Circular pig farm of the future

Designing the circular pig farm of the future – Realising collaboration between arable and pig farmers

ACT 2606

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Confidentiality

Names of involved parties are confidential and were replaced by abbreviations below. Furthermore, feed prices were indicated with X, as these are also confidential and only intended for parties directly involved in the collaboration.

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Executive summary

Circularity in livestock production entails the use of alternative feed sources and edible by-products from rest streams as feed. In this report we looked at the possibilities to establish a circular collaboration between Vallei Varken and arable farmers based on the exchange of crops as feed and manure as fertiliser. First, we gave an overview of the organisational, practical and financial boundaries that must be adhered to in order to establish a collaboration between Vallei Varken, the arable farmers and other stakeholders. Thereafter, we investigated the possibilities to integrate crops and crop by-products from arable farms in pig diets. Including cereal grains in the pig diet is feasible, while other possibilities like using legumes and vegetable by-products need further consideration. Subsequently, we selected suitable crops that the arable farmers could Produce for Vallei Varken, and established various feasible crops in the three scenarios of cereals, protein crops and vegetables. Furthermore, we explored in what form and quantity manure produced by Vallei Varken can be integrated in the fertilisation plan of the arable farmers. Based on the current manure situation of Vallei Varken and the requirements of the arable farmers, we advised AF1 to receive the liquid fraction of separated manure from VV3, while AF2 to receive slurry manure from either VV1 or VV3. Finally, we developed a collaborative framework that describes possible ways to collaborate, lays down the rules and requirements, and provides advice to deal with organisational affairs. Our main finding is that there are multiple options to give substance to a possible collaboration. The next step for the stakeholders to put this into practice is to discuss these options and establish the most suitable collaboration.

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Abbreviations

AF1: Arable Farmer 1
AF2: Arable Farmer 2
ANF: Antinutritional Factors
CP: Crude Protein
DM: Dry Matter
EOM: Effective Organic Matter
K: Potassium
K_2O: Potassium oxide
N: Nitrogen
OM: Organic Matter
P: Phosphorous
P_2O_5: Phosphate
VV1: Fattening farm 1 of Vallei Varken
VV2: Fattening farm 2 of Vallei Varken
VV3: Breeding farm of Vallei Varken
VV4: Veterinarian of Vallei Varken

1 Introduction

It is expected that by 2050 the world population has grown to 9,5 billion people. To prevent exhaustion of the earth's resources, we need to change our way of production and consumption. We do not just need to produce food for the human population, but also feed for the animals that we raise for consumption. In order to achieve this, it is crucial to utilise all biomass optimally (Wageningen University & Research, 2021a). Therefore, the aim of circular agriculture is to minimise the loss of raw materials during the life cycle of biomass by closing the nutrient cycle within the agricultural system as much as possible. These losses can be reduced by using waste streams as input materials for the agricultural system, thereby reducing the inputs from outside the system (Bos et al., 2019).

Another approach in circularity in agricultural production can be the exchange of by-products between two systems. What is regarded as an output that cannot be used in one system, can be used as input for another, and vice versa. By taking this approach, the probability of closing the production cycle across all levels increases. This is ultimately the aim of circular agriculture (De Boer & Van Ittersum, 2018).

Circularity in livestock production entails the use of alternative feed sources and by-products from arable production systems, the food industry and the remainder of the food chain as feed. Hereby, feed-food competition – using land suitable to grow crops for human consumption to grow feed for animals – could be minimised. In arable farming, circularity entails the use of high-quality fertiliser of animal origin (like manure) and crop residues to improve and maintain soil quality (Wageningen University & Research, 2018).

Realising more circularity in the agricultural sector also contributes to the vision of the Ministry of Agriculture, Nature and Food Quality. In that plan, the aim is that by 2030 cycles of raw materials and resources are closed at the lowest possible scale - regional, national or international. In 2030, arable farming, livestock farming and horticulture already primarily use raw materials from each other's chains and residual flows from the food industry and food chains. Crop residues, food residues, process waste and manure are reused or processed into new products (Rijksoverheid, 2019).

Vallei Varken, which is a cooperation between three pig farmers and retailers, currently transports their manure to various farms across the Netherlands, as well as processing facilities. Manure from livestock farms can be used as fertiliser on arable farms, but because of the excess manure in the Netherlands, it is regarded as a waste product. The feed company Agrifirm currently provides the pig farmers of Vallei Varken in the majority of their feed demand. In exchange for manure, arable farmers could provide crops and/or crop by-products as pig feed. This manure-feed exchange is a step towards more circularity in agricultural systems.

A previous ACT project (Van der Heijden et al., 2020) has established that two arable farmers, located in Flevoland and the Veluwe, are willing to investigate the possibilities of a collaboration with Vallei Varken to increase circularity between them. In such a circular system, Vallei Varken would provide the arable farmers with manure to decrease their artificial fertiliser inputs and to increase soil quality for optimal crop yield. In turn, the arable farmers would provide crops and crop by-products to be used as feed for the pigs of Vallei Varken.

As mentioned, the aim of this project is to reach a higher level of agricultural circularity by establishing an exchange of manure and crops between pig and arable farmers. The different stakeholders are currently unsure of how to put such a collaboration into practice. The problem faced is multidimensional and multidisciplinary. The amount and composition of the manure exchanged must meet the requirements of the lands of the arable farmers. The crops and crop by-products which can be incorporated into the pig diets and grown in the arable farms are unknown. More insight in possibilities for crop production in terms of type and quantities of crops to be grown by the arable farmers is required. Similarly, the required adaptions to the current pig feed in order to incorporate these crops while meeting nutritional requirements need to be provided. Another important aspect is that this collaboration could only be established if a relation of trust and loyalty in between Vallei Varken and the arable farmers is established. Finally, the collaboration between pig farmers and arable farmers must also be profitable for the stakeholders involved.

The overall long-term goal of the commissioner of this project is to achieve full circularity in the Dutch agricultural sector. In order to achieve this, incremental steps towards circularity must be taken. Agricultural circularity is an important factor in realising the sustainable production systems that we need in order to reach our sustainability objectives. Reaching total circularity may be achievable from an academic point of view, but it remains to be seen how the concept will stand in practice. This project will be a good start to explore the possibilities of increasing circularity in agriculture.

1.1 Integrative project purpose

Our team (Appendix I: ACT group members) strives to lay the foundation for a cooperation based on circularity (De Boer & Van Ittersum, 2018) and mutual (financial) benefits between Vallei Varken and arable farmers. We aim to achieve this by creating a practical plan to facilitate the exchange of manure as fertiliser and (by-products of) crops as feed, including quantities and compositions of the different resource flows. Based on our expertise, we expect to be able to contribute to fill the knowledge gap about how to put this collaboration into practice. We will address issues about feed formulation, crop selection, manure application and complying with the needs and expectations of each stakeholder.

The most important ethical concern of the project is guaranteeing the privacy of parties involved in our research. We had to ensure total transparency with regards to our project and what we want to achieve with the data gathered. Therefore, we have kept the farmers undisclosed, as well as confidential information. It is also important that we take the academic aspect of our roles seriously and base our choices on scientific literature. For example, we discussed whether it is ethical to call our design circular if the farmers were to desire to include crops specifically for pig feed in their rotation. In fact, this would break the principles of circularity by De Boer and Van Ittersum (2018) on which we base our theoretical framework. This discussion led us to redefine our purpose, setting our sights on practically implementable circularity rather than full circularity.

1.2 Research questions

We have formulated the following main research question:

What are the possibilities to establish a collaboration between Vallei Varken and two arable farmers based on the exchange of crops as feed and manure as fertiliser?

In order to answer this question, we have also formulated four sub-questions. The first question sets the boundaries for an agreement between the actors, based on their interactions and wishes. The other three questions each cover a particular subject within the project, as well as the actor that is mostly associated with that topic.

1. What are the organisational, practical and financial boundaries that must be adhered to in order to organise a collaboration between Vallei Varken, the arable farmers and other stakeholders?
2. What are the possibilities to integrate crops and crop by-products from arable farms in pig diets to reach the nutritional requirements of the pig and to obtain a constant manure profile that fits the requirements of the arable farmers?
3. What are suitable crops for the arable farmers to grow in order to contribute to the Vallei Varken concept and improve the value and resilience of their crop rotation?
4. In what form and quantity can manure from Vallei Varken be integrated in the fertilisation plan of the arable farmers?

2 Materials and methods

To eventually answer our main research question, we obtained information mainly through interviews with the relevant stakeholders and literature research to answer the sub-questions.

We started our research with the report from a previous ACT team, in which an overview of possible arable farmers for the collaboration was established (Van der Heijden et al., 2020). The team made contact with the two arable farmers that were interested in a collaboration between them and Vallei Varken. Unfortunately, one of the arable farmers decided halfway through the project to not partake. Luckily, we were able to successfully reach another arable farmer (AF2) that was seriously interested in such a collaboration.

The group set up interviews with sufficient questions for answering each sub-question and finally the main research question. Per subject, we used the following research approach and methods:

- **Current system and boundaries**: Based on literature research and interviews with the arable farmers and Vallei Varken, we created an overview of their current organisational structure, the requirements that need to be met and boundaries that must be adhered to in order for a collaboration to be established.

- **Feed formulation**: We performed interviews with Agrifirm and Vallei Varken to obtain information on the current feeding practices, and to discover to what degree the different parties are willing and able to deviate. Thereafter, knowing our starting point, boundaries and demands, we explored the possibilities of incorporating crops and crop by-products into pig feed by means of literature research. Eventually, we formulated diets for fattening pigs using the software EvaPig® (2021).

- **Crop selection**: In order to show the arable farmers how they can contribute to the Vallei Varken concept, we came up with three scenarios: grain for pig feed, protein for pig feed, and vegetables for De Kroes. We selected suitable crops for each scenario, and then ranked these based on the preferred harvest period, gross margin per hectare, and potential to yield pig feed. We then highlight some interesting crops and give some general advice to improve the arable farmers' crop rotations.

- **Manure application**: The eventual goal of this project is to establish how to integrate the manure from Vallei Varken in the fertilisation plan of the arable farmers. To do so, we interviewed Vallei Varken in order to obtain the specifications of their manure production (amount, quality etc.), as well as the arable farmers to establish their needs with regards to manure fertilisation. We then conducted a literature research to establish the optimal manure composition contributing to soil fertility of the arable farms. Finally, we provided advice to Vallei Varken and the arable farmers on how to increase manure circularity for the current situation and the proposed crop rotations.

2.1 Literature research

In order to gather relevant, recent literature, we made use of search tools such as Google Scholar, Scopus and the WUR Library website. This literature is peer-reviewed, which means an article can be trusted as a valid and reliable source. As this is a practical report, we also made use of governmental data, mainly concerning manure and involved regulations and costs.

2.2 Interviews

Due to the corona crisis, most interviews with farmers and other stakeholders were conducted through Microsoft Teams or by phone. Some questions were also answered by e-mail. However, we were able to conduct interviews on one of the pig farms and one arable farm. Despite the means of conducting the interview, the team (representative) asked in-depth questions to get a better understanding of the subject and made sure that our most important questions were answered. In terms of the type of interview, we mostly conducted semi-structured interviews. This implied composing a list of questions and possible follow-up questions, most of which were open questions. In practice, most interviews took place in a flowing conversation during which our questions were answered, not necessarily having asked the specific questions.

We started off with a round of exploratory interviews with the veterinarian of Vallei Varken, the three Vallei Varken pig farmers, two arable farmers and Agrifirm to obtain basic information about the current situation and to get an impression of the views and opinions of the parties involved. This provided a general idea of the starting point and boundaries, based on which we started exploring the literature for solutions. We conducted the interviews with a series of explorative questions, to engage in a natural conversation. We kept in touch with the stakeholders and reached out to them in case we needed more information or feedback on our solutions from their practical points of view. This allowed us to have a better understanding of possible feasible solutions and what the different parties' attitudes were towards them. The majority of interviews were in Dutch to ensure the interviewees could express themselves fully. We asked for permission to record the interviews and take notes. Afterwards, the interviewer made a written overview and English translation of the interview and provided it to the team. We then incorporated this obtained information into our project and referred to it as 'stakeholder, personal communication'. The list of interview questions and summaries of each interview can be found in Appendix II: Interview questions and summaries.

3 Current system and boundaries

This chapter will give an overview of the current system of Vallei Varken and the arable farmers. The boundaries for a collaboration will also be elaborated and explained in order to answer the first sub-question: *What are the organisational, practical and financial boundaries that must be adhered to in order to organise a collaboration between Vallei Varken, the arable farmers and other stakeholders?*

3.1 Current system

Vallei Varken is a concept where three pig farms work together and have set up their own supply chain in which they work closely together with their stakeholders. The goal of Vallei Varken is to maintain a high health standard for their pigs. This results in less antibiotic use and healthy pigs. The supply chain of Vallei Varken starts with a breeding farm that produces piglets for the two fattening farms. When the pigs reach a weight of 96 kg, they are slaughtered at Gosschalk slaughterhouse. The meat is then processed by various companies, amongst others Boni and De Kroes. The processed meat is thereafter sold by different retailers (Figure 1). For more in-depth information on Vallei Varken, see ACT report 2461 (Van der Heijden et al., 2020).

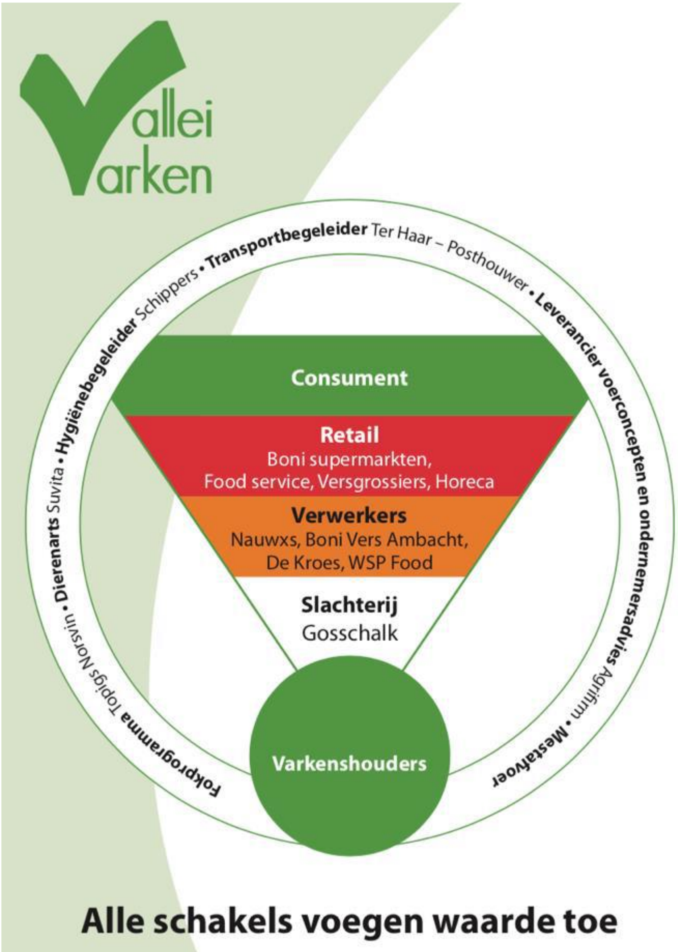

Figure 1: Supply Chain of Vallei Varken (source: VV1)

In this collaboration, Boni and De Kroes play a big role in the revenues of Vallei Varken. In fact, the two companies are their main buyers. Therefore, the main goal of the pig farmers is to keep Boni and De Kroes satisfied. This can be achieved by both delivering higher quality meat and keeping the cost price as low as possible. By creating more circularity, the total cost price can possibly decrease as a result of lower manure disposal costs, but this is also a form of quality that appeals to Boni and De Kroes (VV4, personal communication, February 17, 2021).

3.1.1 Stakeholders

As the goal of this project is to establish a collaboration between Vallei Varken and two arable farmers, all involved stakeholders need to be considered. The needs and wishes of these stakeholders need to be taken into account to come to a concrete plan for the collaboration. These are the pig farmers of Vallei Varken, the arable farmers, Agrifirm and De Kroes. The most important stakeholders will be explained in the remainder of this paragraph. The longlist of stakeholders can be found in Appendix III: Stakeholders long-list.

Vallei Varken 1 (VV1) – VV1 is the head of Vallei Varken and has a fattening pig farm located in Putten. The health of his pigs is what's most important for him, that is the reason for establishing Vallei Varken. VV1 currently has 3,800 pigs on his farm and delivers around 11,300 pigs yearly, of which half goes to Boni and half to De Kroes.

Vallei Varken 2 (VV2) – VV2 is the second fattening pig farmer, located in Dalfsen. He currently has 1,700 pigs. He cooperates with an arable farmer in the neighbourhood who grows spelt wheat for a local bakery. VV2 delivers the pig manure to this arable farmer's land and the waste stream from the bakery is used as a minor portion of pig feed in return. He delivers around 4,700 pigs yearly, of which also half goes to Boni and half to De Kroes.

Vallei Varken 3 (VV3) – VV3 has a breeding pig farm located in Nijverdal. The breeding farm has 660 sows, and around 30 sows farrow every week. VV3 delivers piglets to the fattening farms at the age of 10 weeks. He delivers approximately 20,000 piglets yearly, but 10% of these piglets do not go to the farms of Vallei Varken, as there is a lack of capacity. Besides the breeding farm, he has 40 hectares of arable land on which he either grows silage maize or trades the land with arable farmers in the neighbourhood that grow lilies and potatoes.

Vallei Varken 4 (VV4) – VV4 is the veterinarian of Vallei Varken, who is responsible for the health of the pigs. He is the main contact person within Vallei Varken.

Arable Farmer 1 (AF1) – AF1 is located in Kootwijkerbroek and has 25 hectares of land. He currently rents 35 hectares, to have a total of 60 hectares usable land.

Arable Farmer 2 (AF2) – AF2 is located in Tynaarlo and uses around 110 hectares of land. He owns 80 hectares and rents the rest. Moreover, he trades land with other farmers for crop rotation.

Agrifirm is a Dutch feed cooperative whose mission is to create sustainable, measurable and relevant value for farms, fields and forage industry (Agrifirm, 2021). They are the current feed supplier of Vallei Varken and are willing to cooperate in a circular agricultural system. Agrifirm has several factories across the Netherlands, of which two produce pig feed. These two factories are located in Veghel and Zwolle. Besides being feed supplier, they also offer a consulting and advising service to their clients.

De Kroes is one of the leading companies concerning fresh meals, meal components, fried snacks and traditional meat products. They use meat from Vallei Varken and vegetables from Dutch arable farmers. The vegetables are processed by Groenteproductie Flevoland and the potatoes by Schaap Holland before being processed to meals and meal components by De Kroes (De Kroes, personal communication, February 22, 2021).

3.2 Boundaries

The boundaries for this project entail an overview of restrictions that must be adhered to when exploring new possibilities. These are given in the form of a set of numbers, legislations or beliefs and are divided in three different subjects: organisational, practical and financial.

3.2.1 Organisational boundaries

Logistics

The map in Figure 2 provides a graphical representation of the location of the stakeholders. It is important to look at the locations of the different stakeholders across the Netherlands. The closer the locations are to each other, the cheaper and more sustainable the transport will be. As mentioned, Agrifirm has two factories for processing pig feed in Zwolle and Veghel. The Vallei Varken farms currently receive their feed from the factory in Zwolle. Waste streams from the food industry are processed in the factory in Veghel (Agrifirm, personal communication, March 3, 2021). Third parties are responsible for manure transport and application, this is being paid for by Vallei Varken.

Figure 2: Map of stakeholders

Human relations

For both Vallei Varken and the arable farmers, trust plays a big role in a possible collaboration. All stakeholders have been working with partners for years and know that they can trust each other. Therefore, it is necessary to meet several times per year. Flexibility is also important for AF1, as he wants to meet at least twice per year to discuss the needs and wishes and does not want to get involved in a ten-year contract right away (AF1, personal communication, January 20, 2021).

Vallei Varken strives for continuous improvement of their concept. They are interested in new ideas and innovations. All involved parties are partners of Vallei Varken and it is expected of them that they actively contribute to the concept of Vallei Varken. The head of Vallei Varken also expects this from the arable farmers that are willing to collaborate with him (VV1, personal communication, January 22, 2021).

Collaboration

As human relations are of great impact to this project, the practicalities of a collaboration between pig farmers and arable farmers need to be discussed as well. There are different forms of collaboration. In this specific case, the aim is to exchange manure for feed. For both parties it is important to understand what they mean with collaboration and what their expectations are to achieve a successful collaboration. To help guide the advice (which is elaborated in Chapter 7), a handbook on collaboration between arable farmers and livestock farmers is used. In this handbook a cooperation statute ('samenwerkingsstatuut') is suggested to serve as a basis for a successful collaboration. This cooperation statute includes multiple subjects on which both parties should come to an agreement, such as values, views and communication (Oosterhoff, 2019).

3.2.2 Practical boundaries

The practical boundaries are divided in the three main topics that come across in this report, namely feed, crops and manure.

Feed

The composition and amount of feed is important for the wellbeing and growth of pigs. To be able to propose a new diet, we need to be certain of the requirements and boundaries involved.

As mentioned, Vallei Varken consists of three separate farms: two fattening farms (VV1, VV2) and one breeding farm (VV3). The fattening and breeding farms have different feeding patterns and feed compositions, which need to be taken into account when designing a possible new diet. VV1 uses 47 tonnes of feed per week, while VV2 uses 20 tonnes and VV3 34 tonnes. On average a total of 100 tonnes is used by the three farms together. VV1 and VV2 use three different types of feed, namely 'starter feed', 'growing feed' and 'end feed' (VV4, personal communication, February 17, 2021). These feeds consist of around 70% grains - mainly wheat, barley, silage maize and rye. Additionally, about 20% of the feed is protein rich material: mainly rapeseed meal and rapeseed flakes, soybean meal, sunflower seed meal. The remaining 10% consists of oils and fats, molasses, salt and minerals (calcium and phosphate) (Agrifirm, personal communication, February 22, 2021). The actual composition fluctuates, depending on the raw material prices and nutrient contents. The feed lists from Agrifirm provided good insight into the current composition, which will be further taken into consideration in Chapter 4.

Crops

In order to establish a certain exchange between feed and manure, it must be clear what kind of crops are suitable for this collaboration regarding the needs and wants of both parties and the possibilities and restrictions of the land.

Both arable farmers farm on sandy soils, which means they are subject to several negative soil conditions. These conditions include the faster rate of nutrient leaching, lower water retention capacity, and lower cationic exchange capacity (which affects nutrient availability) as compared to soils with larger components of clay and silt (Voroney, 2007). This means that the correct use of fertilisers and manure is important for crop quality (especially manure that is high in nitrogen in this case). Sandy soils thus have effect on the crop rotation plans as it needs to be more precise in order to optimally exploit the suboptimal conditions.

AF1 currently grows consumer potatoes, onions and grain (Table 1). For his potatoes, he has a contract with Aviko and Avebe: they buy everything he produces for a contractual price. AF1 sells his onions on the international market and is building a storage facility to be able to store onions until the market price hits his desired level. He sells his grain to a local feed processor. However, AF1 is willing to sell his grain to Agrifirm for a similar or higher price compared to what he currently receives. Moreover, he is willing to produce protein rich crops for Vallei Varken (except for legumes, because that enhances the growth of nematodes, which in turn harm the onions) in exchange for good quality liquid fraction of manure and a fair price (AF1, personal communication, February 19, 2021).

Table 1: Crop overview AF1

Crops	**ha**	**Yield (tonne/ha)**
Summer wheat	6.5	6.5-7
Barley	4.5	6.5-7
Potatoes for starch	10	50-55
Potatoes for fries	20	60-65
Onions	20	55-60

AF2 currently grows starch potatoes, sugar beets and barley (Table 2). As AF1, AF2 also delivers potatoes to Avebe. AF2 sells his sugar beets to Cosun and barley to Agrifirm, who delivers it to a beer brewery. He is open to produce alternative crops, such as sweet potato, but does not want to produce onions and flower bulbs. Most interesting would be to grow a crop that can be harvested in July/September, so not all the crops have to be harvested at the same time. He does not want to harvest a new crop in October when the ground is too soggy (AF2, personal communication, February 17, 2021).

Table 2: Crop overview AF2

Crops	**ha**	**Yield (tonne/ha)**
Barley	20	6.5
Potatoes for starch	65	47.5
Sugar beets	25	75

De Kroes can use different types of crops in their meals. The most important ones that are processed in high volumes are potatoes, onions, carrots, leek, chicory, endive and Chinese cabbage. However, there are more crops that they can use in smaller amounts, like sweet potato and pumpkin (De Kroes, personal communication, February 22, 2021).

Concerning the processing possibilities of Agrifirm, the firm is open to process whatever their clients require, as long as the client is willing to pay the additional costs of processing a customised diet (Agrifirm, personal communication, February 22, 2021).

Manure

There are multiple practical boundaries on manure that have to be considered in this project. These boundaries originate from governmental regulations, manure that is available from the pig farmers, the preferences of the arable farmers and the need of their soil/crops.

Policy

The Ministry of Agriculture, Nature and Food Quality came up with a plan to support the transition to circular agriculture. Part of this plan is to revise the Dutch fertilisation policy: to improve the nutrient cycles, decrease the emissions and increase precision fertilisation (Rijksoverheid, 2019). The most important legislation of the current policy is the amount of nitrogen and phosphate that is allowed to be used on one's land. The total amount of nitrogen in manure that can be applied per hectare is 170 kg per year (Oomen, Hendriks, & Lantinga, 1999). And there are the so-called phosphate and nitrogen excretion quotas. That is the total amount of phosphate and nitrogen that can be excreted by the animals in the pig sector. The total amount of phosphate that can be applied on arable land is 40 kg per hectare (RVO, 2020). Depending on the phosphate condition of the soil, the amount of phosphate that can be applied on arable land may increase. This is called phosphate differentiation.

Based on soil research the farmer can register to legally apply more phosphate on his land (RVO, 2021c).

Another regulation is the so-called 'manure processing obligation' (in Dutch: mestverwerkingsplicht). Every farm has a mineral balance, which means that the phosphate produced by the animals and the amount of phosphate that is legally allowed on the land owned by the farmer should be equal. When the animals produce more phosphate than can be used on the land, there is a surplus of manure at the farm. This surplus has to be processed. The amount of manure to be processed depends on the region in which the farm is located. The regions are based on the intensity of manure production in that region. VV1 and VV3 are located the region east, for which the manure processing obligation is 52%. This means that 52% of the manure surplus of the farm must be processed. VV2 is just outside the east region and therefore has a processing obligation of 10% (RVO, 2021a). Processing can be done by either exporting the manure or combustion or gasification of the manure to ashes with a maximum of 10% organic matter (Scharenborg, 2014).

Farmers

Besides legislation and regulations, the available manure of the pig farmers and the wishes for manure of the arable farmers are important. The three pig farms produce a total of 8,500 m^3 manure yearly. VV2 and VV3 already apply manure to their land or the land of arable farmers in the neighbourhood. VV2 applies 500 m^3 manure on his own land and approximately 450 m^3 on the land of an arable farmer. VV3 can apply a total of 1,500 m^3 manure on his own land and on the land of a farmer in the area. He separates the sow and piglets manure and applies most often the manure from the sows on his own land as it is lower in nutritional content. AF1 can use 1,500 kg of nitrogen on his land, the exact amount of pig manure is depending on the composition of the liquid fraction (AF1, personal communication, January 20, 2021). AF2 has a demand of maximum 500 m^3 pig manure, due to the maximum amount of phosphate that he can use (AF2, personal communication, February 21, 2021). An overview of the current manure disposal is given in Table 3.

Table 3: Current manure disposal overview

Stakeholder	**Manure need per year**	**Manure properties**
VV1	-	No option to apply manure on own land
VV2	950 m^3	
VV3	1,500 m^3	Sow/piglet manure, low nutritional content
AF1	*1,500 kg nitrogen*	High in nitrogen, low in phosphate: liquid fraction
AF2	500 m^3	Phosphate preferably as low as possible

Concerning the application of manure on sandy soils, slurry manure may be applied from the 16th of February until the 15th of September every year. However, if maize is being grown on the land, application of manure is only allowed from the 15th of March (RVO, 2021b).

3.2.3 Financial boundaries

Various costs need to be taken into account for the financial boundaries. The collaboration has to be economically feasible for all involved stakeholders. These costs include costs for manure disposal, feed costs, the price of the crops, transportation costs, manure application costs and the fixed cost price per kg of meat of Vallei Varken (which is an income).

There are two main drivers for pig farmers in the Netherlands to implement manure treatment in practice: pressure from policies and regulations, and facilitating the export of manure (Hou et al., 2018). Especially in the pig farming industry this is a major financial driver, as manure disposal costs have been rising the past decade (Wisman, 2014).

Also, in the case of Vallei Varken, these drivers play a big role, as the firm is currently paying manure disposal costs in between €13 – 19.50 per m^3 manure. This adds up to a yearly total of €118,000 for the three pig farms together (VV, personal communication, February 22, 2021). Average manure disposal costs in the Netherlands have risen over the last decade to around €20 per tonne on average, so this creates a drive to look for alternatives of disposal (Luesink, 2020).

Keeping the manure on the farm is the cheapest option, which Vallei Varken is already doing to some extent, at VV2 and VV3 as mentioned before. Exporting manure from the farm usually means that farmers are not getting paid the full nutrient value of the manure, plus they have to pay for the transport and application too (Asai, Langer, Frederiksen, & Jacobsen, 2014). Of these two costs, transport is the most expensive (VV3, personal communication, January 28, 2021): distance up to 20km €5-10 per tonne; 100km €10-20 per tonne; 500km €20-25 per tonne (Rijksoverheid, 2016). Still, this might be cheaper than paying standard disposal costs, which starts at €21 per m^3 at manure processor Merensteyn for example (Lamers, 2021).

Arable farmers usually get paid to have manure applied to their land, which indicates an excess supply of manure. In order to increase the value of manure, it can be separated into a solid and liquid fraction. This is more valuable to arable farmers, because the nutrient composition can be improved. The costs for separating manure into a liquid and solid fraction depend on the technique used for the separation. The average costs to separate more than 1.000 m^3 of manure is between €3 - €5 per m^3 (Schröder, De Buisonjé, Kasper, Verdoes, & Verloop, 2009).

Separating manure to increase the nutrient composition might thus be advantageous for both pig and arable farmers, as pig farmers might pay less than they would have when disposing their manure elsewhere and arable farmers are cheaper off than when having to buy artificial fertiliser.

Another large cost item is the feed, as Vallei Varken uses around 85 tonnes of feed every week. With an average cost price of €X1[1] per 100 kilos of feed, this comes down to a weekly expense of around €X2; €X3 yearly (VV4, personal communication, February 21, 2021).

Another important financial aspect to keep in mind when looking at costs and revenue streams of Vallei Varken, is that Boni is actually covering all expenses, including salaries and investments. In return, every week Vallei Varken delivers 335 pigs weighing around 96 kg. To cover all these expenses Boni offers a fixed price per kg which is re-established every three months. This price is based on a certain quality and weight standard Vallei Varken expects to achieve. The current market price of slaughtered meat pigs in the Netherlands is €1.44 per kg including delivery costs and sales tax, which is represented by the Vion price. This price is leading for the meat pig price in the Netherlands and fluctuates significantly throughout the year (Oogst, 2021). The current contractual price between Vallei Varken and Boni is €X4 per kg, which comes down to a yearly revenue of just under €X5 (VV4, personal communication, January 21, 2021).

[1] For confidentiality purposes, X1…5 have been disclosed in a separate file

4 Feed formulation

For a long time, pigs were fed with by-products of food production and household waste or were left to search for feed. In recent years, increased animal production and genetic improvements have influenced the dramatic development of the feed industry (Behnke, 1996; Rakic, 2012). Research in animal nutrition facilitated the needs and awareness on the composition of feed to meet the nutrient requirements of the animal (Ewing, 1963). Development of new domestic breeds with higher productivity forced feed production to gradually move towards satisfying nutritional requirements at least costs (Milanovic, 2018).

Literature

Pigs are monogastric animals with simple stomachs, most of the digestion is carried out through endogenous enzymes (Vukmirović et al., 2017). Therefore, pigs require highly nutritious and digestible feeds. As mentioned earlier, the genetic improvement has shifted the nutrient requirements needs of the animals to a more sophisticated nutrient requirements to cope with high productivity. However, the cost of production was impacted heavily, as feed represents about 65-75% of the total production costs in the swine operation. Nowadays, feed is the highest expense in pig farming in the Netherlands (Hoste, 2017). Improving feed utilisation by feeding by-products and left-over foods will have a tremendous impact on the cost of production (Goodband et al., 2006; Thielen, 2018). Compared to other animals, pigs can utilise various residues, leftover foods such as bread, fruits and other food waste. However, the low dry matter content of food waste limits the utilisation in highly productive animals, because it cannot satisfy the nutritional requirements. Due to this, pigs require specific feed to maintain and foster their growth rates. Food wastes can contribute partially to meet the nutritional requirements of pigs, but need to be complemented by traditional feedstuff in modern pig farming systems (Van Hal et al., 2019).

Methods and requirements

During this part, we will answer the following question: *What are the possibilities to integrate crops and crop by-products from arable farms in pig diets to reach the nutritional requirements of the pig and to obtain a constant manure profile that fits the requirements of the arable farmers?*

First, we will present the current situation of Vallei Varken in term of feed. Thereafter, we will elaborate on the problem of P excretion linked to the diet and propose potential solutions to tackle this issue. Finally, we will develop three possible scenarios of changes to ingredients of the fattening pig diets. In scenario one and two, we will present a potential diet formulation for the fattening pigs, while in scenario three we will give the possibility of feeding waste by-products in pigs. We decided to focus on the diets for this phase of pig farming because of two reasons. First of all, it represents the main volume of feed in the whole process of pig farming. Compared to piglets and sows, there are much more fattening pigs on the farms; and they have a high feed consumption. Secondly, fattening pigs are less sensitive than piglets. For example, piglets require special care in their feed. Fattening pigs also have less variation in their requirements than sows, which experience strong physiological challenges during gestation and lactation. All these reasons make the formulation for fattening pigs more relevant. Changing the diets for piglets and sows could be a future goal, after circularity has been achieved with fattening pigs.

In order to integrate crops and crop by-products from arable farmers in the pig diets a software program was used - EvaPig® (2021). EvaPig formulates diets which meet the nutritional requirements but also obtain a good manure profile required by arable farmers. The idea behind feed formulation is to meet the nutritional requirements of the pigs, without exceeding them and at a least cost. Not meeting the nutritional requirements would lead to an impaired growth and potentially health problems. While exceed them could lead to a higher cost and more environmental pollution due to a higher level of excretion of certain nutrients. The description of the requirements of the fattening pigs in terms of nutrient content is given in Table 4.

Table 4: Nutrient requirements of fattening pigs. Adapted from National Research Council (2012)

Nutrient	Requirement
ME^2 energy (Kcal/Kg)	3300
Crude protein (g/kg)	135

Amino acids	Total in diet (%)
Lysine	0.84
Threonine	0.56
Methionine	0.25
Typtophan	0.15
Valine	0.57
Phenylanine	0.51
Histidine	0.30
Arginine	0.38
Leucine	0.85
Isoleucine	0.45

2 Metabolisable energy

4.1 Current pig feed used by Vallei Varken

The pigs of Vallei Varken are currently fed with a diet produced by the Dutch feed cooperative Agrifirm. This feed is similar to what is produced for other conventional pig farms, in dry form. Ten different feeds are produced for VV in total, for each life stage of the pigs. The exact composition of the feed of Agrifirm is not known and changes according to the price and quality of raw materials. The main energy sources used are maize, wheat, barley, rye, and oats. While the main protein sources used are sunflower, rapeseed, and soybean meal. On top of that, some by-products such as molasses and wheat semolina are also used in the diets. The rest of the diet is made of enzymes, free amino acids, vitamins, minerals and oils. The right composition of feed is of high importance for Vallei Varken, as it directly influences pig health and growth rate (VV1, personal communication, January 22, 2021). The current average price for the feed of fattening pigs is €X6/100 kg (Agrifirm, personal communication, February 2, 2021).

The farm VV1 uses 47 tonnes of dry feed from Agrifirm weekly. Some liquid feeding can also be done, for using by-products for example, for which VV1 has a storage facility on the farm (VV1, personal communication, January 22, 2021). The pigs of VV2 consumes around 20 tonnes of feed per week, 100% in a solid form obtained from Agrifirm (VV2, personal communication, January 18, 2021). Finally, VV3 uses 34 tonnes of feed per week from Agrifirm. In addition to that, VV3 also uses some bakery by-products, but this represents a negligible fraction of the diets (VV3, personal communication, January 28, 2021).

4.2 Potential dietary solution to mitigate P-excretion

Recently, the development of the feed industry and intensive research in animal nutrition paved the way to the development of the advanced feed processing machinery and software, which enable the modelling and adjustments of the nutrient utilisation and excretion (Van Milgen et al., 2008). With this development, it is possible to play with the feeding matrix and adjust the amount of nutrients to be utilised in animal body and predict the excreted nutrients.

During the interviews, AF2 mentioned that the P content of pig manure often limits its usage (AF2, personal communication, February 17, 2021). In fact, the high P content of pig manure often limits the use of pig manure as fertiliser (Jongbloed & Lenis, 1998). Phosphorus is an important nutrient in pig diets, but only 30-35% of ingested P is retained (Jongbloed & Lenis, 1992). Excreted P accumulates in the soil and can lead to eutrophication. Therefore, the amount of P that can be applied on soils in the Netherlands is limited by legislation (Jongbloed, Poulsen, Dourmad, & Van der Peet-Schwering, 1999). In this part we will give some insights about how to reduce the P content in the manure by adjusting nutrients in diets and adjusting feed processing. These possibilities will help to reduce the P content of manure and maximize the amount of manure which could be spread on the lands of the arable farms.

4.2.1 Adjusting nutrients in diets

One first way to minimise P excretion is to play with the nutrients present in the diet. Nutrient excretion is a result of the inefficiencies associated with digestion and metabolism (Coffey, 1996). To reduce P excretion, attention should be placed on feeding diets with minimal P excesses. For that, the amount of P in the diet should not exceed the P requirements of the pig. The use of different phase diet is a potential solution because it allows to adjust the P content in the diet to the P requirements. In fact, with phase feeding, it is possible to meet more accurately the nutritional needs at one life stage. According to (Henry & Dourmad, 1993) phase feeding resulted in a 10 to 13% reduction in the P content of pig manure. The use of phytase is also a good solution to reduce P excretion; as it can reduce P contents of manure from 25 to 60% in pigs (Cromwell & Coffey, 1995; Simons et al., 1990). In fact, in plants, P is mainly present in phytate form, which is undigestible for pigs; and is directly excreted in the manure (Nahm, 2000). Phytase, which is an enzyme, breaks down the phytate molecules and allow the P to be absorbed by the intestines.

4.2.2 Feed processing

Feed processing, especially grinding, increases the surface area of the feed that is exposed to the animal's digestive system. Processing is also known to facilitate mixing, improve feed density, reduce dustiness, improve palatability, extend "shelf life" and alter nutrient makeup (L. S. Jensen, Ranit, Wagstaff, & McGinnis, 1965; Wilson & Beyer, 1998).

Improper mixing of feeds results in reduced uniformity of the diet, leading to poor animal performance and increased nutrient excretion into the environment (Amerah, Gilbert, Simmins, & Ravindran, 2011). This is the case with enzymes like phytases which do not act properly if they are not mixed well (Classen, 2000; Johnston & Southern, 2000). In fact, products like phytase are present in relatively tiny amounts in the diet. Improper mixing would lead to having some batches of feed with too much phytase, while some would not have enough.

Some care should be put into the pelleting process, during which enzymes such as phytase can be destroyed. Steam pelleting at 80°C had detrimental effect on phytase activity, which resulted in less absorbable P (Jongbloed & Kemme, 1990). The diet of Vallei Varken is pelleted, assessing if the process is affecting the phytase available in the diet could be an interesting point.

It can be seen that via modifications of the diets, the P excretion of the pigs, and so the P content in the manure, can be influenced. The use of phytase, a formulation closer to the requirements or a good control of the feed processing steps are elements which play an important role. However, these steps which are linked to the production of the diet, are controlled by Agrifirm. To be able to see what the room for improvements is, a discussion with Agrifirm would be needed.

4.3 Scenarios

We developed three possible scenarios for the pig diets to be able to cover a large range of potentialities Table 5. These scenarios were created based on the potential issues and opportunities identified during the interviews and the literature research. In scenario one, locally sourced cereals could be used to form the energy part of the diet. In the second scenario, the current protein sources used in the diets are replaced by two locally produced legume crops. In the third scenario, by-products from the processing of vegetables are used in the diets.

Table 5: Possible scenarios for pig diets

	Scenario 1	Scenario 2	Scenario 3
Energy	Cereals (maize, wheat, and barley)	Imported cereals	Vegetables by-products from Boni and De Kroes
Protein	Protein rich crops	Legumes (Faba bean & pea)	

4.3.1 Scenario 1: Cereals as energy source

In this scenario, we considered the potentiality that the arable farmers produce wheat, barley, and maize for the pig diets. The inclusion of locally produced cereal grains is already something that is commonly done in pig production (Agrifirm, personal communication, February 2, 2021). Therefore, it would represent an achievable step in reaching circularity by Vallei Varken. These cereals produced by the arable farmers would replace the imported cereals already used by Agrifirm. For this scenario, there are two possibilities: either the cereals are sent to Agrifirm to be included in the diets; or the cereals are sent to Vallei Varken to be used by the farmers directly. In the latter possibility, cereals are stored and processed by Vallei Varken, before being fed to the pigs with a complementary feed made by Agrifirm. This solution would require Vallei Varken to invest in silos and hammermills to store and process the cereals.

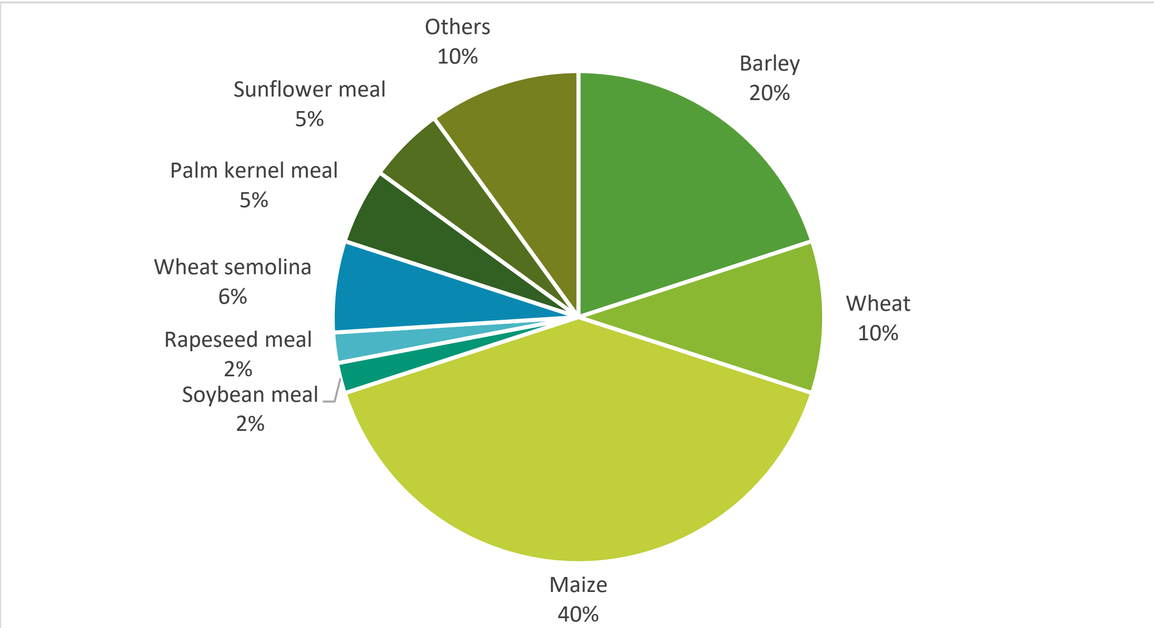

Figure 3: Ingredients and their percentage of inclusion for the fattening pig diet of scenario 1

In this scenario, we used potential cereals from arable farmers (wheat, maize and barley) as energy sources (Figure 3). They are the core of the diet, by representing 70% of it. The rest is made of the common protein sources and a small amount of by-products that were already used. By using a software (EvaPig), we managed to get an estimate output which meet the requirements (Standard VV) in terms of crude protein, crude fat, crude fibre and phosphorous (Table 6). Also, metabolisable energy requirements are met (National Research Council, 2012).

Table 6: Results of the proximate analysis of scenario 1

Item	Standard VV	Estimate (EvaPig)
Crude protein (g/kg DM)	132	130.6
Crude fat (g/kg DM)	38	40.3
Crude fiber (g/kg DM)	60	53.7
Phosphorus (g/kg DM)	3.9	2.3
Metabolisable energy (Kcal/kg DM)	3350[1]	3334

Furthermore, we managed to meet requirements of all essential amino acids (Appendix IV: Feed analysis). However, there is an excess of arginine, which should not have any detrimental effect on the growth, as an arginine concentration of lower than 1% had no effect on pig performance (Ma et al., 2015). This is to say that an increase in arginine will be advantageous in the excreted manure, because it will be adding more nitrogen content to the manure. Generally, amino acids are the building blocks of protein, in order for the pig to convert feed into protein. All amino acid requirements should be met, because otherwise the pigs will not grow properly. Some free amino acids can be added to the diet if needed to fully meet the nutritional requirements.

4.3.2 Scenario 2: Legumes as protein source

In this scenario, we considered protein rich crops from the arable farms that could replace the protein sources that are currently present in the diets. Replacing the current imported protein sources for protein rich crops from local arable farmers requires less arable land than grain does, as protein rich crops generally represent up to 20% of the diet (Florou-Paneri et al., 2014). This would mean less volume demanded, so less hectares of lands required to grow the crops. However, protein rich crops are not usually being grown by arable farmers in the Netherlands, in contrast to grains. Currently, soybean and rapeseed meal are mainly used as protein sources in the diets (Agrifirm, personal communication, February 2, 2021). We decided to use a combination of faba beans and peas to replace this fraction of the diet. This decision will be elaborated below.

The use of these two legumes in pig diets has already been widely studied (Degola & Jonkus, 2018; Jezierny, Mosenthin, & Bauer, 2010; Mariscal-Landı́n, Lebreton, & Sève, 2002; White et al., 2015). These crops have the advantage to containing a relatively high protein content, although it is around half of what is found in soybean meal. However, this is compensated by the fact that the beans have a higher starch content than soybeans. Therefore, faba beans and peas would require to be included in higher quantities than soybean meal (Table 4), but would also provide part of the energy requirement, thanks to the starch. The amino acid profile of protein is also important, which shows the proportion of amino acids compositing the crude protein (CP) fraction (Table 4). Faba beans and peas have a good amino acid profile regarding most essential amino acids compared to soybean meal (Jezierny et al., 2010). However, faba beans and peas contain less methionine and tryptophane than soybean meal. Therefore, these amino acids might need to be supplemented in the form of free amino acids in the diets.

We decided to combine faba beans and peas, because legumes are often rich in antinutritional factors (ANF) (Jezierny et al., 2010). Antinutritional factors are deleterious plant metabolites which negatively affect health and production of animals (Makkar, 1993). These compounds, such as tannins, protease inhibitors, lectins or alkaloids, have different effects. Some compounds like protease inhibitors and lectins negatively affect nutrients digestion, alkaloid can be toxic, and some others can also induce feed refusal (such as tannins). Mixing the grains form two different crops allows to limit the effect of the potential concentration in one ANF in the feed from one crop.

Table 7: Nutrient composition (g/kg) of faba bean, pea and soybean meal (Adapted from Jezierny et al. (2010))

	Faba beans	Peas	Soybean meal
Crude protein	301	246	541
Essential AA (g/kg CP)			
Arginine	88	85	73
Histidine	26	25	27
Isoleucine	39	41	45
Leucine	71	71	76
Lysine	61	70	61
Methionine	7	9	13
Phenylalanine	42	48	50
Threonine	35	37	39
Tryptophan	9	9	14
Valine	88	85	73
Starch	437	506	60
NSP[1]	89	67	67

[1] Non starch-polysaccharide

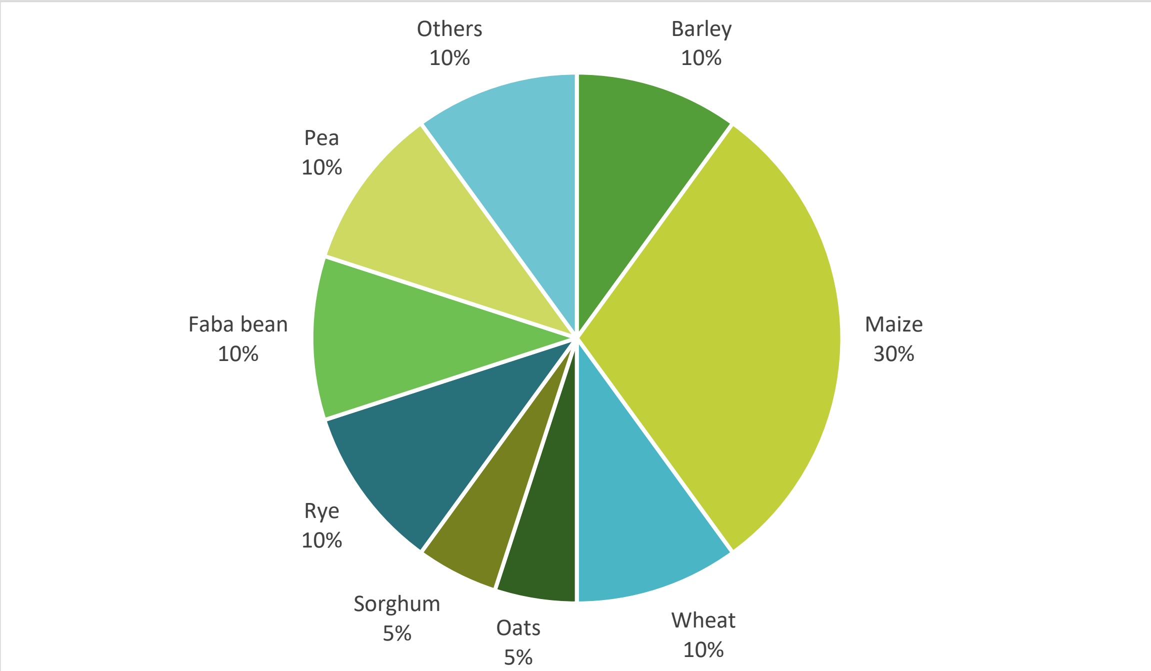

Figure 4: Ingredients and their percentage of inclusions for the fattening pig diet of scenario 2

In this scenario, we used faba beans and peas as protein sources (Figure 4). We managed to meet the requirements in terms of crude protein, fat and fibre (Table 8). In terms of metabolisable energy, we are also in range with what is required (National Research Council, 2012). Concerning the amino acid profile in peas and faba beans, we have a slight deficiency of some amino acids (Appendix IV: Feed analysis). This could be compensated for by adding some free amino acids in the diet. Due to the less balanced amino acid profile of peas and faba beans in comparison to soybean meal, there would also be an excess of amino acids. This might lead to more nitrogen excretion in the urine, which in turn will lead to a more nitrogen rich manure. More importantly, in this scenario we managed to lower the phosphate level to 1.87g/kg DM. A lower phosphate level in the manure is more beneficial for arable farmers since they have sandy soil.

Table 8: Results of proximate analysis of scenario 2

Item	Standard (VV)	Estimate (software)
Crude protein (g/kg DM)	132	130.4
Crude fat (g/kg DM)	38	36.6
Crude fiber (g/kg DM)	60	40.8
Phosphorus (g/kg DM)	3.9 g/kg DM	1.87g/kg DM
Metabolisable energy (Kcal/kg DM)	3350	3450

4.3.3 Scenario 3: Vegetable by-products from Boni & De Kroes

The third scenario includes incorporating vegetable by-products from Boni and De Kroes into the pig feeds. We could not formulate any diet using the software, because these by-products are not available in software and their composition is not well known. However, some important points can be raised. In Chapter 5.2.3, the possible crops that can be grown for De Kroes to include in their meals are explored. To be included in meals, the vegetables need to be processed in factories, which will lead to wastes. These wastes could come from processing steps, problems of conformity of vegetables or expired for human consumption. These wastes could be potentially included in the diets of the pigs of Vallei Varken, either fed to the pigs directly or mixed with the other ingredients. Steamed potatoes peelings are already partly used in animal feed, because of their low economical value (Schieber & Saldaña, 2009). They are especially of interest as they are a good source of energy and fibre, although their protein content is relatively low. Their main drawback is that they are bulky and have a high moisture content, which could impair feed intakes (Ncobela, Kanengoni, Hlatini, Thomas, & Chimonyo, 2017). One study reported that steamed potato peeling could be included in growing pig up to 25% of the diet, but with slightly detrimental effects on feed intakes and growth (Nicholson, Snoddon, & Dean, 1988). It is likely that in a modern pig farming system, potatoes peelings could not be included in the diets to such a level, in order to maintain growth performances. Despite this, they could be still used in a steamed form, to constitute a low fraction of the diet.

In most of the cases, the use of vegetable by-products as animal feeds has been investigated for ruminants. This is because by-products often have a high fibre content, and fibre is more easily digested by ruminants (Correddu et al., 2020; De Evan, Vintimilla, Marcos, Ranilla, & Carro, 2019). It was shown that vegetable by-products have a low dry matter content, but a good level of protein and starch (De Evan, 2019). However, it is likely that a large shared of these nutrients is trapped in the cell wall matrix. These cell walls are not easily digested by pigs; therefore, the nutrients are not easily available for them. One review mentioned that most of by-products from vegetable processing have a similar composition and therefore can be regarded more or less homogenously (San Martin, 2016). Due to their relatively low nutritional value compared to conventional feed stuff, their inclusion is recommended to not excess 6% of the diet. To include vegetable by-products in diets, it is recommended to carefully store them and assess their quality, then mix and finally dry to reduce the water content (San Martin, Ramos, & Zufía, 2016).

This use of vegetable by-products could be a potential solution for Vallei Varken however, it could not provide a major part of the diet. The possibilities to evaluate would be to store and process the vegetable by-products on the farm, or to see if it is possible for Agrifirm to do it. Using the by-products on the farm would require investing on equipment to do it and to be able to assess the nutritional value to adjust the diet composition.

4.4 Advice

The three presented scenarios all offer different advantages regarding the feed aspect of the project. The first scenario is based on a practice often already done by pig farmers, which is using locally sourced cereals in the diet. This scenario is a good step towards circularity, because cereals represent the largest share of the diet. For the second scenario, the idea of using locally produced protein rich crops is a more ambitious step. It is feasible in terms of diet formulation; however, the cost should be evaluated to assess feasibility. In the third scenario, the aim is to utilise all by-products which are regarded as waste to produce more valuable pig meat. If implemented correctly, this scenario will reduce waste streams, which is a positive step towards circularity. It could also decrease feed costs, as these wastes are usually quite cheap, but more conventional feed ingredients would still be required to meet nutritional requirements. For both scenario 1 and 2, it would require more farmers to be involved in the project in order to have a sufficient production of cereals and legume crops to be used in the feed of Vallei Varken's pigs.

5 Crop selection

In order to increase circularity, Vallei Varken wants to explore the possibilities for the production of pig feed by local arable farmers. These farmers would be included in the Vallei Varken concept and deliver products based on fixed prices. Following principles of circular agriculture and circular food systems by De Boer and Van Ittersum (2018) and Van Zanten, Van Ittersum, and De Boer (2019) as discussed in Chapter 1, land should primarily be used to produce human food from plant biomass and animals should be fed on rest streams from human food production. Thus, the approach of Vallei Varken conflicts with how these papers define circular agriculture. However, we argue that producing feed locally would decrease travel distances and contribute to setting up a local circular system. Therefore, it is still an improvement of the current situation. De Boer and Van Ittersum (2018) also raised the issue that currently, crops have been selected for one purpose, yet there is no effort in optimising the quality and yield of by-products, which makes usage in animal feed difficult. For the short term, producing feed crops locally may be a practical solution in the short-term. We will therefore consider both feed crop and crops that produce by-products in this chapter.

Crop rotations

Crop rotation is the practice of growing a sequence of plant species on the same land over time (Bullock, 1992). Having a diversified crop rotation is beneficial for the farmers on many aspects, whether it is soil fertility, disrupting diseases and pests' cycles or preventing weeds (Edwards, Wood, Thurlow, & Ruf, 1992; Honeycutt, Clapham, & Leach, 1996). The crop rotation is at the basis of an arable farming system, as it forms the temporal structure in which all other techniques and principles operate.

The order and length of a crop rotation affects mineral uptake, soil quality, crop yield and economic results. Crops differ in the degree to which they use nutrients and the amount of organic matter left behind through crop residues, which affects the nutrient surplus and supply of organic matter in the rotation. By including crops that improve soil quality, the overall crop yield will increase which will lead to a decreased nutrient surplus. The order plays a role in the nutrient exchange between crops: e.g., deeper rooting crops can use nutrients that were not accessed by previous crops, whereas certain crops may affect the presence of diseases and pests in the soil. Crops differ in terms of harvest period and mechanisation related to the harvest. Including crops with an early harvest allows for the inclusion of catch crops, while late crops increase risk of soil compaction. Crops also differ in terms of margin per hectare: rooting crops and vegetables have a higher margin than cereals. In practice, financial concerns are the main driving factor in crop rotation design (De Haan, Van Geel, Verstegen, Hendriks-Goossens, & Zwart, 2010).

According to Aerts, Kromwijk, and Bosch (1989), factors that play a role in the design of a crop rotation are: gross margin, labor requirements/division, mechanisation, soil type, climate, crop succession, maintaining soil fertility, available market for products, value of by-products, rules and regulations, soil-borne pests and diseases, and weed issues.

Method

In this chapter, we answer the question: *What are suitable crops for the arable farmers to grow in order to contribute to the Vallei Varken concept and improve the value and resilience of their crop rotation?* In order to answer this question, we first discuss the current situation of the arable farms, including the (dis)advantages of each of the crops in the current rotation and their preferences with regards to new crops. Thereafter, we will rank suitable crops for improving the current rotation based on three criteria that we established based on the principles of circular agriculture and the farmers' requirements: a) harvest period, b) net margin and c) potential to yield pig feed. Three scenarios in which the arable farms produce different types of inputs for the Vallei Varken concept are discussed and relevant crops are selected for each, based on the findings in Chapter 4 and generalisations thereof. Slightly different requirements may apply in different scenarios, and because they contain similar crop species, their effects can be somewhat generalised, which allows us to give a broad advice within the time available. They different scenarios are respectively: producing cereals for feed; producing protein for pig feed; producing vegetables for De Kroes. For each scenario, the crops are ranked according to the three selection criteria and the resulting ranking is discussed afterwards, highlighting some interesting crops for each of the arable farms. This was done using a sorting function in Excel. Table 9 indicates the degree to which this method addresses the factors of crop rotation design as formulated by (Aerts et al., 1989). We will conclude with some general advice and insights based on our findings.

Table 9: The presence of the factors of crop rotation design according to Aerts et al. (1989) in our method

Factor in crop rotation design	Presence in report analysis
Gross margin	Indicator: Gross margin(€/ha)
Labour requirements/division	Indicator: Harvest time
Value of by-products	Indicator: potential to yield pig feed
Soil type	When available, data from crops on sandy soils were used
Climate	Sources from the Netherlands, and if available the local area, were used for data and information on crops.
Available market for products	Already available through Vallei Varken and De Kroes
Crop succession	Limited, we consider the effects of the plant on the soil and thereby subsequent crops, but do not look at specific interactions between specific species.
Maintaining soil fertility	Limited.
Rules and regulations	
Soil-borne pests and disease	Not accounted for
Weed issues	
Mechanisation, buildings	

5.1 Current situation

First, we will discuss the two arable farms and the crops they are currently growing. AF1 consists of a total of 60 hectares, with a rotation based on potatoes, onions, cereals (wheat/barley) and corn. AF2 owns 80 hectares and rents out about 20-30 hectares annually, with a rotation consisting of starch potatoes, sugar beets, barley and some maize or grass silage used by dairy farmers. Rotating land with dairy farmers is beneficial for AF2 as he can extend his rotation that way, adding an extra step of maize in the rotation without cultivating that crop himself. In both cases, rotations are 1:4, with high demand crops (potato, sugar beet, onion) as the main cash crops. Then, in both cases, cereals (wheat, barley, corn) are used to diversify the rotation and improve soil fertility (AF1, personal communication, January 20, 2021). Rooting crops such as potato and sugar beet are generally the most valuable but have a net negative effect on the soil as their limited root systems do little to improve soil quality, take many nutrients from the soil, and the soil structure risks being damaged as the crops are dug up during the harvest, which often falls late in the year. The margins per hectare of cereals tend to be low, although some types are more valuable than others (e.g., summer barley). Cereals are generally included in crop rotations because have positive effect on the soil quality, as was confirmed by AF2 in Interview 1.

Crop rotations are designed around practical limitations of crops (such as nutrient uptake efficiency and pest pressure), but they are also some motivations in terms of market and agreements. In fact, AF2 mentioned that he has contracts to produce certain quantities of potato starch and malting barley (AF2, personal communication, February 12, 2021). Similarly, AF1 mentioned that he has several partnerships (AF1, personal communication, January 20, 2021) for the buyers of his crops. These motivations in terms of agricultural practice and partnerships need to be taken into account when designing new crop rotations. As established earlier, both farmers are on sandy soils and the land of AF2 is acidic (pH 5.3, 1 sample). This should be taken into account when selecting crops. Potatoes require relatively low soil pH (4.5-6), but for most crops this lies within the range of 6 – 7 pH. The pH level affects plant growth, functioning of soil microbes, and is an indicator of the availability for nutrients in the soil (Plaster, 2014). Each plant grows best in a specific pH range and growing in a soil with a deviation pH level will lead to nutrient deficiencies, stunted growth and yield losses (Brady & Weil, 2008). In case the farmer decides to introduce new crops, he should consider whether they fit the acidity level of his soils.

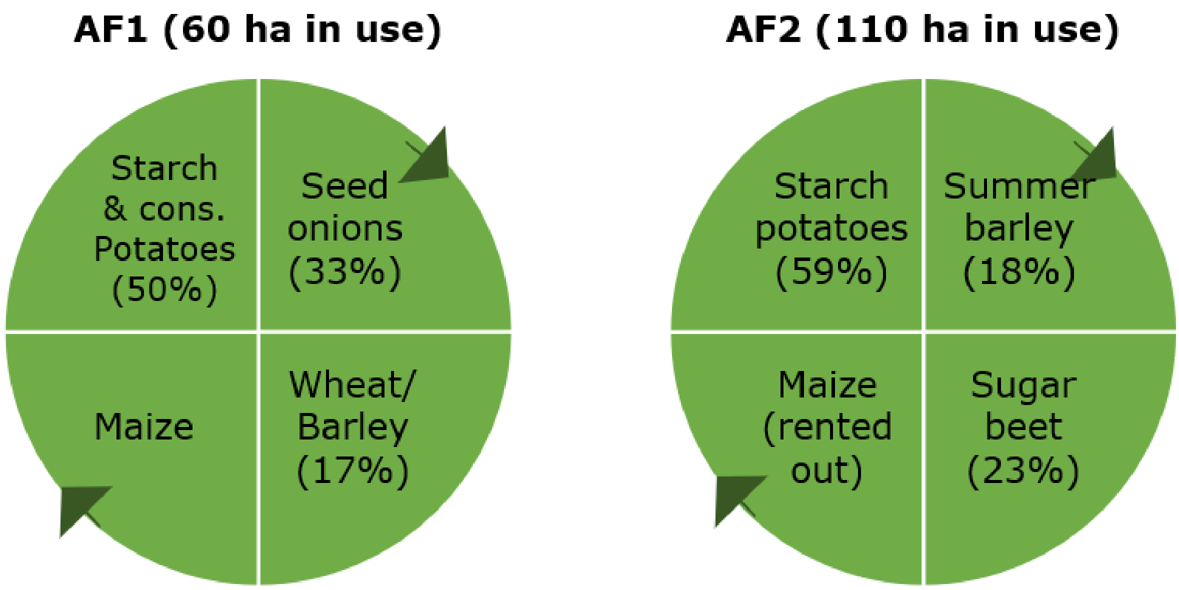

Figure 5: A global representation of the current crop rotations of the arable farmers

Due to specialisation in specific crops, the size of crop rotations has reduced over time. Potential effects of this include decreased nutrient uptake efficiency, increased disease and pest pressure, and decrease soil quality (De Haan et al., 2010). Depending on the amount of land that is exchanged to grow maize, AF1 and AF2 would have a potato rotation of between 1:3 and 1:4 (Figure 5), which is the same as the average potato rotation in the Netherlands in 2017 (Kennisnet, 2017). Therefore, the farmers have an average to above average rotation in terms of width. Since we assume that a larger rotation is better due to increased diversity and inclusion of crops with positive soil effects, we will consider potential crops that could replace current crops or could be added to widen the ration. AF2 acknowledged that this is a wide rotation, explaining that he is able to do so because of plentiful opportunities to exchange land with local dairy farmers for them to grow maize on.

See Appendix V: Crop selection for a simple analysis of the crops currently crops. All of these are yielding relatively well, with barley and maize as the lowest value crops. There are some feed crops and other crops with useful by-products. Only the onion crop grown by AF1 does not provide any material that could be used as feed. There are a number of crops with negative impact on soil, like potatoes, sugar beet and onion. In order to improve the soil quality, it would be better to find alternatives to these. Maize kernels could be processed into the Vallei Varken feed, however the current variety is silage maize and this maize is used by dairy farmers. Grain maize has a higher margin than silage maize and may this provide an alternative. Exchanging land with dairy farmers and allowing them to grow maize on it does widens the crop rotations while keeping the share of potatoes in the farmers’ effective rotations constant. It could be worthwhile to look into the possibilities of exchanging land for other purposes than maize. The starch potatoes that are currently grown are not particularly high yielding compared to consumption potatoes. Factors like the quality of the land may play a role in this decision. AF1 already grows onions and consumption potatoes that could be sold to De Kroes.

Table 10: The effects of widening a reference potato crop rotation (Van Dijk, Spruijt, Runia, & Van Geel, 2012)

Region	Treatment	Description	Net profit (€/ha)	EOM[1] input (kg /ha)
Northern sand and valley soils	1ref	1:2 starch potato, 16.7% sugar beet 33% summer barley+green manure	1195	1545
	1a	1:3 potato, 17% summer barley added	-100	225
	1b	1:3 potato, 17% silage maize/chicory/carrot added	20	-35
	1c	1:3 potato, 17% rest crop added	-220	260
Southeastern sand soils	2ref	1:4 consumption potato with a variety of vegetables and maize/triticale	2380	1090
	2a	Summer barley instead of maize/triticale	-85	360
	2b	Summer barley instead of maize/triticale, green manure instead of green pole bean	-185	415
	2c	Exchange of land with dairy farmer[2], consumption potato instead of lily	370	225

[1] Effective organic matter

[2] The article explains how through exchange of land the rotation of both arable and dairy farmer is combined, which decreases the growing frequency of a crop on field level, but may increase it on farm level.

Van Dijk et al. (2012) investigated the effect of extending a potato crop rotation with new crops (treatment 1) and swapping crops in an existing potato rotation (treatment 2). Some relevant data for sandy soils can be found in Table 10 and give some insights in the effects of changing a crop rotation.

The crop rotation in treatment 2ref, although a bit wider, could be compared to the rotation of AF1. Treatment 2c is the one most similar to that of AF2. It is the most profitable treatment, although it has a lower EOM input rate, which suggests a less positive effect on the soil. Replacing maize with summer barley in 2a leads to decreased profits compared to 2ref (-4%) and 2c (-17%). On the other hand, EOM input is increased by 33% and 10%, respectively. In 2b, profits are even more decreased compared to the other treatments, but EOM is increased further as a result of using a green manure instead of a cash crop. This suggests that replacing their maize with a cereal may be worth considering if the arable farmers want to improve their soil quality, although not if they place a greater emphasis on maintaining income. This is in line with the assumption that cereals lower the value of crop rotations but improve soil quality.

Table 11 summarises practical boundaries of the arable farmers as discussed in Chapter 3. We will use these to formulate our selection criteria and data selection.

Table 11: Summary of practical boundaries of the arable farmers

	AF1	AF2
Interests	Protein crops in exchange for good quality slurry manure and a good price	Alternative crops (e.g. sweet potato); a crop harvested in July/September.
Reservations	Cannot grow carrots due to soil type	Does not want onions or flower crops; does not want a crop with a harvest date in October or later to prevent damage to soil
Biophysical restrictions	Sandy soil	Sandy soil, acidic

5.2 Scenarios

In order to realise a circular system, the farmers must be connected to the Vallei Varken concept on both the input and output side. On the input side, arable farmers use Vallei Varken's pig manure, which we will discuss in depth in Chapter 6. On the output side we see, as established in Chapter 4, the potential for the arable farmers to contribute to the cereal and protein components of the pig feed. Furthermore, we see an opportunity in the locally oriented demand for vegetables of De Kroes. We will treat these three opportunities as separate scenarios in which we look for suitable crops that fit the particular interests and reservations of AF1 and AF2. These crops will then be ranked according to their alignment with the preferred harvest period, net margin and potential to yield pig feed. Thereby, we address, respectively, the practical concerns of farmers, financial concerns of farmers, and the interests of Vallei Varken.

For the harvest period, we used general information from websites and articles to give an indication for each crop. We then ranked each crop in order on whether its harvest; falls within, overlaps with, or is earlier/later than the preferred period of early July through late September. For the net margin, we used data from KWIN-AVG (2018), although this publication only covers the most common crops in the Netherlands. If data was available for the specific soil type/region of at least one of the farmers we used that, if not we used what was available for that crop. We classified the crops based on the following four categories: <€500, €500-1000, €1000-2000, and >€2000 gross margin per hectare. For some crops, the prices used are those for the consumption rather than feed market: therefore, total revenue and therefore the margin may be lower in practice. We managed to find a net margin for soybean (Engwerda, 2015), but were unable to find data for most other novel crops. For the potential to be used as pig feed, we ranked each crop in order of usefulness to that purpose, based on (generalisations of) our findings in Chapter 4. We made the assumption that a feed crop is better than a crop that provides by-products that can be used as pig feed, and that crops that are already used in pig feed by Agrifirm are better than those that could potentially be used in feed formulation. Based on that, we have established the following categories, in order of rank; feed crop, usable by-product(s), potential feed crop, potentially usable by-product(s), not usable.

5.2.1 Scenario 1: Cereals for pig feed

In this first scenario, the arable farmers produce cereals for pig feed. In 2020, 11.2% of the total arable land in the Netherlands (excluding greenhouses) was used for the production of cereals (Statline, 2020). Cereals, specifically wheat, barley and corn, are already present in the current rotations of the arable farms, which makes this plan easy to put in practice. Nitrogen fertilisation is an important factor increasing the yield of cereals (Fageria, 2011). They have a high N demand, which makes them interesting in case of exchanging crops for manure with pig farmers. For example, winter wheat has a fertilisation advice of 150-200 kg N/ha in solid form, and 80-100 kg P_2O_5 (Darwinkel, 1997).

The national production of wheat (1.3 million tonnes) is almost equal to the national consumption as human food (1.32 million tonnes) (Figure 6). Even if all wheat was used as feed, it could only fulfil 65% of the amount that is currently used for that purpose. We can conclude two things from this: either that there are too many animals, or that we produce too little cereal feed by ourselves. The answer probably lies somewhere in between.

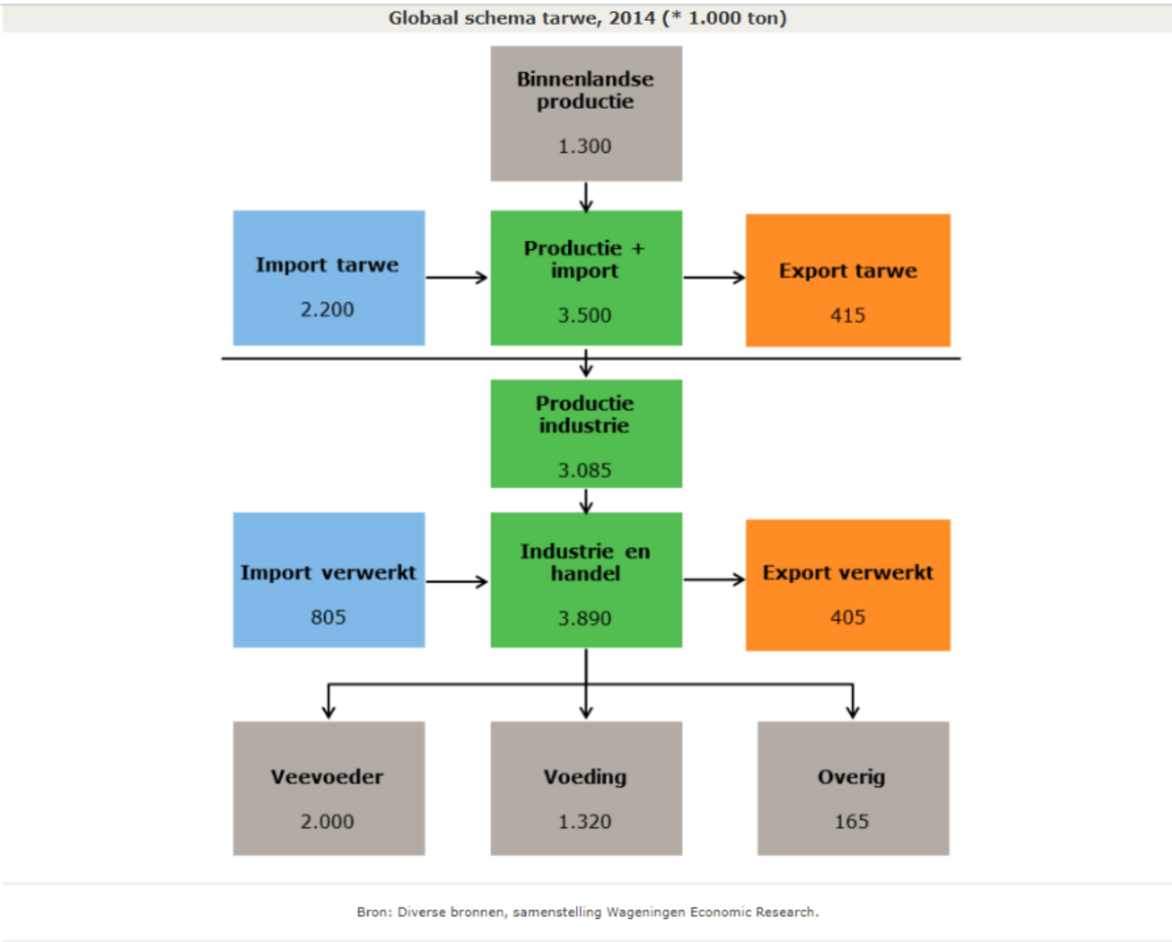

Figure 6: Global flow scheme of the Dutch wheat market in 2014 (Berkhout, 2016)

Including cereals in the arable farmers´ crop plans has the advantage that it positively affects the soil quality with a large and deep rooting system that can obtain nutrients and water deep in the soil and improves the structure. Cereals also add a lot of organic matter to the soil through these roots as well as aboveground crop residues. Another advantage is that harvests are generally early, giving the option to introduce a winter crop or green manure. Combined with the production of straw that can be used for livestock bedding to produce solid manure, this make cereals ideal crops for a circular system (Jonkheer, 2020). Lastly, the farmers both already have grains in their rotations. Thus, they have experience with the crop and the introduction of a new grain crop should be relatively simple.

The main drawback of grains is that their margins per hectare tend to be relatively low, which makes them less competitive in a country with high land prices. The majority of wheat around the world is grown in countries with extensive flatlands where hectare prices are in the hundreds, or thousands of euro’s, rather than in the high ten thousand of euro’s like in the Netherlands. Thus, our cost prices exceed those of the global market. Increasing the fraction of grain in the rotation at the expense of cash crops like potato positively affects the nutrient uptake rate and soil quality, but lowers the profitability (Spruijt, 2013). Van Dijk et al. (2012) proposed an extension for the crop rotation with high-value crops like vegetables and bulbs to compensate for these losses, or to exchange land with dairy farmers. The latter is already being implemented by the farmers, with their 1:4 rotations. Another issue with regards to land scarcity is that the farmers do not have enough land available for a producing significant share of the grains in the feed demand Vallei Varken.

Crops

The crops in this scenario were selected based on the most common grain crops grown in the Netherlands. They are: winter wheat, winter barley, winter rye, oats, triticale, sorghum, grain maize and spelt. All of these crops fit the criteria of the harvest period. Their margins are relatively low, as expected. Note, that these take into account the value of straw. Except for sorghum, which is not grown in the Netherlands outside of trials, all grains that we looked at are used as sources for pig feed.

Based on the ranking (Appendix V: Crop selection, winter wheat, winter barley, oats, spelt and grain maize are the most promising crops for this scenario. Winter grains, like wheat, barley and rye, may be good crops to sow after a protein crop, as the legumes' early harvest period allows a new crop to be planted. Based on net margins from KWIN-AVG (2018), some winter grains have a higher gross margin than their summer cereal counterparts. Additional benefits like having crop cover during the winter are not expressed in prices but may be beneficial to the farmer in some other way. Both winter and summer wheat as well as grain maize have high margins, although for the latter its late harvest period may be unsuitable. It is unfortunate that we do not have any data on margins of spelt and sorghum, which makes it difficult to get an idea of the feasibility.

5.2.2 Scenario 2: Protein crops for pig feed

In the second scenario, arable farmers produce protein crops for pig feed. The diets of pigs need a certain amount of protein, often fulfilled by soybean meal (Agrifirm, personal communication, February 2, 2021). Soybean is the most grown crop legume globally. Highly productive cultivars have been developed for warmer and dryer areas. In the temperate climate zone, breeding efforts are still in the early stages (Van der Mheen & Timmer, 2013). Soybean are imported mainly from the America's and then processed into food and other products in the Netherlands. By-products like cake and pressings are sold as feed ingredients. High production costs in the Netherlands compared to global average lead to imports of soy being highly competitive compared to nationally grown protein crops (Van der Mheen & Timmer, 2013). High availability and quality of soy also play an important role in this. This practice of importing soy is subject to a lot of controversy, partly because of the long travel distance of the product which causes an increased carbon footprint of subsidiary products. Producing soybean or alternative crops locally would therefore incur fewer food miles and thus be more sustainable. It is possible to produce local legumes and replace the imported soybean meal in the diets of pigs (Grabež et al., 2020; Hanczakowska & Świątkiewicz, 2015). Apart from being interesting in the diets of pigs, adding legumes to a crop rotation has advantages. Firstly, they increase N content in the soil via N fixation, thereby reducing the need for mineral fertiliser. Secondly, diversification through the introduction of a crop from a new family leads to the breaking of cycles of pests and diseases (L. S. Jensen et al., 1965), and thereby improves the resilience and value of the entire rotation. Lastly, harvest periods of legumes tend to fall in the summer, thus there should be a lot of species in this scenario that fit the preferred harvest period.

The main disadvantage of introducing protein (feed) crops is that the cultivation of a lot species is still in the experimental phase in the Netherlands. Yields are low compared to established crops, because of several reasons: they may be less adapted to the local climate, less time and effort has been spent to develop cultivars with optimal yield potential and other desired characteristics, and there is a lack of knowledge and experience with growing such crops in the Netherlands (Engwerda, 2015). However, yields have grown over time and can be further increased through the use of improved cultivars and growing techniques. The margin of these crops is (usually) lower than that of cash crops, although usually better than that of grains. In 2014 the margin per hectare of soy bean was higher than that of summer wheat, respectively € 757 compared to € 601 (excluding the value of straw) (Engwerda, 2015).

Another hampering factor is that due to N-fixation, legumes require little N fertilisation. Therefore, less manure would be required per hectare. This is a disadvantage because it is in the interest of Vallei Varken to maximise the amount of pig manure the farmers use. Lastly, the arable farmers are currently not growing any protein crops, therefore there may need to invest in education and there is increased risk due to inexperience.

Crops

The following crops were selected based on literature (Van der Mheen & Timmer, 2013) and our knowledge of protein crops: faba bean (winter and summer), rapeseed (winter and summer), soybean, pea, sunflower, lucerne, lupin (white and blue), white clover, flax and camelina. Most crops match the criteria with most harvest periods falling in August and September. Soybean has a noticeably late harvest, because current cultivars are adapted to warmer climates and need a longer period of time to grow in our temperate climate. We lack data on the net margin of 7 out of 13 crops. For the crops that we have data on, the margins are higher than or comparable with more profitable grains. Note that the prices do not account for the value of N-fixation and may not do accurately represent the value of the by-products. Some of the crops are feed crops and others have by-products that are already used by Agrifirm or could be used in the future.

Based on our ranking method, faba bean (summer/winter), pea, lupin (white/blue), flax and summer rapeseed are the most promising crops for this scenario (Appendix V: Crop selection). Unfortunately, we lack financial data on winter faba, lupin and summer rapeseed, therefore it is hard to accurately compare the feasibility of these crops. Faba beans and (yellow) peas are among the most popular protein crops in the Netherlands and were ranked as having the highest average yields out of a number of protein crops (Table 12). Lupin is more comparable in oil and protein contents to soy than faba bean and pea are. Therefore, lupin is a more convenient (Van der Mheen & Timmer, 2013), flax is associated with clay soils, but there are experiments on sandy soils. A manual for growing flax on sand and valley soils (Bakker, 2014), mentions that the crop requires a minimum pH of 4.5 and is capable of growing deep roots if the soil profile is not disturbed. They also mention that there is an increased risk of trips when growing flax after summer barley, onions or peas (Van der Mheen & Timmer, 2013). The cake and meal left after processing are used as pig feed.

Table 12: Yields of several protein crops in trials on sandy soils in the Netherlands, with reference yields from two grain crops (Van der Mheen & Timmer, 2013)

Crop	Yield (kg DM/ha)	Protein content
Pea	4,672	20-35%
Faba bean	5,332	25-30%
Soybean	1,833	40-50%
White lupin	2,015	30-35%
Blue lupin	2,497	30-35%
Flax	1,487	NA
Rapeseed	3,295	30%
Camelina	2,380	NA
Wheat (winter)	6,545	-
Barley (summer)	5,015	-

There are some crops with a lower potential that may still be interesting. Camelina grows well on sandy soils and its seeds contains an oil that could be used for biofuels. The by-products of this process are used as pig feed (Van der Mheen & Timmer, 2013). Sunflower is not currently grown commercially on any serious scale as a fodder crop in the Netherlands, but is used in other countries with a warmer climate. Future cultivars may be able to flourish in the Dutch climate. Lucerne is a suitable crop for dry conditions on sandy soils because of its deep rooting system (Li, Zhou, Denton, & Cong, 2019). This could potentially be interesting with the perspective that our climate is predicted to become dryer in the future.

5.2.3 Scenario 3: Vegetables for De Kroes

In the third scenario the arable farmers produce vegetables for De Kroes, which processes a wide selection of vegetables procured from contracted growers into ready-to-serve meals. They use a range of crops, including potato, onion, carrot, leek, chicory, endive, Chinese cabbage, pumpkin and sweet potato. The latter two crops are used in relatively small quantities. To give a sense of scale, last year De Kroes used 700 tonnes of peeled potatoes and 2.6 tonnes of sweet potato (De Kroes, personal communication, February 22, 2021). In the same personal communication, representatives of De Kroes expressed that they were open to including smaller amounts of new crops in their recipes or develop new meals, based on the local supply.

The main advantage of growing vegetables is that they are (generally) high value cash crops and will increase the value of a crop rotation. Such an increase in value may also support a substitution or widening of the rotation with lower value grain and protein crops (Van Dijk et al., 2012). Another advantage is that compared to grains and legumes, vegetables require a lot of N and P fertilisation, which is not in short supply in the Vallei Varken concept.

There are also some drawbacks to this scenario. Firstly, as established in Chapter 4, Agrifirm currently does not use vegetables in the Vallei Varken feed, and the current feeding systems of Vallei Varken do not facilitate incorporation of other kinds of feed. Therefore, the potential for this scenario to provide pig feed is limited. Also, many vegetables have a negative impact on the soil because they deplete the soil of nutrients and often are either root crops (e.g., potato, carrots) and need to be pulled out which damages the soil structure in the process, or they are crops with a small root system (e.g., pumpkin and endive) which have decreased positive rooting effects, such as creating pores and bringing OM into the soil, compared to deep rooting crops like grains. Lastly, vegetables may be more difficult to grow than commodity crops or require specific equipment or expertise that AF1 and AF2 do not currently have at their disposal. Since we do not know exactly what equipment the farmers have, we aim to give an overview of information and highlight interesting findings. It is then up to the arable farmers to apply this information to their own situation. Lastly, vegetables tend to have higher labour requirements per hectare compared to arable crops. This may make them a mismatch for the current availability of labour on the farms or limit the cultivation of such crops to just a couple of hectares.

Crops

We selected crops based on what De Kroes currently uses. This resulted in the following list of crops: consumption potatoes, carrots, pumpkin, leek (summer, autumn, winter), chicory, endive, and sweet potato. With regards to the harvest period, there are a number of crops that fit the criteria, although for some that is only due to early varieties. The margins of all crops that we have data for are very high and could greatly improve the value of crop rotations. None of these crops have (by-)products that can be used in the current feeding system of Vallei Varken, except for potato, of which the starch and peels could potentially be included in the future.

Based on our ranking (Appendix V: Crop selection), Chinese cabbage, leek (summer/autumn), onion, consumption potato, pumpkin and chicory are the most promising crops. The seed onions currently grown by AF1 also hold up well in the general ranking and could be sold to De Kroes in the future. AF2 doesn't want to grow onions, but has not voiced concerns with carrots like AF1 has. However, carrots were found to be unsuitable due to their late harvest period. Leek and Chinese cabbage have the most favourable harvest periods, the others are generally later in the season around the beginning of autumn. Potatoes are currently grown by both farmers and could provide starch and peels to be processed into pig feed.

5.3 Advice

We have discussed the advantages and disadvantages of three scenarios through which the arable farmers can contribute to the Vallei Varken concept and ranked a selection of crops based on indicators representing the interests and practical concerns of arable farmers, and the interests of Vallei Varken. In the following subsection, we will give an overview of the outcomes. Thereafter, we will give some general advice based on insights gained from this study.

5.3.1 Advice on the scenario's

We found that there are a number of crops that our arable farmers could potentially grow in order to provide useful inputs to the to Vallei Varken concept and thereby improve circularity and shorten the food supply chain.

Cereals were found to be a good crop to provide pig of feed and improve soil quality, but its low margins per hectare are a problem for the profitability of a crop rotation. Winter cereals tend to have higher margins and thus it could be interesting to use such a crop. Both farmers are already growing a grain and therefore this would lie within their field of expertise. Grain maize may be an alternative to silage maize, providing a higher margin per hectare (€ 1445 against € 1317) but having a later harvest period.

There are also several protein crops that can serve as feed crops or have useful by-products and could be grown on the sandy soils of the arable farms. Their early harvest period could allow for the sowing of more valuable winter grains in the subsequent year, and the legumes can provide additional nitrogen through N-fixation. However, this could potentially lead to decreased N fertilisation demands, which might go against the interests of Vallei Varken. Other drawbacks include a large yield gap due to a lack of breeding, experience and knowledge with regards to growing these crops in the Dutch climate. Neither of the farmers are currently growing a legume or other protein crop, which means there will be additional risk and they will have to take steps to obtain knowledge and experience.

Vegetables have high margins compared to cereals and protein crops, and can improve the crop rotation of the farmers, allowing room for the cultivation of low-value crops that can benefit the soil quality. This is important, as vegetables generally are not beneficial to the latter. An advantage, at least for Vallei Varken, is that the fertilisation demands of vegetables are high: thus, demand for pig manure may be increased or at least remain constant. Several vegetables were found to match our indicators, however, the question remains whether they are feasible, as some have high labour requirements and require investments in machinery (Table 13).

Table 13: Pros and cons of different corps per scenario

Scenario	Crops	Pros	Cons
Cereals	Winter wheat, winter barley, oats, spelt, grain maize	Positive effect on soil quality	Decrease value of crop rotation
		High demand for N in manure	Lot of acreage required to fulfill total Vallei Varken demand
		Early harvest period	
		Farmers have experience with	
		Produces pig feed	
		Straw could provide opportunities to extend the circular network: it is a useful resource but not used by VV at the moment	
Legumes	Pea, faba bean (summer, winter), lupin (white, blue), oil flax, summer rapeseed	Diversification improves the resilience of the system (farmers don't have a legume yet)	Large yield gap until better cultivars and growing methods are developed
		N-fixation provides additional N to the plant, decreasing fertilisation costs and improving the	Potentially lower manure requirements
		Early harvest period, allows for winter grains	Limited knowledge and experience with cultivation in the Netherlands
		Produces pig feed	Farmers may lack experience and knowledge of these crops
Vegetables	Chinese cabbage, leek (summer/ autumn), seed onion, consumption potato, pumpkin and chicory	Increase value of crop rotation	Negative effect on soil quality
		High manure demand	Produces little to no pig feed
			Late harvest period
			Farmers may lack experience and knowledge of these crops
			May require specialised machinery and have different labour requirements

5.3.2 General advice

The fact that cereals and protein crops have relatively low margins per hectare is the main factor that lowers their feasibility. A possible way to improve this could be through intercropping, the practice of growing multiple species of crops together. Cereal-legume mixtures are gaining popularity and are used as fodder in countries abroad. The cereal and legume are sown as a mixture and produce a yield that is higher than the yields of both crops in monoculture (Ofori & Stern, 1987; Pelzer et al., 2012). The primary reason is the complementary nutrient acquisition as a result of N-fixation by the legume (Corre-Hellou & Crozat, 2006; Hauggaard-Nielsen et al., 2009). Through this mechanism, intercrops of legumes and cereals can reduce the need for synthetic fertiliser (E. S. Jensen, Carlsson, & Hauggaard-Nielsen, 2020). Increased productivity could lead to an increased margin per hectare; thus, it might be worth looking into ways to incorporate a cereal-legume mixture into a feed. A challenge is that the crop is usually harvested as silage. The crops also tend to ripen after different growing periods; therefore, the quality may be lower compared to that of crops grown in monoculture.

The demand for vegetables of De Kroes provides an opportunity to give the arable farmers a financial incentive to get seriously involved with the Vallei Varken concept. The fixed prices of the Vallei Varken concept would lead to more income stability, and the increased margins give more financial room in the cropping plan to introduce grains and protein crops.

There may also be an opportunity in careful selection of catch crops. Catch crops, or green manures, are usually used as a way to improve the soil quality and are ploughed over or cut before they get the chance to ripen, to serve as a slow-release fertilisation of the next crop. It was unclear whether the farmers are already sowing catch crops, but we would recommend doing so as sandy soils are especially prone to leaching. Although it is purely speculative, we think there could be for growing catch crops over winter and harvesting them to be used as feed. Because there is plenty of manure, the nutrients exported through the harvest can be easily replaced. However, there may be more potential for such applications for ruminants than for pigs as it might be easier to harvest such crops for a silage than for kernels.

6 Manure application

> "Manure is not a waste. It is valuable nutrition for plants and soil, and a source of energy and other substances" (Leenstra et al., 2019).

Manure, a mixture of animal excreta and water or straw, is a natural source of plant nutrition and can replace a large part of artificial fertilisers used on arable land, if applied correctly (Sommer, Christensen, Schmidt, & Jensen, 2013). Man has only recently started to discover the drawbacks of (excessive) artificial fertiliser use. One of these negative effects of excessive artificial fertiliser use is nitrate leaching. Moreover, a prominent drawback of artificial fertilisers is that although it provides instantly available nutrients to the plant, the process of organic matter being transformed into available nutrients is bypassed. This lack of organic matter starves the soil biota which, over time, destroys the soil's capacity to degrade organic matter into nutrients, followed by the ceasing of other useful ecosystem services (Figure 7). Examples of such ecosystem services include water retention and natural disease and pest controlling mechanisms. However, excessive use of animal manure also leads to nitrate leaching. Nitrogen in animal manure might only become available to the plant after it was required, which would lead to an increased possibility of nitrate leaching.

Figure 7: Process of soil degradation and reduction of ecosystem services due to excessive artificial fertiliser use

Manure is an organic fertiliser that increases soil quality, fertility and nutrients. Pig manure is especially preferred because of its high organic and inorganic nutrient content (Makara & Kowalski, 2018) that improves soil fertility (Palm, Myers, & Nandwa, 1997) and for increasing the N concentration in the soil (AF1, personal communication, February 19, 2021). Slurry manure is a form of manure where no, or very little, bedding materials (like straw) are added. In pigs, the majority of manure is used in slurry form as fertiliser (Foged et al., 2012).

In this chapter the following sub question will be addressed: *In what form and quantity can manure from Vallei Varken be integrated in the fertilisation plan of the arable farmers?* This will be done by firstly providing an overview of pig manure in the Netherlands, followed by a description of the current manure situation of Vallei Varken and the arable farmers. Thereafter, we will provide a description of various forms of manure that could be used in this collaboration. Finally, for Vallei Varken and the arable farmers on how to use manure optimally for their current situation, as well as for the proposed crop scenarios (Chapter 5.2) follows.

Overview pig manure in the Netherlands

In the Netherlands, most pig farms are landless and thus have to transport their manure to farms that are able to receive manure. Generally, manure in the Netherlands is transported by manure transporting companies from livestock farms with a manure surplus to farms that are able to receive manure (mostly arable farms or livestock farms without a manure surplus) (Yan, De Buisonjé, & Melse, 2017). Currently, many livestock farmers might regard manure as an output, but not a resource as they just want to get rid of the manure as cheap as possible. Due to this, farmers might overlook the importance of manure quality, in terms nutrient composition, and need for it to match the requirements of the arable farmers that will use this manure. Focus on manure quality could be increased if livestock farmers have a stake in both the production and use of the (pig) manure. Cattle manure is generally more valued in the Netherlands, as it has a high organic matter content and a more favourable N:P ratio than pig manure. Because of the higher P_2O_5 content of pig manure slurry, pig farmers incur more costs to get rid of their surplus manure than cattle farmers (Luesink, 2020). Pig manure is usually treated and exported to neighbouring countries like Belgium, France and Germany because of the high phosphate content of the manure (Table 14; Luuk Gollenbeek, personal communication, February 18, 2021). Manure export from the Netherlands has increased since the manure processing obligation has been established in 2014 (Meststoffenwet, 2017; PBL, 2016).

Table 14: Average organic matter, nitrogen (N), phosphate (P_2O_5) and N/P_2O_5 ratio of pig and cattle slurry and manure in the Netherlands (adapted from Yan et al. (2017)

	Organic matter (g/kg)	Total N (g N/kg)	P_2O_5 (g P_2O_5/kg)	N:P_2O_5
Fattening pig slurry	43	7.1	4.6	1.5
Solid fraction Fattening pig slurry	116	10.5	12.4	0.9
Cattle slurry	64	4.1	1.5	2.7
Solid fraction Cattle slurry	188	7.8	4.4	1.8

Manure in agricultural circularity

The main focal points of circular agriculture include the most efficient use of nutrients and resources (starting from the lowest scale) and using residual streams to one's benefit. Based on the definition of agricultural circularity, manure from Vallei Varken should be used as fertiliser on arable farms as close to the manure source as possible. Moreover, for increasing circularity in manure and its nutrients, one should, amongst others, minimise total nutrient loss, form a collaboration between livestock farmers and arable farmers, and process manure based on the market and crop or soil demands (Leenstra, Vellinga, Neijenhuis, De Buisonjé, & Gollenbeek, 2019). In an ideal circular system, manure should be separated into solid and liquid fractions instead of being stored in a pit in liquid form to decrease overall nutrient losses to the environment (Thijssen, 2018). Furthermore, manure should be stored correctly to minimise nutrient losses from storage (Beusen, Bouwman, Heuberger, Van Drecht, & Van Der Hoek, 2008).

6.1 Current manure situation

6.1.1 Vallei Varken

As mentioned, the three pig farms of Vallei Varken currently have approximately 5500 fattening pigs (on two farms) and 660 breeding sows. These three farms produce around 8500m^3 manure in total per year. For VV1, the only way to store manure is in the slurry manure pit underneath the pig stall, which can store around 2700 m^3 manure. VV1 is able to store manure for nine months, but empties the slurry pit when there is a demand for manure, with peak removal during spring (VV1, personal communication, January 22, 2021). Moreover, VV2 is able to store manure on his farm for own use after emptying the manure pits. The rest of the manure (around 1000 m^3) of VV2 is transported to either other farmers or to a processing facility in Coevorden (VV2, personal communication, January 18, 2021). VV3 empties the manure pit of the piglets after each round of piglets, but that of the sows is only emptied in spring. Furthermore, VV3 currently uses sedimentation as manure separation technique to obtain a solid and liquid manure fraction. VV3 is thus able to provide arable farmers with both the liquid and solid fractions of manure. As mentioned, VV3 has around 1500 m^3 manure transported from his farm yearly (VV3, personal communication, January 28, 2021). Finally, these three pig farms have around 6000 m^3 manure per year that needs to be transported from the farms.

Animal housing systems account for around 31 – 55% of all emissions from the livestock sector globally (Beusen et al., 2008). In order to mitigate these emissions from the pig housing systems, both VV1 and VV3 have air scrubbers installed. Air scrubbers mainly decrease odour and dust pollution, as well as ammonia (NH_3) emission to the air. VV1 adds the trapped compounds (high in N) to the stored manure to increase the N content, as the washing water in of the air scrubber contains a high amount of N, but practically no phosphate. VV3 also uses the trapped compounds rom the air washer by applying it to the arable land. Both of these practices aim at increasing the N content of the manure and land, with a minimal increase in phosphate content. Despite these potential benefits, VV2 does not currently have an air scrubber (VV4, personal communication, February 23, 2021).

A major problem with pig manure is that the composition differs, amongst others, between farms, diets and the life stages of the pigs (Van der Heijden et al., 2020). This is also true for the farms of Vallei Varken. These values are roughly in line with the values reported by Starmans et al. (2015) (Table 15). Furthermore, manure of sows is mostly used when there is a need for N in the soil, as this has a higher N content than piglet manure (VV1, personal communication, January 22, 2021). Although VV3 provided only the average N and phosphate content of the manure (sows and piglets), both the solid and liquid fractions of the separated manure should be analysed when transported from the farm (Van Dijk & Galama, 2019). There is a greater difference in the N content of manure from fattening pigs and sows than in phosphate and potassium oxide content (Starmans et al., 2015). Both the N and P_2O_5 content in the manure of VV3 is relatively low compared with that of both VV1 and VV2, as well as Starmans et al. (2015). VV1 and VV2 provided the manure analysis of their farms, but VV3 was unable to do so and thus only provided the values based on his knowledge. Average values of both the solid and liquid fractions of breeding farm manure (thus both sows and piglets) after sedimentation are provided in (Table 16).

Table 15: Nitrogen (N), phosphate (P_2O_5) and potassium oxide (K_2O) contents of manure from three different pig farms of Vallei Varken (VV1, 2 and 3)[1] in comparison with Starmans et al. (2015)

	N	P	K
	g N/kg	g P_2O_5/kg	g K_2O/kg
VV1[2]	8.4	3.7	5.3
VV2[2]	6.7	3.1	4.5
VV3[2,3]	2.5	1.5	2
Sows (with piglets)[4]	4.2	3.0	4.3

[1]VV1 and VV2 were able to provide the manure analysis, but VV3 was unable to do so

[1]VV1 and VV2 are fattening farms and VV3 is a breeding farm

[3] VV3 does not measure the K_2O content of the manure

[4] Values obtained from Starmans et al. (2015)

Table 16: Nitrogen (N), phosphate (P_2O_5) and potassium oxide (K_2O) content of solid and liquid manure fractions from breeding farm after separation by sedimentation (Melse, De Buisonjé, Verdoes, & Willers, 2004)

	N	P	K
	g N/kg	g P_2O_5/kg	g K_2O/kg
Manure	4.2	3.0	4.3
Solid fraction	6.7	6.6	4.3
Liquid fraction	3.4	1.8	4.3

6.1.2 Arable farmers

Overview of arable farmers

AF1 is currently using cattle slurry and fertiliser for his land. The reason AF1 is not using pig manure at the moment is due to the high phosphate levels of pig manure. Cattle manure has a low N content, so AF1 uses artificial fertiliser to fulfil the N requirements of the crops. AF1 currently uses both Calcium Ammonium Nitrate 27 (CAN27, which is a high N-content fertiliser) and Patentkali (K_2O fertiliser with a high sulphur and magnesium content) as artificial fertilisers. He is able to only add the liquid fraction of the pig manure to his fertilisation plan to decrease, or even replace, the artificial fertiliser use. AF1 does not have any manure storage facilities, but many farmers in the area do. He applies the majority of the manure in spring (March or April), and receives more manure, if possible, in August after harvesting the grains (AF1, personal communication, February 19, 2021).

AF2 aims to use as little as possible artificial fertiliser and as much as possible animal manure. Currently, AF2 has the soil examined at the end of the season, and determines the manure needed based on this analysis. In general, AF2 uses equal parts pig slurry manure, cattle slurry manure and digestate (which he receives from a digester). Although AF2 needs roughly 2000 m^3 manure yearly, a maximum of only 500 m3 is allowed to be pig manure. This is due to the maximum allowed phosphate on the land (Paragraph 3.2.1). Besides, if more pig manure will be used instead of cattle manure, the amount of N and K (more specifically potassium oxide) in the manure to be used as fertiliser will decrease. Moreover, AF2 owns two manure silos, with a mixer, that can store and mix a total of 2000 m^3 manure throughout the year. This enables AF2 to have a homogenous slurry manure mixture and increases the certainty of the manure composition. Currently, AF2 uses the bigger silo (1100 m^3) for storing pig and cattle manure, as well as digestate. The smaller silo (900 m^3) is used for only cattle manure and digestate to be applied to the sugar beets and barley (AF2, personal communication, February 17, 2021).

Manure needs based on current situation

Both AF1 and AF2 are located on sandy soils. Sandy soils are prone to more N leaching than, for example, clay or peat soils, which leads to more environmental pollution, nutrient loss and a need for more frequent fertiliser (or manure) application. Sandy soils are also more porous, which increases the water and nutrient runoff from the soil (Voroney, 2007).

The arable farmers have different manure needs for their current practice. The first difference is the form in which they want to apply the manure. AF1 is interested in the liquid fraction of the pig manure, as it has a low phosphate content. After separation of manure, the solid and liquid fractions can be used individually. The solid fraction is viscous and phosphate rich, while the liquid fraction is nitrogen and potassium oxide rich (Melse, 2000). AF2 has his own storage for manure and consequently prefers (unseparated) slurry manure.

Pig manure will serve as replacement for the artificial fertiliser that AF1 currently uses. CAN 27 has an N content of 27%, whereas Patentkali contains 30% potassium oxide. In the past year, AF1 applied approximately 16,500 kg of CAN27 (4,388 kg N) and 19,500 kg of Patentkali (5,850 kg K_2O) to the arable land. AF1 indicated that he needs 1,500 kg of N from pig manure (AF1, personal communication, February 19, 2021). This will decrease his use of artificial fertiliser by approximately 35%, based solely on the N content.

AF2 bases his manure requirement on the yearly soil analysis and crops that he is growing. He consequently determines the nitrogen, phosphate and potassium oxide needed to apply. On average, AF2 requires manure with the following composition: ± 6 g N/kg manure, between 3.5-4.0 g P_2O_5 /kg manure and ± 5 g K_2O/kg manure. Moreover, he tries to fertilise as minimally as possible. For example, a crop requires between 140 – 200 kg of pure N per hectare land, he applies a maximum of 140 kg N, as it is better for the crops and the soil and limits the chances of eutrophication and acidification. Still, it is important to provide enough nutrients to prevent the crops from being deficient (AF2, personal communication, February 17, 2021).

6.2 Forms of manure: slurry, separation & pellets

Manure can be applied to arable land in various forms of fertiliser, including slurry manure, separated fractions or manure pellets. Hereafter a brief overview of each form of manure, how this would fit into the advised collaboration between VV and AF and finally a recommendation for the form of manure to be used as fertiliser.

6.2.1 Slurry manure

As mentioned above, slurry manure is a liquid mixture of manure and urine (and water) with a 10% dry matter content on average. This mixture can be directly applied to arable land, as long as the N and phosphate content does not exceed the allowed values for that land. An advantage of using slurry manure as fertiliser is that the application thereof does not have high greenhouse gas emissions. Arable farmers usually get paid to accept manure from livestock farmers, as discussed before, and can then store the slurry manure for when needed. Another advantage of slurry manure is that farmers can store the manure and use it when needed (VV1, personal communication, January 22, 2021). A disadvantage of using slurry manure as fertiliser is that relative heavy machinery, like tractors with manure spreaders or injectors, are needed to apply the slurry manure. Moreover, slurry manure could have negative environmental effects, including soil acidification, greenhouse gas emission and air pollution with ammonia (Geelen, 2001; Jongbloed et al., 1999; Leenstra et al., 2019). Arable farmers usually get paid to accept manure from livestock farmers, as discussed before, and can then store the slurry manure for when needed. Another advantage of slurry manure is that farmers can store the manure and use it when needed (VV1, personal communication, January 22, 2021). Finally, as slurry manure has a low dry matter content, around 90% of slurry manure transported is just water.

6.2.2 Separation

Slurry manure can also be further processed and separated into a solid and liquid fraction. In comparison with slurry manure before separation, the solid fraction has both lower N/P_2O_5 and K_2O/P_2O_5 ratios (phosphate rich), while the liquid fraction has higher N/P_2O_5 and K_2O/P_2O_5 ratios (N and potassium oxide rich (Melse, 2000; Van Dijk & Galama, 2019). The dry matter content of the of the incoming manure has a major influence on the efficiency of manure separation. The quantity and dry matter content of the solid fraction increase with an increasing dry matter content of the incoming manure. Moreover, the separation efficiencies of nitrogen, phosphate and potassium oxide also increase with an increasing dry matter content of the incoming manure (Schröder et al., 2009).

The separation, and subsequent removal, of the solid, phosphate rich, fraction could be advantageous to arable farmers in the Netherlands, as the amount of N applied as fertiliser can be increased without having an equal increase in the amount of phosphate applied or exceeding the phosphate limit (Melse, 2000). The solid fraction can either be processed into compost or used to produce manure pellets. A disadvantage of manure separation is that there might be additional processing costs involved.

Manure separation techniques include, amongst others, by centrifuge, screw press, screening or sedimentation (Schröder et al., 2009). Separation techniques differ in efficiency (Table 17). With manure separation by using a centrifuge, around 50 – 70% of the incoming phosphate can be separated. Using a screw press is another mechanical separation technique, but is more suited for separating cattle manure than pig manure. A screw press usually only separates less than 25% of the phosphate of the incoming pig manure. Moreover, separation by screening is also a mechanical separation technique that is more suited for the separation of cattle manure. Screening separators are relatively cheap, but the composition of the liquid fraction is similar to that of the incoming manure. Finally, during manure sedimentation, solid fraction settles at the bottom of the manure basin. Sedimentation is only possible on breeding farms, as sow (mixed with piglet) manure has a lower dry matter content (Melse et al., 2004). The manure can subsequently be separated into a liquid and solid fraction. The composition of these fractions from the separation tank are comparable to the fractions obtained from mechanical separation. The liquid fraction generally contains 20 – 22 g/kg dry matter and 0.6 – 1.1 g/kg phosphate (Melse et al., 2004).

Table 17: Separation efficiency of different techniques (mechanical, centrifuge or sedimentation) for solid and liquid fraction pig manure. Adapted from Melse et al. (2004)

Separation efficiency (%)	N		P_2O_5		K_2O		Dry matter	
	Solid	Liquid	Solid	Liquid	Solid	Liquid	Solid	Liquid
Fattening pigs slurry manure								
Mechanical	25	75	25	75	20	80	40	60
Centrifuge	20	80	70	30	15	85	45	55
Sow slurry manure								
Sedimentation	40	60	55	45	25	75	60	40

6.2.3 Pellets

By pelleting pig slurry manure, farmers can use the pellets as fertiliser while also decreasing the negative environmental impact of slurry manure (Pampuro et al., 2017). Manure pellets is a more concentrated product than slurry manure and could thus be transported easier (and cheaper). Manure pellets made of the solid fraction of separated slurry manure increased the NPK concentration, biomass and the N content in the roots of maize (Pampuro et al., 2017). Manure pellets could be produced by making use of the AMAK process. This is a technological process whereby pig slurry manure can be treated with sulfuric and phosphoric acid. This process consists of various steps in order to finally obtain a product that contains bioavailable nutrients for plants (Makara & Kowalski, 2018). Manure pellets can thus be used as a slow-release fertiliser on arable farms (Pampuro et al., 2017). Makara and Kowalski (2018) proposed the combination of pig manure, which serves as fertiliser, and manure pellets produced by the AMAK process to serve as a mineral-organic fertiliser. Mineral-organic fertilisers contain both organic and artificial components. A disadvantage of manure pellets is that there is additional processing involved which might lead to higher costs and thus a higher expense to arable farmers.

6.3 Advice

We will provide advice to Vallei Varken and the arable farmers on how to use manure optimally for their current situation, as well as for the proposed crop scenarios (Chapter 5.2).

6.3.1 Advice for manure use in current situation

Hereby advice for manure use that can be implemented directly, without making major changes to the current situation.

As previously stated, AF1 would like to receive 1,500 kg of N from the liquid fraction of pig manure. The short-term advice would be to provide AF1 with the liquid fraction of the sow manure of VV3, as this is already separated by sedimentation. As mentioned, the complete manure composition of VV3 is unknown, as is the quantity of each of the fractions after sedimentation. Based on the composition of the liquid fraction of Melse et al. (2004), which we used as average representation of manure separation by sedimentation, AF1 could use 440 m^3 of the liquid fraction to fulfil the need of 1,500 kg N. However, this manure will contain a total of 792 kg phosphate. A limitation to this is the amount of phosphate that AF1 is allowed to apply to the land. He is allowed to apply only 2,400 kg phosphate due to the phosphate regulations (60ha x 40kg/ha = 2,400 kg). Further advice would thus be to reduce the application of cattle slurry to his land in order to comply with the regulations.

Long-term advice would be that either VV1 or VV2 separates (a part of) the manure. This could be done by, for example, centrifugation, as only sow slurry manure can be separated via sedimentation (Melse et al., 2004)) into solid and liquid fractions. Although VV3 currently already separates the manure, manure from VV1 and VV2 both have more desirable compositions, namely higher nitrogen contents (Table 15). The solid fraction of the separated manure can subsequently be processed into compost or manure pellets. However, Vallei Varken is currently considering manure processing and chose to keep information on this confidential (VV1, Personal communication, January 22, 2021). Hence, we will not explore the possibilities of pelleting manure.

As mentioned, the different manure separation techniques vary in separation efficiency. We calculated the expected compositions of the solid and liquid manure fractions when the manure of VV1 and VV2 would be separated by centrifugation (Table 17), based on the calculations of Schröder et al. (2009). The values used as inputs are based on the current manure composition of VV1 and VV2 (Table 15) and on the separation efficiency of centrifugation. We assumed that the solid fraction after separation by centrifugation is 10% of the total incoming slurry manure, while the liquid fraction is 90%. However, these values depend on the composition of the incoming manure and will thus vary per farm (Schröder et al., 2009). The potassium content does not change with manure separation, thus these values were kept constant throughout (Melse et al., 2004). As we knew the separation efficiency of centrifugation, we used the following formula to calculate the (nitrogen and phosphate) content in the solid and liquid fractions (Schröder et al., 2009):

$$Separation\ efficiency\ (\%) = \frac{content\ in\ solid\ fraction \times amount\ solid\ fraction \times 100}{content\ in\ incoming\ slurry\ manure \times amount\ incoming\ slurry\ manure}$$

Calculations are estimations to give an impression of the possibilities of manure separation by centrifuge and to indicate the difference in nitrogen and phosphate content of slurry manure and separated manure. Finally, the last column in (Table 18) indicates the amount of liquid fraction that AF1 has to receive from either VV1 or VV2 to meet the nitrogen requirement of 1,500 g N/kg based on the values used for the calculations.

*Table 18: Expected composition of the solid and liquid manure fractions of VV1 and VV2 after centrifugation, as well as amount AF1 should receive**

	N (g/kg)	P_2O_5 (g/kg)	K_2O (g/kg)	Manure (m^3) based on required 1,500 kg N of AF1
VV1 – Solid fraction	16.7	26	5.3	X
VV1 – Liquid fraction	7.4	1.2	5.3	203
VV2 – Solid fraction	13.3	21.6	4.5	X
VV2 – Liquid fraction	5.9	1	4.5	254

* calculations based on the formula provided in Schröder et al. (2009)

The advice for AF2 based on his current situation is that it would be best to receive manure from VV2, as it is the closest Vallei Varken farm (Figure 2). Moreover, the composition of the manure of VV2 also fits the requirements of AF2 (Table 19). Despite this, AF2 could also receive manure from VV1, as the distance between these two farms is still manageable. The nitrogen content of the manure of VV2 is slightly higher than required, while the phosphorous content is lower. Whereas the nitrogen content of the manure from VV1 is much higher.

AF2 mentioned he could apply a maximum of 500 m^3 manure based on the maximum phosphate allowed when the phosphate content of the manure is between 3.5 – 4 g P_2O_5/kg manure. However, the phosphate content in the manure of VV2 is lower (3.09 g P_2O_5/kg manure), so it could be possible for AF2 to apply more of the pig manure on his land. This depends on the actual values of the manure and the actual needs of the farmers.

Table 19: VV1 & VV2 manure composition and manure requirements of AF2

	N (g/kg)	P_2O_5 (g/kg)	K_2O (g/kg)
Composition of VV1 manure	8.4	3.7	5.3
Composition of VV2 manure	6.7	3.1	4.5
Requirements of AF2	± 6	3.5 - 4	± 5

6.3.2 Advice for manure use in proposed crop scenarios

The manure requirements of the arable farmers vary between the different crop scenarios proposed in Chapter 5.2. As mentioned, the first scenario entails producing cereals to be used as pig feed, whereas the second scenario entails legumes for pig feed. Finally, the third scenario is where both arable farmers do not produce pig feed, but rather vegetables to be used by De Kroes.

The fertilisation, and thus manure, requirements of arable farmers depend one a wide spectrum of factors. Firstly, the crops that the farmer produces undoubtedly influence the manure requirements. Legumes require the least nitrogen in comparison to grains and vegetables, as they are able to obtain nitrogen from the atmosphere via nitrogen fixation (Mahmud, Makaju, Ibrahim, & Missaoui, 2020). Thus, arable farmers with legumes in the rotation (scenario 2) have a lower manure requirement than when producing mostly cereals or vegetables (scenarios 1 and 3) (Appendix V: Crop selection. Secondly, the soil mineral nitrogen (usually measured during spring) influences the nitrogen requirement of the soil (De Haan & Van Dijk, 2015), therefore also the fertiliser requirement. Nitrogen is the nutrient in the soil that can be influenced the most, as processes like nitrification, denitrification, mineralisation and immobilisation all lead to decreased soil nitrogen content (Möller & Stinner, 2009). Moreover, soil characteristics like the texture, moisture, temperature, pH, soil organic matter, aeration and compaction also determine the manure requirement as these influence the response of the soil to the fertiliser, especially to phosphorous (Armstrong, 1999). These soil characteristics all determine the manure requirements of arable farmers.

Because of the wide range of environmental factors influencing the fertilisation needs and the limited time for this project, we were unable to establish exact fertilisation plans for each proposed crop scenario. Advice would include that the arable farmers first establish their preferred crops, followed by (yearly) soil analyses before calculating the manure needs.

7 Collaborative framework

This chapter will provide an overview of the proposed collaboration between Vallei Varken and arable farmers, including direct stakeholders. The outcomes given in the previous chapters are illustrated in Figure 8. As it is a circular system, the outcomes affect each other. The crops that can be selected for the feed will have an influence on the manure that needs to be applied on the land. Moreover, the feed composition will also influence the choices for the crops, so the framework works both ways. Overall, the boundaries of Chapter 3 serve as restrictions for a collaboration. The following paragraphs explain what is needed to establish a successful collaboration between the farmers within those boundaries. First, a method on how a collaboration can be put in practice will be provided, which will be used to guide farmers.

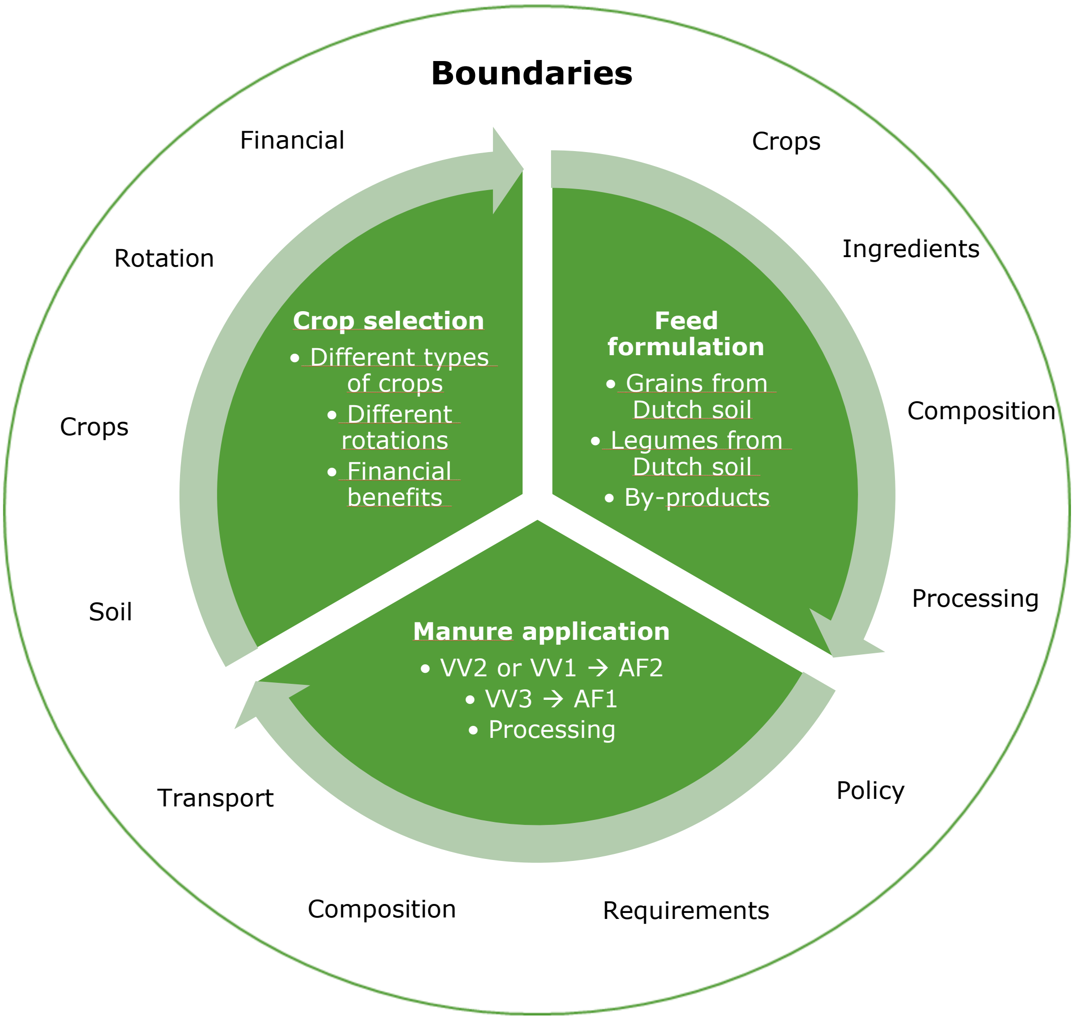

Figure 8: Overview of the outcomes

7.1 Cooperation statute

As briefly addressed in Chapter 3, a potential guidance for a collaboration between arable and livestock farmers is the cooperation statute. In this concept, potential partners discuss several subjects in order to come to an effective collaboration. An overview of subjects to be addressed according to the cooperation statute is given in Table 20.

Table 20: Cooperation statute subjects adapted from Oosterhoff (2019)

	Subject
1.	Introducing each other
2.	Values
3.	Vision
4.	Decision-making
5.	Deliberation and conflicts
6.	Communication
7.	Work and exchange
8.	Advising and coaching
9.	Money and granting
10.	Re-assessing the agreements

In this case, especially the subjects values, vision, communication, work and exchange and money and granting are important aspects to discuss. Vallei Varken has a strong vision and values circularity and animal welfare highly, which collaborating partners should share in order to be able to work well together. Moreover, trust plays a big role in a collaboration. Therefore, (agreements about) communication is important, as all parties have mentioned that they value personal and regular contact.

This communication should also be clear on the more concrete part of the collaboration: the actual work and exchange of manure and feed. The financial aspect also plays a role in this collaboration. To whichever extent the parties value the improvement of circularity, it should not be at the expense of their profit. Therefore, it is important to elaborately discuss the financial aspects of a potential collaboration.

Oosterhoff (2019) framework serves as a guidance establishing a collaboration and also provides four forms of collaboration, namely: entrepreneurial, exploratory, transactional and functional collaboration. In this case, transactional collaboration is most appropriate, as it concerns bringing together activities in both companies, resulting in the transactions becoming shorter or faster. This is intended to achieve financial benefits in particular, but also to improve circularity in this case. In a collaboration between arable farmers and livestock farmers this may concern the exchange of manure for feed/crops.

7.2 Current situation

Based on the current situation, multiple options for a collaboration between Vallei Varken, arable farmers, Agrifirm, Boni and De Kroes are available (Figure 9).

As AF1 is only interested in applying the liquid fraction of separated manure, while VV3 is able to provide him with this, it would be possible for AF1 to receive the liquid fraction of manure from VV3. We would suggest bringing AF1 and VV3 into contact with each other to discuss the possibilities of such a collaboration. AF1 should decide whether the composition of the liquid fraction of VV3 is acceptable for him. If AF1 is able to use this, the amount of manure needed, as well as when it is needed should be agreed on. Furthermore, manure transportation and application methods should also be established.

AF2 would like to receive around 500 m^3 manure, which can be obtained from VV1 or VV2. The amount of manure that AF2 is able to apply partly depends on the manure composition of VV1 and

VV2. Therefore, AF2, VV1 and VV2 should discuss the possibilities together. As AF2 has his own storage facility, they can also decide when the manure can be transported to the farm.

Above-mentioned, possible collaborations could be put into practice in the short-term. For the long term, our advice is to explore the options for separating the manure from VV1 or VV2 for AF1 (if needed and if the composition of VV3 is insufficient).

AF1 is currently producing onions, which might be interesting for De Kroes to use in their meals, as onions are already one of the main products used. Therefore, AF1 and De Kroes should meet and discuss the possibilities of adding the onions in the Vallei Varken collaboration. Points of discussion could include quantity, price, type and transport of the onions in order to establish what both parties could mean for each other.

Moreover, both arable farmers are currently producing wheat and barley. These crops can already be added to the diet of the pigs. We suggest AF1 and AF2 to come into contact with Agrifirm to discuss the options of feed prices and transportation. They should compare the current yield and price with the possibilities that Agrifirm can offer in order to determine whether this will be a profitable collaboration. Such a collaboration will lead to more circularity, as the wheat and barley will then be processed to feed for the pigs.

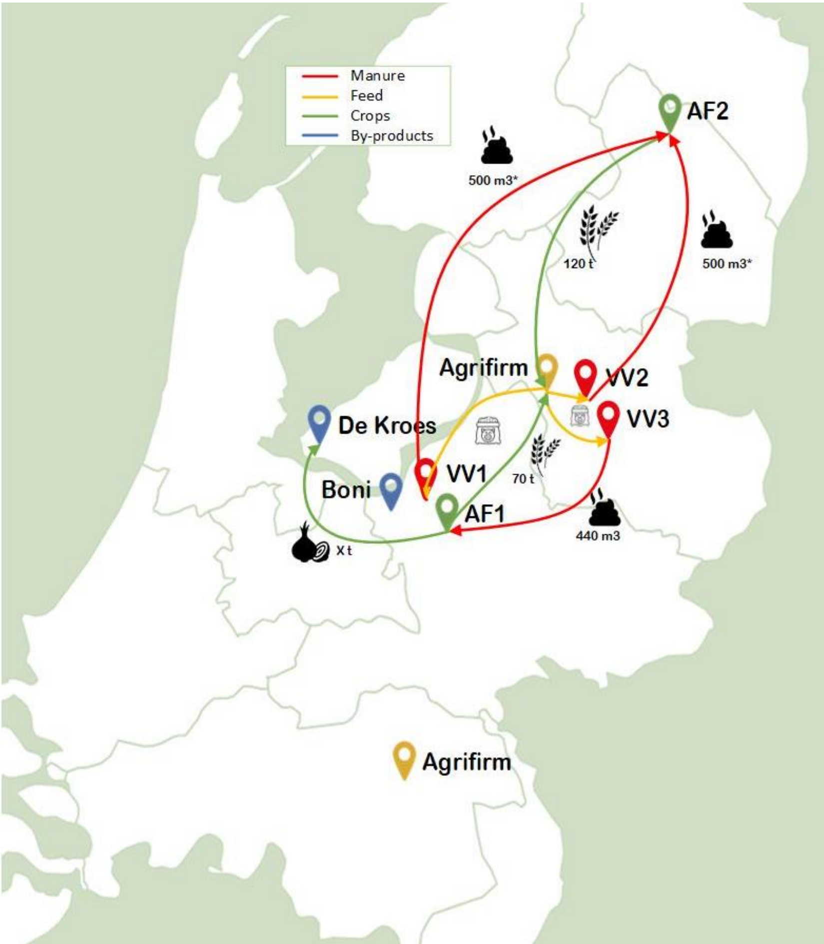

Figure 9: Logistic overview of short-term possible collaborations

**The total of 500m^3 manure will come from either VV1 or VV2 (or combined)*

Long term advice could also include the option for Vallei Varken to process the wheat and barley themselves with a hammermill and build a storage for it. To assess this practice, the investment costs should be compared to the alternative processing costs of Agrifirm.

7.3 Changing the crop rotation based on feed formulation

Chapter 4 provides multiple options for changing the feed composition of the diet. Whether these options can be put into practice depends on the crops that will be grown by the arable farmers. The options and possibilities for the crops that can be grown are discussed in Chapter 5.

To make changes to the current diet, farmers would have to come into contact with each other and weigh up the various possibilities. Questions to be answered during these meetings could include the following: What are the wishes, what can and do the arable farmers want to produce, and what is profitable? How will these choices lead to a change in diet? What are the possibilities of Agrifirm to change something in the diet formulation? What are the financial outcomes of such a change?

As mentioned, the proposed scenarios for changes to crops to produce include producing mostly grains, legumes or vegetables. By-products of the vegetables could subsequently be used as feed ingredients. The changes to crops produced will influence the feed ingredients, which will in turn influence the manure composition. Vallei Varken, the arable farmers and Agrifirm should thus get in contact with each other and discuss the proposed possibilities and what the effects will be on the other parties.

Based on the crops presented in Chapter 5, winter wheat, winter barley, oats, spelt and grain maize are the most promising cereals for the current arable farmers to grow. At the moment both arable farmers are growing summer grains instead of winter grains. The option to grow winter cereals should be discussed with AF1 and AF2, as some winter cereals have a higher gross margin than their summer cereal counterparts. Besides wheat and barley, grain maize could be a good option to grow as it is the main component of the diets. An advantage of a crop rotation consisting of mostly cereals is that it requires more manure from Vallei Varken than a crop rotation consisting of more legumes. This should also be considered by AF1 and AF2. It should be discussed with Agrifirm whether they can buy these crops from the arable farmers.

AF1 mentioned he prefers to not produce legumes. Therefore, the legumes options should be discussed with AF2. Together with Vallei Varken and Agrifirm the possibilities of adjusting the diet with for example faba beans or peas should be explored. Besides the possibilities of AF2 to grow these types of crops need to be taken into account.

Concerning the scenario of producing vegetables, Chinese cabbage, leek, onion, consumption potato, pumpkin and chicory are the most promising crops. AF1 is already growing onions and consumption potatoes, AF2 mentioned he would consider growing consumption potatoes or pumpkins. AF2 and De Kroes should discuss the possibilities for this. The disadvantage of potatoes is that AF2 prefers to not use pig manure for the fertilisation of the potatoes. This option is thus not the most suitable for Vallei Varken.

The three scenarios are not necessarily mutually exclusive, they can be implemented in parallel. Such a combination of crops is called intercropping. For example, cereal-legume mixtures are gaining popularity and are used as feed in countries abroad. In fact, this intercropping practice could potentially produce a higher yield than both crops in monoculture. AF1 mentioned that he does not want to grow legumes, so this option is not useful for him. Therefore, this option should be discussed with AF2 and Agrifirm.

An overview of how these proposed changes can come to a collaboration is depicted in Figure 10. In this example future collaboration, both arable farmers grow crops for De Kroes and for pig feed. As mentioned in Chapter 4, farmers will need to have a crop rotation. In this example, they have included vegetables and crops for the feed in their rotation. The manure requirements might change depending on these different crops. Manure will still be needed, only the amount should be calculated. It might be possible to collect waste streams from De Kroes and add these by-products from the vegetables to the diet. These by-products have to be processed in Veghel (at an Agrifirm factory) and can then be added to the diet, in which also the crops of the arable farmers will be added. Vallei Varken will subsequently receive their feed from Agrifirm.

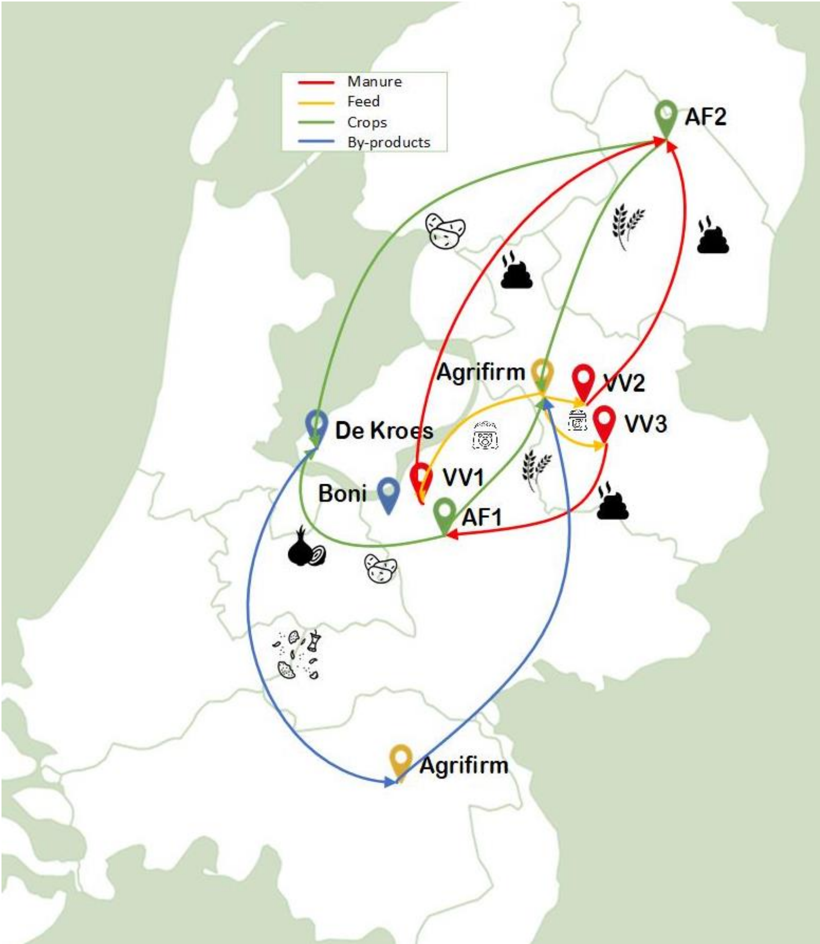

Figure 10: Logistic overview of long-term possible collaboration

As mentioned earlier, to make a collaboration like this work, the involved stakeholders need to discuss whether it is feasible and profitable. AF1 and AF2 should discuss with Agrifirm and De Kroes which crops they can grow and at what price this can be provided to them. Agrifirm should investigate the possibilities of adding vegetable by-products in their diets with De Kroes. The Vallei Varken farms should discuss the amount of manure to be applied with the arable farmers. Such a collaboration will typically be a long-term collaboration. If all the parties come to an agreement, they should do that for multiple years as they should learn from each other and see how they can improve circularity.

7.4 Financial aspect

Concerning the financial aspect, it is important to take all the possibilities into account and calculate the profits and costs of the proposed collaboration. As it is not known yet which crops the farmers will choose to grow, for which purpose and at what cost, it is hard to give a good estimation on how much the manure should be paid for. An opportunity to make it more profitable for the arable farmers is the demand for vegetables by De Kroes, as the margins for these crops are higher than for the cereals and legumes.

Moreover, one of the goals of Vallei Varken is to reduce manure costs. All manure costs involved in the proposed scenarios, should be calculated to finally establish the most financially advantageous collaboration. When the arable farmers will get involved in the Vallei Varken concept, it might be possible to fix the price for the manure in the same way as they do now with their meat. However, we did not come up with a good solution for this yet.

Our advice is to first make a financial overview of the current revenues and costs of all farmers. Thereafter, the different possibilities proposed in this report should be explored to finally establish the most profitable collaboration.

Concluding, various crops can be added to the crop rotation of the arable farmers, taking into account the different advantages and disadvantages. Therefore, our main advice is that all relevant stakeholders, namely, Vallei Varken farmers, the arable farmers, Agrifirm, Boni and De Kroes should establish which collaboration scenario would be most feasible and profitable for all parties.

8 Conclusion

In this study, we aimed to set up an exchange of manure as fertiliser and crops as feed between pig farmers and arable farmers to increase agricultural circularity. We divided our work around four themes, namely the boundaries, the feed, the crops and the manure. The results of this research were then combined in a collaborative framework which gives a combined view of how to put that collaboration into practice.

In the first sub-question, we gave an overview of the organisational, practical and financial boundaries that must be adhered to in order to organise a collaboration between Vallei Varken, the arable farmers and other stakeholders. The information provided in this sub-question was meant to serve as a foundation for the other three sub-questions.

In the second sub-question, we aimed to establish what the possibilities are to integrate crops and crop by-products from arable farms in pig diets. We provided possible adaptions to the current feed through three scenarios in which different components were replaced using local resources: cereals, legumes (protein) and vegetable by-products. The first scenario could easily be put in practice if enough arable land is available to produce the cereals. The second scenario is technically feasible but some more investigation on the costs of using legumes in the diets is required; as well as more land. The third scenario would be interesting to reduce food waste, but vegetable by-products cannot contribute to a large share of the pig diets. In any case, Agrifirm should be closely involved to discuss the feasibility of each option.

In the third sub-question, we gave insights in suitable crops for the arable farmers to grow in order to contribute to the Vallei Varken concept. To answer this question, we used the scenarios presented in the previous paragraph to select potential crops and found several that may be suitable. For cereals, the most suitable crops were winter wheat, winter barley, oats and spelt. Suitable protein crops were found to be pea, faba bean (summer, winter), lupin (white, blue), flax, and rapeseed (summer, winter). Vegetables that were most suitable are Chinese cabbage, leek (summer, autumn), seed onion, consumption potato, pumpkin and chicory.

In the final sub-question, we explored in what form and quantities manure produced by Vallei Varken can be integrated in the fertilisation plan of the arable farmers. We attempted to do so for each of the three scenarios but found that the wide range of factors on which fertilisation depends, make fertilisation a highly situational and specialised affair. We were thus unable to establish exact fertilisation plans for each scenario. However, based on the current situation, AF1 should receive around 440 m3 liquid fraction of the separated manure from VV3, while AF2 should receive 500 m3 slurry manure from either VV1 or VV2.

In order to facilitate a lasting collaboration, we developed a collaborative framework which describes possible ways to collaborate, lays down the rules and requirements, and provides materials and advice to deal with organisation affairs. With the suggestions made to give substance to a possible collaboration, a step towards agricultural circularity can be made.

9 Discussion

In order to achieve our goal of providing possibilities for establishing a collaboration between Vallei Varken and two arable farmers based on the exchange of crops as feed and manure as fertiliser, we first explored the boundaries of such a collaboration. These boundaries served as guidance for answering the three other sub-questions based on feed, crops and manure respectively.

As mentioned, we performed both interviews and literature research to finally establish what the possibilities for a collaboration between Vallei Varken and two arable farmers are. The majority of interviews were conducted online due to Corona. Conducting online interviews hampers the process of forming an overall image of the stakeholders and their needs. Furthermore, basing the project on interviews allowed us to get a better understanding of all the stakeholders and their current systems. However, making use of interviews also creates the risk of not interpreting the information correctly or not receiving accurate information. Throughout the project, we tried to support the information received during interviews with proven literature. This was not always possible, as the current project is specific to the situation of each stakeholder. For example, VV3 was unable to provide a complete manure analysis, hence we were unable to provide accurate advice for manure use. In that case, we based the values for our calculations and the advice on research from a similar situation.

Time was also a major limiting factor throughout the project. If more time was available, advice provided would have covered a broader spectrum, while also being more specific. One aspect that is highly important is the financial feasibility of the entire collaboration. This includes the feasibility of changes to feed ingredients and crops produced, as well as the various forms of manure, transport and processing. Moreover, we were unable to provide entire crop rotations for each arable farmer, partly because of time constraints but also because of the limited data available on the soil characteristics and plots of lands of the farms. Consequently, we were also unable to provide entire fertilisation plans for these crop rotations.

After deepening our knowledge on the topic, we realised that the initial research question and sub-questions should be adapted, as they were too specific for the time available. We made minor adaptions to these in order to make it more applicable on the actual collaboration between Vallei Varken and arable farmers.

Outcomes and limitations

Potential ingredients and by-products suggested in the project will reduce the imports of the ingredients and provide good quality pig feed for Vallei Varken. We developed three scenarios for adaptations to the pig feed. Scenario one involves inclusion of locally grown cereals in the diet. This scenario is beneficial and feasible in terms of circularity, as all the mentioned cereals are grown in the Netherlands and commonly used in pig diets. However, due to the limited number of arable farmers, the amount of cereal grains grown will not be sufficient to cover the need of Vallei Varken in terms of quantity. More farmers would need to be involved in the collaboration. The way these cereals should be included in the diet is a point that remains unclear. It could be directly included in the diets produced by Agrifirm; however, the feasibility of this should be discussed in terms of logistics and costs. Or farmers could directly store, process and give the cereals to the pigs at the farm, which would require some more investments.

In scenario two, the aim of this scenario is to reduce the importation of protein sources, mainly soybean meal from South America. Faba beans and peas are not widely used in pig feeds, although some studies showed that they can be incorporated in pig diets (Degola & Jonkus, 2018; Jezierny, Mosenthin, & Bauer, 2010; Mariscal-Lanďin, Lebreton, & Sève, 2002; White et al., 2015). The benefits of including faba beans and peas are that they replace soybean meal, enhance crop rotation for arable farmers and requires a small area of land because only 20% is used in the diet. However, their yield per ha is lower than that of cereals. Also, it is feasible in terms of nutritional composition of the diets but aspects regarding profitability and organisation remain unclear. The costs of producing legumes need to be assessed, and the possibility of using these crops in the diets should be discussed with Agrifirm.

In scenario three we explored the possibility of utilising by-products like vegetable leftovers to incorporate into pig feed. It is feasible and beneficial to use by products in feeds as they are cheap and help to recycle biomass into more valuable pig products. However, these by-products have low nutritional values so, they would constitute a small fraction of the diet. Also, they need further processing like drying to reduce the moisture contents if they must be incorporated in the pelleted diet. If implemented, vegetable by-products can offer a cheap pig feed and strengthen circularity by ensuring that all products and by products are efficiently utilised.

Furthermore, we decided to only focus on fattening pigs, because piglets and sows are very sensitive in terms of nutrition, and their diets need to be maintained for the better performance. Due to the limited information from Agrifirm, we were unable to know the exact feed composition of the current feed, hence we formulated the feeds based on the proximate analysis results. Understanding the feed composition would have been helpful in advising Agrifirm what to adjust in their feed in terms of inclusion level of each ingredients depending on the nutrient content. Especially energy, crude protein, crude fiber and phosphorous concentrations of each ingredient are important to take into account. Lastly, we used an online version of software (EvaPig) in formulating our diets, the software had limitation on its options. We were unable to formulate feed for scenario three, because there was no option for including vegetable by-products.

For the crop aspect of this collaboration, we proposed three different crop scenarios that could be feasible for the collaboration. These three scenarios included producing either mostly cereal crops for pig feed, legumes (protein crops) for pig feed or vegetables for De Kroes. Moreover, both arable farmers are already producing some cereals and vegetables, therefore this would lie within their field of expertise.

Cereals were found to be a good crop to provide feed for pigs and improve soil quality, but its low margins per hectare are a problem for the profitability of a crop rotation. There are also several protein crops that could be grown on the farmers' sandy soils. Their early harvest period could allow for the sowing of more valuable winter grains. Cereal-legume crop mixtures have several advantages. The demand for vegetables by De Kroes provides an opportunity to anchor the arable farmers to the Vallei Varken concept as the high margins could give the arable farmers a clear financial incentive to get seriously involved. If the farmers are already involved with Vallei Varken through De Kroes, it may be simpler for them to engage in more forms of collaboration within the concept, such as optimising by-product production and matching manure supply with demand. Although AF2 expressed interest in growing sweet potatoes, we would not recommend growing this as an additional crop due to its late harvest period. However, it could be an alternative to regular potatoes which could increase diversity. Therefore, further research should be done into the margins and requirements of sweet potato before any conclusions can be drawn.

Despite these findings, we were unable to conclude on a specific scenario to be implemented, as there are multiple factors influencing this decision. Moreover, we lack financial data for farms to perform analyses to aid with such decisions. Similarly, the three proposed crop scenarios can also be applied simultaneously.

As AF1 is only interested in applying the liquid fraction of separated manure, while VV3 is able to provide him with this, it would be possible for AF1 to receive the liquid fraction of manure from VV3. A major uncertainty of this proposition is that VV3 was unable to provide a manure analysis. This might influence the feasibility of such a collaboration, as we used data from a previous study to obtain an average manure composition that could resemble that of VV3 (Melse et al., 2004). Long-term advice would be to explore manure separation or processing techniques to ensure the most optimal use of manure in terms of circularity and financial benefits. If VV1 and VV2 want to separate manure via centrifugation, AF2 could receive 203 m^3 or 254 m^3 manure, respectively. Furthermore, VV2 is located closer to AF2 and also has a slightly more preferred manure composition than VV1.

Despite the calculations, propositions and advice on manure application, the composition of manure constantly varies. Therefore, the amount of manure that the arable farmers are able to receive was calculated with uncertainty and could slightly change in the future. Moreover, the financial aspects involved with manure separation, processing, transport and application were not addressed in this report. The aim should be to dispose of as much manure possible on the arable land of Vallei Varken farms or neighbouring farms already receiving manure, whereafter the most financially viable collaboration for the entire manure collaboration should be established.

Although we aimed at also providing fertilisation plans for the proposed crop scenarios of the arable farmers, we were unable to do so because of the wide range of environmental factors influencing the fertilisation needs and the limited time for this project. Furthermore, only two arable farmers were included in the collaboration, not all opportunities were explored. Currently, only around 1000 m^3 of the 6000 m^3 manure available from Vallei Varken can be applied to the land of the two arable farmers. Consequently, more farmers are needed to dispose of all the manure of Vallei Varken, however the manure processing obligation should be considered.

Initially, the idea was to establish a concrete plan for a collaboration between Vallei Varken and arable farmers in order to increase agricultural circularity. However, due to the complexity of such a collaboration, the current collaborative framework serves more as advice for the possibilities of a collaboration between Vallei Varken, arable farmers, Agrifirm, Boni and De Kroes.

The proposed scenarios for collaborations could improve agricultural circularity, as arable farmers will produce feed for Vallei Varken, while Vallei Varken provides manure for arable farmers. In this way nutrient cycles will be more closed. Based on the scientific definition of agricultural circularity, as defined by De Boer and Van Ittersum (2018) this collaboration is less circular, however. The definition states that only by-products should be used as feed for Vallei Varken.

As an academic concept, circular agriculture is relatively new and at this moment limited literature is available. Papers that we used to define the concept focus primarily on the use of animals in a circular system: circular agriculture specifically with regards to arable farming and the soil remains to be defined. A future paper that provides such a definition may formulate the principles circular arable farming. Lacking such a theoretical framework, we instead extended the definition to also cover arable farming.

Finally, we have learned a lot during this project, especially regarding teamwork and incorporating stakeholders' needs and wishes. We enjoyed working with all involved parties who are all well-willing, ambitious and enterprising people. We are honoured that we have been given the opportunity of applying our knowledge and experience to a practical problem and are proud to have made a contribution to this project. We wish all the parties involved the best of luck in setting up a mutually-beneficial collaboration, and we look forward to see Vallei Varken develop into a true circular pig farm of the future.

10 Advice

During this project, we aimed to implement an exchange of manure as fertiliser and crops as feed between pig and arable farms to increase agricultural circularity (Figure 11). We presented three different scenarios in terms of crops to be produced for setting up this collaboration. In the first two scenarios, respectively cereals and protein crops are produced by the arable farmers to be included in the pig feed. Finally, in the third scenario, the arable farmers produce vegetables for the retailers of Vallei Varken and the by-products are used to serve as pig feed. Furthermore, we provided advice on manure as fertiliser on the arable farms. In this chapter, we will first formulate short-term advices, whereafter we will provide long-term advices and several possibilities to consider in the future.

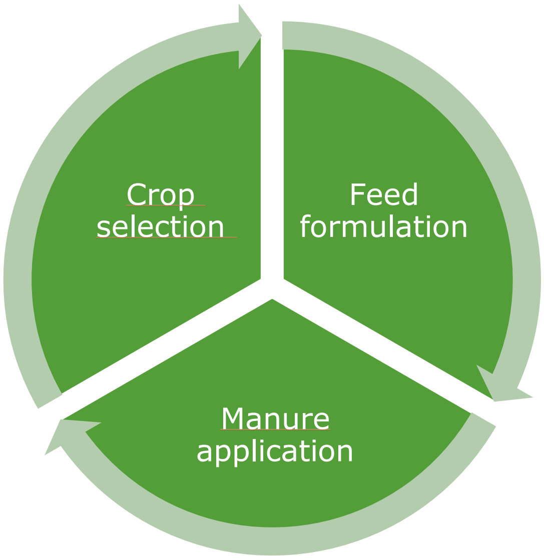

Figure 11: Circularity of the three main components (feed, crops and manure) of a collaboration between Vallei Varken and arable farmers

10.1 Short-term advice

As trust and loyalty form the basis for the Vallei Varken concept, it is advised that the arable farmers should firstly meet with Vallei Varken to have a better understanding of their motivations, wishes and goals for such a collaboration. Once they have established a common vison for the collaboration, they should consider the proposed scenarios and advices of this report before determining the most financially suitable collaboration. All this, while keeping in mind to strive improving agricultural circularity. Finally, once the relevant parties have reached an agreement on the collaboration, it should be made contractual by, for example, a cooperation statute.

One of the first actions to be taken is to decide on the manure exchange aspect of the collaboration, that is, decide from whom the arable farmers will receive manure, in what form this manure should be, the compositional requirements thereof, as well as the quantity.

As AF1 is only interested in applying the liquid fraction of separated manure, while VV3 is able to provide him with this, it would be possible for AF1 to receive the liquid fraction of manure from VV3. AF1 should decide whether the composition of the liquid fraction of VV3 is acceptable for him, as he has a need for liquid fraction of pig manure with high nitrogen and low phosphate content. If AF1 is able to use the manure of VV3, the amount and moment of application should be agreed on. Furthermore, manure transportation, financial aspects and application methods should also be established.

AF2 would like to receive approximately 500 m^3 slurry manure, which can be obtained from VV1 or VV2. The amount of manure that AF2 is able to apply partly depends on the manure composition, as he is restricted by a maximum amount of phosphate content that may be applied. Therefore, AF2, VV1 and VV2 should discuss the possibilities together. As AF2 has his own storage facility, they can also be more flexible in establishing when the manure will be transported to the farm.

Another high-priority aspect of the collaboration is establishing the crops to be produced by the arable farmers and the feed requirements of Vallei Varken. AF1 is currently producing onions, which might be interesting for De Kroes, as onions are already one of the products mainly used. Therefore, AF1 and De Kroes should discuss the possibilities of incorporating the onions to the collaboration with Vallei Varken. Points of discussion could include quantity, price and transport of the onions.

Moreover, both AF1 and AF2 are currently producing wheat and barley. These crops could already be added to the diet of the pigs. We advise the two arable farmers to get in contact with Agrifirm to discuss the options of feed prices and transportation. They should compare the current yield and price with the possibilities that Agrifirm can offer in order to determine whether this will be a profitable collaboration. Since both arable farmers produce barley and wheat, the first proposed scenario (cereals) would be more feasible than the second proposed scenario (protein crops) in the short term. The feed requirement of Vallei Varken is larger than what can be produced by the two arable farmers. However, this is not an obstacle in establishing the collaboration, the available amount of cereals can be incorporated in the diet while discussing the possibility of growing more cereal crop.

Transporting all feed ingredients to Agrifirm is more feasible than Vallei Varken producing their own feed, as it does not require any extra investments. However, arable farmers and Agrifirm should contact each other to discuss and plan the transportation of crops to the nearest Agrifirm factory to decrease transportation cost.

Moreover, Boni could possibly also become more part of the collaboration. Once their needs and wishes have been established, it might be an opportunity for them to benefit from the arable farmers.

Finally, the Science Shop should act as mediator to establish such a collaboration and to fulfil the demands of Vallei Varken.

10.2 Long-term advice

Once a long-term collaboration that continually strives to increase agricultural circularity has been established, we would advise to consider further adaptions to the manure application, feed formulation and crop selection.

As manure costs are currently of high importance to Vallei Varken, the forms in which manure could be applied on the arable land should be explored. Long-term advice would be that either VV1 or VV2 separates (a part of) the manure. This could be done by, for example, centrifugation. After separation, the solid fraction of the manure can subsequently be processed into compost or manure pellets. We would advise both Vallei Varken and the arable farmers to research the most suitable form of manure processing. Moreover, VV2 should consider investing in an air scrubber, as this could be beneficial for the environment and the manure composition. Such investments would contribute to improve manure quality and make it more competitive in the current saturated manure market of the Netherlands.

Regarding feed formulation and crop selection, multiple long-term options could be possible. Apart from what the two arable farmers are currently growing, there are also other crops that can possibly be produced to comply with the nutritional demands for pig feed. These have been divided into three categories: cereals, protein crops and vegetables.

Winter wheat, winter barley, oats, spelt and grain maize are the most promising cereals to grow. Both arable farmers are currently producing summer grains instead of winter grains. The option of incorporating winter cereals in the crop rotations should be discussed with AF1 and AF2, as some winter cereals have a higher gross margin than their summer cereal counterparts. Besides wheat and barley, grain maize could be a good option to grow as it is the main component of the diets. For Vallei Varken, an advantage of a crop rotation consisting of mostly cereals is that it requires more manure to be applied than a crop rotation consisting of more legumes. AF1 and AF2 should discuss with Agrifirm whether they can buy these crops to be incorporated into the pig diets of Vallei Varken.

Faba beans and peas are the most promising legumes. These options should be discussed with AF2, as AF1 mentioned that he prefers to not produce legumes. Together with Vallei Varken and Agrifirm, the possibilities of adjusting the diet with, for example, faba beans or peas should be explored, whereafter the possibilities of AF2 to grow these crops should also be discussed.

Concerning vegetables, Chinese cabbage, leek, onion, consumption potato, pumpkin and chicory are the most promising crops. AF1 is already producing onions and consumption potatoes, so he should continue doing so. AF2 mentioned that he would consider producing sweet potatoes, consumption potatoes or pumpkins. AF2 and De Kroes should therefore discuss the possibilities of growing and processing by-products of these crops into pig feed. The disadvantage of potatoes is that AF2 prefers not to use pig manure for the fertilisation of the potatoes. This option would thus not be the most suitable for Vallei Varken.

It is important that the farmers, as well as the Science Shop, gather more in-depth knowledge into the proposed crops to judge whether they would be a good addition to their crop rotation plan. It is important that the farmer is directly involved in this consideration. In fact, in order to put such a shift into practice, the farmers' expertise, preferences and interests are key.

10.3 Future possibilities

With the suggestions made to give substance to a possible collaboration, a step towards agricultural circularity can be made. However, as the goal for the future is to reach 100% circularity, some possibilities for the future are provided to increase the circularity even more.

As the number of hectares of both arable farmers is not sufficient for the amount of manure that has to be disposed from the Vallei Varken farms, more arable farmers could get involved in the concept. With more arable farmers, more feed for the pigs can be produced as well. It might be interesting to involve arable farmers that are already producing protein crops. Practices such as intercropping and catch crops should be further investigated, and if found to be suitable implemented to further improve the productivity and resilience of the crop rotations.

Besides producing protein crops, research can be done to use insects as a protein source. Incorporating insects into the livestock industry, as well as the food industry, as an alternative protein source is an interesting option to be researched. Although insects can feed on food waste streams, their nutritional value is comparable to that of fishmeal products and soyabeans. Incorporating insects as protein source could thus contribute to the circularity and sustainability of the collaboration (Wageningen University & Research, 2021b).

Regarding the diets, it would be interesting to assess the possibilities of reducing phosphate excretion. This could be done via adaptions to the feed composition. In fact, by the use of phytase, a more precise nutrition or a controlled feed production process, phosphate excretion by the pigs could be reduced. This would be interesting, as the amount of phosphate in manure limits the use of pig manure. All these options should be discussed with Agrifirm as they are in charge of the feed production.

The costs and feasibility of processing manure into pellets could be investigated. Pellets could provide various fertiliser advantages and could ensure a more homogenous composition than slurry manure or separated manure. Moreover, the transportation of manure pellets is more convenient than slurry manure. Furthermore, Vallei Varken could also consider investing in a manure digester. Not only will they be able to produce biogas, but the amount of manure to be processed due to the manure processing obligation will decrease.

Another possibility for the future is to investigate whether it will be worthwhile for Vallei Varken to install hammer mills and storage facilities for crops. This could enable Vallei Varken to provide crops of arable farmers directly to the pigs instead of transporting crops to Agrifirm and subsequently receiving all feed from them. It might be cheaper and feasible as the cost of feed and transportation will be minimised.

With the advice provided, the Vallei Varken concept could be one step closer towards reaching agricultural circularity.

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Appendix I: ACT group members

The relevant expertise of our team includes the following topics: animal sciences (nutrition, physiology, feed formulation and production), animal production systems and nutrient cycles modelling, agricultural business economics, supply chain management, agroecology and organic production systems, soil science, biosystems design and farm technology. Thanks to their background and experience, most group members have an affinity with agriculture in practice, although not particularly with the pig sector. Our team is composed of people with different academic backgrounds and cultures. This diversity will help us to tackle the challenge that was given to us.

Coenraad van Zyl (Manager) - Coenraad was born in South Africa, where his family has a sheep and grain and a dairy farm. He is currently in the first year of MSc Animal Sciences after completing his bachelor's in Animal Sciences at WUR. In his studies, he specialises in dairy cattle and systems approach in animal sciences. As a manager, he was in charge of all the communication and planning and was also leading the group throughout the process. During this project, he worked mainly on the aspects of manure management.

Larissa Groenwold (Secretary) – Larissa grew up on a dairy farm in the north of the Netherlands She is currently a first-year master student in Biosystems Engineering, following a track in farm technology. She did her bachelor Industrial Engineering and Management at RUG. Currently, she also works in logistics at the Ministry of Defence. She used her knowledge to focus on organisational and legal aspects. As a secretary, Larissa also kept track of meetings and took the minutes.

Clément Garçon (Controller) - Clément is a second-year student in MSc Animal Sciences, majoring in animal nutrition. Before coming to the Netherlands, he completed his bachelor's in Agriculture in France. As the controller of the group, he took take care of the weekly agenda and the budget. He also used expertise on animal nutrition to work on the pig diets.

Jelle Janssen (Team member) – Jelle is in the second year of MSc Organic Agriculture, doing a specialisation in agroecology. Before that, he completed his bachelor's in Economics and Governance at WUR, specialising in agricultural economics. He grew up on a dairy farm in Achterhoek. Thanks to his expertise on crop rotation, cultivation techniques and agroecology he worked on designing a relevant crop system in the arable farms.

Gervas Felix Ilomo (Team member) - Felix is from Tanzania, where he also completed his bachelor's in Animal Sciences. Thereafter, he worked at a feed mill and animal feed research farm for a few years. Currently, he is in the second year of MSc Animal Sciences, majoring in animal nutrition. For this project, he mainly focused on developing the pig diets.

Pepijn Heerkens Thijssen (Team member) – Pepijn is in the second year of MSc Management, Economics and Consumer Studies, following a specialisation in business studies. He did a bachelor's in Business and Consumer Studies at WUR as well. During this project, among other things, he focused on building the collaborative framework of the cooperation between Vallei Varken and the arable farms.

Appendix II: Interview questions and summaries

Questions for the pig farmers

First thank the farmers for their time and give a short explanation of the purpose of the project and the interview. Ask permission to record the interview

Historical Background

- Can you tell a brief history of the farm?
- Why did you become a farmer?
- What goals do you want to achieve?

General farm information

- How many people are working on the farm and how is the work organised?
- How many pigs do you have on the farm? And in which different growth phases are the animals?
- How many hectares of land do you have?
- Who are your most important trading partners?
- What does your current revenue model look like in terms of buyers of the pigs? And manure
- Are there any particular differences in requirements for carcass quality (fat, weight, …) with Vallei Varken compared to conventional pig farming companies?
- Do you have air scrubbers? If so, what do you do with the water stream coming from it?

Feed

- How is the pig feed currently acquired?
- What is the composition of the feed?
- What is the current feed system?
- How many tonnes of feed do you need per week?
- Do you have any remarks about the current feed you are using in terms of quality, growth performance etc.?

Manure

- How much manure do you currently produce per year?
- How and how much manure can you store?
- How often do you empty your manure pit?
- What are the average manure disposal costs?
- How much manure can you apply on your own land?
- How much manure is transported from your farm?
- Do you add something to the manure?
- How much is your manure surplus? And how much do you have to pay for the manure processing obligation?

Challenges/future goals

- Do you face any organisational challenges? For example: pigs' health, personnel, excess of manure, legal issues etc.
- Do you face any production challenges and how do you cope with that? For example: production costs, overproduction, meeting quota's etc.
- What would you like to improve in the next 5 to 10 years?
- Would you invest in a silo and hammer mill etc. to produce part of the feed yourself?

The collaboration/the project

- What are the advantages of your current collaboration with Vallei Varken?
- What benefits do you expect from a collaboration with arable farmers in terms of exchanging manure for pig feed?

- What would stop you from collaborating with arable farmers?
- We would like to stay in contact with the participating farmers during our project, so we can ask questions and involve your views. Would you be open to this? Which way of communicating do you prefer?

Thank the farmer for the interview.

Questions for the arable farmers

First thank the farmers for their time and give a short explanation of the purpose of the project and the interview and the project. Ask permission to record the interview

Historical Background

- Can you tell a brief history of your farm?
- What is your motivation to farm and to produce crops?
- What goals do you want to achieve?

General farm information

- How many hectares of arable land do you have?
- What crops do you currently grow and why these crops?
- What is the distribution of the crops on the hectares?
- What is your current farm managing system, rotation?
- How do you see your farm in the future? What are your long-term goals?

Crops

- Do you have capacity to store crops?
- What is the average yield per hectare per crop?
- What do you do with crop residues?
- Do you meet the demand of your buyers?
- To whom do you sell your crops? Are they the final buyer of the crops?
- How is the current cooperation with other farmers, retailers, companies etc?
- Do you have any interesting crops that you would want to grow in the future?
- Would you be interested in including legume crops in your rotation?
- Would you be interested in producing crops for Boni and/or De Kroes?

Manure

- What is your soil type? How does this affect what you can produce/your yield?
- What types of artificial fertiliser and manure do you apply and what is the ratio?
- To what degree can you swap current fertilisers with pig manure?
- What is the composition of the current fertiliser you use?
- What is your requirement for manure in terms of NPK?
- How do you calculate the amount of fertiliser you need?
- When do you need the manure and how often do you apply it on your land?
- Why do you want pig manure?
- Would you be interested in more pig manure if the phosphate level is lower?
- What is the financial situation of the manure?

Collaboration with Vallei Varken

- What is your motivation to participate?
- What is your expectation of this collaboration?
- What opportunities do you see?
- Do you expect to produce crops for pig feed and/or valorise by-products?
- To what degree are you willing to change your operations for this collaboration?
- The project as we knew it is called ‘circular pig farm’. What do you think about the word 'circular’? What does it mean to you?
- What do you think of feed-manure exchange?
- Do you think you will encounter any problems during his project?

- We would like to stay in contact with the participating farmers during our project, so we can ask questions and involve your views. Would you be open to this? Which way of communicating do you prefer?

Thank the farmer for the interview.

Summaries of interviews

Summary interview VV1

Maureen, Jelle and Larissa interviewed VV1 via Teams on the 22nd of January in Dutch. The interview lasted for almost 2 hours, as VV1 is very passionate about his farm and company and wanted to share his ideas on how the Vallei Varken (VV) concept can develop the coming years.

We first gave a short introduction to the project and then started with our questions. As the first question was on the history of the farm, VV1 came with a story about his farm and company VV. A lot of question we had were already answered by this story. It included the high health standards of his pigs, his cooperation with Boni and De Kroes and other partners and the revenue model. Also, his goal to make the feed of VV circular with the waste streams of Boni and De Kroes and crops grown by Dutch farmers. VV exists of three pig farms, two fattening farms and one breeding farm. Arable farmers that join VV can produce crops for feed or for Boni and de Kroes. For him circularity is everything within one hour from his farm, more or less everything within the Netherlands. During this story, we asked additional questions for more clarity on certain subjects.

They selected a specific breed for the wishes of Boni and De Kroes in combination with Topigs Norsvin. So the meat of the pigs had less ham and more bacon in.

He has a feeding computer, CDI, to make a mix of the feed. If there is a waste stream, he can mix it himself with the feed he gets from Agrifirm. Then he needs to know the composition of the waste stream and Agrifirm has to change the composition of the feed to keep it optimal. Also, some liquid feed, based on water and with waste streams included. He has the possibility to store waste products at the farm, however it is easier to get the feed completely from Agrifirm. He feeds 46 tonnes of feed per week.

His 3800 pigs produce 3500 m3 of manure per year. Manure is a high-cost item and therefore he wants to attract arable farmers in the VV concept. So, they have a partner to dispose their manure and do not have a trader in between. They should come to an agreement on when the arable farmer needs the manure, it is better to store it first, so he knows the exact composition of the manure. That is better than when the arable farmer calls and wants the manure directly. Every farmer has a manure processing obligation ('mestverwerkingsplicht'), when he gives all his manure directly to the arable farmers have to buy off the obligation. So, we should process the manure or buy it off. The percentage of processing manure differs per region in the Netherlands. Depending on the market he buys VVO's around 6000 euro. The average price for manure disposal is yearly 78,000 euro. The manure of sows is used when there is a need of nitrogen. The manure of pigs has more phosphate and less nitrogen. All the farms have a manure analysis report on the composition of the manure.

VV is looking for ways to improve the concept. He has a lot of ideas for the future and plans that they are already introducing. Chips in the ears of the pigs, quite with cutting tails, energy from solar panels, working with a manure processing company, expand the market and maybe do something with insects as replacement for soy in the feed.

The main goal of VV1 is to have his own Vallei Varken feed. How can he make that as much circular as possible? All waste streams from partners of Vallei Varken go to Agrifirm in Veghel. Less input from other countries. Try to get all partners and input in a range of 1 hour. It is for the arable farmers interesting to produce food for Boni and or de Kroes and be part of Vallei Varken. In exchange for the manure of the pigs.

Summary interview VV2

Maureen had an interview with VV2 at his farm on the 18th of January. Due to Corona, only one person could visit the farm. We gave our questions for the first interview to Maureen, so she could ask him. For the second round of questions, we contacted him via WhatsApp on the 18th of February.

VV2 has around 1700 pigs and wants to expand in the future. He would like to have his own sows. He loves to work outside with the animals. He also has some arable land (17 hectares) on which he grows corn, and also rents out land to arable farmers. The pigs arrive at an age of 9/10 weeks and leave the farm after 3.5 months. He delivers 108 pigs and gets 120 piglets per week. Not all his pigs are in the Vallei Varken concept, only around 70 pigs per week, he would like to have 100% in the Vallei Varken concept, however the demand is not enough.

He feeds on average 32 tonnes of feed per week. The current feed is sufficient, however the pigs grow too fast. He would like them to grow slower.

His pigs produce 2000 m3 of manure per year, of which he disposes 400-500 m3 to the arable farmer he works with and he applies 500 m3 on his own land. Manure is his main financial cost, he has to pay around €17.50 per m3 of manure that he cannot apply to his own land. He sent us his manure analysis.

About the VV pigs he says: the price deal is different and set. Healthy pigs without antibiotic. Since they are born, very few treatments, makes them more robust and they need less treatment. Lot of disinfectant. No mixing of different piglet siblings.

Summary interview VV3

Maureen, Coenraad, Jelle and Larissa interviewed VV3 on the 28th of January via Teams in Dutch. Besides this interview, we also asked him some additional question via e-mail. We first gave a short introduction on our project and the purpose of the interview.

VV3 has a breeding farm that he took over from his parents, with 660 sows of which around 30 per week farrow. His piglets leave the farm at an age of 10 and leave to the other VV farms. Only 10% of the piglets can't go to VV as there is not enough capacity. Those piglets are sold to others. He has also some arable land himself, around 40 hectares on which he can apply part of his manure. He is working with VV as he gets to know more about the process and how his pigs are doing. He gets more feedback from VV than he would get usually. He works with VV for 1.5 years now.

His arable land is used to grow potatoes, lilies and silage maize by other farmers. He doesn't want to grow the potatoes himself. The farmer that is growing the potatoes could be interested in doing something different with his potatoes. Someone of Agrifirm has been looking at his arable land and see if there were possibilities to grow something for the pigfeed. However, he wants to apply most of his own manure on his land which has a high nitrogen level, so a lot of crops cannot be used.

He feeds his pigs dry feed because of its simplicity compared to liquid feed. The sows get all the feed in the morning to grow their stomach. Pigs in the farrowing pen are fed twice a day to stay fit. He feeds 1250 kg of feed per sow per year.

Piglet manure and sow manure are different and get separated. The manure from the farrowing is very thin in terms of quality. He tries to get rid of the manure as much as possible himself as transport is the most expensive. The farrow pen manure and sow manure are viscous/thin enough so he does not have to process it, with sedimentation he separates the solid and liquid fraction. The average manure compositions in terms of nitrogen and phosphate are, 2.5 g/kg N and 1.5 g/kg P_2O_5. He has a total of 3000 m3 manure. Certain crops need certain manure. He is surprised that the majority of farmers do not care too much about manure quality. The serious arable farmers know what they want in terms of manure. His advice is to store 80% and then see what the quality is and what to add. Thick pig manure is phosphate rich and has to be separated. The price for manure disposal is between €15 and €17.

Summary interview VV4

The whole team interviewed VV4 via Teams in English on the 21st of January. After this conversation, we have had a lot of contact with VV4, as he was our main contact for VV. He managed to get answers on additional questions we had, also from the VV farmers.

The first meeting was an introduction of us and of him, to get to know each other. He gave us a lot of information on the concept of VV. He has been the veterinarian of VV1 for years and together they made a plan to make sure the pigs are very healthy. So, he is not there to cure the animals, but too coach VV1 on how to keep his pigs healthy. There is no antibiotic use because of the precise and structured way of working by VV1. There is a lot attention paid to internal hygiene, sisters and brothers are kept together, so there is not mixing of the animals from different litters. The pigs grow around 900 g a day and are slaughtered at 96 kg. Because they are so healthy, they can grow very fast. Problems with Boni if they grow too fast, then the structure is not good, too much water in the meat. Quality of meat has to be the best.

The collaboration with Boni is unique, no trader in between. Boni wants to have more fat in the meat, so a genetic pig was chosen based on the wishes of the retailer. The collaboration is based on a fixed cost price, where all labour, investment, interests are also included. Another stakeholder is De Kroes, which uses the meat of Vallei Varken for their catering. Bread that is left-over from Boni is used for the feed of the pigs. VV is looking for more circularity throughout the whole chain. That is why they want to have arable farmers in the concept as well. Manure of pigs is not always wat arable farmers want, so how can we make the arable farmers happy with the manure we have.

After this meeting we have been in touch with VV4 multiple times. He provided us the manure analysis of VV1 and VV2, gave us some information on the manure processing, prices of the current feed and the feed labels of Agrifirm. VV4 ensured that we receive the information from the other VV farmers as soon as possible, as it was difficult to contact the VV farmers directly at times.

Summary interview AF1

Maureen and Pepijn went to see AF1 at his farm on the 20th of January. On the 19th of February Larissa had a phone call with him for some additional questions all in Dutch.

He told us about how he changed from a dairy farm to an arable farm, as he didn’t want to depend on the animals. He started with 25 hectares that he owns and is now renting more hectares to have a total of 60 hectares in use on sandy soil. The current crops he grows are potatoes for Aviko and Avebe, onions, grains and silage maize. His grain products are already processed to pig feed, however not to Agrifirm. He is open to sell it to Agrifirm, as long as he will receive more or less the same price for it. He is building a storage for the onions, so he can sell them when the price goes up. He is happy with the crops he currently grows and does not want to grow legumes as they can negatively influence the growth of onions the year after.

We asked him about his manure need and why he wants to have pig manure. He currently uses cattle manure and artificial fertiliser (CAN27 and Patentkali). He would like to have the liquid fraction of pig manure as it has a high level of nitrogen and lower level of phosphate. With this manure he can reduce his use of artificial fertiliser, which is better for the soil. He wants around 1500 kg of nitrogen in pig manure yearly, depending on the composition of the pig manure. The manure is mostly applied in spring, sometimes in August as well. He does not apply the manure to the land himself.

His motivation to participate in the collaboration with Vallei Varken is financial. Sustainability is important as well as the soil fertility and rotation. Soil health is important.

He provided us his crop registration (teeltregistratie).

Summary interview AF2

Larissa spoke with AF2 in Dutch, at his farm on the 12th of February and on the phone at 17th of February for some additional questions. The interview on the farm was to introduce him to VV and the project and investigate the possibilities if he would be an interesting partner for VV. He first gave some background information on his farm and his reasons to be a farmer. It is a family farm and he took over from his father. He has 110 hectares of land in use on sandy soil on which he grows potatoes, sugar beets and brewing barley. Besides is own land and rented land, he also trades land with farmers in the area for the 1:4 crop rotation. Those farmers grow grass or silage maize on his land.

He currently sells the potatoes to Avebe, the sugar beets to Cosun, and the barley is sold to Agrifirm. However, he is open to change and grow other crops in the future. For example, sweet potatoes or pumpkins as there is a market for it. As long as it can be harvest before October. He prefers to not grow legume crops currently and does not know much about it yet, but is interested as it can be profitable.

We also asked him about the manure needs he has. His farm is located on sandy soils and he currently uses pig manure, cow manure and digestate and tries to limit the use of artificial fertiliser. He has his own manure storage, existing of two silos of 900 m3 and 1100 m3 which are filled with manure in December. The maximum amount of pig manure he can use on his land is 500 m3, due to the amount of phosphate allowed on the land. AF2 performs a soil analysis every year, on which he bases his fertilisation plan.

For the collaboration with VV he is very interested in the possibilities and does not have any expectations. He is curious about the plans we are going to make for this collaboration.

He provided us his soil analysis of last year and the analysis of the pig manure he had last year.

Summary Agrifirm

On the 2nd of February Coenraad, Clement, Felix and Larissa had an interview with the product marketing manager pigs of Agrifirm in English on Teams. Thereafter Larissa had a phone call with the salesman of Agrifirm for some additional questions on the 22nd of February.

The product manager gave us a short introduction on Agrifirm, they are market leader in feed for ruminants and the main compound feed producer in the northern of Europe. Their production facilities are located near canals, transport by boat is cheapest.

He knows VV1 for a long time, before VV started he was already the salesman of VV1. Trust is very important and they try to improve the process together. A triangle of veterinarian, farmer and feed company is important and they collaborate as a team.

Currently they do not process specific feed for Vallei Varken, however this could be in the future. They are willing to fulfil wishes and requirements of the farmers or retailers, but that is not profitable for them yet. He gave an example in which they already do that: Hamletz.

The main ingredients that are used in diets are for 70% grains (wheat, barley, silage maize and rye) and 20% protein rich sources (rapeseed meal, rapeseed flakes, soya meal, sunflower seed meal and what semolina). The other 10% consists of oils, fats, molasses, salt and minerals (calcium, phosphate). He mentions the seasonal variation causing the current composition fluctuates due to raw material prices and the nutrient contents of the raw materials. They base the diets on nutritional levels, within boundaries. They try to continuously optimise the composition of the feed. For piglet feed is more strict and price is less important. For growing/finishing pigs bigger changes are possible.

He also mentioned some restrictions for adding by-products to the feed. Onions are not possible, they use large amounts of raw materials so it should be available throughout the year. Currently cereals com from France and Ukraine, protein rich sources from South America. Enzymes and amino acids are also added to the feed.

Their goal in the end is to help farmers!

Summary De Kroes and Boni

On the 28th of January Maureen had an interview with Boni and de Kroes via Teams about the collaboration with Vallei Varken. Larissa had a phone call with De Kroes for some additional questions.

The fresh vegetables for De Kroes are processed by Groenteproductie Flevoland and the potatoes by Schaap Holland. It is possible for an arable farmer to produce vegetables for them. If the farmer knows what type of vegetable, how much and the price he wants to have for it. They can negotiate about the possibilities. The crops they use in large volumes are onions, carrots, leeks, chicory, endive and Chinese cabbage. Besides, they used 700 tonnes of peeled potatoes last year.

They are happy with the transparency of the supply chain and that they have an influence on how the pigs are grown. It is only time consuming to have such a close partnership. For the coming years they hope the transparency will even become bigger, especially to the consumer.

Appendix III: Stakeholders long-list

The Science Shop is the commissioner of the project, represented by Francine de Jonge. They are part of the Wageningen University and Research, supporting research projects from organisations or civilians with limited budget. Science Shop has a stake in the general development and implementation of circular agriculture in the Netherlands. Science Shop regards Vallei Varken as an interesting partner for such a project due to their willingness to apply circular agriculture. The project has to contribute to solving a societal problem and produce promising outcome which can be used in further research. Finally, the Science Shop has a steering committee that will also be present at the final presentation of the project. The commissioner wants to show the feasibility of circular agriculture in practice and obtain knowledge on how to best set up a circular pig farming system that can be applied elsewhere (ScienceShop, 2020). The commissioner wants to show the feasibility of circular agriculture in practice and obtain knowledge on how to best set up a circular pig farming system that can be applied elsewhere (ScienceShop, 2020)

Vallei Varken's goal is to increase the stability and add value to all steps of the supply chain of pork, while simultaneously striving for high animal welfare and low environmental impact. They currently do this through agreements with different actors in the chain, but they also want to involve further actors. Vallei Varken also aims at solving their problems related to manure surplus by exploring the possibilities to exchange their manure with local arable farmers for crop residues, to be processed into feed by Agrifirm.

- Fattening farm (VV1)
- Fattening farm (VV2)
- Breeding farm (VV3)
- Veterinarian (VV4)
- The pigs

Two arable farmers want to investigate the possibilities to exchange crop residues for manure with Vallei Varken. They want to obtain pig manure that has more consistent nutrient contents and they want to increase their profits by valorising the by-products of their cash crops. In order to investigate the possibilities for a collaboration they need to know which types of crops are suitable for such an exchange, and they need to be confident that the manure of Vallei Varken is of better quality than that on the market.

Agrifirm is a Dutch feed cooperative that has the mission to create sustainable, measurable and relevant value for farms, fields and forage industry (Agrifirm, 2021). They are the current feed supplier of Vallei Varken and willing to cooperate in a circular agricultural system. Agrifirm has factories all over the Netherlands. Besides being a feed supplier, they also have a consulting and advising role.

The government is a stakeholder as there are many regulations the farmers have to consider managing their farms. Policy makers could also obtain knowledge from this collaboration.

The Vallei Varken product chain also has an indirect interest in the problem. It is important that the meat from the pigs can be processed and sold for a fair price. The retailers want to be able to sell good quality meat.

- Export slaughterhouse: Gosschalk
- Retailers
    - Boni
    - Catering company De Kroes
    - Several local butcheries
    - Boerenhart
- Manure transporters (VV1, VV2 and VV3)
- Miscellaneous parties
- Artificial insemination company
- Transport companies

Society has an interest in food production in two ways. Firstly, it depends on agriculture for the provision of sustenance. Secondly, it is influenced by positive and negative externalities that differ based on the type of products that are produced, and the way in which this is done. As citizens, people have an interest in food production through such topics as food security, a clean and healthy environment, job availability, landscape aesthetics, and animal welfare. In the role of consumers, they are interested in the price, quality and safety of food. Residents have an interest in diminishing pollution and nuisances, as well as in the appearance of the farm as well as the availability of local products.

Our ACT Team has a short-term interest in the potential for collaboration and the success of the project, because this may allow us to get a high mark, to create a product that we are proud of, to learn as much as possible, and to have a real-life impact. Surely we will be interested in the way the project develops in the future, but after our contribution is done our direct involvement stops.

Appendix IV: Feed analysis

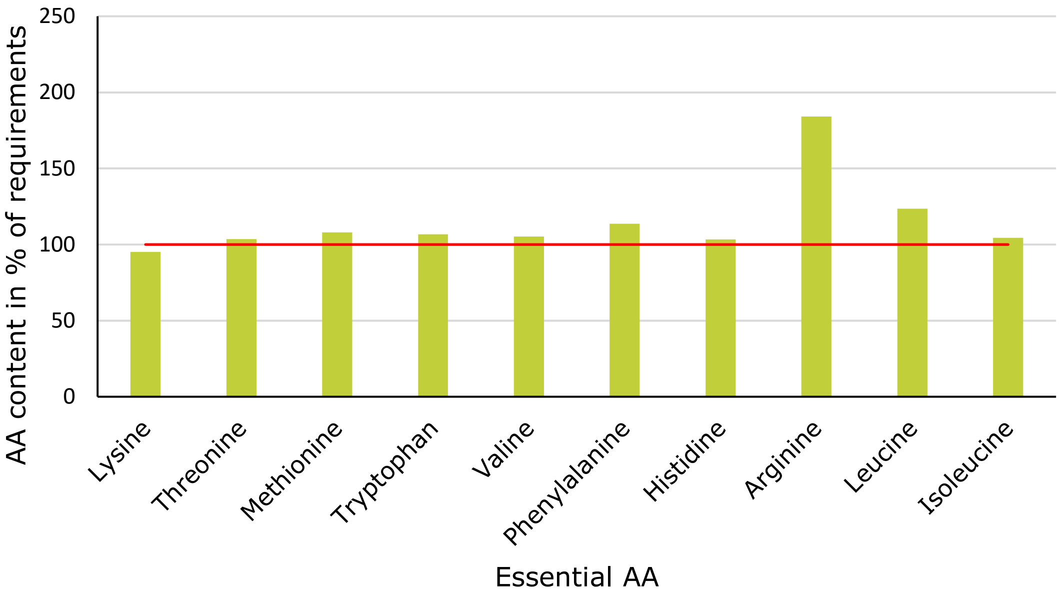

Figure 1: Essential amino acids profile of the diet of scenario 1, expressed in percentage of NRC requirements

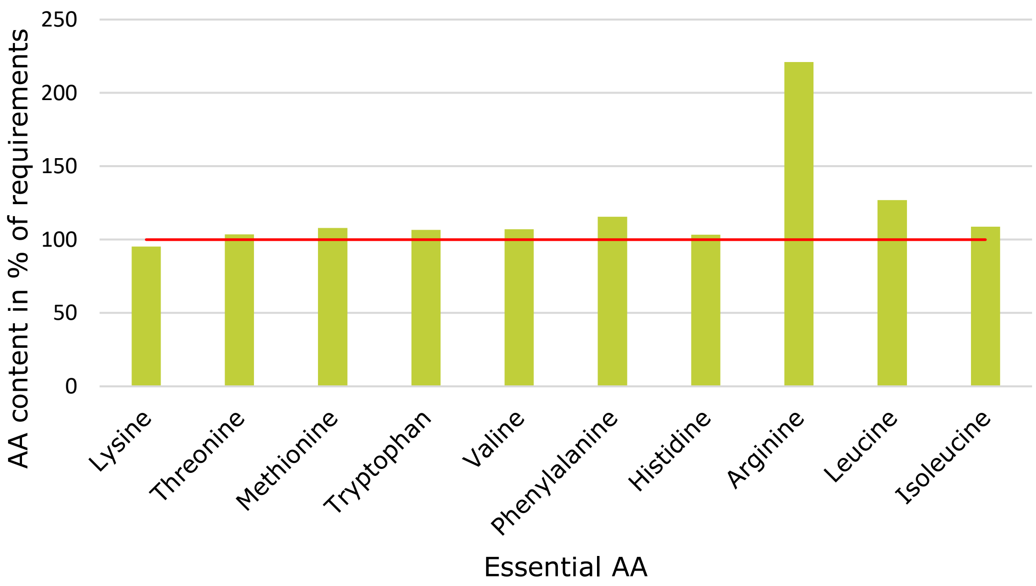

Figure 2: Essential amino acids profile of the diet of scenario 2, expressed in percentage of NRC requirements

Appendix V: Crop selection

Table 21: Ranks and legend to the corresponding colour indication per selection criterium

Rank	Harvest period	Net Margin	Feed rating
1	Falls between July and September	>€2000	Feed crop
2	Falls partly between July and September	€1000-€2000	Usable by product(s)
3	Too early	€500-€1000	Potential feed crop
4	Too late	<€500	Potentially usable by-product(s)
5	-	NA	Not usable

Table 22: The crops currently grown on the arable farms, ranked based on the selection criteria used in 5.2

Common name	*Latin name*	Harvest period	Gross margin (€/ha)*	Pig feed rating
Wheat (summer)	*Triticum aestivum*	Mid-August	1069	Feed crop
Barley (summer)	*Hordeum vulgare*	Mid-August	889	Feed crop
Onion (from seed)	*Allium cepa*	September	2107	Not usable
Sugar beet	*Beta vulgaris*	September until December	2508	Usable by product(s)
Potatoes (for starch)	*Solanum tuberosum*	July until October, early and late varieties	1026	Usable by product(s)
Maize	*Zea mays*	late August/early October	1317	Potential feed crop

* price given uses market price of crop, not specifically as feed: may be lower in practice; own mechanisation.

Table 23: Cereal crops (scenario 1) ranked according to columns 3-5, respectively

Common name	Latin name	Harvest period	Gross margin (€/ha)*	Feed rating	Matches criteria?
Wheat (winter)	*Triticum aestivum*	Late July/early August	1170	Feed crop	Yes
Wheat (summer)**	*Triticum aestivum*	Mid-August	1069	Feed crop	Wheat (summer)
Barley (summer)**	*Hordeum vulgare*	Mid-August	889	Feed crop	Barley (summer)
Barley (winter)	*Hordeum vulgare*	Late July/early August	824	Feed crop	Yes
Oats	*Avena sativa*	Late July/mid-August	660	Feed crop	Yes
Spelt	*Triticum spelta*	Late July/early August	NA	Feed crop	NA
Triticale	*Triticale x Triticale*	Late July/early August	481	Feed crop	No
Rye (winter)	*Secale cereale*	Summer	54	Feed crop	No
Maize (kernel)	*Zea mays*	Late September/late October	1445	Feed crop	Yes
Sorghum	*Sorghum bicolor*	Late September/early October	NA	Potential feed crop	NA

* price given uses market price of crop, not specifically as feed: may be lower in practice; own mechanisation

Table 24: Protein crops (scenario 2) ranked according to columns 3-5, respectively

Common name	Latin name	Harvest period	Gross margin (€/ha)*	Feed rating	Matches criteria?
Pea	*Pisum sativum*	August	1269**	Feed crop	Yes
Faba bean (summer)	*Vicia faba*	late August/early September	1066	Feed crop	Yes
Faba bean (winter)	*Vicia faba*	summer	NA	Feed crop	NA
White Lupin	*Lupinus albus*	late August/early September	NA	Feed crop	NA
Blue Lupin	*Lupinus angstifolius*	late August/early September	NA	Feed crop	NA
Flax	*Linum usitatissimum*	August	876	Usable by product(s)	Yes
Rapeseed (summer)	*Brassica napus subsp. napus*	mid/late August	NA	Usable by product(s)	NA
Camelina	*Camilina sativa L.*	August	NA	Potential feed crop	NA
Sunflower	*Helanthus annuus*	NA, before autumn	NA	Usable by product(s)	NA
Rapeseed (winter)	*Brassica napus subsp. napus*	June	647	Usable by product(s)	Yes
Lucerne	*Medicago sativa*	Multiple cuts until late autumn	706	Potential feed crop	Yes
White clover	*Trifolium repens*	Multiple cuts until late autumn	NA	Not usable	No
Soybean	*Glycine max*	October/November	757	Feed crop	No

* price given uses market price of crop, not specifically as feed: may be lower in practice; own mechanisation

Table 25: Vegetable crops (scenario 3) ranked according to columns 3-5, respectively

Common name	*Latin name*	Harvest period	Gross margin (€/ha)*	Feed rating	Matches criteria
Chinese cabbage	*Brassica rapa var. Pekensis*	July	NA	Not usable	Yes
Leek (summer)	*Allium porrum*	June til August	15487	Not usable	Yes
Onion (from seed)**	*Allium cepa*	September	2107	Not usable	
Leek (autumn)	*Allium porrum*	September until December	8755	Not usable	Yes
Potatoes (for consumption)**	*Solanum tuberosum*	July until October, early and late varieties	4442	Potentially usable by-product(s)	Yes
Pumpkin	*Cucurbita maxima*	September/early October	NA	Not usable	Yes
Chicory	*Cichorium intybus* var. *Foliosum*	September until December	3554	Not usable	Yes
Leek (winter)	*Allium porrum*	January until June	18292	Not usable	No
Endive	*Cichorium endivia*	November	NA	Not usable	No
Sweet potato	*Ipomoea batatas*	October/November	NA	Not usable	No
Carrots	*Daucus carota*	October/November	4363	Not usable	No

* price given uses market price of crop, not specifically as feed: may be lower in practice; own mechanisation

** crop is in current rotation of one or both farmers