noted that these feedback loops can go both ways, i.e. contributing negatively and positively to starch potato prices and production. It should also be noted that in most reinforcing feedback loops, stochasticity plays a role, i.e. it is partly up to chance whether genetically improved starch potato varieties are found, whether new starch and protein products from starch potato will be derived, whether relatively bad production years will be experienced. In contrast to this (stochastic) uncertainty, decline in soil quality is perceived as a steady, long-term pressure. Improving soil quality in combination with not too many bad years and the timely arrival of genetically improved crops and innovative starch potato products seems essential to counterbalance the main balancing feedback loop in the system that currently has a inclination to decline.

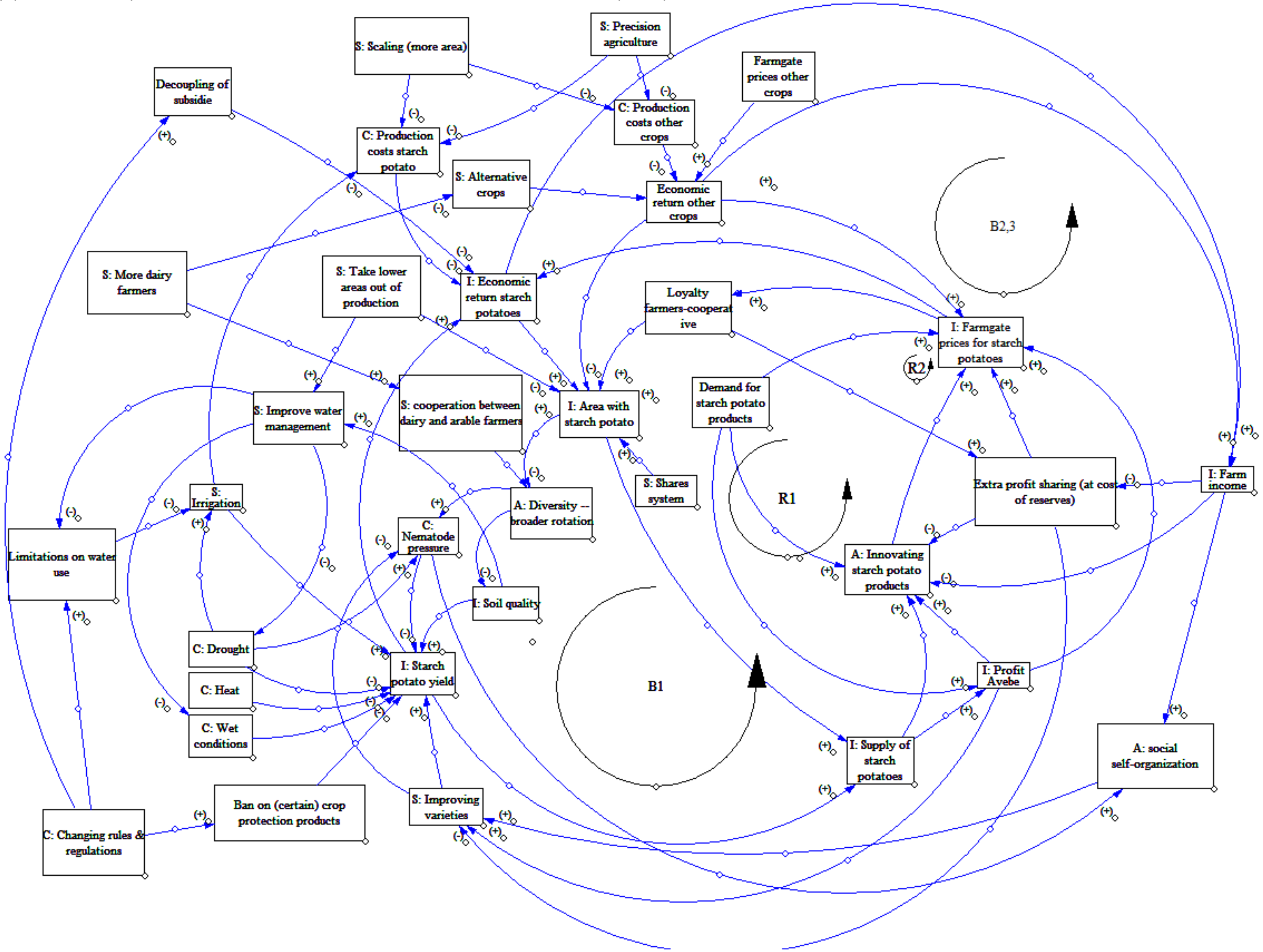

Figure 2. Causal loop diagram of the farming system in the Veenkoloniën. A + implies a positive cause-effect relationship and a - implies a negative cause-effect relationship. B stands for a balancing feedback loop and R stands for a reinforcing feedback loop. I indicates an important system indicator related to the system's functions. C indicates a system challenge. A indicates an indicator related to a resilience attribute. S indicates a strategy (to be) applied to maintain current functionality of the system.

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3.5 Linking alternative systems to scenarios

For maintaining the current system in the future or realizing the proposed alternative systems, soil quality should not further decline and resource use should become more efficient, implying also an increase in technology. Based on the workshop results, soil decline seems less an issue in the alternative system “Alternative crops”, on the other hand, participants mentioned increased circularity, implying lower losses of water and nutrient from the system, in which soil quality plays an important role. Maintenance of natural resources is more important in “Nature -inclusive” and efficient use of resources is especially important in “Precision agriculture” and “Nature-inclusive”. Increase in technology is most important in the alternative systems “Precision agriculture” (for agricultural techniques). Maintaining the current system and realizing alternative systems in the future also requires the continuation or even increase international trade and affordable agricultural inputs. This is especially the case for maintaining the status quo and “Precision agriculture”, and less the case in “Alternative crops” that could benefit from more local food chains. The maintenance of the current system or realizing alternative system could all benefit from the development of the rural areas. This is especially the case for “Alternative crops” for which a new value chain needs to be developed, for “Precision agriculture” for which infrastructure is key for accurate availability and exchange of information, and “Collaboration & water”, for which re-organization of the landscape might be necessary. “Collaboration & water” also could benefit from more from multi-level cooperation for innovative water management, where “Nature-inclusive” could benefit from this for developing agro-environmental management plans. For “Alternative crops” diversity of value chains in the EU could help to find a niche for a new crop and product. Economic growth is important for maintaining the current system and for all alternative systems. Increased commodity prices are most important for “Alternative crops”, “Precision agriculture” and “Nature-inclusive” for which participants specifically mentioned that a good business model was necessary, i.e. a good valorization of agricultural products. Given low profitability, a good valorization of products seems also necessary for the current system and “Collaboration & water”. Urban-rural linkages and environmental awareness of citizens could help to reach the good valorization of products, especially when produced in an environmental responsible way, as for instance in “Nature-inclusive”.

Technological development and attention for natural resources in combination with effective policies and institutions in SSP1 (sustainability path) align well with the needs of the current system and alternative systems (Table 6). However, in SSP1, international trade is decreasing because more local food chains are preferred and input prices are increased to internalize environmental costs. This makes the maintenance of the current system and “precision agriculture” in this scenario least obvious. In SSP1, improved commodity prices could support a good business model, provided reductions in environmental pressure are realized and result in higher income for farmers. Therefore, “Nature-inclusive” seems the most aligned with SSP1.

Table 6. Compatibility of alternative systems with different Eur-Agri-SSPs (Mitter *et al.*, 2019)*. Where values -1 to -0.66: strong incompatibility, -0.66 to -0.33: moderate incompatibility, -0.33 – 0: weak incompatibility, 0-0.33 weak compatibility, 0.33-0.66: moderate compatibility, and 0.66-1: strong compatibility. Colors reflect compatibility categories.*

	Scenarios				
Systems	**SSP1 “Sustainability”**	**SSP2 “Established paths”**	**SSP3 “Regional Rivalry”**	**SSP4 “Inequality”**	**SSP5 “Technology”**
Maintaining status quo	0.65	0.21	-0.76	0.18	0.31
Alternative crops	0.76	0.17	-0.76	0.02	0.05
Precision agriculture	0.61	0.19	-0.77	0.32	0.36
Nature-inclusive	0.86	0.27	-0.88	0.01	0.04
Collaboration & water	0.72	0.26	-0.79	0.13	0.19

Continuing on established paths (SSP2) is not contradicting the current or proposed alternative systems, but seems to provide little with regard to avoiding further depletion of natural resources, which is essential for the farming system in de Veenkoloniën (Table 6). Policies and institutions are also not further improved to stimulate more collaboration, are staying at the same level of efficiency and subsidies are also maintained at the current levels. For “Alternative crops”, the decrease in diversity of value chains is further reducing the alignment with SSP2.

SSP3 (Regional rivalry) undermines many of the prerequisites of the current and alternative systems, such as economic growth, effective policies and institutions, environmental standards, technology development and uptake. Commodity prices increase, but so do agricultural input prices. In SSP3, direct payments are expected to be increased, thus potentially improving profitability. Direct payments are not well aligned with the business model of “Nature-inclusive” where subsidies are more related to environmental services.

SSP4 (inequality path) has good and bad points with regard to the prerequisites of the current and alternative systems. In SSP4, policies and institutions are effective and multi-level cooperation is possible. Also international trade is stimulated. Technology development and uptake in agriculture is good and even partly financed with public payments. However, investment in rural infrastructure and urban-rural linkages are declining. With this, also environmental awareness of citizens, environmental standards are declining. Although resource use efficiency increases, further resource depletion is not stopped. “Precision agriculture” is most aligned with SSP4. After that come “Status quo” and “Collaboration & water”, being weakly compatible with SSP4, that

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both benefit from effective policies and institutions, multi-level cooperation and technological development. For the other alternatives, pros and cons are balanced with regard to SSP4.

SSP5 (technology path), shows similar patterns to SSP4, but is expected to do better on investments in infrastructure in rural areas, educational levels of farmers, economic growth rate and keeping agricultural input prices low. On the other hand, direct payments and public investment in agricultural technology will decline. This results in an increase in alignment for maintaining the current system, and a smaller increase in alignment for all alternative systems in SSP5, compared to alignment with SSP4. Overall, maintaining the current system and "Precision agriculture seem most aligned with SSP5, but only into a moderate extent.

Participants in the workshop indicated that a combination of all proposed alternative systems was desired for the future. In that sense, all alternative systems have equal likelihood. This suggests that the farming system in the Veenkoloniën is moderately to well-prepared for SSP1 and only weakly prepared for SSP2. However, investment costs might force stakeholders in de Veenkoloniën to put priorities. Putting priorities on gearing the system towards precision agriculture will prepare the system moderately well for SSP4 and SSP5 as well. All alternative futures as presented in the workshop are strongly incompatible with SSP3.

3.6 Strategies

Participants indicated that they need a shared vision before they could talk about what strategies to implement. In general, participants indicated that the strategies implemented in the past are still important for the future. In fact, some strategies implemented in the past align well with certain alternative systems. Increased use of precision agriculture for instance contributes to "Precision agriculture", but also to better resource efficiency, which is important in all alternative systems to improve profitability and decrease pressure on the environment. Another example is the strategy on improving starch potato varieties: in all alternative systems, starch potato production stays important, which is why this strategy stays important towards the future to maintain and improve yields. Also strategies related to soil quality need to be implemented continuously into the future to keep the system afloat with regard to keeping adequate yield levels.

Still, there are a few strategies necessary for alternative systems that have not been implemented yet. In "Alternative crops", the introduction of a new (local) value chain would help to support a good business model. Keeping the value chain local, implying a production for a home market, would help to establish a new value chain in the Veenkoloniën (Strijker, 2003). However, this strategy would require to interfere with current positive reinforcing feedback loops in the system where starch potato is consciously maintained as the most profitable crop. Participants indicated that alternative crops should primarily substitute other crops than starch potato. However, it is questionable how feasible this is. Ideally, an entry point for a new value chain in the system should be a point where the starch producing cooperative is directly benefitting from this change, rather than ending up in competing with the new value chain. For most alternative crops, experiments at field level could be sufficient to link up with existing value chain activities at national scales, which is for instance the case for onions and carrots. On the other hand, when an alternative crop is entirely new, experimenting at field level will not automatically instigate new value chain activities. In "Collaboration & water", strategies require high levels of collaboration, investment, innovative land & water management and land consolidation. In the Veenkoloniën, a large land consolidation that took more than 25 years has recently been finished (de la Court, 2017), which makes it unlikely that a new land consolidation will take place again in the near future. For most strategies in "Collaboration & water", (inter)national policies and regulations need to change in order to make such a change possible. Entry-points for these strategies seem therefore to lie primarily outside the farming system. This was also argued for "Nature-inclusive agriculture". However, at experimental level, collaboration between multiple stakeholders and adaptations at field/farm level seem realizable in the current socio-technical regime. Returning point of concern for experimentation is that often no financial means are available.

4 Conclusion

Proposed alternative systems, where starch potato continues to play a big role, suggest that the farming system is at the moment more adaptable than transformable. Although, transformability might be found in the potential for a different organization of the system, as is for instance suggested by the alternative system "Water & collaboration". Participants expected that main resilience attributes, such as social self-organization and infrastructure for innovation, mainly improve, which will mostly improve robustness and to a lesser extent also adaptability and transformability in the future. Improved robustness and further focus on adaptability is definitely necessary, given the system's perceived closeness to critical thresholds with relation to profitability, starch potato production, soil quality and the availability of water. Critical thresholds in the farming system in the Veenkoloniën are interlinked, such as nematode presence, low yields and low profitability, which make the system more vulnerable for undesired transformations, i.e. low performance of main indicators and resilience attributes. Further, the maintained or increased lack of attention for natural resources in four out of five SSP-scenarios suggest that there will be little external incentive and/or support to avoid trespassing critical thresholds with regard to soil quality and consequently water availability in the future, regardless the alternative system.

Main threats towards the future continue to be the plant parasitic nematodes in the soil, lowering soil quality, low profitability and the presence of weather extremes. Also continuous change of policies and regulations is a point of concern, especially with regard to the ban of certain crop protection products. Therefore, current strategies to improve resilience of the system will also be needed in the future. Important strategies are innovating starch potato products and improving starch potato varieties for higher yields and nematode resistance and/or tolerance. These strategies are partly influenced by stochastic processes, i.e. it is not exactly known when innovations or new breeds are discovered. This while the pressure from declining soil quality and nematodes is more continuous and certain and pushing the system towards a critical threshold. The proposed alternative systems show potential to decrease the pressure on the system. Most participants were in favor of all proposed alternative systems, i.e. they thought the future would be a combination of all four alternative systems. However, all alternative systems require substantial investments, implying that it is not likely that all strategies for these alternatives can be implemented. Therefore a shared and coherent vision for the system should be developed, before deciding on concrete strategies that are necessary for the future.

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