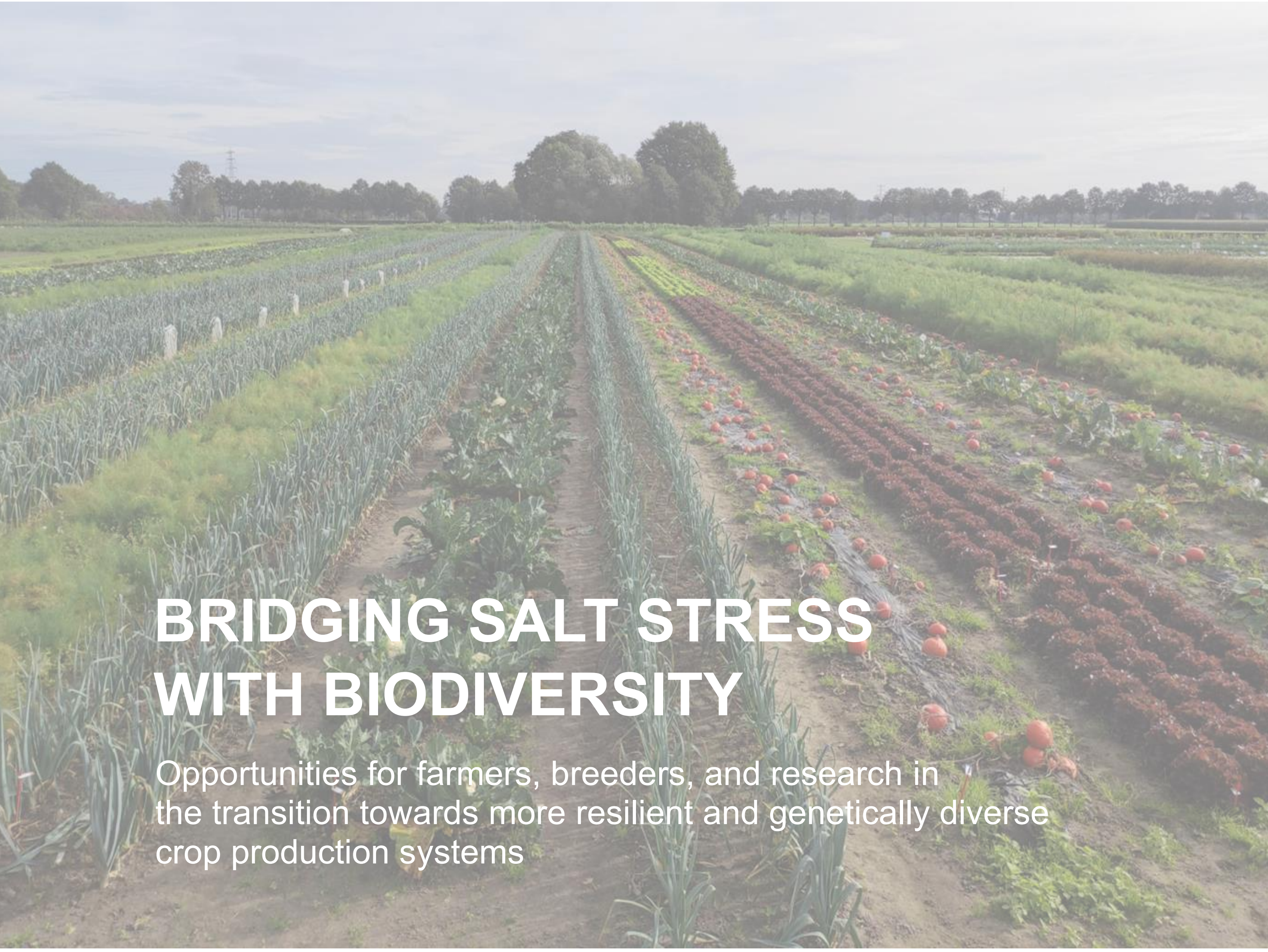

BRIDGING SALT STRESS WITH BIODIVERSITY

Opportunities for farmers, breeders, and research in the transition towards more resilient and genetically diverse crop production systems

TEAM 3.181

The role of plant and animal breeding in transitioning towards resilient food systems

Authors:

Kelvin Besenzon, Hanna Brandjes, Elisa van Geldorp, Maxime Landwier, Michelle Pijpers & Reza van Welie

October 2023

Commissioner: Ir. Sipke Joost Hiemstra

Contact Details

Commissioner: Ir. S.J. (Sipke Joost) Hiemstra

- Head of the Centre for Genetic Resources, The Netherlands (CGN) of Wageningen University & Research
- Email: sipkejoost.hiemstra@wur.nl
- Phone: +31 317 480506

Team Manager: Hanna Brandjes (contact person)

- Email: hanna.brandjes@wur.nl
- Phone: +31 6 57128656

Team secretary: Maxime Landwier

- Email: maxime.landwier@wur.nl
- Phone: +31 6 50919720

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Executive Summary

Food production systems have become very specialized, resulting in a loss in biodiversity and a less resilient system. Because of climate change and other challenges, this might lead to problems for food security. Therefore, Dutch and European policy makers are looking for ways to bring biodiversity back in food production systems. The Kennisbasis project “New system requirements for breeding for resilient production” has been called to life to advise the Dutch government on the transition towards more resilient food production systems. This report is an advice to the Kennisbasis project with the most promising opportunities for the transition to biodiverse, salinity-resilient crop production systems in the Netherlands.

To come up with opportunities for research, as well as for farmers and breeders, we did a literature study on salinization, biodiverse crop production systems, and promising combinations of underutilized crops for salinity resilient systems. We interviewed experts on soil salinity and intercropping, and sent a survey to farmers. Quinoa and proso millet came forward as the most promising crop combination. These were used in a hypothetical system for an analysis. Through our research, challenges were identified and divided into six different clusters (Research, Communication, Breeding Focus, Regulations and Funding, Farm Management and Sales Market). The clusters were ranked on priority via a decision matrix.

Our first advice to the Kennisbasis project is to focus their research on current knowledge gaps in plant-plant and plant-soil interactions, beneficial crop combinations, resilience to multiple stressors and cultivation of underutilized, salt tolerant crops. Regarding communication, the main challenge was the limited communication between the KB project and its stakeholders. Our advice here is to set up a communication plan with the help of a new ACT group specialized in communication, or to set up a Professional Field Committee. Lastly, we advise the Kennisbasis project to design a protocol for farmers on the transition towards biodiverse resilient food production systems. This is an important long-term opportunity to implement the knowledge gathered from research and link it to practice.

Key words: Soil Salinity, Intercropping, Quinoa, Proso Millet, System Analysis, Opportunities.

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1. Introduction

Over the past centuries, food production systems have become very specialized, due to an increase in knowledge, improved farming techniques and a higher food demand (Bos et al., 2013). Especially the discovery of synthetic fertilizer and pesticides, and advances in breeding, decreases the necessity of crop rotation and animal manure (Bos et al., 2013; Venkatramanan et al., 2020). It allowed farmers to focus on productivity and specialize in either crops or livestock. Because of this, the genetic and species diversity in agricultural fields has decreased. To illustrate, nine crop species are responsible for 66% of the crop production worldwide, the so-called staple crops (FAO, 2019). More specifically, only three crops make up for 90% of all cereal production in Europe (Schils et al., 2018). A decrease of crop biodiversity (in this report used as a term for genetic diversity between species, not within species) increases the vulnerability of a food production system to stressors and decreases the system's recovery. This is because different species react differently to stressors, so together they form a buffer to overcome a stressor (Lin, 2017). Resilience, the capacity to recover and maintain particular properties in the face of stressors of various kinds, is decreasing with a loss of biodiversity, as recovery is not maintained (FAO, 2019). Especially now that stressors like drought or salinity (an increased salt concentration in the soil) are becoming more common challenges because of climate change, this can become a huge problem for food security in the future (Arora & Dagar, 2019). For example, drought increases the need for irrigation, while irrigation increases soil salinity (Srivastava, 2019). In turn, high soil salinity also threatens food security as one of the major abiotic stressors or current and future crop systems (Harper et al., 2021; van 't Hoog et al., n.d.). This is an ongoing downward spiral. In response to these challenges, Dutch and European policies are working towards more sustainable and resilient food systems, like with the Green Deal (European Commission, n.d.).

Table 1 Glossary. Terms are in alphabetical order.

Term	Description
Biodiversity	Here: genetic diversity between species within a certain area.
Glycophytes	Plants that are relatively intolerant to salt and soil salinity.
Halophytes	Plants that thrive and successfully go through their life stages under elevated salt level conditions.
Intercropping	Cultivation of two or more crop species, varieties, or genotypes in the same field, at the same time.
Mulching	Covering of the soil with organic material like woodchips or sawdust to reduce evaporation
Resilience	The capacity to recover and maintain particular properties under stressed conditions.
Salt tolerant species	Plants that can grow relatively well on saline soils.
SCFS	Strip Cropping Farming System, as used in our system analysis
Short food chain	Farmers that produce directly for the consumers, or with a single link in between.
Rich picture	Illustrated overview of a system as part of a system analysis, which includes all relevant processes, inputs, outputs and stakeholders.

At Wageningen University and Research, a Kennisbasis (KB) project titled "New System Requirements for Breeding for Resilient Production Systems" has started to set up the WUR research agenda and advise Dutch and European policies on this topic of transitioning to resilient food systems (Hiemstra, n.d.). The KB project is a joint effort of three Wageningen Research groups: Wageningen Plant Research, Wageningen Livestock Research, and Wageningen Environmental Research. The collaboration of researchers was asked to advise policy makers, breeders, food companies and farmers on how to make better use of domesticated biodiversity (both crops and livestock) and biodiverse production systems in order to facilitate a transition towards more sustainable, resilient, and healthy food production systems. Researchers of the KB project hypothesize that increasing biodiversity in production systems will contribute to increased resilience at farm and farming system level. To support this, the project group has come up with five different production systems with increased biodiversity, suitable for the

Netherlands. These production systems include mixed cropping, sustainable greenhouse horticulture, nature-inclusive dairy, climate smart forestry and agroforestry (Hiemstra et al., 2022). However, for these systems to function properly, more research is required on various topics.

As mentioned before, crop production is affected by a plethora of biotic and abiotic stressors. Food safety therefore requires systems that are resilient towards all these stressors. In this ACT project, however, we will focus solely on soil salinity stress. Because of rising sea levels and increased salt concentrations in irrigation water, soil salinity increases in farmlands all around the world (Wicke et al., 2011). This soil salinity reduces the water uptake of plants, and simultaneously causes accumulation of sodium and chloride in the soil, up to toxic levels. Each year, 0.3 to 1.5 million hectares of global arable land are lost due to salinization (Harper et al., 2021). The FAO estimated that because of this, the economic loss per year is 27.3 million US dollars (FAO, n.d.). In the Netherlands salinity issues are increasing as well, especially in coastal areas (van Bakel et al., n.d.). Since plant species have different tolerance levels to salinity, we believe it is interesting to find out which salt tolerant crop species could be used to increase both biodiversity and resilience in modern and future crop production systems.

Our team of Biodiversity Boosters will identify opportunities and potential of different combinations of crop species to be able to deal with salinity stress and to make farming systems more resilient to salt. We will give advice based on the opportunities we find, not only for researchers, but also for breeders and farmers since they are part of the solution too. We will specifically focus on crops that are underutilized (in the Netherlands), as their introduction already increases biodiversity and because they might have a lot of unexplored potential. The main research question is as follows:

What is required to enhance genetic diversity in crop production, in terms of opportunities for farmers, breeders, and researchers, to assist a transition towards more salinity resilient food production systems in the Netherlands?

To answer this question, we will first answer the following sub questions:

1. *What are the current practices and known strategies against salinity stress by means of enhancing genetic diversity?*
2. *What are the current challenges for Dutch crop farmers regarding intercropping and salinity stress?*
3. *What are the current strategy and challenges for plant breeders regarding salinity stress and plant-plant interactions?*
4. *What crops or crop interactions can potentially increase resilience against salinity?*
5. *What are the trade-offs of implementing intercropping in a salt-stressed crop production system?*

We will answer these sub questions through a literature study, interviews with experts and a farmer survey, and an analysis of a hypothetical crop production system located in the Netherlands. From there, research opportunities for the KB project and other researchers will come up, as well as opportunities that should be communicated to farmers and breeders.

1.1 Reader's Guide

This general introduction is followed by an introduction to current farming practises around the world and in the Netherlands (Chapter 2), to give a better illustration of the problem to readers that do not have experience with common arable farming practices. If a reader has sufficient understanding of this topic, the chapter can be skipped. In Chapter 3 we describe the methods that are used to answer the research questions. Chapters 4 to 7 form the results of our project. Chapter 4 contains an in-depth description of what salinity stress entails (Section 4.1), why it is a problem in the Netherlands (Section

4.2) and what is currently done about it (Section 4.3). Chapter 5 compares different types of intercropping and other ways to increase plant biodiversity. Chapter 6 describes three different ways of using salt tolerant plants to increase salinity resilience while increasing biodiversity by intercropping. Chapters 4, 5 and 6 end with a section about the challenges that came forward in that particular chapter. With that information a new, hypothetical crop production system is set up with the selected crops. This is described in Chapter 7. The trade-offs and challenges of this system are analysed in Section 8.1. The discussion continues with integrating all these different challenges and identifying opportunities to overcome these challenges. Conclusions from the entire research are drawn in Chapter 9, after which we mention the limitations (Chapter 10) and present our final advice for the KB project (Chapter 11).

2. Current Practices in Arable Farming

This chapter contains information on the current practices of arable farming. Starting with the size of arable farming worldwide, the chapter then zooms in on the Netherlands. The most commonly grown crops are described, as well as the effect of monocultures on the environment. This chapter is meant as an introduction to arable farming practices for readers who do not have a background in this field of study.

Currently, staple crops are the most extensively produced crops worldwide, forming the majority of our diets. In 2021, sugar cane was the most produced crop with 1.86 billion metric tons, followed by maize with 1.21 billion metric tons (Trading Economics, 2023). In addition, cereals, including species as wheat, rice, and maize dominate crop production.

The Netherlands is one of the biggest exporters in the world with an annual export of agricultural products valued at 65 billion euros, accounting for 17.5% of the total Dutch exports (Government of The Netherlands, n.d.). The main trade partners are Germany, Belgium, the UK and France. The Dutch agricultural sector accounts for 10% of the Dutch economy and employment (Government of The Netherlands, n.d.). In 2020, 1.82 million ha of land was used for agriculture, which is approximately 50% of the total surface area of the Netherlands (Centraal Bureau voor Statistiek, 2021). Of the agricultural land, 54% is grassland, 29% is used for arable production, and 11% for green fodder crops. The remaining land is used for horticulture (H.A.B. van der Meulen, 2021).

Figure 1 Example of a monoculture.

The staple crops of the Netherlands are grains, maize, legumes, potatoes, sugar beets and onions. The grown crops vary per region, as it depends on the climate and soil type. In the Netherlands, crops are mainly grown in monocultures (Figure 1), rotated per field of the years. This means that every year, for three or four years, a different crop is cultivated on a field. A common crop rotation schedule is consumption potato's, summer barley, sugar beet, winter wheat (Vlaams Instituut voor Landbouw- Visserij- en Voedingsonderzoek, 2023). The rotation of crops prevents the accumulation of crop-related diseases, pests, and weeds (Nederlandse Akkerbouw, 2017a). There is national legislation on the crop rotation, to prevent the spread of diseases such as potato eelworm. In addition, in some areas of the Netherlands it is prohibited to cultivate certain crops, like potatoes for example (Nederlandse Voedsel- en Warenautoriteit, n.d.)

There are several positive and negative effects of the intensification of crop production. On the one hand, yield per hectare has increased over the years. Cereal yield, for example, has increased from 8.4 tons per hectare in 2000 to 9.6 tons per hectare in 2022 in the Netherlands (Centraal Bureau voor Statistiek, 2023). After World War II, Europeans never wanted a famine again, and so the intensification of crop production started. Farmers have become very efficient in using limited resources. For arable farming, big machines (between 3 and 22 meters wide) are used, which increases harvest efficiency. However, these wide machines are only useful when the field is homogeneous. In modern arable farming, everything has been automated, from preparing the land and sowing to harvesting and

Figure 2 Wheat harvesting with a combine.

simultaneously processing the crops. For example, when wheat is harvested, a combine cuts the plant down to approximately 20-60 centimetres above the ground, as well as simultaneously separating the grain from the stem. The stem is pushed out of the machine and laid on the field, and the grain is collected in a big container (Figure 2). Another positive effect of crop intensification is that it has led to a market with consistently high-quality foods and feeds. Products are always the same. Consumers can expect that their favourite products are always available.

In contrast, crop intensification has major negative effects on the climate. To illustrate, crop intensification in the form of monocultures causes loss of biodiversity, reliance on non-renewable inputs, soil degradation, changes in land use, and loss of genetic diversity (Bourke et al., 2021). Furthermore, the intensification of cropping systems has resulted in an increased use of synthetic fertilizers and pesticides, resulting in higher drainage and requiring more irrigation. All this caused major damage to arable ecosystems (Stoate et al., 2001). This environmental impact and loss of biodiversity by conventional farming practices has been illustrated by research on the amount of bird species in arable ecosystem. It has been shown that since the 1960s there has been a great decline in bird species around conventional arable farms (Government of The Netherlands, 2023).

Furthermore, less resilient monocultures are more vulnerable to biotic and abiotic stressors. Examples of biotic stressors are pathogens, herbivores, weed competition, and parasitic plants. These biotic stressors can be an indirect effect of climate change. Abiotic stressors, on the other hand, are mostly direct effects of climate change, such as drought or flooding, salinity, and nutrient deficiencies. Monoculture fields are more vulnerable to these biotic and abiotic stressors, as often there is only one variety or genotype on the field. According to the organic seed producer that we interviewed, this loss of diversity in species is a result of the efficiency of monocultures. As mentioned in the introduction, for this project we will focus solely on salinity.

To summarize, crop intensification has led to loss of biodiversity and genetic diversity within agricultural fields. This loss of diversity resulted in a decrease of resilience of complete farming systems against biotic and abiotic stresses. As climate change continues to exacerbate and stressors will get stronger, increasing the resilience of cropping systems is crucial. Therefore, there is a need to redesign the current agricultural fields, moving away from susceptible and unstable monocultures towards more resilient crop production systems. Several strategies for this will be described in Chapter 5, but first we will go further into the effects and threats of salinity and salinity stress.

3. Methods

The main goal of this project is to identify opportunities for the KB project, farmers, breeders, and research in general. By doing this, the KB project will be better able to advise farmers, breeders, and policy makers. To come up with these opportunities, first we needed to identify their current challenges. To get a broad picture, we assessed the problems of non-resilient, non-diverse crop production systems from different angles, both on crop level and on system level. These angles come back in the sub questions described in the introduction. To answer these sub questions, we combined the results of literature studies, interviews with experts and a system analysis.

3.1 Literature Study

First, we started with an extensive literature study on current crop production systems in the Netherlands, soil salinity, and modern national and international solutions to cope with salinity stress. Furthermore, we investigated how biodiversity can be increased in agriculture, specifically in the form of intercropping, and what crops could be used to increase salinity resilience. In our study we used peer-reviewed scientific literature, as well as information from major organizations such as the FAO and grey literature such as farming websites.

To identify suitable crops for a salinity resilient intercropping system in the Netherlands, we started with searching for crops that are tolerant to salinity and show normal development under saline conditions. In addition, we focused only on underutilized, edible crops. This means that the crops that we chose are barely grown at all, or that they are more common in other countries but not in the Netherlands. The first crop selection criterion we used was their ability to grow in the Dutch climate, as this is part of the delineation of our project. Next, we searched articles on intercropping with these crops, because we wanted to do a system analysis on intercropping. The resulting selection was divided into three categories: salt tolerant crops for intercropping with salt sensitive crops (1), halophytic crops with a soil desalinizing potential (2), and salt tolerant crops intercropping together (3). We selected the category with the most potential, based on a comparison of advantages and disadvantages. The most promising example of a crop combination within this category was selected based on the benefits reported in the article about this combination of species.

3.2 Interviews and Survey

To get a better idea of the current and future challenges Dutch farmers and breeders are facing regarding salinity and intercropping, and to get their opinions on these topics, we interviewed experts in the field. The interview questions we used can be found in Appendix A. We got our starting contacts via the KB project. Within the project's time span, we were able to interview two researchers, an organic plant breeder, an organic seed producer and an organic intercropping farmer. One of the researchers is doing experiments with (non-organic) intercropping in Zeeland. The other researcher is from WUR, though not connected to the KB project, and is specialized in sustainable agriculture. They are involved in multiple projects about resilient farming systems, including intercropping. The organic plant breeder is working on a project where different vegetables are intercropped. The organic seed producer's main focus is breeding for diversity. Lastly, the organic intercropping farmer is doing intercropping for the short food supply chain, which means they deliver their products directly to the consumer. The interviews were analysed by highlighting the most important points made by the experts in the interview notes. The notes were sent for approval to all interviewees. The interviews gave us multi-angular insights on increasing biodiversity by intercropping and the challenges that arise from it, as well as some insights on salinity.

To be able to reach more farmers, we made a short survey with questions about intercropping and salinity challenges. We sent out the survey to Dutch farmers ourselves, and we asked two organizations to spread it under their members. We received eight responses. We analysed the survey by selecting the questions we believed to be most valuable for the report. Thereafter, we used Microsoft Excel to graphically display the different responses (found in Appendix B).

3.3 System Analysis

The selected combination of species was used to set up a hypothetical strip cropping farming system. For the system analysis we focussed on Zeeland, since this region in the Netherlands is most affected by high soil salinity. The region of Zeeland is further described in the system analysis in Chapter 7. There, the system is also described in a rich picture, where all the processes that take place within the system are illustrated. Furthermore, we did a stakeholder analysis, which can be found in Appendix C. Finally, we performed a trade-off analysis between the hypothetical strip cropping farming system with our selected underutilized crops, and a conventional monoculture arable farming system with staple crops.

3.4 Ranking of Opportunities

From each chapter, challenges came forward regarding salinity, biodiversity, and resilient farming systems. We combined these challenges into clusters. We used a decision matrix (Appendix E) for each key stakeholder (farmers, breeders, and researchers) to rank the clusters on importance. The criteria on which the clusters were ranked are feasibility (to what extend is this under the control of the stakeholder), cost effectiveness (benefits gained per unit cost), relevance (of outcome KB project for the stakeholder), long-term sustainability (duration of benefit from opportunities) and environmental impact (positive influence of stakeholder on environment when opportunities from this cluster are applied). For each criterion we ordered the clusters from least to most applicable. No weighting factors were used for the different criteria.

Then, for each cluster we came up with opportunities that could tackle one or multiple challenges. These opportunities either already came forward in the results section of this project, or they emerged from the insights we gained. Our advice to the KB project is based on the outcome of the decision matrix, and the opportunities within the most important clusters that could cover more than one challenge.

4. Soil Salinity

As mentioned in the introduction of this report, soil salinity is an upcoming problem for farmers and crop production systems. In this chapter, we will further explore soil salinity. In the first section we will explain soil salinity in general, diving deeper into the cause and the consequences on plants and crop production systems. Then, we will zoom in on the Netherlands and the problems with soil salinity there. After that, some national and international mitigation strategies for soil salinity are discussed. This chapter will end with a summary of the challenges perceived with soil salinity and salt stress.

4.1 Soil Salinity and its Impact

It is widely known that the occurrence of abiotic stressors such as droughts, extreme temperatures, and soil salinity is increasing worldwide. These abiotic stressors have a negative impact on the cultivation of crops, as they affect plant growth and soil quality, ultimately leading to a loss of yield (Shahbaz & Ashraf, 2013; Yamaguchi & Blumwald, 2005). According to Yamaguchi & Blumwald (2005), from this list, soil salinity is one of the more destructive and widespread stressors. In fact, without taking desert lands into account, an estimated 20% of global arable land is affected by soil salinity, and these salinized areas keep increasing (Jamil et al., 2011; Yeo, 1998). This causes a problem for the increasing population and demand for agricultural products. Since freshwater resources are declining, the use of more saline irrigation water is inevitable in some parts of the world. Together with droughts, extreme temperatures, increased surface evaporation and improper management of the soil, these factors contribute negatively to the further salinization of soil and declining of suitable arable lands (Jamil et al., 2011; Shahbaz & Ashraf, 2013; Shrivastava & Kumar, 2015; Yamaguchi & Blumwald, 2005).

Table 2 An overview of the salinity classes, as determined by the Department of Primary Industries and Regional Development (2022).

Salinity class	ECe range (dS/m)
Non-saline	0-2
Slightly saline	2-4
Moderately saline	4-8
Highly saline	8-16
Severely saline	16-32
Extremely saline	>32

Soil salinization is characterized by an elevated salt concentration, an increased sodium concentration (Na^+) and a high pH. This change can lead to disruption of biological, biochemical and erosional characteristics of the soil (Smith et al., 2015). Generally, soil salinity is determined by the electrical conductivity in Ds/m and an overview of approximate division of salinity can be found in Table 2 (Department of Primary Industries and Regional Development, 2022). The concentration of salt in the soil that is completely limiting roots to absorb water, is about 50 dS/m (= approximately 27,500 ppm), but there is a large variety in salinity tolerance between plants (Munns et al., 2005). We can define two types of salinization mechanism (Daliakopoulos et al., 2016). Primary salinization originates from natural sources such as geological deposits, groundwater, or intrusion of seawater. Secondary salinity, on the other hand, results from human activities, particularly due to irrigation with saline water, poor soil drainage, and the subsequent accumulation of salts in the upper layers of the soil. A future warmer climate will cause variations in the hydrological cycle. Furthermore, the rising sea levels in combination with excessive groundwater extraction, increase evapotranspiration and consequent high demand of irrigation, are expected to expand the geographical areas affected by this form of issues (Daliakopoulos et al., 2016).

Plant symptoms of drought stress and soil salinity are often quite similar, as the mechanisms behind it are comparable (Ma et al., 2020). For example, under both stressors, plants are wilting and drying out. However, the solution for the symptoms is different depending on whether they are caused by drought or soil salinity. To illustrate, when crops in a field are struggling with drought, increased irrigation could help. Yet when soil salinity is the culprit, more irrigation does not in every situation fix the problem. Irrigating with water that is (slightly) saline will only worsen the problem. In that case, it is best to opt for other methods of dealing with soil salinity, like planting a neighboring crop that absorbs salt from the soil. This strategy is currently used in Australia (see also Section 4.3). Nevertheless, these two stressors are often interacting and it can be difficult to tell them apart. An easy way to find out, is to test the irrigation water and/or the soil for salinity.

4.2 Soil Salinity in the Netherlands

In our report, the primary objective is to highlight research opportunities, particularly within regions that have come across significant environmental challenges in the past century. These areas, for example the coastal regions of the Netherlands, have been subject to natural floods, strategic wartime inundation and intense agricultural activities, all of which have contributed to elevated soil salinity levels (Raats, 2015). This combination of primary and secondary soil salinization, especially in the province of Zeeland or other Delta areas, serves as a case study for our project on this complex issue of salinity hazard.

Further zooming in on the Netherlands, Figure 3 shows the current availability of fresh ground water in the Netherlands, thereby indicating the areas that are experiencing salinity stress (P.G.B. De Louw et al., 2015). The prospect for 2030 is that 125.000 hectares of arable land in the Netherlands will be salinized to such an extent that only salt tolerant crops can be grown (De Kempenaer et al., n.d.). As a coastal nation, rising sea levels threaten to increase the salinity of ground water. This rising gradually allows salt water to reach the root zone via capillary rise on arable lands that are close to or below sea level. This is an increasing problem for farmers in coastal areas such as Zeeland, the western and the northern provinces. Additionally, the balance between fresh and saline water in estuaries can become disturbed due to rising sea levels, as the pressure of saline water increases (de Boer & Radersma, 2011; Koninklijk Nederlands Waternetwerk, 2019a). Another specific reason that leads to salinization of soil in the Netherlands are the measures taken in favor of fish migration: opening sluices that separate the sea from fresh or brackish water sources. As a result, many Dutch farmers are at risk of salinizing their soil, as they rely on these areas for their fresh irrigation water (Starmans, 2014). A third factor at play is the division of freshwater resources in the Netherlands between agricultural purposes and drinking water, especially in times of freshwater scarcity (de Boer & Radersma, 2011). When fresh water is in short supply for farmers, they divert to other water resources. Simultaneously, the Netherlands also experiences an increasing demand for irrigation water due to changing climate conditions, resulting in an increased deposition of minerals in the soil through evaporation (de Boer & Radersma, 2011; Munisense, 2022).

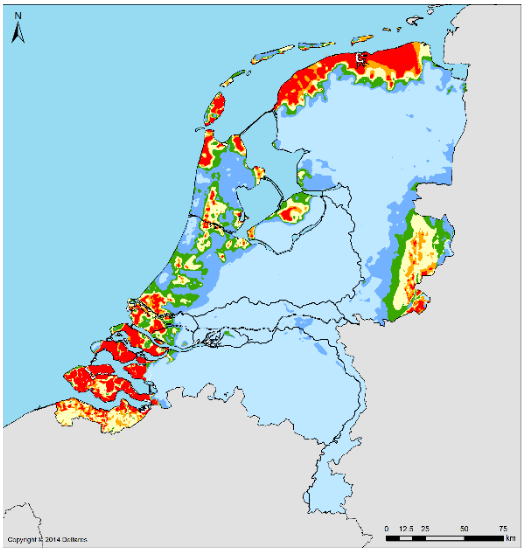

Figure 3: The availability of fresh ground water in the Netherlands based on data until 2014. The colours represent the depth of the border between fresh and saline water below ground level, acting as a measurement of fresh water availability. Red indicates saline water that is close to the surface, whereas orange, yellow, green, and blue indicate a greater depth of saline ground water and therefore higher availability of fresh water above it (P.G.B. De Louw et al., 2015).

From our survey that was distributed amongst Dutch farmers, most of our 8 respondents stated they had little to no problems with soil salinity (Figure 4). Two farmers, from Flevoland and Noord-Holland, did indicate problems, but not higher than medium (average was 1.38 out of 5). Average scores for heat and drought stress, on the other hand, were reported a little above medium (3.13 and 3.25 out of 5, respectively), and overall soil quality was rated at an average 3.38 out of 5. Half of the respondents stated that they had tested their soil on salinity, and two of those had tested their irrigation water as well. Salinization of surface water (used for irrigation) was mentioned as a challenge only once. Other challenges that were mentioned were restraining legislations (e.g. about fertilization), fluctuating groundwater levels, and drought. None of the interviewees indicated that they experienced any trouble from soil salinity.

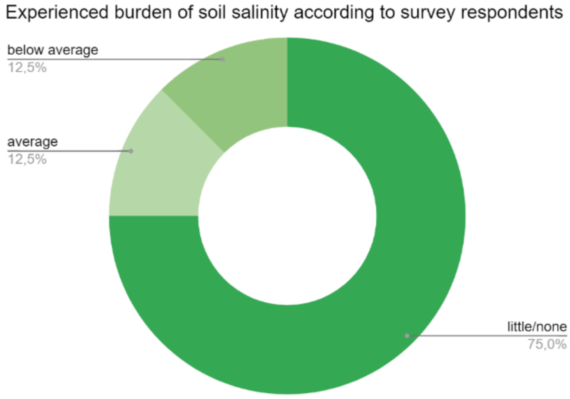

Figure 4: Pie chart with the level of burden survey respondents experienced with regard to soil salinity.

4.3 Mitigation Strategies for Soil Salinity

Various researchers have come up with strategies to mitigate soil salinity. For example, De Boer & Radersma (2011) suggest that, apart from combatting soil salinization in the Netherlands through the use of dikes, adapting farming practices to salinization is a viable option Additionally, they recommend using salt tolerant species in crop production and rotation, selective breeding for salt tolerance, and more efficient use and desalinization of fresh water. Furthermore, Starmans (2014) suggests molecular genetic engineering as a possible solution, but does point out that more research is needed in the mechanisms behind salinity resilience. In contrast, Munns et al. (2005) pointed towards the use of currently underutilized genetic variation underutilization as a strategy to increase salinity resilience in crops and believes genetic engineering to be unnecessary. Additionally, they believe both a change in agricultural practices, as well as the acknowledgement of society that there is a need for change in the way we practice agriculture, are crucial. Finally, they refer to the root system as a promising direction for research because they can directly limit the amount of salt acquisition. The root system was also mentioned as a key player by the organic plant breeder and researcher from WUR that we interviewed. Another research group concluded that their stakeholders found the preservation of existing crops, decreased soil salinity and increased crop yield to be the most important factors when it comes to technologies for management of soil salinity (Daliakopoulos et al., 2016). Their study compared three strategies that could help mitigate soil salinity in greenhouses: the collection of rainwater (which is naturally free of salt), crop rotation (to ensure green manuring and balancing of the soil), and the use of bio-agents (to increase salinity tolerance in crops). After considering several criteria and weighing factors, they identified the collection of rainwater, although costly, as the most viable mitigation strategy.

Other countries also have interesting strategies to mitigate soil salinization. Shofi et al. (2022) reviewed the methods and techniques used by Bangladeshi farmers struggling with soil salinity. They found that the collection of rainwater in mini-ponds and mulching (i.e. covering of the soil with organic material like woodchips or sawdust to reduce evaporation) were the most common practices amongst farmers. This strategy is called the '*sarjan method*' (also referred to as *sorjan method*) and is used to create arable land from coastal areas that are soggy after heavy rain, but have dry and saline soil during the dry months. The sarjan method combines (vegetable) crop farming on raised beds together with aquaculture by means of digging ponds or trenches that house fish and simultaneously act as irrigation water reservoirs (Neogi, 2018; The Daily Star, 2016). Looking at another country, a strategy used in western Australia is to plant rows of Australian saltbush in between crops to alleviate the effects of saline soil on cash crops. After harvesting, salt bush is sold as feed, mostly for sheep. Additionally, in

Australia and Senegal, mulching and growing crops on raised beds is used to prevent waterlogging. Raised beds are also a common practice in Australia to increase the distance between the root system and the saline ground water (Department of Primary Industries and Regional Development, 2023).

In our interviews, we also discussed some mitigation strategies. A strategy that is already implemented by two of our interviewees is drip irrigation. For this, drip hoses are put underneath the topsoil before sowing. During the growth period, a farmer can irrigate the soil through these hoses, whenever and as much as needed. They concluded that, because this limits evaporation and the amount of water used, it could be an effective way to mitigate soil salinity. In addition, the organic plant breeder, the researcher from WUR and the researcher from Zeeland both believed that the use of clover as a cover crop on arable fields generally increases soil quality and reduces evaporation. Therefore, it is also a potential strategy to mitigate soil salinity. Breeding for salt tolerance, on the other hand, was not perceived as a mitigation strategy by the organic seed producer. They believed it to be like fighting a losing battle, since it does not fix the actual problem of soil salinization. The organic plant breeder and organic intercropping farmer agreed with the organic seed producer that organic farming and/or intercropping could help preserve soil quality to a better extent than conventional farming, and therefore they believed it could positively affect soil salinity.

4.4 Challenges of Soil Salinity

As mentioned before, there are a lot of challenges for farming under salinity conditions. To summarize, soil salinity will increase in the common years, due to rising sea levels, decreasing freshwater resources, the increasing demand for fresh irrigation water, and the salinization of existing irrigation water. Additionally, governmental regulations with regard to the opening of sluices also pose a challenge to the fresh and saline water balance. Furthermore, there is a gap of knowledge on the mechanisms behind salt tolerance, as well as on the combination of salt stress with other stressors like drought, and the use of salt tolerant species in farming systems. Generally, there is limited under-standing on how to differentiate salinity stress and drought stress via plant physiology, since the symptoms are much alike. The underlying mechanisms might differ, though. On top of that, many changes in farm practices and strategies directed towards soil salinity mitigation are expensive, and breeding goals are currently mainly focused on staple crops, with insufficient use of underutilized, salt tolerant species in the gene pool.

All these challenges threaten future farming systems and food security. There are, however, also several opportunities regarding soil salinity. These will be discussed in Chapter 8. First, in the next chapter, we will go further into intercropping as a strategy to increase system resilience by increasing diversity.

5. Intercropping for Diversity

Improving the resilience of a farming system can be achieved by increasing the biodiversity within that system (Erisman et al., 2016; Lin, 2011). As mentioned earlier, the current farming system with monocultures has limited biodiversity in a field. For this project we focus on increasing biodiversity in agricultural fields through increasing the diversity in plant species. In this chapter, we will first discuss the reasoning behind choosing an intercropping system to increase plant species diversity. Then, the different types of intercropping will be described. Lastly, the advantages and challenges regarding intercropping will be presented.

5.1 Why Intercropping?

There are multiple ways to increase the diversity in plant species in a field, for example through crop rotation, field margins, cover crops, agroforestry, and intercropping (Brooker et al., 2015; Lin, 2011; Liu et al., 2022). The latter has our preference, as we believe it has the biggest potential for development, as well as being economically interesting for farmers and breeders. Intercropping is kind of a hot topic nowadays, with a lot of research projects showing interest in it, recently. Here, we are also interested in intercropping, specifically in the context of salinity challenges. First, however, we will dive deeper into the examples of diversity increasing strategies mentioned above.

First is crop rotation, a commonly used strategy where an agricultural field is filled with a different crop each season. In contrast to intercropping, crop rotation has already gotten well-developed over the years. It is known to increase the soil health, and it promotes pest and disease control over time (Liu et al., 2022). However, as aforementioned, crop rotation offers less potential for development than intercropping.


Figure 5 An agricultural field with wildflowers in the field margins (National Institute for Public Health and the Environment, 2023).

The next strategies are field margins and cover crops. Both are not as economically attractive as intercropping, since the additional crops in these systems are mostly not cost-effective. Using field margins to sow a diversity of plant species can aid in attracting pollinators to the main crop field, as well as preventing nitrogen leaching into the nearby environment (Wszelaki & Broughton, 2012). Making use of the field margins will reduce the crop production area, though. This is not the case for cover crops. They prevent nitrogen leaching like field margins, as well as protect the soil against erosion, and provide a winter soil cover for microorganisms and small animals. In addition, cover crops can reduce winter feed costs for livestock (Wszelaki & Broughton, 2012). However, for cover crops, controllability is important, as well as absence of a negative interaction with the crop that is sown next season, which reduces the opportunities.

In agroforestry, a diversity of crops and trees are grown together over multiple years (Nair et al., 2022). The benefits are a lower pest and disease pressure. Furthermore, the trees protect the smaller plants from abiotic stressors such as unfavourable temperatures, sunlight, and storms (Liebman & Schulte, 2015). However, an agroforest requires a long time until it is productive, as trees take a long time to mature, and it is a labour-intensive system (Current et al., 1998), making it a less economically attractive system than intercropping.

Lastly, in intercropping, two or more crop species, varieties, or genotypes are being cultivated in the same field at the same time (Brooker et al., 2015). Even though intercropping has its challenges, it has a plethora of advantages too. The weight of the pros and cons of this system are dependent on the type of intercropping that is applied. The various types of intercropping will be further elaborated below.

5.2 Intercropping Types

Intercropping is a broad term for various cropping strategies. The strategies can differ in spatial and temporal aspects, as well as the type of crop combinations. The choice of which crop combination will be grown is most important for determining the type of intercropping.

Spatial types of intercropping are alley cropping, row cropping, strip cropping, patch or mosaic cropping, and mixed cropping (Figure 6). In alley cropping, annual crops are grown in strips between rows of perennial shrub or tree crops (Mohler & Stoner, 2009). The higher plants protect the lower crops from wind and sunlight. In addition to this, the larger perennial crop can protect the field from soil erosion with their root system (Sergieieva, 2020). In row cropping, single or multiple rows of a crop are planted between single or multiple rows of another crop (Sergieieva, 2020). Narrow rows can increase the resource capture of the crops (Mohler & Stoner, 2009). Strip cropping is quite similar to row cropping, as a strip of one crop is planted next to a strip of another crop. However, the strips are wide enough for independent cultivation of the crops, and machine operations can be executed separately for each crop (Sergieieva, 2020). In patch/mosaic cropping, one crop is grown in patches, with every patch containing a different crop (D. Singh et al., 2021). The patches can have sizes that vary between cultivation strategies. For example, when the patches are as small as one individual plant, this is called pixel cropping. Mixed cropping differs from the aforementioned spatial types of intercropping, as the combined crops are not grown in separated spatial arrangements. Instead, the seeds of both crops are mixed, after which they are sown and harvested together (Sergieieva, 2020).

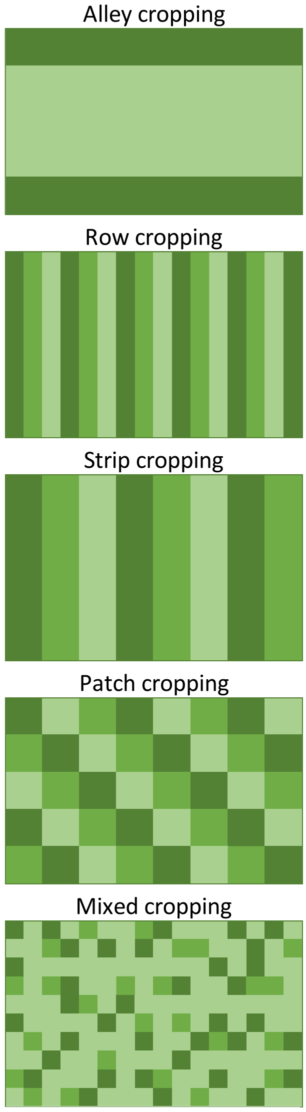

Figure 6 Schematic overview of spatial intercropping types. The different shades of green represent different crops in a field. Here, two or three crops are intercropped.

The second category of intercropping methods is based on separation in time (Figure 7). One method is called temporal intercropping. There, crops with a differing maturing time are grown together. When the fast-developing crop is harvested, the slow-developing crop has more space to grow. This increases the economic usage of arable land over time (Sergieieva, 2020). Another method is called relay intercropping, in which the second crop is planted after the first crop has flowered. This reduces the temporal overlap in harvesting different crop species, and thus lowers the competition for resources between the crop species. The second crop must tolerate the shadow of the first crop until that one is harvested, though (Sergieieva, 2020). In conventional farming systems, relay cropping can be used to increase the yield with the same resource input (Stomph et al., 2020).

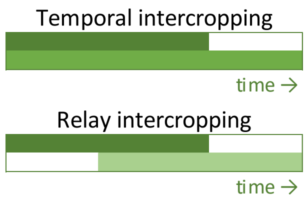

Figure 7 Schematic overview of different types of intercropping based on separation in time. The different shades of green represent different crops. The presence of a crop at a certain time is shown, relative to the other crop.

Some types of intercropping specific to crop combinations and interactions are companion cropping, nurse cropping, trap cropping, interseeding, and using living mulch. In companion cropping, a non-crop is planted with a crop in order to attract beneficial insects for the crop (Mohler & Stoner, 2009). For nurse cropping, a fast-growing crop is grown between a slow-growing crop to suppress weeds while the slow-growing crop establishes (Mohler & Stoner, 2009). Trap cropping entails cultivating a second, pest-attracting crop in between the main crop. This way the main crop is protected against the pest and the usage of chemical pesticides can be lowered. There is a risk of resistance development in the pest for the trap crop, though (Sergieieva, 2020). Another type is interseeding, where seeds of a crop are directly sown into the field between another crop. The sowing of one species can be either simultaneous or at a different time from the other species (Mohler & Stoner, 2009). Lastly, using living mulch means having permanent rows of perennial grasses or legumes between rows or beds of the other crop (Mohler & Stoner, 2009).

Intercropping is used worldwide. In western Europe, there is a focus on intercropping to aid organic, sustainable cultivation of crops. The largest difference in intercropping around the world is the crops that are selected. The type of intercropping system that is applied is not that different.

5.3 Advantages of Intercropping

Intercropping has multiple advantages. Some advantages are specific for the type of intercropping that is applied, but most of the mentioned advantages apply for all types. These cover the following categories: plant combinations, farmer, abiotic stress, biotic stress, and the environment.

In some combinations of intercrops, one crop can provide physical support to the other crop (Farm Practices, 2019). In addition to this, in some crop combinations, the intercrops can use natural resources like water, light, and nutrients more efficiently (Mohler & Stoner, 2009). This results in a reduced need for application of fertilizer, and in a higher yield (Sergieieva, 2020). The organic plant breeder we interviewed also saw a similar or higher yield of crops in an intercropping field compared to a monoculture field.

Intercropping can stabilize the total yield in a field as one badly performing crop can be compensated by the other crop (Stomph et al., 2020). As an intercropping expert told us, intercropping could provide economical security for large farmers as insurance companies might reduce their coverage for yield losses caused by the climate in the future, due to increased occurrence of extreme weather conditions by climate change. Intercropping can also be advantageous for small farmers, especially those who want to be part of a short food chain. When farmers want to sell their produce to the local market, it is optimal to cultivate multiple crops in relatively small quantities in an intercropping system. This is the case for the organic intercropping farmer we interviewed. The farmer later also told us that they started intercropping to create a more robust cultivation system, and to distinguish themselves from other farmers on the market. Another advantage they noticed is that intercropping fields are visually more attractive than monocultures, which also makes the farm stand out.

Some other challenge that came up during the interview is that intercropping might require the usage of fixed driving paths between the crops. According to the organic intercropping farmer, this can be a huge advantage, though. This is because the need for tillage reduces, as arable soil in the field does not get compacted due to the weight of machinery.

Another benefit for farmers is that intercropping can save space and increases efficient usage of arable land over time, as the crops' development times overlap (Farm Practices, 2019; Sergieieva, 2020). This was also mentioned by the organic intercropping farmer, as they take the differing growth rates of their crops into account when making a planning of sowing and harvesting dates.

Next, intercropping can increase the protection of the main crop against abiotic stresses, like wind and sunlight (Jodha, 1980; Sergieieva, 2020). Furthermore, intercropping can control soil erosion, enhance soil fertility and lower the chances of formation of soil crust (Farm Practices, 2019). This was confirmed by the organic plant breeder and the organic seed producer, as they have seen improvement in soil health in their intercropping fields as well.

Intercropping can protect crops from biotic stress as well, as the crops have lower densities of pests and diseases (Mohler & Stoner, 2009). This was also seen by the organic plant breeder and the organic intercropping farmer. The lower densities of pests and diseases can be caused by the physical distance between the host plants. In a field of the organic plant breeder, a distance of 1.5 meter between strips of a crop lowered the rate of the spread of pests, while a distance of 6 meters between the strips could completely block the spread of pests and diseases. In addition to this, the organic plant breeder suggested that a high biodiversity of crops and thus organic pest control also contributes to the lower densities of pests and diseases. This means that the usage of pesticides could be reduced or redundant. Applying intercropping can also reduce the number of weeds in the field, as the crops can cover a larger surface area and thus leave less sunlight for weeds (Sergieieva, 2020). The advantages of protection against biotic and abiotic stresses depend on the type of intercropping system that is applied (mostly the physical distance between the strips or plots of a crop), as well as the choice of crops within that intercropping system.

The last advantage of intercropping that we found is that intercropping enhances biodiversity and ecological stability (Sergieieva, 2020). The researcher from Zeeland confirmed this via research that was done by another company in the same area. According to the organic plant breeder, a fellow colleague of them found that the presence of intercropping fields could even increase the well-being of people living nearby, as it would enrich the living environment.

5.4 Challenges of Intercropping

However, intercropping also has some challenges. These can be divided into the following categories: limited knowledge about optimal crop combinations, difficulty in translating research into practice, little research on breeding for intercropping, an unchanging food chain, difficulty in transitioning to intercropping, and a lack of suitable machinery and technology. Below, we will elaborate on these challenges.

The crops that will be combined in an intercropping field must be chosen well, as various crops can affect each other beneficially or detrimentally. The crops can have allelopathic effects, which means that biochemicals produced by one crop affects the growth and/or reproduction of the other crop. In addition, some intercrops can alternate as host for pests and diseases of the other crop (Farm Practices, 2019). In this scenario, controlling the spread of diseases and pests can be complicated in a conventional intercropped field as applying pesticides on a crop might not be an option if the pesticide is not allowed near the crop next to it. Intercropping can also cause the crops to compete for natural resources (Farm Practices, 2019). Based on our interviews with the researcher from WUR, the organic plant breeder, and the organic intercropping farmer, there is too little known about how crop combinations interact, the mechanisms behind these interactions (especially below the surface), and which crop combinations are beneficial. Especially when we look at crop combinations which are well suited for salinity stressed soils, little information is available.

The researcher from WUR mentioned another big challenge for farmers: translating the findings of research about crop interactions and beneficial crop combinations into practice. The organic intercropping farmer agrees with this point. Intercropping can be quite difficult as there are many factors that affect the decision on which crops to cultivate together and in which type of intercropping system. At the moment, there is not enough practical advice about intercropping for farmers that is based on research.

Next to this, there is limited knowledge on the performance of crops in intercropping systems in comparison to their performance in monocultures. This was mentioned by the researcher from WUR and the organic plant breeder. However, the organic plant breeder stated that research and breeding for intercropping is quite challenging in itself as well, as a huge amount of data is collected per study. The analysis of this data is a lot of work, and it slows down both research and breeding practices. In general, there are only a few companies that focus on breeding crops for intercropping systems. For the organic seed producer this produced even more problems, as patents for crop genes are mostly owned by large companies, which limits the freedom of other, smaller plant breeders.

None of the eight farmers that responded to our survey is currently practicing intercropping. Therefore, it is not surprising that there was low interest among them in breeding for crop suitability for intercropping. This might be a trend in general; a low demand for crop varieties that are suitable for intercropping systems.

Another challenge for intercropping is that currently, the food chain is mainly designed for products of monocultures, as reported by the researcher from WUR. Both food processing companies and the sales market want a uniform product with a constant quality. Crops from an intercropping system might vary too much, which decreases the sales market for intercropping farmers.

According to the organic plant breeder, transitioning to intercropping is too difficult and the process can take years. Determining which crops to cultivate, in which type of intercropping system these should be grown, and how to apply crop rotation to the intercropping fields can be challenging, as there is little knowledge about optimal combinations for the situation of each farmer. Planning when to sow and harvest the crops, and planning when and where to apply irrigation and fertilization are both complicated processes as well. The field procedures must be timed carefully, as crops can have differing needs and differing growth rates (Farm Practices, 2019). Non-organic intercropping farmers need to plan the application of pesticides as well, though, which complicates the planning process even further. The placement of paths for machinery needs to be taken into account too. The organic plant breeder told us an example where the organization took four years for an organic farmer. That farmer has a farm that is slightly larger than the average conventional Dutch arable farm as reported by Wageningen University & Research (2022). The organic plant breeder mentioned that farmers who transition from monocultures to intercropping systems, need to change their mindset on cultivation practices all together. This could be quite a difficult and long process.

According to both researchers we interviewed, intercropping is not always economically viable at the moment. Long-term costs for an intercropping farmer are higher, as intercropping is more labour-intensive than monocropping. To minimize the competition between the cultivated crop species, special interventions may be needed, which also increase the workload (Mohler & Stoner, 2009). The organic intercropping farmer mentioned that the increase of workload depends on the number of crop species that are grown in the system. In addition, next to higher costs for labour, the researcher from Zeeland added that fuel costs also increase as a farmer may have to go over fields more often with their smaller machines. Consequently, intercropping farmers might have to increase the price of their products in order to compensate for the higher costs, which could affect consumer behaviour.

In addition to that, the initial investments for a farmer that transitions to intercropping, are high. New machinery is most often needed as conventional machines are too wide and too heavy for strip cropping, let alone for row cropping or patch cropping. The researcher from WUR told us that most modern machines and technologies are not equipped to handle genetic diversity in a field, whether that is genetic diversity between species or within a single species. However, the organic intercropping farmer told us that machines in the recent past were smaller and that some are still available on the market. These machines might not be optimal for use, though, as they have not been as well-developed as the machines for monocultures. Thus, there is a lack of highly developed, widely available machines and technologies for intercropping which can handle diversity. The development of these machines and technologies is too slow according to both the organic plant breeder and the researcher from WUR.

From the results of our survey for farmers, we concluded that high necessary investments and mismatch of current mechanization with intercropping were main reasons for not transitioning to an intercropping system. Inconsistencies in research results regarding the advantages and trade-offs of intercropping were also mentioned as a reason to ignore the idea of intercropping. Other reasons were the questionable economic profitability, lack of information or trainings, foreseen problems with food safety due to drift of pesticides in strips, and possible risks of transition. In total three out of eight survey respondents claimed their farm was not suitable for intercropping.

6. Underutilized Salt Tolerant Crops

To combine the previous chapters on soil salinity and intercropping strategies, we did a literature study on underutilized, salt tolerant crops that are suited for intercropping. In our research we found three different strategies to increase salinity resilience by increasing biodiversity: intercropping a salt tolerant glycophyte with a salt sensitive crop (Section 6.1), a combination of halophytic crops to desalinize the soil (Section 6.2), and intercropping two salt tolerant species together (Section 6.3). In this chapter, we will give a short description and examples of the first two categories, and a more detailed description and example of the last category. The combination of crops we select for this last category will also be used in the hypothetical salinity resilient intercropping system, described in Chapter 7.

Our approach to identifying suitable crops for salinity resilience began with an initial literature review, considering various studies and trials related to intercropping with salt tolerant and halophytic plants (Appendix D). From the 34 crops we found, we eliminated species that are toxic for animal or human consumption and those that cannot thrive in the Netherlands or Northern Europe. This resulted in a list of 17 crops. We divided the remaining crops over the three categories, if we were able to find information on intercropping these species.

6.1 Intercropping Salt Tolerant and Salt Sensitive Crops

There are two types of plants when it comes to salinity: glycophytes and halophytes. Glycophytes are plants that did not experience natural selective pressure on high salinity during their evolution, and therefore are often sensitive to salt (Cheeseman, 2015). However, glycophytes vary in their ability to cope with salinity, as there are multiple strategies to reduce damage caused by salinity. In this part we will look at relatively salt tolerant glycophytes intercropped with salt sensitive glycophytes.

Multiple studies found beneficial effects of this first strategy to combine salt tolerant glycophytes with salt sensitive (staple) crops. For example, intercropping mustard greens (*Brassica juncea)* and fruit trees can result in a more salinity resilient fruit-based agroforestry system (Dagar et al., 2016). Some varieties of mustard greens have a relatively high salt tolerance, due to metabolic pathways that control damage by antioxidants (Singh et al., 2022).

One of the advantages of this intercropping strategy, is that at least one of the produced crops can be a cash crop, so there is a market demand. Another benefit is that intercropping these crops might also result in beneficial effects on other stressors. An example of this is asparagus (*Asparagus officinalis*), which is salt tolerant through an interaction with arbuscular mycorrhizal fungi in the soil (Zhang et al., 2019). When combining the salt tolerant asparagus with cucumber, it has been shown to reduce whiteflies (Zhao et al., 2014).

However, there are also quite some disadvantages to this intercropping strategy. To really exploit the benefits of such an intercropping system, a lot of research is needed to identify which species work well together and how to optimize their positive influence on each other. It is not always true that a salt tolerant glycophyte has a positive influence on the salinity resilience of other crops. And even if beneficial combinations of crops can be identified, the implementation will be a big challenge as well. In general, the salt tolerant glycophytes are underutilized as crops. This means that there is not a lot of research done on those species, and often they do not fit well into the current sales market.

Overall, we think this way of increasing salinity resilience is not the best option at the moment. For each salt tolerant glycophyte, the mechanisms underlying this increased tolerance need to be known before assessing if other crops could also benefit from this. Few studies found evidence that salt tolerant glycophytes could improve salinity resilience of an intercropping system. At the same time, the results from these experiments really varied between years and circumstances. If there are only beneficial effects for some of the years, it might not be worth all research and investments.

6.2 Intercropping Halophytic Species with Salt Sensitive Crops

In contrast with glycophytes, halophytes are plants that possess the ability to thrive and successfully go through their life stages in habitat characterized by elevated levels of salt, all while experiencing minimal detrimental effects on their growth or development (Flowers & Colmer, 2008). Based on the mechanism to overcome high soil salinity, halophytes can be categorized into three broad groups: salt excluding, salt excreting, or salt accumulating species. In salt excluding species, apoplastic barriers at the roots serve to effectively exclude salt from the root system and function as filtration mechanism (Munns et al., 2006). Salt excreting species employ a unique epidermal structure known as salt glands, to secrete salt ions onto the leaf surface and to effectively maintain cellular ion homeostasis (the equilibrium between Na^+ uptake and Na^+ efflux) (Lu et al., 2021). Salt accumulating species possess effective mechanisms that provide salt tolerance by accumulating high levels of Na^+ and Cl^- in their leaves and stems, all while preserving their photosynthetic efficiency. These species often possess succulence leaves due to the enlarged and elongated mitochondria which supply the additional energy necessary for the sequestration and compartmentalization of salt (Rahman et al., 2021).

Various studies have discovered that intercropping with halophytic species can have a beneficial impact on mitigating salt-related damage to sensitive crops. This is attributed to the halophytic species' ability to accumulate salt in their tissues, thereby reducing the salt concentration in the immediate environment (examples of species can be found in Table 3). Specifically, in the research conducted by Zuccarini, it was observed that intercropping tomatoes with halophytic plants like purslane (*Portulaca oleracea*) or garden orache (*Atriplex hortensis*) resulted in a reduction of both sodium and chloride concentrations in tomato tissues, ultimately leading to higher fruit yields compare to non-intercropped plants (Zuccarini & Paolo, 2008). The yield of tomatoes increased by approximately 44% when intercropped with purslane, reaching yields similar to those obtained in non-saline conditions.

Another way to use halophytic species is by phytoremediation. Phytoremediation is the extraction of contaminants from the soil by plants (Srivastava, 2019). This can also be done for salt. Phytoremediation is similar to using halophytic species for salt extraction, except for that is not done in a spatial intercropping system. Therefore, we will not go further into this.

Although there are many studies that validate this type of intercropping combination to mitigate salt damage, there are also different disadvantages. Firstly, many of these halophytic species are predominantly wild and have limited agricultural significance. Consequently, a substantial amount of research is required to understand their interaction with other species or even start the domestication, both fundamental to create a solid intercropping plan. Furthermore, the added economic value of these species is very low. Therefore, to establish a market for products derived from them, a breeding program in conjunction with a well-structured marketing campaign is needed. This takes time.

Considering all these aspects, the intercropping with halophytic species seems very promising, but without market value they would only serve as cover crops. Therefore, we believe that this approach for mitigating salt damage can be effective only in specific region affected by high soil salinity, where even salt tolerant crops struggle to thrive.

Table 3 Underutilized crops with a potential for desalinization.

Species	Salinity resilience	Growth in the Netherlands (NL)	Intercropping (IC)	Harvest time
***Cakile maritima* (Sea fennel)**	Facultative halophyte, develops succulence under salt stress	Native in NL	Not found	Flowers from June to October, germinates in April
***Eryngium maritimum L.* (Sea Holly)**	Halophyte, grows better in nitrogen-deficit and saline conditions	Native in NL	Not found	Harvest seeds in early winter, harvest leaves in summer
Inula crithmoides L. (Golden Samphire)	Succulent plant	Mediterranean/ Atlantic species, recently arrived in NL	Not found	March to early June
***Mesembryanthemum crystallinum L.* (Ice plant)**	Succulent plant, stores water and salt in bladder cells	Grows in NL	Not found	June to October
***Portulaca oleracea L.* (Common Purslane)**	Halophyte	Mediterranean but introduced to NL before 1500 and now common	Could increase watermelon yield, and improves growth of tomato plants under salinity	Juni to September
***Salicornia ramosissima / europea* (Glasswort)**	Halophyte	Native in NL	Not found	May to June

6.3 Intercropping Different Tolerant Crops

The last strategy to increase salinity resilience in an intercropping system, is by growing different salt tolerant crops together. In this system there is no need for one species to positively influence salt tolerance of the other species, since both are already salt tolerant. Hence, the benefits of this system depend only on the beneficial interactions between the two crops.

From literature, we found two combinations that work well together. These combinations are amaranth with millet and quinoa with millet (Table 4). Amaranth is used as a border crop of millet fields in Nepal (De Avila et al., 2023). In India, an experiment was done where quinoa and millet were planted in rows (Vahidi et al., 2021). There it was shown that the yield of both crops increased when grown in an intercropping system. Because of the small market of amaranth in Europe and because the beneficial effects of intercropping amaranth and millet were not as clear, we chose to focus the rest of this report on the example of quinoa and millet intercropping system.

Table 4 Salt tolerant species suitable for intercropping.

Species	Salinity resilience	Growth in the Netherlands (NL)	Intercropping (IC)	Harvest time
Amaranthus	C4 species, moderate tolerance. Diverging results in literature, influence of genotype	The edible *Amaranthus caudatus*, *Amaranthus hypochondria-cus* and *Amaranthus cruentus* can be found in NL	Used as border crop along millet fields in Nepal	Greens can be harvested almost immediately, seeds ripen 3 months after planting, so in mid- to late summer
***Chenopodium quinoa Willd.* (Quinoa)**	Facultative halophyte, and some varieties are able to cope with salinity levels as high as those present in seawater. Epidermal Bladder Cells are salt sinks for external sequestration for Na^+	Grows in NL	IC with millet, resulted in increased yield for both species	Late August to mid-September
Millets (Finger millet, foxtail millet, proso millet, great millet)	Resistant to salt pressure	Grows in NL	IC with quinoa resulted in increased yield for both species. Also grown with amaranth	August to October

6.3.1 *Chenopodium quinoa* Willd (Quinoa)

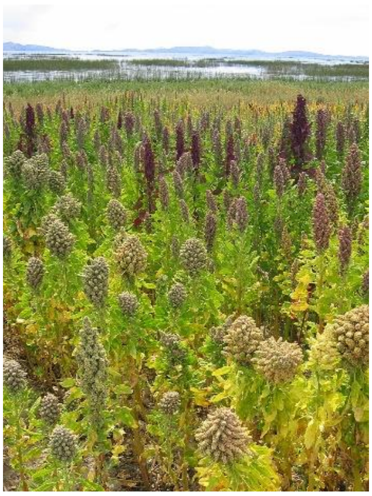

Figure 8 Chenopodium quinoa *Willd (Quinoa). Source: (Wageningen University & Research, 2014).*

Quinoa (Figure 8) is a genetically diverse crop native to the Andean region, and it has earned global recognition for its exceptional nutritional and health benefits. What sets quinoa apart is its adaptability to different harsh environmental conditions, including high soil salinity and drought conditions (Hinojosa et al., 2018). Quinoa is an annual plant with the potential to reach up to 3 meters, with variability in size depending on genotype and environmental conditions. The root system is an extensive branching taproot that can reach up to 1.5 meters deep. Quinoa inflorescences take the form of a panicle and are located at the upper portion of the plant. The inflorescences do not have branches. This plant has hermaphrodite flowers, resulting in a higher rate of self-pollination compared to cross pollination(Jancurová et al., 2009). In the Netherlands, the sowing dates can vary, from the late March to early May. Harvesting time is then between late august and late September. A challenge for European conventional production of quinoa is the lack of approved chemicals (Wageningen University & Research, 2014).

Quinoa is a nutritious crop, which means it has potential for the market and consumption. Quinoa seeds have a more complete nutritional profile in comparison to most staple cereals. Next to this, their protein content typically ranges from 8% to 22%, surpassing the protein content of common cereals like rice, wheat, and barley (Jancurová et al., 2009). Nevertheless, quinoa seeds contain less protein content compared to the majority of legumes. In addition, the pericarp of quinoa seeds contains saponins, which are plant glycosides known for their bitter taste and the tendency to foam in aqueous solutions. These saponins can be effectively removed from quinoa seeds through methods such as rinsing the seeds in cold alkaline water, though to increase the uses of this crop, saponin-free varieties are needed.

Quinoa is a versatile food that can be used as a rice substitute. Additionally, quinoa seeds can be popped similarly to popcorn, ground into flour for various culinary purposes, or sprouted. When opting for sprouting, it's important to wait for the sprouts to turn green before adding them to salads.

6.3.2 *Panicum miliaceum* (Proso Millet)

Figure 9 Proso millet. Source: Wikipedia (https://creativecommons.org/licenses/by/4.0)

Proso millet (Figure 9) is categorized as a warm-season grass, salt tolerant glycophytic species, characterized by a growth cycle of approximately 60 to 100 days. The plant typically reaches a height of 30 to 100 centimetres with a modest number of tillers and an adventitious root system. While proso millet primarily relies on self-pollination, there is also the potential for natural cross-pollination. The seeds, measuring around 3 millimetres in length and 2 millimetres in width, show variations in colour from white, cream, yellow, orange, to brown (Baltensperger, 2002). Proso millet, classified as a C4 crop, has a highly efficient carbon fixation, especially in harsh environmental conditions such as drought, high temperatures, and when nitrogen and carbon dioxide resources are limited (Baltensperger, 2002). Following the release of the proso millet genome, there has been increase research interest around this species. Notably, this research interest has highlighted the superior tolerance to abiotic stress due to its relatively high salt tolerance (Yuan et al., 2021).

Proso millet is considered an underutilized crop, with its primary market share in western countries for birdseed industries. In contrast, proso millet plays a crucial role in developing countries, contributing to one third of the protein and energy. Recent increasing demand for gluten-free cereals has brought back interest in ancient grains. Proso millet is emerging as a prominent candidate in this category (Das et al., 2019). Other qualities that can play a role in creating a solid market for proso millet are the nutritional value. It is rich in essential minerals such as calcium, phosphorus, potassium, sodium, magnesium manganese, iron and zinc. In terms of nutritional components like protein, carbohydrates and energy content, proso millet aligns closely with staple cereals like rice, wheat and barley. Notably, the lower glycemic index in comparison these staple cereals make proso millet a favourable choice for individuals with type-2-diabetes (Das et al., 2019).

6.3.3 Methods for Intercropping Quinoa and Proso Millet

The intercropping method for proso millet and quinoa involves strip cropping. The primary goal is to harvest grains suitable for human consumption. Strip cropping, as described in Chapter 5, allows the cultivation of these two salt tolerant species together in the same field, thereby increasing biodiversity. In the study conducted by Vahidi et al. (2021), the optimal intercropping system was assessed by Land Equivalent Ratio (LER), a concept that describes the proportion of land needed to achieve an equivalent yield between monoculture and intercropping. This value was achieved when both crops were planted at a density of 40 plants per square meter, with a planting ratio of 25% millet and 75% quinoa. The relative yield obtained in that trial indicated that millet in those specific environmental conditions shows superior use of resources to quinoa, due to its prevalence and competitive advantage (Vahidi et al., 2021).

6.3.4 Advantages and Disadvantages of Intercropping Quinoa and Proso Millet

As explained above, in this system both crops can thrive even in moderate soil salinity. Hence, this system is most likely to increase salinity resilience at farm-level. And because the focus does not have to be on species increasing each other's salt tolerance, the focus can be on other beneficial effects. This makes it even more valuable, as intercropping then might result in higher yield or higher resilience to other stressors.

However, the problem of using underutilized species is applicable here as well. Most halophytic species are under-investigated and there might not be a large market demand. Furthermore, millets are dominant species and influence the yield of quinoa (Vahidi et al., 2021). Consequently, many trials are still needed in the climate of the Netherlands to optimize this intercropping combination.

Still, we identified this system as the most promising, as research in this direction is most likely to pay off. The biggest challenge does not lie with finding combinations to improve salinity resilience, but with making it a profitable system so that farmers are more willing to make the transition. From all the tolerant species that can grow temperate areas as the Netherlands, quinoa and millet already have a market. In addition to this, considering the increasing consciousness of food and diets in the last decade, the demand for these new grains could rise.

6.4 Challenges of Underutilized Salt Tolerant Crops

The primary challenge that comes forward from this chapter is the lack of information, about beneficial combinations of crops to increase salinity resilience in general, and about quinoa and proso millet specifically. Even though beneficial interactions between quinoa and proso millet are shown, a substantial knowledge gap about the specific effects of intercropping these crops to withstand high soil salinity remains. Furthermore, it could be that this combination works poorly in respect to other stressors, or in other climates. More research in this area might lead to a selection of different crops, as it is impossible to really find the most promising combination with the current information.

Since quinoa and proso millet are not key players in agriculture at the moment, information is lacking about their cultivation in general, especially for temperate climates. Aspects that need to be considered for example are use of chemicals and genotypes suitable for the Netherlands.

Another challenge is that the current sales market is small for most of the crops we found. Introducing new crops to the Netherlands, or cultivating wild species, increases biodiversity in the crop production system. If farmers cannot sell their products, though, they will not produce them. Specifically for quinoa, the high saponin content in some varieties could push back the adoption of this crop by the farmers. This is because the grains require an extra processing step before they can be put on the market, and thus additional expenses and intermediaries have to be incorporated into the supply chain. We will further go into this in the system analysis in Chapter 7.

Lastly, optimise intercropping with quinoa and proso millet, more breeding effort is required. This includes climate adaptation, for example developing early maturing varieties, altering plant architecture to enhance beneficial interaction between the two crops, and improvement of the grain qualities.

7. A Hypothetical Strip Cropping Farming System

In the previous chapters, we explained the problems of monocultures, the difficulties of salt stress, different ways of intercropping, and the search for a combination of salt tolerant species, i.e. quinoa and proso millet. Taking all our findings into account, we will now outline a hypothetical new strip cropping farming system that deals with salt stress and grows quinoa and proso millet (from now on referred to as SCFS). With this information we will be able to assess the trade-offs of implementing intercropping (with quinoa and proso millet) in a salt-stressed crop production system in the next chapter, to answer one of our sub-research questions. It should be noted that this and the next chapter are meant as an approximation or a systems approach to get insight in the challenges and opportunities regarding the implementation of intercropping and the use of quinoa and proso millet. Below we will first give a description of the chosen region and the SCFS with proso millet and quinoa. We will end with an explanation of the stakeholders connected to this system.

7.1 Region Description

Currently, the coastal regions of the Netherlands experience the most salt stress (de Boer & Radersma, 2011; Koninklijk Nederlands Waternetwerk, 2019b) (see also Chapter 4). One of those regions is the province of Zeeland, which is also the biggest arable farming province of the Netherlands in terms of attributed surface area. Zeeland has a loamy soil, which is a mixture of sand and clay, that is fertile, easy to work with, and has excellent water management (Wageningen University & Research, n.d.). This type of soil makes it very suitable for different types of crops to be grown. For this reason, the agricultural sector in Zeeland mostly consists of arable farms, of which 9% is producing for the short chain (Venema et al., 2021). Mostly onions, potatoes, legumes, sugar beets and grains are cultivated (Zeeland.com, n.d.). Next to arable farming, there are other agricultural sectors thriving in Zeeland, for example, fisheries, saline agriculture, and fruit cultivation. Figure 10 illustrates the distribution of different types of agricultural businesses in Zeeland. In Zeeland, there are approximately 2,776 agricultural businesses in 2020, of which 16% sell their products via the short food chain (Venema et al., 2021). This means that the products are sold to the customer either directly or via one intermediate step. This is economically beneficial for the producer, as intermediates are cut and thus the costs are reduced, resulting in a higher margin for the farmer. Additionally, beyond the economic benefits, there are also environmental benefits, such as a reduced distance that goods have to be transported, resulting in a lower emission of fossil fuels (Manfredi De Fazio, 2016). Compared to the whole of the

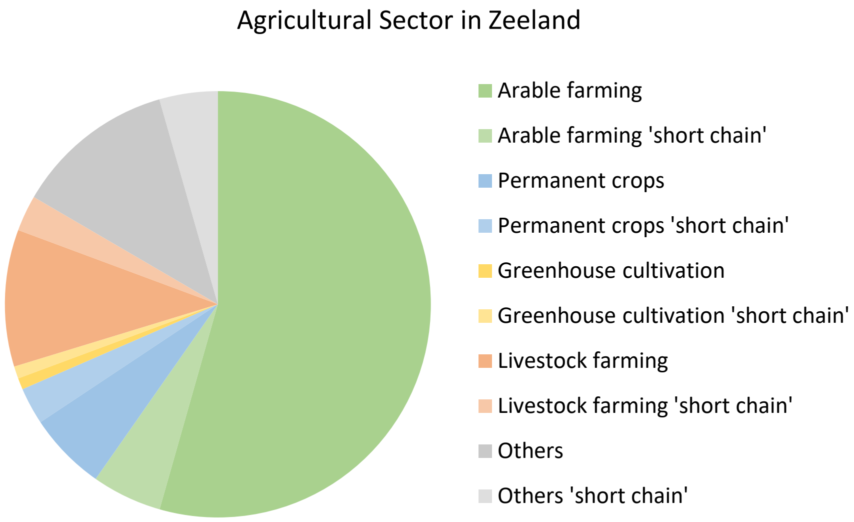

Figure 10 Types of agricultural business in Zeeland, divided into conventional businesses, and businesses producing for the short chain (Venema et al., 2021).

Netherlands, Zeeland is leading in producing for the short chain: there is a difference of +2.5% between Zeeland and the national average. Some of the off-farm/on-farm activities around the short chain producing farms are agricultural childcare, agritourism, farm education, nature conservation, generation of renewable energy for supply and care farms (Venema et al., 2021). This shows that Zeeland has a very dominant and progressive agricultural sector and that our new strip cropping system could be a good addition to the diverse agricultural landscape found there.

The province of Zeeland, like any other Dutch province, gives substance to European and national policy and adds their own provincial goals. Their focal points are sustainability, agricultural nature management, and agricultural innovation. To this end, the province of Zeeland has written an implementation program for rural areas, which outlines their visions, goals and ambitions with regard to agriculture and nature until 2030 (Provincie Zeeland, 2021). To be able to realize the visions in the report with the implementation program, Zeeland has decided on the availability of multiple subsidies for parties involved (i.e. research institutes, farmers and entrepreneurs). One of the key visions addressed in this report is a sustainable agricultural system that is in balance with its environment and ensures financial gain. Another vision of theirs includes preserving and increasing biodiversity within existing and new types of farming and in nature reserves. This is based on their belief that biodiversity can contribute to economic development in agricultural systems from the perspective of creating an ecosystem and that the role of biodiversity in agriculture should soon be self-evident. Combined with the previously acquired knowledge that Zeeland already practices saline agriculture to an extent, that their regular arable lands experience salt stress, and that their agricultural scene is very diverse, this leads us to believe that our hypothetical SCFS with quinoa and proso millet would fit very well into this progressive agricultural region, explaining our choice of region.

7.2 Description of the Hypothetical SCFS with Quinoa and Proso Millet

In this section our hypothetical SCFS with quinoa and proso millet will be explained. The reason for choosing quinoa and proso millet is because of the aim of the KB-project group. In Chapter 1, it is explained that their aim is to increase biodiversity within systems, and that using underutilized species is one way to do that. We decided to focus on strip cropping after taking the advantages and disadvantages mentioned in Chapter 5 into account. The most important advantage is that with intercropping, and strip cropping for that matter, the biodiversity at farm level is increased, which improves the resilience of the SCFS. This compliments the aim of the KB-project group.

This description of the system is of one year, so from sowing quinoa and proso millet in April, harvesting in August, and then sowing a green manure (e.g. a clover grass mixture) until the new rotation starts. According to the WUR in 2022, the average Dutch arable farm is 59 ha (Harold van der Meulen, 2022). On our strip cropping farm with quinoa and proso millet in Zeeland, there would be two people who work full time, that is the farmer and his wife. During the harvesting and seeding, the farmer hires contractors to help with the work. The field is made up of alternating rows of proso millet (1 row of 3 meters) and quinoa (3 rows of 3 meters, so 9 meters in total), with a density of 40 plants per square meter. The ratio is chosen, because in the (semi-)arid conditions of the experiments of (Vahidi et al., 2021), proso millet showed a more effective use of resources compared to quinoa, as a consequence of its prevalence and competitive advantage. Additionally, the harvest of quinoa and proso millet strips will be done separately.

Quinoa is a pseudo grain. Its seeds are grown and processed in a similar way to grains. Quinoa is sown between the end of March and the end of April and harvested between the end of August and September. It can be harvested with the same type of machine that grains and grasses are harvested with, a combine harvester with settings adjusted to the size of the grain. When quinoa is grown in a monoculture, the yield is around 3 tons per ha (Wageningen University & Research, 2014). The price for quinoa in May 2022 was €2151,94 per ton (IndexBox, 2022b). Another advantage of quinoa is that it has a high ground coverage, which makes it more difficult for weeds to grow. In 2023, the quinoa production in the Netherlands increased to 250 hectares. The UN declared 2013 to be the 'year of quinoa' which resulted in a global increase in both sales and prices. WUR has recently developed different species of quinoa, that do not contain the bitter layer (consisting of saponin) on the outside. This also reduced costs, as it does not need to be washed off during processing (Wolkers, 2015). Proso millet is a grain, meaning it can also be harvested with the same combine as common grains and quinoa. Proso millet is sown between the end of April and the end of May and harvested at the end of August, which is comparable to quinoa. The yield of proso millet when grown in monoculture is 6 tons per ha. The price for proso millet in May 2022 was €569.18 per ton (IndexBox, 2022a). Quinoa and proso millet can both be used in a similar way to how other grains are used after processing (PPO Akkerbouw & Groene Ruimte en Vollegrondsgroente, 2012).

For the SCFS system analysis, we followed the example of Vlaams Instituut voor Landbouw- Visserij- en Voedingsonderzoek (2023a). We first identified all of the processes, inputs, outputs and activities which are ecologically and economically relevant. These are illustrated in Figure 11. The impact of the system is analyzed from cradle to gate over one rotation (thus one year). This means that the analysis is applied to the process that starts with natural resources and ends at the moment the products leave the farm. In the rich picture there are two system boundaries, the background system boundary and the farm system boundary. The background system boundary includes all of the inputs, like infrastructure and purchased products. The farm system boundary entails the actual strip cropping farm with quinoa and proso millet. It contains three subprocesses: crop management, storage of the products, and product delivery. Within the crop management subprocess (the large green square in Figure 11), there are seven subsystems (in beige in Figure 11). First is *Preparation of fieldwork*, which includes all ground preparation that is needed to prepare the field for sowing. *Fertilization and liming* includes the amount and type of fertilizer and the method of manure application. *Sowing and planting* covers all operations involved in sowing and planting crops, whereas *irrigation and drainage* involves all that is connected to irrigation and drainage of the crops and fields. *Crop protection* entails all chemical, mechanical and biological processes involved in pest, disease and weed control. *Harvesting* includes everything connected to the harvesting of the crops; transportation of the harvested product to the farm is also included in this subsystem. Lastly, *Post*-harvest operations includes processing the harvest residues (removal, underworking) and sowing catch crops or post-harvest crops. Then there are two other subprocesses within the farm boundaries: storing and product delivery. The former includes all processes on the farm that happen after the quinoa and proso millet are harvested and stored. The latter covers all processes that are done to prepare the quinoa and proso millet to be sold directly to consumers, retailers, or to processors of products that contain quinoa or proso millet. Finally, the stakeholders of the system are placed strategically within the rich picture of the system, where their influence and/or interest is largest.

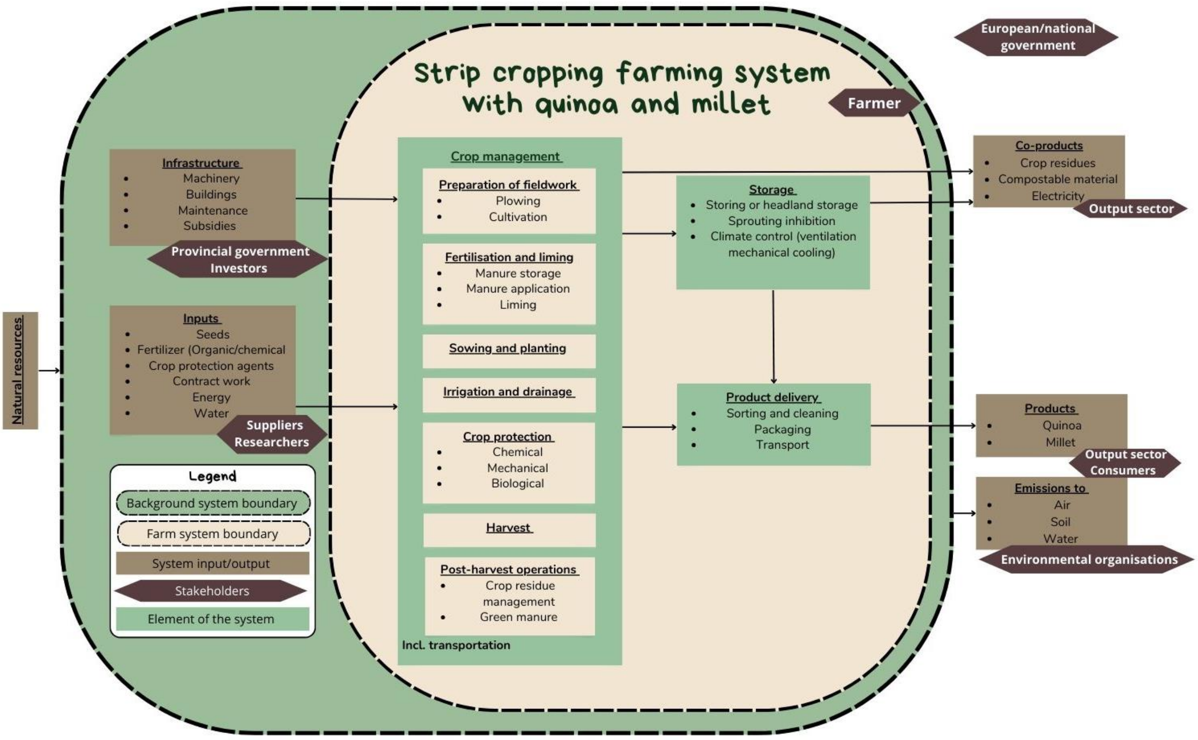

Figure 11 Rich picture of hypothetical strip cropping system with quinoa and proso millet for one rotation (1 year), inspired by the rich picture of (Vlaams Instituut voor Landbouw- Visserij- en Voedingsonderzoek, 2023).

7.3 Stakeholders Analysis of the Hypothetical SCFS with Quinoa and Proso Millet

The key stakeholders of this system are the farmer, the provincial government of Zeeland and (other) investors, as we believe they have high influence and high interest in the SCFS. More stakeholders of the system are for example researchers, the sector (retailers/processers/feed companies), environmental organizations, national and European government, consumers, the local community, and suppliers. These secondary stakeholders are all presented in Appendix C, together with an explanation of why they are stakeholders, what their interest and influence is in the SCFS, how much they are affected by the new system, and whether they are in partnership or conflict with other stakeholders. The key stakeholders will be described in more detail below.

The farmer, being the owner of the SCFS, is an obvious key stakeholder. They decide on how the farm is run and what plans are set in motion. Other stakeholders, like investors or researchers might influence their decisions, but ultimately the farmer decides. We assume that the farmer of the SCFS has profitability as one of their main interests, as it is their livelihood. However, since the SCFS is a progressive farming system that aims to increase, among others, biodiversity and sustainability, we also consider the farmer's interests to lie with these topics. The reasoning behind this is that a farmer does not willingly take risks and go through all the trouble to change a farming system if they do not believe in the purpose of such a system.

In Section 7.1, the visions and goals of the provincial government of Zeeland, the second key stakeholder, have already been addressed. We think the SCFS fits very well within these visions, as its main goals are to improve biodiversity, handle salinity stress and create a more resilient agricultural system. Therefore, we expect Zeeland is willing to grant subsidies that they have reserved for these kinds of ideas. This is also because to reach their goals, they need the help of many other parties, like researchers, investors, other governments, and, perhaps most importantly, farmers that are willing to change. This means that the provincial government of Zeeland has high influence in the system of SCFS, as transitioning to a new farming system and keeping it running requires investments. If a farmer is not able to receive subsidies, that could have a large impact. The possibility of subsidy denial, combined with other possibly restraining regulations (like pesticide use or harvesting moment), could lead to conflicts with the farmer. Nevertheless, we expect these two will mostly be in partnership, due to their shared goals.

The remaining key stakeholders are the other investors. These can include for example banks, private companies, or funding institutes. To be able to transition into a new farming system, investments need to be made in reorganization of the land and farm, purchase of seeds, machinery, et cetera. This money can come from subsidies of the local government, but the majority of it will probably be provided by other investors. This means they also have high influence. Investors are quite evidently interested in what they are putting their money in. In other words, they are interested in the profitability and success of the SCFS. Additionally, some investors have specific requests or ask their receiver to head into a certain direction. This could lead them to be in conflict with the farmer and other stakeholders, that might have different plans, but it could also lead to agreement and partnership.

Now that we have explained the region where the system is located, the system itself, and the stakeholders that are involved in the system, in the next chapter we will continue with the analysis by looking at the trade-offs, challenges and, eventually, the opportunities.

8. Integration of Trade-offs, Challenges and Opportunities

This chapter will integrate and discuss all the information from previous chapters. Section 8.1 contains a trade-off analysis of the SCFS with quinoa and proso millet. It compares strip cropping with monoculture and summer wheat with quinoa and proso millet. It draws a conclusion on what system is the better choice and lists a few important challenges and opportunities that are solely connected to the trade-off analysis of the SCFS. Next to the challenges connected to the SCFS there are also some challenges related to the whole KB-project. These will be clustered, ranked and discussed in Section 8.2, integrated with all the important challenges and opportunities found in the rest of the report.

8.1 Trade-off Analysis of the SCFS with Quinoa and Proso Millet

In this section, we use the previous chapters to assess the trade-offs of implementing strip cropping with quinoa and proso millet in a salt-stressed crop production system, which will answer the fifth subquestion of our report (*What are the trade-offs of implementing intercropping in a salt-stressed crop production system?*). The section will compare our hypothetical SCFS with quinoa and proso millet, to a conventional similar sized arable farm with grains. The trade-off analysis is divided into two parts to be able to make a comparison with as little variables as possible. First, we compare the use of quinoa and proso millet on a conventional monoculture farm to the cultivation of grains, also on a conventional monoculture farm. In the second part, we compare strip cropping to monoculture, regardless of the crop type. After the two comparisons, we will list the assumptions and conditions under which the comparisons are made. Then, we will give a conclusion on the trade-offs of implementing intercropping (with quinoa and proso millet) in a salt-stressed crop production system. Finally, we list the challenges and opportunities that result from and specifically belong to the system analysis and do not come back in Section 8.2.

8.1.1. Trade-Offs and Challenges of Quinoa and Proso Millet Compared to Summer Wheat

The comparison between cultivation of quinoa and proso millet in monoculture (separately) compared to summer wheat in monoculture comes with some trade-offs and challenges. Many of the points mentioned in this section have been mentioned in Chapter 6 and Chapter 7. In these chapters, additional info about the trade-offs and challenges can be found.

8.1.1.1 Trade-offs at Farm Level

We choose to focus on comparing with summer wheat, because summer wheat is sown in March or April, and harvested in August (Nederlandse Akkerbouw, 2017b). This is the same for quinoa and proso millet (see also Chapter 7). The same kind of machine is used for the sowing of proso millet, quinoa, and wheat. Also for harvesting, the same machine is used, with the only difference that the settings of the combine have to be adjusted for the size of the grain. During the harvesting of the grain, the rest of the plant is excreted from the back of the combine, onto the field. The crop residues can be used in different ways, which will be further discussed in the next section. The width of the combine varies between 3 and 22 meters. This means that when it comes to the machines that are used for harvesting (that we looked into), there is no difference between quinoa or proso millet and summer wheat.

The average yield per hectare in 2020 for quinoa was 3 ton/ha. For proso millet this was 6 ton/ha, and for summer wheat the yield was 7.1 ton/ha (Centraal Bureau voor de Statistiek, 2020). Other than the difference in yield, there is also a difference in price per ton. For quinoa, the market prices in 2022 were €2,151.94 per ton, for proso millet €569.18 per ton, and for summer grain €206.00 per ton (Akkerwijzer, 2023; IndexBox, 2022a, 2022b). Currently, quinoa has a very specific niche market as a superfood, which results in the very high sales prices. The sales price for proso millet is more than twice as high as summer wheat, even though the yield per hectare is quite similar to summer wheat. So, despite the lower yield per hectare, the high sales prices of quinoa and proso millet could be an incentive for a farmer to cultivate these crops instead of grains.

8.1.1.2 Trade-offs at the Level of the Value Chain

The sales market of quinoa and proso millet is much smaller than that of summer wheat. Summer wheat has a global sales market of €145.4 billion in 2021, while that of quinoa was €57.89 billion and that of proso millet was €11.70 billion (Data Bridge Market Research, 2022; EMR, 2023; Raghav A.-Raghav, 2023). For our SCFS, we used quinoa and proso millet, which are currently underutilized crops. This means that there is an opportunity for the sales market of quinoa and proso millet to expand.

For the sales market to expand, consumers would need to consume more quinoa and proso millet. The sales of summer wheat that is produced in The Netherlands is mainly intended for animal feed. However, summer wheat is also used for the baking industry and flour sales. Quinoa can be popped into popcorn, used in salads, and can be turned into flour as well. Proso millet is currently used in birdseeds, but in other countries it is used in a way similar to couscous. Quinoa has a high protein content, which ranges from 8% to 22%. Proso millet is rich in essential minerals and is more similar to summer wheat when it comes to nutritional values than quinoa is to summer wheat (see Chapter 6). Because the use of quinoa and proso millet is similar to summer wheat, quinoa and proso millet can easily be incorporated into the diet of consumers and possibly also in processed foods as a replacer for summer wheat. Quinoa and proso millet are gluten-free and sometimes seen as superfoods, which offers a wide range of marketing possibilities. So, growing quinoa or proso millet means that the farmer would compete on the market with those that grow summer wheat.

The grains of the quinoa, proso millet and summer wheat can be consumed by humans and animals, while the rest of the plant can be used as straw for bedding for animals or as feed for livestock. Since the protein content of quinoa crop residues is higher compared to summer wheat, it can be used in animal feed as an extra protein source, or as a replacement for e.g. a grass/clover mixture or soy.

To summarize, when comparing summer wheat and quinoa or proso millet on the level of the value chain, it is currently easier to cultivate wheat. One reason for this is that the sales market is bigger, though this also means that there is more competition. In terms of waste streams, the crop residues of quinoa and proso millet could add a higher nutritional benefit to livestock feed, but the applications should be researched further.

8.1.1.3 Trade-offs at the Level of the Environment

The goal of the new SCFS with quinoa and proso millet was to improve the resilience to salt. In Section 6.3 of this report, the reasoning for using quinoa and proso millet has been explained. Al-though summer wheat can grow well in nutrient deficient soils, quinoa and proso millet are both much more salt tolerant. Consequently, these crops can better withstand higher salinity levels in Zeeland than summer wheat. As mentioned before, quinoa and proso millet are categorized as underutilized species. This means that these crops are a better fit to the view of the KB-project to increase diversity in food systems than summer wheat is, as that is a staple crop in the Netherlands. Additionally, as far as we know, no Life Cycle Assessments (LCA, used to compare systems on for example nutrient leaching, emissions, and eutrophication potential) or nutrient balances have been performed on (a production system with) quinoa or proso millet. Therefore, we are unable to compare the two crops on their environmental impact, such as global warming or eutrophication potential.

8.1.2 Trade-Offs and Challenges of Strip Cropping Compared to Monocultures in Zeeland

When it comes to the comparison between monocultures and our SCFS with quinoa and proso millet in Zeeland specifically, there are quite a few trade-offs and challenges. In this paragraph, that comparison will be made. Many of the points made in this paragraph have already been mentioned and explained in Chapter 5. Additional information can be found there.

8.1.2.1 Trade-offs at Farm Level

Looking at harvesting, this is much easier and cheaper for monocultures, in our opinion, than it is for strip cropping. With monocultures, bigger machines can be used and less fuel and less personnel is needed. On the SCFS, harvesting is done per strip. The strips are not of the same width, which means more movements are needed and the settings of the machines need to be adapted per crop. It could even be possible that the 3:1 division requires two different machines. With both strip cropping and monocultures, it is possible to include fixed driving paths on the field, which prevents compacting of the soil under the weight of the machinery and the need for tillage. However, with strip cropping the machines are less heavy, meaning the effects are less profound. With regard to the machinery, according to the organic intercropping farmer we interviewed, there still are older machines available on the market that are smaller than the modern machinery. Unfortunately, these older ones are behind in technology and limitedly available. The purchase and development of new machines that are adapted to the smaller width of strips, however, is expensive. To conclude, currently, there is a lack of well-developed, widely available machines and technologies which can handle diversity like in a strip cropping system.

Also, since strip cropping knows many forms, strip cropping farmers need a more complicated plan than for a monoculture, for example with a rotation scheme, what combination of crops to use, the ideal width of the strips, and so on. However, currently there is limited information available on this. Examples of questions of farmers are: How do my plants interact above and underground? Do they increase or decrease each other's yield? Is the yield bigger than in monocultures? Considering food safety of contaminants, can I use the same pesticides and will it pollute neighboring crops? For all this, much more research is needed, also to fix existing inconsistencies in results. Monocultures on the other hand, have been optimized in the last decades. A ton of information, technology and numbers are readily available, and the farming plan consists of much less elements. For example, with one crop in a field, pesticide and fertilizer use is easy to determine. Considering all this, monocultures are the easier choice for now.

Touching on economics, the SCFS has the advantage of economic security. When one crop fails because of a certain stressor, other crops could be unaffected. Monocultures, on the other hand, would fail in total, since every individual is genetically identical and as tolerant to the stressor as its neighbor. Due to the increase of extreme weather occurrences as a result of climate change, some expect insurance companies to lower their yield loss coverage in the future. Strip cropping is then more economically secure, which would especially benefit small farmers. Additionally, from previous chapters we know from research and our interviews that with the right combination of crops, strip cropping yields are in some cases higher than in monocultures. Strip cropping, however, is more labor intensive and currently requires higher investments and fuel costs than monocultures. Zeeland does offer subsidies for initiatives that fit into their goals for 2030 though, such as their goals of creating sustainable agricultural systems that are connected with nature as well as an increase of biodiversity. So, we believe that a SCFS in Zeeland can receive funding to cover their costs. We hope that the Dutch national government and other provinces believe in and support the plans for alternatives as much as Zeeland does. It is difficult to decide which system seems more economically beneficial, since we have not looked at the real numbers or dived into the necessary investments, labor and yield stability.

8.1.2.2 Trade-Offs at the Level of the Value Chain

Currently, the food chain requires ingredients of constant quality to facilitate easy processing and ensure consistent high-quality end products. This is exactly what monocultures can bring. Intercropping performs less on uniformity. Putting multiple different crops together can have varying results in yield, taste, and growth, as mentioned previously. This variation could affect the selling potential of the crops. However, consumers are increasingly interested in 'special' products like organic foods, products that come directly from the farmer, or products that are better for the environment like *Kipster, Rondeel eggs* or those labeled *Planet Proof.* Especially in Zeeland, an agriculturally progressive region with short chains, strip croppers could have a better position on the local and broader sales market than monoculture farmers. However, since the costs of intercropping are higher than monocultures, products that originate from the SCFS are certainly more expensive, which puts the SCFS at a disadvantage.

8.1.2.3 Trade-Offs at the Level of the Environment

In previous chapters, it was explained how intercropping can make a system more robust, as it is much less affected by both biotic and abiotic stressors than monocultures are. To name a few: the physical distance and lower densities of plants lead to lower pressure from pests and disease, the higher biodiversity in crops attract a larger variety in pollinators and organic pest control, and the interaction between plants have the potential to limit negative impact from wind, sun, salinity, and soil erosion. Moreover, the allelopathic plant-plant interactions can improve crop growth and repro-duction, increase nutrient availability, and enhance fungal and bacterial enzyme activity in the soil (Wang et al., 2014). As a result of a higher soil quality, less fertilization is required, which was the experience of some of our interviewees as well. Altogether, we expect an SCFS would be better suited to withstand the soil salinization of Zeeland's arable lands. To our knowledge, no LCAs or nutrient balances have been done with the purpose of comparing the environmental impact of strip cropping (or intercropping) to a monoculture. Therefore, we are not able to draw a conclusion on these types of environmental impact.

With the growing world population and an increasing demand for agricultural products, it is difficult to structure global feed and food production to keep up with this progression. It could be that currently only highly optimized monocultures are able to meet those needs. But have we really looked at whether that is true? And could that still be the case with the increasing pressure of climate change and the need for resilient systems? It has been mentioned several times before, but research, innovations, evidence-based trade-off studies, and effort in general are lacking, which means the comparison of food supply between monocultures and SCFS cannot be made yet.

8.1.3 Refining and Nuancing Limitations and Conditions

To apply the system in the real world, we have made some assumptions and conditions to be met before this system could work. The first conditions take place at European or national level. The vision of the EU has already shifted towards a more sustainable food system, for example through sustainable development goals and climate summits, and by restricting nitrogen emissions of countries. However, national governments should align their goals to each other and take action as well. We believe that this is currently insufficient. We hope that an increase in national determination for improving the environment will result in higher subsidies for farmers who change towards progressive systems that improve the diversity and resilience of the food system, like an SCFS. Additionally, if the farmer has the financial means to change, there are assumptions on the adequacy of their resources as well: knowledge and tips for such a switch should be readily available.

Another assumption on farm level is that quinoa and proso millet also grow well together outside of the (semi-)arid climate where the intercropping experiment with quinoa and proso millet took place

(Vahidi et al., 2021). A limitation at farm level is that there is no clear overview of whether the higher price for quinoa and proso millet (or other crops suitable for strip cropping) compared to summer wheat (or other single monoculture crops) is compensating for the higher costs associated with intercropping. An economic analysis could be done on an SCFS to figure this out. There are also limitations on the use of fungicides for quinoa that we did not take into account. For example, at the moment, it is not allowed to use a fungicide against downy mildew in the Netherlands (a common oomycete that harms quinoa and other plants) (CTGB, 2023). Adding to this, another limitation is that it is not known yet how pesticides and fungicides used on quinoa affect proso millet, and vice versa. A last limitation on farm level is that we did not look into machinery, other than combines, associated with the cultivation of crops.

Our system analysis also has some limitations, due to our focus on Zeeland only. Moreover, we only assessed one crop rotation. We did not look into crops that could be used in the next year, while generally crops are rotated to maintain the quality of the soil. Besides, our analysis was only from cradle-to-gate, so processes outside of the farm gates, like seed and fertilizer production or processing, were not assessed. Lastly, we had no real figures to draw conclusions from; we did not perform an actual nutrient balance or LCA, which could have provided those numbers.

In the trade-off analysis, we compared the SCFS with quinoa and proso millet with a summer wheat monoculture. This means that we did not take the costs of a possible transition towards an SCFS system into account. These costs could be investments in new machines, schooling, and extra labour. Moreover, it will take some time to learn how an SCFS system should be managed and what rotation and what crops fit best to the particular situation.

8.1.4 Conclusion of Trade-off Analysis of the SCFS

Up until now, we have compared strip cropping to monocultures, and quinoa and proso millet to summer wheat via a system analysis, as well as listing the assumptions and limitations. Now, we can bring it all together and give our conclusion. At this moment, we believe that monocultures are the better choice when it comes to yield, cost-effectiveness and labor. This is due to the years of optimization. With the current lack of knowledge, experience and efforts, strip cropping, as well as intercropping in general, cannot be directly compared to monocultures. However, strip cropping has potential to be superior to monocultures. Currently, it already is the better option in terms of soil quality, durability and resilience. However, more technological innovations, subsidies and research are needed to reduce costs and help farmers in the transition. Essentially, there is a need for a shift in all corners of society. For this, a good collaboration and frequent communication is crucial between researchers, farmers, governments, consumers and the sector. We do believe in the implementation of an SCFS (and intercropping in general), but without these changes, we do not think it is feasible. There are opportunities to change this, though, which will be discussed in the next sections.

8.1.5 Challenges and Opportunities Specific to the Trade-Off Analysis of the SCFS

Although the trade-off analysis had some limitations, it does provide us with new opportunities. In this section the most important challenges, specific for our SCFS trade-off analysis, will be repeated, and the opportunities that emerge from these challenges will be discussed. We will continue listing opportunities in Section 8.2, together with the important challenges and opportunities from the rest of the report.

The first challenge, specific to the SCFS system analysis, is the niche market of quinoa and millet. Quinoa and millet are very specific products, and do not yet have a big sales market in the Netherlands, or in Zeeland for that matter. We need to create more demand and increase this sales market in order to make growing these crops appealing. More resilient systems will lead to a market that is more economically stable and independent of the combination of crops. This is because the diversity in available crops ensures food security in a way that big yield losses due to stressors are less common. For example, the risk of a biotic stressor breaking out, wiping out complete crop fields and causing a total loss of a year's yield, may be considerably reduced.

The second challenge, specific to the system analysis, is about farm management. There has not been much research on intercropping yet, meaning that there is limited knowledge about plant-plant interactions that increase yield. Additionally, we could not find any research on pesticide use in intercropping systems. It is important to look at this, since pesticides might leach into and contaminate neighboring strips. Some pesticides have specific regulations on what species they can be used on, for example. This lack of knowledge on intercropping management also results in some opportunities, however. To illustrate, at the start of the transition to an SCFS with crops that are harvested in a similar way to quinoa, proso millet and summer wheat, the farmer could still use the same machinery as with most monocultures. This is because the farmer can harvest all of the quinoa and proso millet at once. This could also work for other grain-like crops, provided that they have the same harvesting time. This method does not require any extra fuel or smaller machines. The availability of suitable combines should not pose a big problem in our SCFS with quinoa and proso millet, though, as currently there are combines on the market that fit a wide range of strip widths. Another opportunity regarding farm management is to look into new applications of quinoa and proso millet. For example, we believe the crop residues could be used as bedding (like straw), in animal feed or for new applications in the human food industry. Going further into this, when quinoa and proso millet crop residues are used for animal feed, the manure of the livestock can be used as fertilizer to create some circularity. Another option for the crop residues could be to only harvest the seeds and leave the rest of the plant on the field. This way, the nutrients that were taken out of the soil by the plant are returned to the soil again.

8.2. Discussion of Challenges and Opportunities

In the previous chapters, various challenges came forward regarding (the transition to) intercropping for salt tolerance. To create some clarity and structure, we categorized the challenges into six different clusters: Research, Communication, Breeding Focus, Regulation and Funding, Farm Management, and Sales Market. The importance of each cluster is determined by the decision matrices in Appendix E, and the method behind it is further explained in Chapter 3. In this chapter, we will go over the challenges from all chapters again, per cluster. These challenges are then integrated into future opportunities for farmers, breeders, and researchers. The full list of challenges and opportunities can be found in Appendix F.

8.2.1 Research

In the previous chapters, we have identified a plethora of challenges related to knowledge gaps and research. These challenges will be integrated into opportunities in this section.

First, as seen in Chapter 4, the mechanisms behind salt tolerance of crops are not yet completely understood. Research on underutilized salt tolerant plant species could advance this understanding of salt tolerance mechanisms. However, in agricultural fields, crops endure not only salinity stress, but they might be affected by other stressors at the same time. There is limited literature on how crops react to the combination of multiple stressors. More research could be done on this topic, with a better understanding of how agricultural crops can respond to climate change as a result.

Overall, understanding of the interactions between plants and the soil is limited. More fundamental research on these interactions, soil health, and sustainability of soil management could be conducted. Next to knowledge, the conclusions of studies on this could provide tools to enhance soil fertility and plant resilience against abiotic stressors. Research on soil, as well as research on intercropping, results in a huge amount of data that needs to be analysed. This is a bottleneck for both research and breeding practices, also described in Chapter 5. Thus, new tools for the analysis of big data in field research need to be developed.

In chapter 5 and 6, we found that there is little known about beneficial crop combinations. Breeders and researchers can both attribute to gaining knowledge on this, especially on which specific combinations improve and which decrease the growth and development of the crops. Crop combinations which are well suited for salinity stressed soils could be studied in particular. Here, the performance of the crops in intercropping systems could be compared to their performance in monocultures as well.

Going further, in Chapter 5 we identified a knowledge gap on plant-plant interactions, and the underlying mechanisms. Especially below the surface, these interactions are not well understood. Researchers could focus more on fundamental research, discovering the mechanisms of plant-plant interactions, both below and above the surface. This would advance both research in general and breeding goals, as target traits could be discovered.

As seen in Chapter 4 and Chapter 6, there is little know about the requirements for the cultivation of underutilized, salt tolerant crops. More research on these crops could be conducted. This includes finding more underutilized, salt tolerant crops that are suitable for consumption by humans or livestock. In addition to this, research could include studying the optimal cultivation requirements of the crops. The outcomes of this research could be useful for the practices of farmers and breeders.

The lack of figures on economics and environmental impact of strip cropping systems (or intercropping in general) and the comparison of those numbers to monocultures, was one of the challenges that was identified in the system analysis of Chapter 7 and Section 8.1. We think there is an opportunity to compare strip cropping (or other types of intercropping) and monocultures by means of nutrient balances and LCA's. This way, a conclusion could be drawn on illustrative trade-off between the need for extra fuel and the decreased need for fertilizer, thereby finding if an intercropping system performs better than a monoculture when it comes to environmental impact. The comparison could be made based on, for example, leaching nutrients, emissions, land use, energy use (like diesel, gas, and electricity), global warming potential (in CO_2-eq.), or eutrophication potential (in NO_3^--eq.). The decision about which one of the two types of farming would have lower environmental impact depends in part on the boundaries of the system, the attributing factor (is the outcome e.g. expressed per farm or per kg product?) and/or whether off-farm processes would be included. Interestingly, depending on the factors chosen in such analyses, organic farming does not always perform better than conventional farming either, against popular belief (Mondelaers et al., 2009). Therefore, it would be interesting to see where intercropping systems, legislation or research and development could improve on, after such analyses. Additionally, it could be used to convince policymakers to change towards these more resilient systems.

Lastly, we think there is a great opportunity to have (agricultural) economics experts analyze intercropping systems, as this could provide clarity on the trade-off between the financial gains and the forecasted extra costs. Moreover, it could reveal what the highest expenses are and where there is still room for improvement. Currently, there are very little figures available, so a complete analysis on this could help farmers in making the decision to transition to intercropping.

8.2.2 Communication

The second most promising cluster of challenges is communication. The most important challenge concerning communication is the lack of frequent and effective communication between farmers, breeders, and researchers. This problem was mentioned in multiple interviews. We should aim to create a sense of responsibility for the preservation of the planet in all corners of society. That includes farmers, breeders, researchers, governments and consumers. By educating people at different levels and using several strategies (like social media, advertising, television, et cetera), the problem of resilience and food security will be raised, which might lead to more support for the change towards more resilient food systems.

Also, the frequency of communication between researchers and relevant stakeholders is limited. Options to increase the frequency of the communication between researchers on one hand, and relevant farmers, breeders, and other organizations on the other hand, is to include the latter group in research, projects, network events, seminars, courses, and open days.

A lot of findings from research are not shared outside of academia. Universities and other research institutes mostly publish papers in scientific journals, but these media are not targeting breeders and farmers. Therefore, methods of communicating findings from academia to farmers could be improved, for example through farming journals or online articles, as these are other main knowledge sources for farmers (Figure 12).

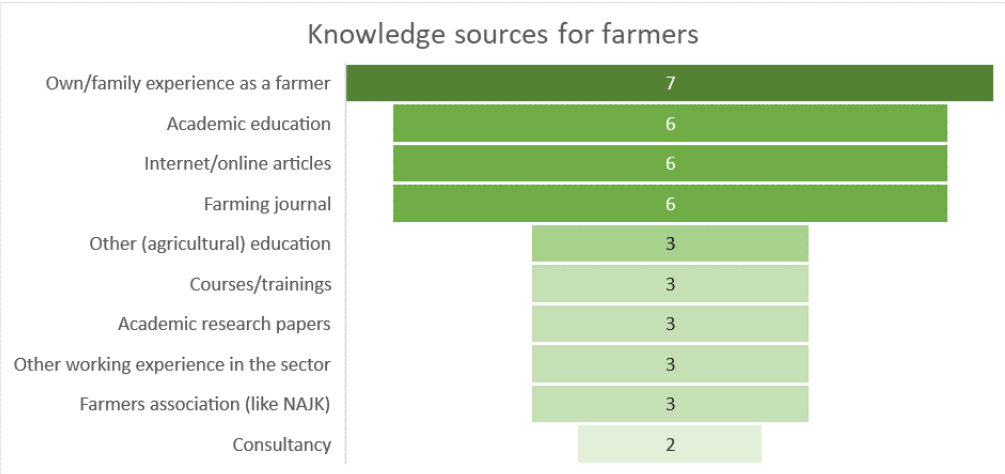

Figure 12 Knowledge sources for farmers, reported by the respondents of our survey.

Another challenge for researchers is how to communicate research outcomes effectively with the relevant stakeholders, which includes translating research findings into practical advice for farmers. All types of communication should be clear and clear enough to ensure understanding of all parties. Further research needs to be done on how to improve the effectiveness of communication between researchers and the relevant stakeholders.

Next to the difficulties in communication from research to farmers and breeders, there are also challenges in the communication the other way around. Farmers and breeders could communicate their challenges better to universities and other research institutes. Farmers could also take more initiative to share their challenges and needs to breeders. Breeders have the opportunity to be the link between researchers and farmers, as they can use the information from researchers, incorporate them into their own findings, and spread this to farmers.

8.2.3 Breeding Focus

As analysed in our case study in Chapter 6, the adoption of underutilized species by the farmers is mainly impeded by the low optimization of those crops to the current agricultural system. This raises the question about the role of plant breeding in this transition. We believe that breeding plays a fundamental role in introducing underutilised salinity resilient species in the current food system.

Currently, plant breeders mostly focus on breeding large staple crops as well as other crops with a market demand, as these breeding efforts are most profitable. The main interests of the breeders are to increase the yield of a crop, and to increase the resistance to biotic and abiotic stressors. For the latter, the focus of breeders could shift more on identifying underutilized and promising salt tolerant crop species from gene banks. Introducing underutilised crop species in agricultural practices enlarges the genetic diversity in agricultural fields. By integrating the underutilized species in plant breeding efforts, we can ensure that their valuable traits are not lost. According to the organic seed producer, another benefit of focussing on underutilized crops, is that there could be less hinderance of patenting problems as less companies are focussed on the genes of the underutilized species.

Breeding programs, with specific breeding goals related to the salt tolerance of the underutilized crops, can be set up in order to adapt the plants to specific environmental conditions and local climates. By optimizing the performance for local climates, breeders can encourage farmers to grow these species. Alongside the plants' climate adaptation in the fields, plant breeding could ensure that the harvested products meet consumer demand. For instance, reducing market barriers by improving taste, appearance, and expanding possible application of these underutilised species. This makes the product more appealing to consumers and consequently more economically attractive for farmers.

The selected crops could be adapted to intercropping systems as well. Examples of target traits are a narrower root architecture, and more compact bush structures to prevent growing over neighbouring crops. This would provide the opportunity to cultivate the new, underutilized species together with more well-known crops. This could persuade farmers to start cultivating the new species as well. Overall, plant breeders could add underutilized salt tolerant crop species to their portfolio in order to incentivize their customers to cultivate these in the future. As aforementioned, to start this process, more research needs to be conducted on underutilized salt tolerant species, in monocultures but also in intercropping systems.

8.2.4 Regulations and Funding

The biggest problem with the transition towards intercropping is the costs. Part of these costs are for farmers, but others can also be taken up by the government or regional water authorities by changing policies and providing subsidies. Now, it is most efficient for farmers to design their fields as monocultures, but this is also at least partly a consequence of how subsidies are distributed.

The government could be advised to put subsidies in the direction of change towards resilient systems and responsible water use in fields. This is beneficial for both farmers and the government. Farmers are able to cover the extra costs that intercropping might ask for, while the government is one step closer to reaching the country's climate goals. An example of subsidizing responsible water use in agricultural fields is the funding of drip irrigation. Regional water authorities covered 80% of the construction costs of the drip irrigation system in the intercropping fields of the organic plant breeder we interviewed. If this coverage would be extended to other farmers as well, this might increase willingness of farmers to transition to intercropping.

Another opportunity for the government is to invest in short chain markets and local food production. This increases revenues for the farmer, as there are fewer intermediate parties that require a cut of the money. In addition, there are less emissions to the environment with short chain markets compared to long chain markets (which is where most products in the supermarkets originate from). Here, it is important to educate and convince consumers of the value of resilient farming and sustain-ably produced foods. This can be done by setting up campaigns, for example. An additional benefit of this is the reduced emission because of less transportation.

8.2.5 Farm Management

A huge challenge for farmers is that drought and heat periods are increasing and lengthening as a result of climate change, demanding more irrigation for agricultural fields. However, simultaneously fresh water is getting more and more scarce, and the future prospective is the use of lower quality water for agricultural purposes. This, and suboptimal soil management of conventional farmers, with dry soil as a result, precedes further salinization of the soil. An example of a possible opportunity to tackle this problem is using drip irrigation in fields, on which a lot of experiments and trials are done currently. For this, tubes are located into the ground at a depth that is adjustable to what crop is grown. Using such a system prevents drying out of the soil and there is less evaporation, therefore less concentration of salt in the surface. Also, drip irrigation allows better development and growth of the crops, as irrigation can be altered for different crops.

In Chapter 2, another challenge regarding farm management was identified: the loss of biodiversity as a consequence of intensification of crop farming in the form of monocultures and standardization of market requirements for agricultural products. We found intercropping as a good solution to this problem, but there are also some management challenges to be solved, which are discussed below.

Modern machinery is not adapted to intercropping systems, as the machines are too large for most intercropping systems and they cannot handle genetic diversity. Development of new agricultural machinery and technology, or adaptation of existing ones, can help farmers transition to intercropping. Improvements could be made by developing agricultural machines, robots, sensor technology, and artificial intelligence. During the developments, communication with farmers and breeders about their needs and challenges should be prioritised.

Next to this, crops that are planted in fields as seedlings, mostly vegetables, are difficult to obtain for intercropping farmers. Seedling-producers are inflexible in the number of seedlings that they want to sell, which often means that the seedlings are sold in quantities that are too large for intercropping farms. A possible solution from the farmers perspective, is to order seedlings together with other (intercropping) farmers or through farmer organizations.

Another farm management challenge is the financial feasibility of transitioning to intercropping. Farmers often need to invest in new machinery to transition to an intercropping system. This is a large obstacle for farmers, as well as the increased costs for the inflated labour intensity and fuel usage of intercropping. An opportunity to cover these expenses is to increase the price of the products of intercropping fields, but this could have effects throughout the food chain. A possibility to start finding solutions to this problem could be to start investigating possible regulations and subsidies that could make intercropping more economically attractive for farmers. Investigating how food chains in other countries deal with higher prices of products from intercropping farms is also an option, as other countries are ahead of the Netherlands in this aspect according to the organic plant breeder.

Furthermore, transitioning towards intercropping is a difficult process for farmers. They need to make drastic changes in the planning and organization of their fields, and perhaps adopt a new mindset. An opportunity to solve this problem could be to write a protocol for farmers on how to transition from a monoculture to an intercropping system, and what to expect during and after this transition. This would include advice on how to start intercropping in general, with theory to fill the potential gaps in the farmers' knowledge on the topic. However, the most important aspects of the protocol would be advice on creating an action plan for an optimal intercropping farm, for example a strip cropping system. This includes information on which beneficial crop combinations to grow under various soil circumstances, the applicable crop rotation schemes, and a blueprint on how to divide the farmers' fields in strips and where to put fixed machinery paths. Protocols like this already exist for smaller projects, but not for extensive transitions into intercropping systems.

On the shorter term, less intense forms of increasing the genetic diversity of plants in a field, for example using field margins or cover crops, can already have a great influence on biodiversity and resilience of a field. Transitioning to systems like these are not as drastic as for example strip cropping, as large investments in machinery and knowledge are not required.

8.2.6 Sales Market

Lastly, we will go into challenges regarding the sales market. A problem here is that both retailers and consumers demand cash-crops, and underutilized crops are less popular foods. Most consumers have little willingness to spend more on foods that are produced sustainably or organically. An opportunity with great potential outcomes is to invest time and effort into changing the sales market and consumer perspective. The researcher from WUR has indicated that it is possible to move away from monocultures and into the direction of more resilient agricultural systems, when consumers are willing to pay the price. For this, (government) campaigns could be designed to get consumers to incorporate new foods in their diets. According to the WUR researcher, we need to increase the number of species we use for food, and we have to reinvent and reintroduce new species on quite a large scale to achieve this. This requires also the involvement of big companies in the food chain, as they have to be willing to process other products. Collaborations should be formed between those who are willing to change to put these opportunities into action.

Another challenge is that the sales market is not yet advantageous for intercropping and intercropped goods, as those are more prone to vary in quality and size compared to products of monocultures. The market and food processors ask for uniform products with a constant quality. This seems logical, but is also really inflexible. This problem could be dealt with through opportunities that are not dependent on a change in consumer behaviour and market demand. For example, farmers could focus on intercropping with crops that already have a market. This not only attracts consumers towards intercropped goods, but it also attracts conventional farmers to intercropping in general. In addition, this is a first step towards more short chain markets and local production, as farmers then produce multiple crops in small amounts, instead of a small number of crops in vast amounts. Moreover, the fact that desalinizing or halophytic crops are not popular foods does not mean that they cannot be used for animal feed. Salt is often added to feed diets anyway, and a diverse diet is healthy for all animals, also according to the interviewed organic seed producer.

One challenge that emerged from Section 8.1 is that there currently is a niche market for quinoa and proso millet (and other underutilized species for that matter). It is not yet woven into our daily consumption pattern. For the application of quinoa and proso millet in our diet, consumers should be made aware of the nutritional benefits. For example, by advertising the higher protein content of quinoa.

Because there is only a niche market for quinoa and proso millet at the moment, farmers need to be convinced to cultivate these crops. One incentive for them could be that there is a higher selling price per kg for these products compared to more conventional crops. Another incentive could be that quinoa and millet can be used as animal feed, which means the sales market is much broader than just for human foods. When advertising new underutilized crops to farmers, it should be taking into account that farmers are looking at the practical reasons to change underutilized crops as well, for example the economic benefit.

9. Conclusion

In this report, we have identified what is required to enhance genetic diversity in crop production, in terms of opportunities for farmers, breeders, and researchers, to assist a transition towards more salinity resilient food production systems in the Netherlands.

We have looked at the current farming practices in the Netherlands, known strategies against salinity stress, and ways of enhancing genetic diversity in agricultural fields by means of intercropping. We interviewed a farmer, plant breeders, and researchers about the latter two topics and asked them about the current challenges they face. To the best of our knowledge, we concluded that there are no current practices against salinity stress through enhancing crop diversity in the Netherlands.

Next to this, we selected a combination of crops that can potentially increase the resilience of the crop production system against salinity; quinoa and proso millet. Then, a hypothetical strip cropping farming system in salt-stressed Zeeland with these two crops was set up and analysed. From this system analysis it became clear that the current situation of the Dutch food production system is not yet ready for a change towards resilient systems like intercropping. However, we identified opportunities to make this transition feasible.

The combination of these insights helped us answer our main research question. We identified a plethora of challenges and opportunities to enhance diversity in crop production to assist a transition towards more salinity resilient food production systems in the Netherlands. These opportunities were grouped in the six clusters: Research, Communication, Breeding Focus, Regulation and Funding, Farm Management, and Sales Market. Through a decision matrix (Appendix E), we identified the most important clusters. Research came forward as the most important for all key stakeholders combined, and Communication was found to be most important for researchers. An important side note here is that is not true that the lower-ranked clusters like Sales Market are not important, they are currently just less important for the KB project.

We found a lot of opportunities for research. The plant-plant and plant-soil interactions happening in an intercropping system need to be better understood, while it is also important to find crops that work well together in an intercropping system. Soil health plays an important role in resilience, but is understudied. The organic plant breeder pointed out that they had a lot of data, but were not able to process these. Therefore, one of the first things to be done is looking into efficient data analysis methods, as both soil research and research on plant-plant interactions will have to process loads of data. Data analysis methods are also important for research on combinations of abiotic stressors. In practice, an agricultural system has to deal with more than one stressor at a time, and therefore it is important to study the effects of combined stressors, and which crop combinations can handle a multitude of stressors. Furthermore, the salt tolerance mechanisms of underutilized species need to be studied, in order to identify which species are best suited for salinity resilient intercropping systems. Once the most promising species are selected, research on cultivation and agricultural management of these underutilized crops needs to be done before they could be proposed to farmers and breeders.

The importance of communication did not only appear from our decision matrix, but also came back in multiple interviews. Farmers, breeders, and researchers should form a contact triangle in which all parties keep each other updated. Farmers should communicate their challenges and needs to researchers and breeders, and researchers their findings to farmers and breeders. Breeders can also form the link between research and practical implications.

From the other clusters, the main conclusions are that breeders can help the transition by breeding underutilized species, and by breeding for intercropping as other traits are of importance here. The government and regional water authorities should play a role in stimulating the transition to a more biodiverse and resilient system by means of subsidies. Drip irrigation came forward as a promising way to reduce water utilization and salt accumulation, this should be further investigated. To overcome challenges regarding farm management, machines need to be adapted to intercropping, meaning that they should be smaller or adjusted in another way. Another factor to be looked into is how to make intercropping financially feasible for farmers. Subsidies can play a role here, but there might be other ways as well. To make the transition easier for (large-scale) farmers, a protocol should be made that guides farmers step-by-step. Because it will take some time before most farmers can make the transition to biodiverse resilient systems, they could first implement in-between steps such as field margins and cover crops. Lastly, the sales market needs to be altered so that consumers are willing to buy underutilized crops. Big companies in the food chain also play an important role in this.

10. Limitations

For our project, we ran into a couple of limitations that might influence our findings and conclusions, and might have affected our advice to the KB project group. Our project had a scope of eight weeks, in which we chose our own small direction in the broadness of the KB project. We chose topics that fitted best to the combined expertise of our group: a genetically diverse plant production system in the form of intercropping, threatened by only abiotic salinity stress. This system is located in The Netherlands.

With this delineation, unfortunately, we omit a lot of other potential solutions or opportunities for the KB project. For example, we did not spend time on the other four production systems with increased genetic or biodiversity proposed by the KB project. In addition, we did not include livestock in our results, nor in our system analysis (only animal feed). Both could have resulted in additional or alternative conclusions. Furthermore, focusing on our chosen production system, we were researching a situation where the system was only stressed by one single stressor. This situation is unrealistic, as plants are normally influenced by a combination of multiple stressors, especially when grown in a crop field. However, knowledge and literature on the effects of multiple stressors on plants is lacking, which made it difficult for us to investigate a more realistic example. A lot more research on the effect of combined stressors on plants should be done to solve this problem and allow us to investigate a realistic situation. The location that we chose influences our system on policy-level. Most policies are location-bound, and therefore vary between countries and regions. Furthermore, the location determines the climate of our system, thereby influencing the choice of grown crops. This means that if we chose another location, the outcome of our system analysis would have differed as well.

Method-wise, there were also some limitations to our project. We stopped searching for salt tolerant crops after a week, as we felt that 34 species were enough to choose from and we needed to make a selection for the system analysis. We selected species for which some literature on intercropping could be found already, while no literature does not mean they will not work well in an intercropping system. And also the lack of research in other areas, like cultivation in the Netherlands, influenced the crop selection. For the system analysis, there were some limitations as well, these are elaborated in Section 8.1.3.

We have contacted farmers, breeders and other experts to interview them on current challenges, but only a limited handful. The survey we sent out also did not get a lot of responses, potentially because our project was timed in the harvest season. This means that we could not apply statistical methods to these results, which should be taken account in the interpretation of the results. Besides, the experts that we got to interview might have a bias, as we were able to contact them through the university. A big fraction of the interviewees was focused on organic practices, as well, which could have pushed us in that direction. Furthermore, six out of eights survey respondents indicated that they got their knowledge on farming through an academic education. This might bias our results in a way that academically educated people have an interest in modern, innovative techniques and therefore they are more willing to transition towards intercropping. However, this also has an added value, since the interviewees actually had an opinion on our research and they know, to some extent, what they are talking about. Both points should be taken into account when interpreting our results. Unfortunately, we were not able to find a policy advisor to interview, meaning that our overview on the situation, and then especially the legislation and regulation part, might not be complete. This has to be taken into account when interpreting our results.

Since our group was not specialized in any other elements of the food chain than production, we cannot provide insights on consumer behaviour, market research, or communication. These elements might show to be of great importance to the KB project, though, for example in identifying and including other stakeholders that were now left out. With the delineations we used, a big part of the story is not told, and more research on the rest of the food chains is required to be able to give the full context. This should be taken into account in the interpretation of our results, and also should be included in our advice.

11. Our Advice to the KB Project Group

The KB projects wants to contribute on the transition towards more resilient food production systems by increasing biodiversity. Based on our research and conclusions, **our advice to the KB project is that the WUR research agenda should look into:**

- **Plant-plant and plant-soil interactions**
- **Crop combinations for intercropping**
- **Resilience to multiple stressors**
- **Cultivation of underutilized species**
- **Communication between the KB project and its stakeholders**
- **Designing a protocol for farmers**

11.1 Plant-Plant and Plant-Soil Interactions

Do more research on plant-plant and plant-soil interactions. When looking into biodiverse food productions system, it is essential to have sufficient knowledge on interactions of plants with each other and with the soil. The mechanisms behind the yield increase of quinoa and proso millet should be studied, so that these interactions can be exploited. In addition to this, the effect on the soil should be studied when quinoa and proso millet are intercropped together. Before this research can be done, it is important to look into efficient data analysis methods, as these experiments will result in a large amount of data.

11.2 Crop Combinations for Intercropping

Do more research on identifying optimal crop combinations for intercropping. For some combinations of crops it is already known that there are some beneficial effects under specific circumstances. This research needs to be expended to look at effects on resilience under Dutch climate conditions. Furthermore, other combinations of crops need to be tested on beneficial effects as well, as currently no articles on intercropping can be found for a lot of crops. This research should also include under-utilized crops.

11.3 Resilience to Multiple Stressors

Do more research on plants' resilience to multiple stressors. Research often focuses on one specific stressor, while in reality systems have to deal with a multitude of stressors. Therefore, it is important to study the effect of intercropping on a combination of stressors, both biotic and abiotic. This will require the use of models, as it will be a very complex interaction system.

11.4 Cultivation of Underutilized Species

Gather information on the cultivation of underutilized species. An overview should be made on what is already known about the cultivation of the most promising underutilized species, and this information should be supplemented by new studies with field experiments. This information includes optimal sowing and harvesting time, optimal growth conditions, farming practices and how to plug-in to the food chain and sales market. This knowledge is needed before the underutilized species can be produced on large-scale.

11.5 Communication between KB Project and Stakeholders

Improve communication between the KB project and their stakeholders. A communication plan needs to be made to inform farmers and breeders on why they should transition to a more resilient production system, and how they can do this. There is an opportunity for the KB project to ask a new ACT team to consult on how to set up an effective communication plan. A set up for an ACT project description can be found in Appendix G. A challenge within this project is to determine the relevant stakeholders, those who could be interested in adopting new developments of the research and thus transition to a more resilient production system. Another opportunity is to set up a Professional Field Committee (PFC). A PFC is a committee of alumni and other people from the field, who get in touch with university once or twice a year. During a meeting, the PFC can discuss the current challenges, as well as to find solutions together. It is a nice way to get and keep in touch with the professional field.

11.6 Designing a Protocol for Farmers

Design a protocol for farmers on how they can transition towards a biodiverse resilient food production system. This is more of a long-term goal, as the previously mentioned points of advice will need to come first in order to make a protocol of quality. This protocol should include advice on which crops can be combined, and also information on cultivation when it concerns underutilized crops. There also needs to be an assessment of the environmental impact, like nutrient balance or an LCA to stress the value of such systems. The communication network needs to be strengthened for this protocol to have the desired impact. Another important element is to find out what drives the stakeholders involved to make this transition happen. For farmers for example, the profitability is important. Therefore, an economic analysis of such a transition should be part of this protocol, so farmers can make well-informed decisions based on these numbers.

11.7 Ethical Implications of Advice

There might be some ethical implications of our advice, when crops start to be produced in the Netherlands that are currently imported from other countries. This could lead to loss of profits for those countries, and therefore it needs to be considered. Another aspect that needs to be taken into account is that farmers could get the feeling that the whole problem of climate change and food insecurity is put on them. However, this could be prevented by good communication. Farmers should feel supported instead of blamed and forced into making a transition.

12. Acknowledgements

We would like to thank our commissioner Sipke Joost Hiemstra and Peter Bourke for their guidance and the fruitful meetings where we discussed the course of our project. Also, we would like to give thanks to the KB project group for giving us the opportunity to work on this project with them. Additionally, we have really appreciated the feedback we got on our intermediate and final products from our academic advisor Mario Calus, as well as the coaching on consultancy and teamwork from our coach Albert Aalvanger. Lastly, we would like to extend our gratitude to all the people who were willing to do an interview with us, and those who filled in our survey.

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Appendices

Appendix A: Interview Questions

A.1 Breeding for Plant-Plant Interactions and Intercropping

Complementary growth habits

- How do you breed for beneficial plants interaction?
- What are the main challenges when it comes to breeding for interaction?
- Do you focus on breeding for the combination of two species or breeding for adaptation of one species to another?
- What are your sources of information? Are there any collaborations with research institutes or Universities?

Yield stability

- Is your breeding program focusing also on resilience against abiotic stress?
- In your trials, did you observe any mitigation of abiotic stress damage when combining different species as opposed to monoculture?
- What are, for your company, the long-term breeding goals for the future?

Farmers/market adoption

- What drives your business in making decisions on the breeding project and long-term goals?
- How do you choose what species to work with? (research, market demand, price, trends, et cetera?)
    - How does the market/the farmers affect the decisions within your breeding program?
- Do you track market trends, or do you try to create your own unique niche market?

Policy regarding intercropping

- Are there any policy limitations regarding breeding for intercropping?
- Are there any differences in the national/international market that you consider?
- What do you think about the current legislation?
- What would you like to see research in?

A.2 Breeding for Salinity Tolerance

Motivation / demand

- Where does salinity rank in terms of your priorities, and what are your primary motivations in the breeding process?
- Do you currently see an increase in the demand for salinity-resilient crops?
- Is there a difference in national/international demand for abiotic stress (salinity)?

Environmental variability

- What is your current experience with …
- How do you breed for variability in salinity level?
- How do you determine the success of a salinity-resilient crop?

Interaction with other stressors

- How do you distinguish the plant's response to drought and salinity?

Challenges / trade-offs

- What salt tolerant species are currently used in the Netherlands?
- How do you determine which species to breed for?
  - Do you consider underutilized species?
  - Do you only choose crops that are salinity resilient already or do you also try to diversify more common / staple crops?
  - Do you focus on non-cash crops or main crops?
- How do you deal with the trade-off between resilience and high yield?

A.3 Intercropping Farmers

Labor intensity / harvesting time

- Was the transition towards intercropping system profitable for your crop production?
- After the transition, do you see any side effects?
  a) Do you see a change in soil quality?
  b) Do you experience an effect on yield?
  c) Do you use more pesticides/fertilizer than with monoculture?
- What investments in machines etc. did you have to make in the transition to intercropping?
- Is harvesting time affecting your planning schedule?
- Is the labor intensity higher or lower than monoculture?
- Did your sales market change after the transition?

Knowledge and training

- Where do you get your information from?
- Did someone help you during the transition? Do you have a consultant?
- Did you change from monoculture, or did you immediately start with intercropping?
  a) What is your motivation for changing this? (climate change/advice/profitability/etc.)

Crop selection and planning

- Are you still using the same crops as in the beginning? If not, why did you change?
- What crops do you grow and why these specifically (motivation for crop choice)? → Did you consider the use of underutilized crops?
- What is your opinion on the use of non-cash/trash/restoration crops?

A.4 Farmers Suffering from Salinity

Combination with other stressors

- How do you define the factors affecting your plant? Through visual observation or do you conduct tests on irrigation water / soil?
- How do you experience the difference between drought and salinity stress on your farm?
- Where do you get your information from?

Irrigation

- What are your current irrigation practices?
    a) Why did you choose this irrigation practice?
    b) Do you consider the potential side-effects of using poor-quality irrigation water (high salinity), and how do you manage these potential side effects in irrigation practices?

Soil degradation

- Have you seen (long-term) changes in…
    a) Your soil fertility?
    b) Yield?
    c) Growth/development of the crops?
- Considering the current state of your soil quality, what factors do you believe have contributed to its current condition?
- Do you take into account soil salinity when determining the application of fertilizers and pesticides?

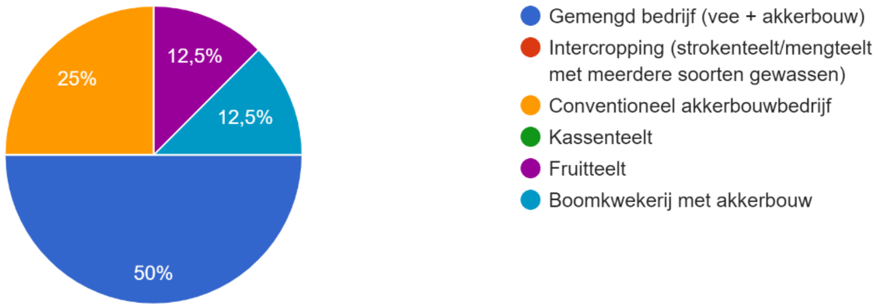
Climate change / future

- What do you think might be future challenges for your farm?
    a) Do you have plans to do something about this?
    b) Have you thought about mitigation strategies for this?

Appendix B: Survey Answers (in Dutch)

Wat voor soort bedrijf heeft u/ werkt u voor? Indien u intercropping gebruikt op uw bedrijf, kies graag deze optie.

8 antwoorden

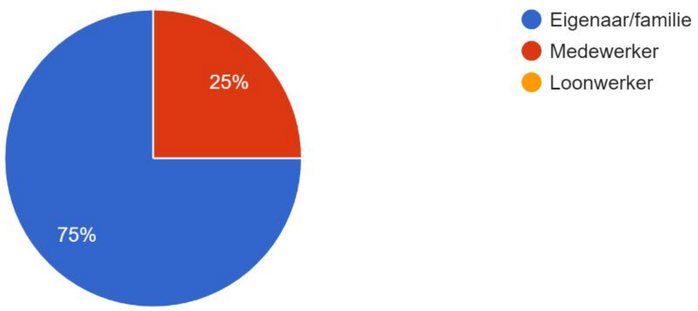


Locatie van uw bedrijf

8 antwoorden

Wat is uw rol op het bedrijf?

8 antwoorden



Wat voor gewassen verbouwt u op het bedrijf?

8 antwoorden

(Kruiden)Gras, Mais, Aardappelen, Suikerbieten, Tarwe, Luzerne

Hard- en steenfruit

Gras

Mais en gras

Maïs gras aardappels Veldbonen mais+stokbonen kruidenrijkgrasland

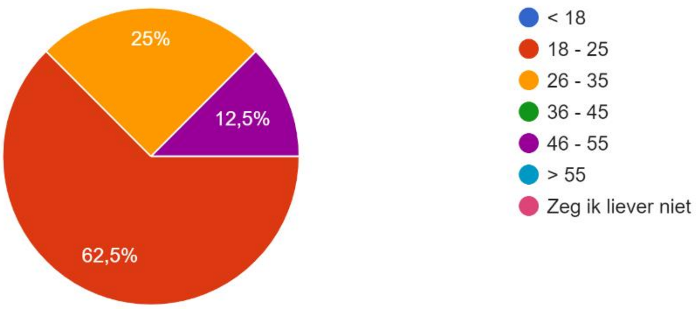
Aardappels (friet), zaai-uien, suikerbieten, peen, wintertarwe

Miscanthus, lupine, bomen, gras, mais,

Zetmeel aardappelen gerst winterveld bonen gras agrarische natuur suikerbieten

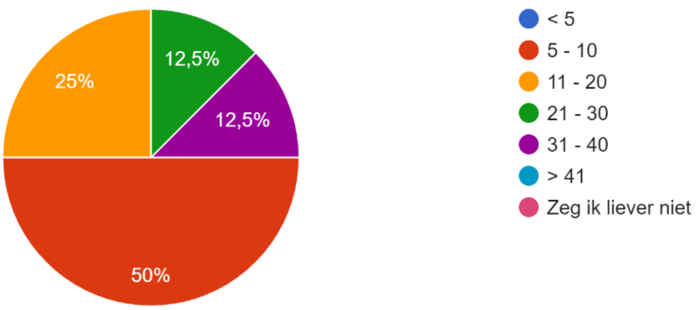
Wat is uw leeftijd?

8 antwoorden

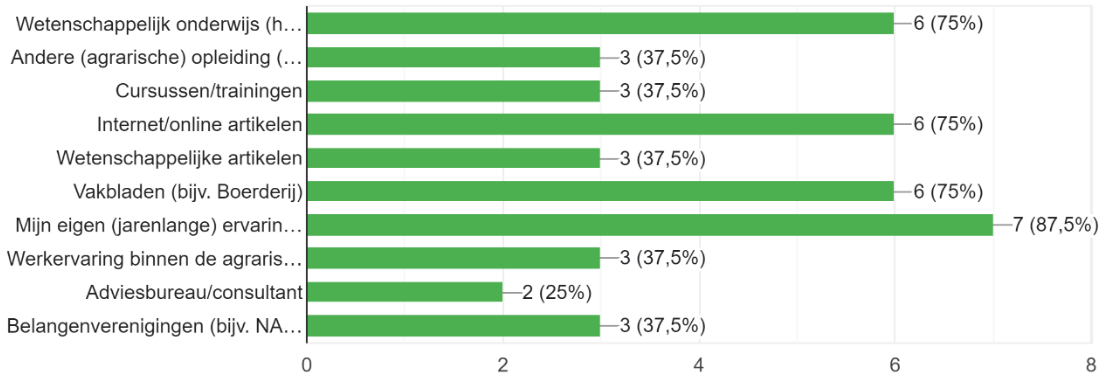


Hoeveel jaar ervaring heeft u binnen de agrarische sector?

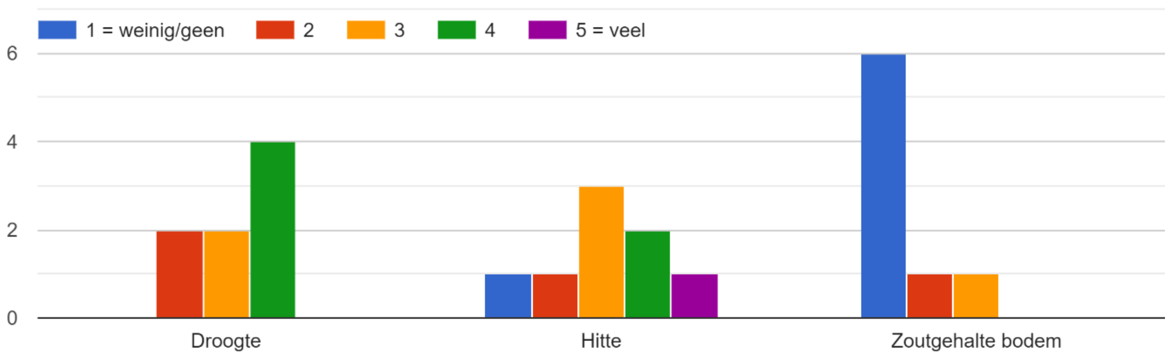
8 antwoorden



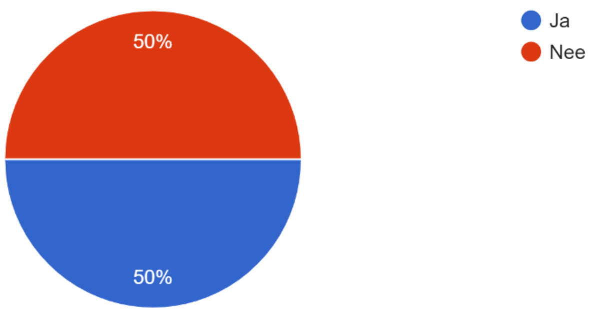
Mijn achtergrond en kennis over de agrarische sector komt van...
8 antwoorden



Hoeveel last ervaart u van de volgende abiotische stressoren op een schaal van 1 tot 5?

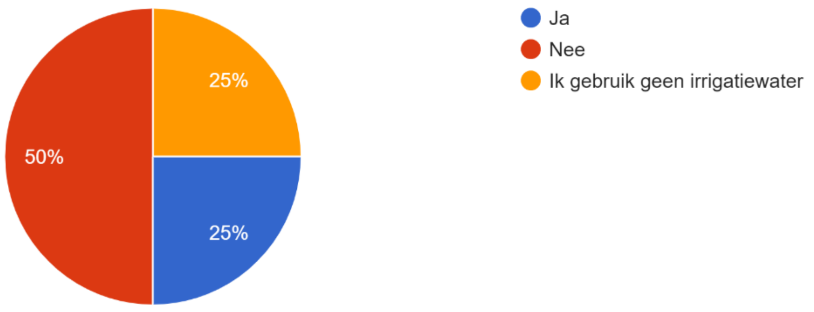


Heeft u ooit het zoutgehalte van de bodem getest?
8 antwoorden



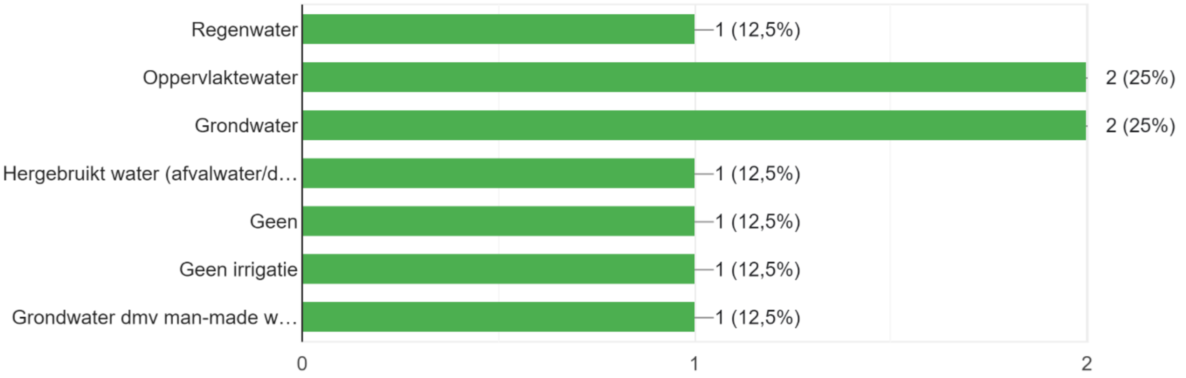
Heeft u ooit het zoutgehalte van het irrigatiewater getest?

8 antwoorden

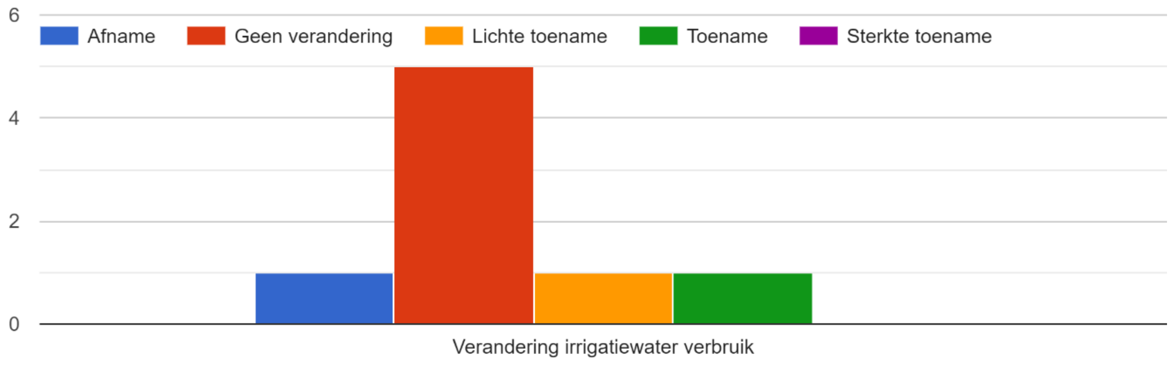


Waar haalt u uw irrigatiewater vandaan?

8 antwoorden

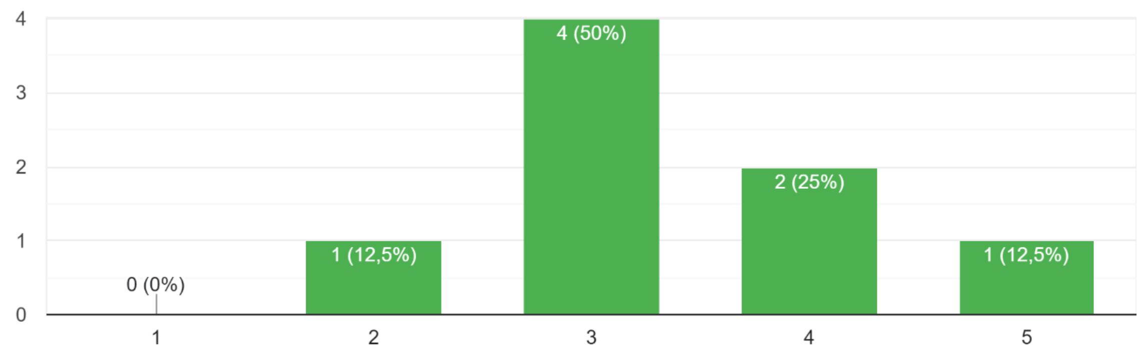


Is het irrigatiewater verbruik veranderd over de laatste 5 tot 10 jaar?



Hoe beoordeelt u de bodemkwaliteit, gemiddeld over het laatste jaar, op een schaal van 1 tot 5?

8 antwoorden



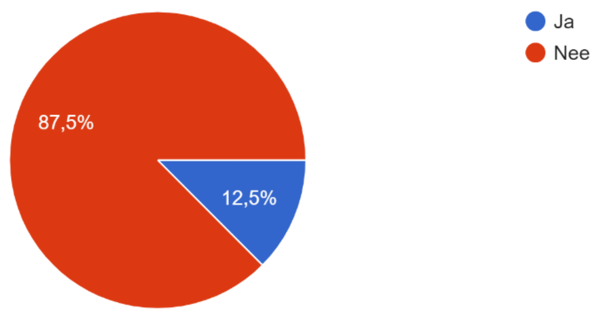
Wat voor uitdagingen/problemen ervaart u, specifiek met betrekking tot de bodemkwaliteit?

8 antwoorden

- Drogere grond, slechter te bewerken, slaat sneller dicht bij harde regenval
- Verzilting door oppervlaktewater
- Droogte, extreem laag grondwater Un zomer. Hoog grondwater/plassen in de winter
- Voorjaar bereidbaarheid zomers droogte
- Een storendelagen die er in komen
- Bodemdaling, verdichting, negatieve impact extreem weer (stortbuiten en enorm droge periodes) op bodem en bodemkwaliteit, het feit dat de overheid zich dmv regelgeving ongeveer begint te gedragen als grondeigenaar terwijl ik er als grondeigenaar toch echt zelf baat/belang bij heb om mijn bodem goed te behandelen en/of in optimale conditie te houden
- Droogte
- Te weinig bemesting mogelijkheden

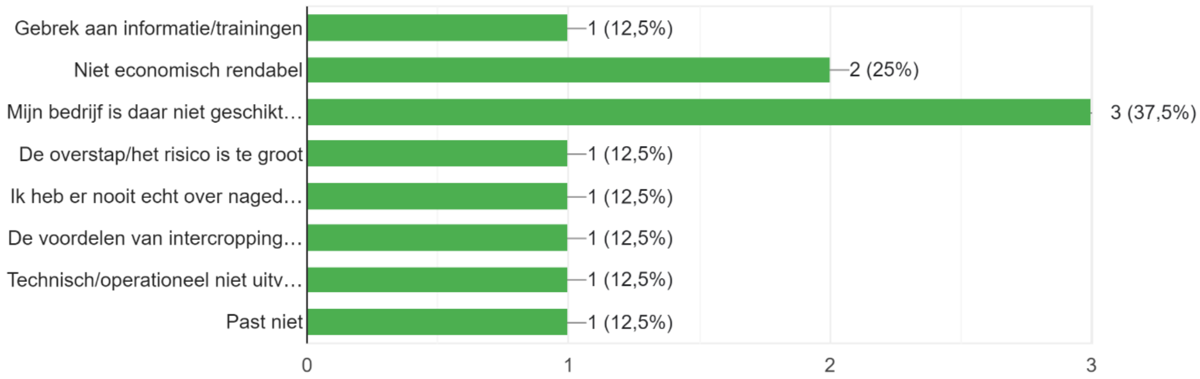
Heeft u ooit overwogen over te stappen naar een intercropping systeem?

8 antwoorden



Wat houdt u tegen om over te stappen op een intercropping systeem?

8 antwoorden



Eventuele uitleg over het antwoord bij de vorige vraag (optioneel)

4 antwoorden

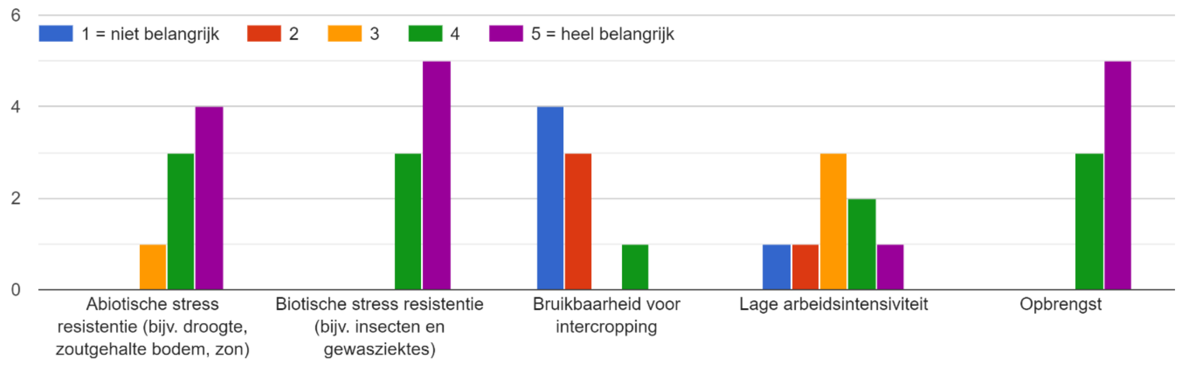
Er is veel onderzoek naar Intercropping gedaan maar de resultaten zijn vaak wisselend. Daarnaast zijn de voordelen het best wanneer je naar een systeem gaat met stroken van 3 meter of smaller, hier zijn de landbouw machines nog niet allemaal op uitgerust en dit kan problemen geven met bijvoorbeeld oogsten. Denk aan een tarwedorser die 6 of 9 meter breed is, bepaalde rooiers waar een kar naast moet rijden, maar als het gewas ernaast nog niet geoogst is kun je daar dus niet rijden.

Alleen gras

Mechanisatie: Oogst van bepaalde gewassen vereist 2 trekkers die naast elkaar rijden (1 met oogstmachine, 1 met kiepwagen tbv transport), als daar dan nog een ander gewas staat gaat het mis. Zou in principe wel kunnen, maar dan zijn we op ons bedrijf een paar ton verder qua investeringen in nieuwe/andere oogstmachines. In gewasbescherming is er zeer strenge controle of bepaalde gewasbeschermingsmiddelen niet in een gewas zitten (want niet toegestaan). Echter is er bij gewasbescherming altijd drift, en als gewassen strak naast elkaar staan is risico op residue van verboden middel in naastgelegen gewas te groot. Als residue gevonden wordt die hele teelt voor dat jaar op je bedrijf afgekeurd (voedselveiligheid) en kan ie naar de vernietiging.

Telen richting steeds meer miscanthus, hier kun je niets bij mengen.

Hoe belangrijk vind u dat gewassen verbeteren in de volgende aspecten:



Eventuele uitleg over het antwoord bij de vorige vraag (optioneel)

2 antwoorden

Gewassen laatste decenia altijd veredeld richting opbrengst (Mansholt) en gezond gehouden dmv gewasbescherming. Vergelijkbaar met top-sporter inc steroids enz. Nu lopen we vast qua gewasbescherming (te grote impact). Daarom veredeling nu enorm richting resistentie tegen grootste ziektes (phytophthora enz). Een gewas dat in potentie 100 ton/ha kan geven maar ziek wordt is slechter dan een gewas dat in potentie 75 ton/ha geeft en dat ook echt doet omdat ie resistent is. Min of meer idem voor abiotische factoren. Liever iets minder opbrengst maar wel oogstbaar en goede kwaliteit.

Een gewas telen met zo min mogelijk inputs. En zo min mogelijk arbeid, want arbeid is schaars.

Overige opmerkingen/meningen/ideeën kunt u hier kwijt:

2 antwoorden

Intercropping klinkt leuk, maar zitten veel haken en ogen aan, nog een extra voorbeeld is dat spuiten tegen ziektes etc ook met intercropping nog wel eens nodig is. De meeste spuitbomen zijn wel 15 meter of veel breder. Zolang hier geen optie op zit dat je bepaalde delen van de spuit uit kan zetten kun je dit dus niet gebruiken. Kortom, ik denk dat het grootste nadeel is van intercropping dat je je hele machinepark moet omzetten

Intercropping enorm interessant. Echter is ook het technische aspect (mechanisatie/teeltsysteem) enorm belangrijk, vergeet die niet!

Appendix C: Stakeholders Long-List for New SCFS with Quinoa and Millet

	Stakeholder	Why a key or secondary stakeholder?	How affected?	Influence?	Interest?	Relation with other stakeholders (e.g., partnership or conflict)
Key Stakeholders	Farmer	The farmer is the owner of the SCFS.	High	They are the owner and decide on how the farm is run and what plans are set in motion.	The farmer wants the farm to be profitable and is interested in the purpose of the SCFS (i.e., increasing biodiversity and soil quality).	Partnership: With most of the stakeholders, as those in favour of innovative and nature-inclusive farming need farmers, to change towards this new system.
Key Stakeholders	Provincial government of Zeeland	They provide subsidies for progressive plans within the agricultural sector that are in line with provincial visions.	High	Since Zeeland is providing subsidies for projects and ideas that aid their ambitions and goals, they have high influence in whether the SCFS can invest and continue to exist.	The province of Zeeland has several clear and progressive visions for the near future until 2030 that they want to realise (i.e. sustainable agricultural systems that include nature and preservation and increase of biodiversity). They need the farmers to reach these goals.	Partnership/conflict: The province can provide the funds if they think it is in line with their visions, which means they are in partnership with the farmers. However, if they do not support the idea, they are in conflict.
Key Stakeholders	Investors	The bank or other investors provide the money, to invest in for example new machines.	Low	Have a high influence, because in the new system, first some investments need to make, and funds are needed for this.	The investors have a direct interest in the success and profitability of the farm, but might also have a specific request or direction they want to send the SCFS in.	Partnership/conflict: The investors can provide the funds, which means they are in partnership. However, if they do not support the idea or have other request, they might in conflict.
Secondary stakeholders	Researchers	Researchers can support the SCFS by doing more research into quinoa and millet, but also in other crops that might work well together to resist high salinity and/or work well in a strip cropping system.	Low	Researchers have a low influence, as they provide ideas and information, but the communication of these results to the farmers is important. However, this communication often does not adequate. Besides, farmers can choose whether they want to implement the obtained information or not.	Researchers have a high interest as this new intercropping system can be seen as a field example of intercropping and can be the source of more research opportunities.	Partnership: Researchers work on the goal of improving biodiversity and sustainability in current and new farming systems, which is beneficial to the farmers of the SCFS that own such a system.
Secondary stakeholders	The output sector (retailers / processers / feed companies)	These companies process and/or sell the outputs of the SCFS. For example: the processing of quinoa into products for human consumption or animal feed.	High	The do not have much influence on the farm, because the farmer can (possibly) find another retailer if there is no match. However, they do have an influence on what price the farmer gets for his products.	They have a low interest. Only if their goal is to become more sustainable and to improve biodiversity, they could be interested in supporting this new system. Local retailers of Zeeland (short chain) for example might have a higher interest, but big multinationals are generally mostly interested in the best deal.	Partnership/conflict: the communication of the farmers with the retailers is an important cause for being in partnership or in conflict. If the retailers want to buy the products of the farmer they will be in partnership, if that is not the case than they will be in conflict with the farmer.
Secondary stakeholders	Environmental organisations	The new system will be an improvement of a.o. the biodiversity,	Low	They have low influence, as they have no say in what the farmer can or cannot do.	They are interested in what the environmental impact will be of this new system.	Partnership: They want to improve a.o. biodiversity, soil quality and lower

		soil quality, and chemical/fertilizer use, which is of concern to them.				chemical/fertilizer use, which is related to the implementation of SCFS.
	National/ European government	They make laws and regulations that the farmer has to abide to. The government can also provide subsidies to the farmers, in order to help with the transition to this new system.	low	The have high influence as they oversee aspects of farming including land use, safety standards, and laws on crop use.	They have a high level of interest as their goal is to reduce climate change, and this system could positively contribute to that. However, the local authorities of Zeeland have much more benefit from and interest in the practices of one farm than National/European governments do, as they work on a much larger scale and have larger ambitions.	Partnership/conflict: The laws laid out by the government can make it more difficult for farmers to manage their farm. But, if these governments have goals aligning with the SCFS, namely to improve biodiversity and make the system more resilient, then they are in partnership and could possibly receive subsidies.
	Consumers	The consumers eat the products that are grown on the farm.	Low	They have no direct influence on the farm, the crops can be grown regardless of consumer opinion. But, if consumers do not buy the products, the crops might need to be sold as animal feed.	The consumers that want to improve the environment are interested in the new system as it improves the biodiversity and is mor sustainable compared to conventional monoculture systems. However, consumers could be unaware of this, do not care, or prefer cheaper products.	Partnership/conflict: Convincing consumers to change their consumption behaviour is very difficult, but it is needed if we want our system to work. This means that communication is very important. If they are willing to buy the products (for whatever reason), they are in partnership, if not, they are in conflict.
	Suppliers	These are the companies that provide the inputs of the new SCFS, such as plant breeders.	High	The influence is high, as the suppliers for example can provide the seeds and machinery the farmer needs to run their farm.	Suppliers might not have a high interest, as they might need to develop new products for the intercropping, or new seeds, but suppliers that already sell quinoa and millet seeds probably have a higher interest as their sales market increases.	Partnership/conflict: See box of interest. They can either provide the inputs that the farmer needs, or not.

Appendix D: List of Underutilized Salt Tolerant Crops (in Alphabetical Order)

Species	Salinity resilience	Human/animal consumption	Growth in the Netherlands (NL)	Intercropping (IC)	Harvest time
***Amaranthus* (Amaranth)**	C4 species, moderate tolerance. Diverging results in literature, influence of genotype	All parts are edible, rich in high quality protein, its oil has skincare applications	The edible Amaranthus caudatus, Amaranthus hypochondriacus and Amaranthus cruentus can be found in NL	Used as border crop along millet fields in Nepal	Greens can be harvested almost immediately, seeds ripen 3 months after planting, so in mid- to late summer
***Asparagus officinales* (Asparagus)**	Most tolerant among common vegetable crops	Vegetable	Grows in NL	Done with multiple species, not focused on salinity. Reduces whiteflies on cucumber	In spring, from year 3 onwards
***Atriplex halimus* (Saltbush)**	Halophyte	Edible, contains some protein	Native in South-Europe, not found in NL	Not found, desalinizes soil	
***Beta vulgaris subsp. maritima (L.) Arcang.* (Sea Beet)**	Facultative halophyte	Vegetable and medicinal	Native in NL	Not found	Sow in March under glass, plant in April/June. Young leaves 35 days after sowing, 60-90 days till beat harvest
***Brassica juncea* (Mustard greens)**	Moderate tolerance	Oilseeds, leaves and stems as vegetable	Grows in NL, cultivated in large parts of the world, including Europe	IC with fruit trees	6 weeks after sowing, throughout the season
***Capparis spinosa L.* (Caper Bush)**	Xerophyte, has an extended root system	Leaves, buds, flowers, and fruit are edible, medicinal	Mediterranean, grows well under high temperatures, frost sensitive, not found in NL	IC with almond trees	
***Carthamus tinctorius* (Safflower)**	Extensive root system capable of extracting subsoil water at greater depths, some genotypes maintain yield at 15 dS m^-1	Multi-purpose: oil, herb, salad, animal feed. High in vitamin A, iron, phosphorus and calcium	Can grow in NL, but optimal growth at 28-35 ˚C	Done with multiple species, not focused on salinity	
***Chenopodium album L.* (Bacon Weed)**	Moderate tolerance	Vegetable, many nutritional benefits, antioxidant	Native in NL	Only mentioned as a weed	Harvest leaves April-November, harvest stem tips April-May

Chenopodium quinoa Willd. **(Quinoa)**	Facultative halophyte, and some varieties are able to cope with salinity levels as high as those present in seawater. Epidermal Bladder Cells are salt sinks for external sequestration for Na+	Both for animals and humans	Grows in NL	IC with millet, resulted in increased yield for both species	Late August – mid September
Cichorium spinosum L. **(Spiny Chicory)**	Halophyte	Leafy vegetable, high nutritional value, antioxidant	Mediterranean, not found in NL	Not found	
Crambe maritima **(Sea kale)**	Moderate tolerance	Edible leaves and shoots	Grows in NL along the coast	Not found	Spring (similar to asparagus)
Crithmum maritimum **(Sea fennel)**	Facultative halophyte, develops succulence under salt stress	Flavoring agent, ingredient in flours and oil. Contains antioxidants	Native in NL	Not found	Flowers from June to October, germinates in April
Cyamopsis tetragonoloba **(Cluster bean/Guar)**	High tolerance, also drought tolerant	Both for humans and animals	Doesn't grow well under 15 ˚C and is sensitive to frost, not found in NL	Significantly increase cotton seed yield under salinity	
Cynara cardunculus L. **(Artichoke Thistle)**	Adapted to saline and water-deficit areas	Supplement in food dishes, whole plant used in cheese production	Grows in NL	Done with multiple species, not focused on salinity	Every 2 weeks if you cut of flower stems, from mid-August to beginning October
Eryngium maritimum L. **(Sea Holly)**	Halophyte, grows better in nitrogen-deficit and saline conditions	Leaves and roots are edible, medicinal, seeds rich in oil	Native in NL	Not found	Harvest seeds in early winter, harvest leaves in summer
Inula crithmoides L. (Golden Samphire)	Succulent plant	Young leaves are edible and medicinal	Mediterranean/Atlantic species, recently arrived in NL	Not found	March to early June
Kochia scoparia **(Mexican fireweed)**	Halophyte, accumulation of Na+	Forage crop, highly invasive, can be toxic	Native in central and eastern Europe, can be found in NL	IC done in field conditions	Regular harvest in summer
Mesembryanthemum crystallinum L. **(Ice plant)**	Succulent plant, stores water and salt in bladder cells	Vegetable crop, contains antioxidants	Grows in NL	Not found	June to October

Millets (Finger millet, foxtail millet, proso millet)	Resistant to salt pressure	Edible, high in fibres, minerals and vitamins	Grows in NL	IC with quinoa, resulted in increased yield for both species. Also grown with amaranth	August to October
***Plantago coronopus* (Buck's-Horn Plantain)**	Survives salinity higher than seawater. Stores large amounts of salt in the leaves	Medicinal, other Plantago species are edible	Native in NL	Not found	April/May
***Portulaca oleracea L.* (Common Purslane)**	Halophyte	Vegetable, medicinal	Mediterranean but introduced to NL before 1500 and now common	Could increase watermelon yield. Improves growth tomato plants under salinity	Juni to September
***Ricinus communis* (Castor)**	Moderate tolerance	Not edible, but can be used as a biodiesel and pharmaceutical uses	Can be grown in NL as an annual plant	Done with multiple species, not focused on salinity	Autumn, risk: chance that season isn't long enough in NL to ripen the seeds
***Salicornia fruticosa* (Shrubby Glasswort)**	Halophyte	Used to reduced salt in cooked sausages, beverages, young shoots as vegetable	Grows in subtropics, not found in NL	Not found	
***Salicornia ramosissima / europea* (Common Glasswort)**	Halophyte	Fresh vegetable with good nutritional value	Native in NL	Not found	May - June
***Salicornia virginica* (Pickleweed)**	Halophyte	Can be use for human consumption	Present in North America, some species found also in Alaska, not found in NL	Not found	
***Salsola soda* (Saltwort)**	Halophyte, accumulation of Na+	Used as a vegetable, medicinal	It is found on Atlantic coast of France/Portugal, not found in NL	IC with tomatoes, good results. Can be grown in association with conventional crops (pepper, tomato)	
***Sarcocornia perennis* (Perennial glasswort)**	Halophyte	Fresh vegetable with good nutritional value	Native in Great Brittain and France, not found in NL	Not found	

***Sesbania* (Riverhemp)**	Moderate tolerance	Now mainly used as animal feed	Grows best in hot, humid environments, so not in NL	IC with Kochia and Guar, increased yield under salinity	
***Sesuvium portulacastrum* (Sea Purslane)**	Halophyte, accumulation of Na+	Edible, human consumption, fodder, alternative source of fertilizer	Widely distributed in tropical and subtropical regions, not found in NL	Done in crop rotation with barley	
***Suaeda fruticosa Forssk.* (Shrubby Sea Blight)**	Halophyte	Seeds high in oil, foliage used as food and forage	Not found in NL, grows primarily in the desert or dry shrublands	Not found, desalinizes soil	
***Suaeda maritima/salsa* (Annual Seablite)**	Halophyte, accumulation of Na+	Human consumption	Grows in Europe on saline soils, also in NL	IC with Zea mais	October (in China,not found for NL)
***Tribulus terrestris L.* (Puncture Vine)**	Moderate tolerance	Animal feed	Rarely found in NL, found in warm/tropical regions in southern Eurasia and Africa	Not found	
***Triticale* (hybrid from wheat and rye)**	Multiple genotypes have high yields at 15 dS m^-1	Mostly animal feed, also for human consumption	Grows in NL	Done with multiple species, not focused on salinity	May-August
***Vigna unguiculata* (Cowpea)**	Moderate tolerance, also drought and heat tolerant	Primary source of protein in sub-Saharan Africa, also used as animal feed	Staple crop in Africa, no profitable growth in Northern countries	Done with multiple species, not focused on salinity	

Appendix E: Decision Matrices

An explanation of these decision matrices can be found in Section 3.4 of this report.

Table E1. Decision matrix for ranking of the opportunity clusters for farmers. A score of 1 means least applicable, 6 means most applicable. The cluster with the highest rank is the most important for this stakeholder.

Criteria ↓ Farmers	Sales market	Farm management	Research	Breeding focus	Communi-cation	Regulation and funding
Feasibility	2	6	3	4	5	1
Cost effectiveness	4	6	1	3	2	5
Relevance	1	3	5	2	6	4
Long-term sustainability	2	1	6	5	4	3
Environmental impact	1	6	3	4	2	5
Total Score	*10*	*22*	*18*	*18*	*19*	*18*
Rank	**1**	**6**	**3**	**3**	**5**	**3**

Table E2. Decision matrix for ranking of the opportunity clusters for breeders. A score of 1 means least applicable, 6 means most applicable. The cluster with the highest rank is the most important for this stakeholder.

Criteria ↓ **Breeders**	Sales market	Farm management	Research	Breeding focus	Communi-cation	Regulation and funding
Feasibility	3	2	5	6	4	1
Cost effectiveness	4	1	5	6	3	2
Relevance	2	1	5	4	6	3
Long-term sustainability	3	1	6	5	4	2
Environmental impact	3	1	5	6	2	4
Total Score	*15*	*6*	*26*	*27*	*19*	*12*
Rank	**3**	**1**	**5**	**6**	**4**	**2**

Table E3. Decision matrix for ranking of the opportunity clusters for researchers. A score of 1 means least applicable, 6 means most applicable. The cluster with the highest rank is the most important for this stakeholder.

Criteria ↓ **Researchers**	Sales market	Farm management	Research	Breeding focus	Communi-cation	Regulation and funding
Feasibility	1	2	6	4	5	3
Cost effectiveness	1	2	5	3	6	4
Relevance	1	2	6	3	4	5
Long-term sustainability	1	2	4	3	6	5
Environmental impact	2	3	5	1	6	4
Total Score	*6*	*11*	*26*	*14*	*27*	*21*
Rank	**1**	**2**	**5**	**3**	**6**	**4**

Table E4. Summary of Decision Matrices for farmers, breeders and researchers. A high score and rank mean high importance.

	Sales market	Farm management	Research	Breeding focus	Communi-cation	Regulation and funding
Farmers	10	22	18	18	19	18
Breeders	15	6	26	27	19	12
Researchers	6	11	26	14	27	21
Total	*31*	*39*	*70*	*59*	*65*	*51*
Rank	**1**	**2**	**6**	**4**	**5**	**3**

Appendix F: List of Challenges and Opportunities per Cluster

The challenges and opportunities for each cluster are listed here, in no particular order.

Sales market (food chain)

Challenges

- Seedling-producers are inflexible in the number of seedlings that they want to sell
- Consumer behaviour
    - No willingness to buy more expensive products
    - Underutilized crops are less popular
- Retailers demand cash-crops
- Food processors want a uniform product with a constant quality (inflexible)
- Market/consumers want a uniform product with a constant quality (inflexible)
- Currently there is a niche market for quinoa, millet and other underutilized species

Opportunities

- Focus on intercropping with crops that already have a market (to attract farmers to intercropping in general in the near future)
- Invest in changing consumer perspective so they can drive a change away from monocultures towards more resilient agricultural systems and are willing to pay the price
    - Start campaigns to get consumers to incorporate new foods in their diets "We need to increase the number of species we use for food. We have to reinvent/reintroduce new species on quite a large scale" – WUR researcher
- Invest in aiding change to short chain market (local production)
- Look for possibilities of a sales market for 'unwanted' desalinizing/salt tolerant crops: Animal feed? (often salt is added to these diets anyway)
- Start collaborations with big companies in the food chain (work with those willing to change) "The big partners in the food chain (like Cargill, Pepsico, Danone, et cetera) have to be willing to process also other products." – WUR researcher
    - In the past processers adapted their processing to the quality of the available ingredients, but nowadays it is the other way around. This needs to be turned around again.
    - "Eating a diverse diet is better for everyone, also cows" – Organic seed producer
- Make consumers aware of the nutritional benefits of quinoa and proso millet and other underutilized species
- Consumers might be more interested in the products when it is advertised as better for the planet
- The higher price per kg gives an incentive to farmers to change to cultivation of quinoa and millet
- Quinoa and proso millet can both be used as animal feed.

Farm-management

Challenges

- The intensification of crop farming has led to loss of biodiversity
- Machines are not adapted to intercropping (handling genetic diversity & machine size)

    - Pesticide-use is harder for intercropping -> automatic organic farming
    - Irrigation is more difficult as different crops have different water needs
- Irrigation problems
    - Decrease in fresh water
    - Increased droughts/high temperatures → increased demand for irrigation water + battle with drinking water during shortages
    - Decrease in soil quality
    - Salinization of irrigation water (due to rising sea levels: capillary rise to root zone & changing fresh/saline water pressure in estuaries and sluices for fish migration) → further salinization of soil
- Improper management of farmers + changing climate (droughts, heat, evaporation) → Soil dries out → Further salinization of soil
- Transitioning to intercropping too difficult for farmers
    - Planning and organization
    - New mindset
    - Investments
- Higher costs of intercropping compared to monocultures
    - Increased labour intensity
    - Increased fuel costs (going over fields more often, more variety in crops)

Opportunities

- Communicate intercropping as an organic farming system (instead of focussing on conventional farmers)
    - Or just go organic (better soil management)
        - Policies hold back organic crop cultivation (Marcels interview notes for more thoughts on this)
- Invest in the development of new agricultural machines (and/or how to adapt existing ones), robots, sensor technology and/or AI for intercropping
- Usage of a drip system for irrigation
    - Works according to both the organic plant breeder and the organic arable farmer
- Use flower strips or strips of clover/grass mixtures or mulching to cover the topsoil in monocultures (e.g. against drying out of soil + fertilization + pest control + pollination)
- Use bio-agents (e.g. fungi) to help salinity-resilience of crops
- Even in monocultures, promotion of crop rotation could be useful for soil management
- Write a protocol for how to change to intercropping and what to expect to make transition a smaller challenge for farmers
    - Development of more general principles, and advice on how to translate those principles to specific situations
    - Further investigate (e.g. via surveys or interviews) what knowledge is missing with farmers (intercropping, salinity mitigation, etc.)
    - Creating blue prints / action plans for which crops to combine in which circumstances (soil type, climate, farm scale, …), when to sow and when to harvest, how to place machinery paths, which crop rotation schemes are possible (focus on crop families, pesticide approval, …), what a farmer can expect during and after transitioning to intercropping (mindset and practice), what to look for when investing in new machinery, where to find guidance/help during the process (which companies, farmers, researchers, breeders are experiences/experts on intercropping)

- Use flower strips or strips of clover/grass mixtures (e.g. against drying out of soil + fertilization + pest control + pollination)

- Investigate how other countries deal with higher prices of products from intercropping farms
- Using drip hoses underneath the soil to prevent drying out, low water use, less evaporation (+ easy weed control)
    - Increases efficiency of watering in intercropping systems, as different crops have different water needs
- Invest in desalination of irrigation water (need government funding)
- Collect rainwater (e.g. through digging ponds)

Research

Challenges

- Intercropping
    - Interactions between plants and their mechanisms
    - Beneficial crop combinations
    - For stress resilience
    - Breeding traits
- Salt tolerance and the mechanisms behind it
- Agricultural management of underutilized species
- Lack of local-oriented research (in different climates)
- Combinations of stressors: plant's response to multiple stressors (mainly drought and heat)
- Data-analysis methods for soil tests and intercropping systems (for farmers, breeders, researchers)
- Difficulty translating research into practical advice
- No numbers on economics or environmental impact (LCA/NB) to compare intercropping to monocultures

Opportunities

- Research on intercropping salt tolerant/ halophytic species, starting with quinoa and millet + how species perform in intercropping system
- More local-oriented research (in different climates) → collaboration with environmental research
- Develop tools (AI) to analyze big data of intercropping research
    - MSc thesis/ PhD on data analysis of soil parameters in an intercropping system
- Develop intercropping machinery that can match the efficiency of monocultures
- Research on underutilized crops showing resilience to multiple stressors
    - More research into the effect of biodiversity on salinity stress and resilience
- Research the effects of (different types of) intercropping on resilience of the farming system
- Research plants' responses to multiple stressors (salinity, drought, and heat)
- Fundamental research on plant-plant interactions
    - 'Underground' research towards root system, microbiome, etc.
    - 'Above ground' research towards shading, volatiles, etc.
    - "A lot of research is about techniques, but we want research on the plants. We would like to get together and breed for biodiversity together" – Organic seed producer
- Fundamental research needed on plant-soil interactions (nutrients, mycorrhiza, et cetera)

    - Research effects of crop combinations on soil salinity
- Research effects of drip system on soil salinity (we see it works in practice, organic plant breeder + Edwin)
- Research beneficial crop combinations
    - And the main ecological and/or technical measures to optimize the combination
    - Look at grey literature: historical data, kitchen gardeners' knowledge, practices in developing countries
- More research in organic agriculture
- Research the best combinations of flowers for flower strips and which insects are attracted to it
- Research how to optimally use pesticides in conventional intercropping
    - Quantity
    - Width of strips in strip cropping
- Research how to translate research into practical advice for farmers
- look at other countries for strategies for (the transition to) intercropping, dealing with higher prices of products, etc.
- have economic experts look into intercropping systems to determine whether financial gains outweigh extra costs and where improvements can be made, so farmers can make wise business decisions
- perform nutrient balances and LCA's to see where intercropping can still be improved and use it to convince policy makers, etc. to change to these systems

Breeding Focus

Challenges

- Gene banks are not used to a large enough extend
- Lack of specific breeding goals related to intercropping (e.g. crop-interactions, strip-bound)
- Lack of specific breeding goals related to salt tolerance
- Not allowed to use GMO for salt tolerance breeding
- Large companies own most patents which slows down breeding

Opportunities

- Breed underutilized salt tolerant crops
- Breeding crops for intercropping
    - Breed for root architecture (more vertical instead of horizontal and to match with other species that have a different root system, so adapt species to each other)
    - Breed for compact plant growth (less competition for neighbouring crops, and easier for machinery and harvesting)
- Breeding duos/specific combinations of crops for intercropping can be economically feasible
    - This can also stimulate/encourage farmers to start intercropping
    - Use border crops/plants to select for interactions
- Use (underutilized) genetic material in gene banks (e.g. for resistance breeding)
    - "There are 300.000 edible crop species on earth, and we are only using a fraction of that. This makes us very vulnerable." – Organic seed producer
- Local breeding (organic seed producer)

Communication

Challenges

- Lack of communication between universities, farmers and breeders
- Improper management of farmers + changing climate (droughts, heat, evaporation) → Soil dries out → Further salinization of soil
- Difficulty translating research into practical advice
- Lack of sense of responsibility

Opportunities

- More collaboration with the actual field (breeders and farmers)
- ACT project on communication to farmers and breeders
- Support companies to pick up research plans and continue them (publicly instead of privately)
- Reach out to include farmers, breeders, and companies in research (increase frequency of communication & share knowledge more easily)
- Reach out to farmers cooperations to invite them to projects, seminars, 'open days', network events, etc.
- Communication between farmers and breeders about intercropping problems and how breeders can help solve these
- Improve communication of practical aspects of intercropping (interesting and useful information for intercropping farmers and breeders is not shared easily, while everyone can benefit from it without spreading confidential information)
- Invest in (communication about) collectively (breeders, farmers, researchers) switching focus to resilient systems, not optimizing monocultures (but this is kind of obvious)
    - also have the managing board that decides on research funding direct their focus to this (that is what we picked up from interviews)
    - Invest in changing breeders' perspective to change from € to future food systems + other crops than the staple crops.
    - Educate farmers on the benefits of having genetic diversity in their field in whatever way
- Invest and organize e.g. trainings to help farmers (and researchers) understand how to use technology (AI, drones, etc.) to analyze all the data of farming / intercropping, to make it more appealing to change to intercropping (more clear results on real effects of intercropping)
- Research how to translate research into practical advice for farmers
- Offering farmers training and support regarding knowledge of soil salinity are necessary to prevent further salinization of the soil.
- Create sense of responsibility in all corners of society through education and strategies like social media, advertising, etc. to increase support for the change towards more resilient food systems

Regulations (subsidies, policies, etc.)

Challenges

- No approved pesticides for quinoa

- Salinization of irrigation water (due to rising sea levels: capillary rise to root zone & changing fresh/saline water pressure in estuaries and opening of sluices for fish migration by policies) → further salinization of soil

Opportunities

- Advice governments and regional water management to put subsidies in the direction of change towards resilient systems and responsible water use/irrigation, less subsidies for monocultures (e.g. intercropping start or smart irrigation like drip hoses).
- Advice government to invest in short chain market (local production)
- Advice government to promote consumers buying from resilient systems
- Molecular genetic engineering has been named many times in literature as a viable way to create salt tolerant species. Could be long-term goal to advice government about this.

Appendix G: ACT Project Description for Communication

The description of a new ACT project is based on the description of this ACT project. Parts of the old description were copied.

ID1	
Title case	**Communication plan for the transition towards resilient food systems**
Case owner	Wageningen Plant Research, Wageningen Livestock Research, Wageningen Environmental Research
Description of the assignment	**General introduction of the problem:** Current food production systems have become uniform and specialized, and are dependent on a limited number of crops and varieties. In the face of climate change and other future challenges, this dependency reduces adaptability to changing conditions and leads to decreased resilience and potential food security issues. Making best use of genetic diversity between and within crops, livestock, aquatic and tree species is expected to play an important role in overcoming major challenges and to contribute to the transition towards sustainable, circular, and resilient future food and forestry systems. Breeders and farmers play a key role in enhancing resilience in future food systems. Breeders can make available diverse and complementary breeds and varieties (genotypes) for a large range of future production systems, environmental conditions, and consumer and farmer needs. Farmers can incorporate more diverse species or varieties in their farming system. The challenge is to effectively communicate scientific knowledge and techniques on this topic of transitioning towards a resilient food system with the relevant stakeholders. Another challenge within this project is how to determine the relevant stakeholders who could be interested in adopting new developments of research, and thus transition to a more resilient production system. **The ACT team is asked to design a communication plan to inform relevant stakeholders, like farmers and breeders, on why they should transition to a more resilient production system, and how they can do this.** **The following research questions form a starting point:** • How can current and potentially future stressors affect the resilience of production systems (global perspective)? • How could the current food production system transition to become more resilient? • Which stakeholders are crucial for a transition towards a more resilient food production system? • What are the socio-economic opportunities and risks of transition towards more (bio)diverse production systems? • How do socio-economic factors, such as policy frameworks and regulations, cultural values, social equity, market developments, influence the transition towards a more resilience food systems?
Background	The case owner is a collaboration between three Wageningen Research groups that work together on a '*Kennisbasis'* project: "*New System Requirements for Breeding for Resilient Production Systems*".

	Decades of focus on agricultural intensification have led to problems related to the use of pesticides, antibiotics, fossil fuels and fertilizers; environmental pollution and high greenhouse gas emissions; issues with animal welfare, human and animal health; and soil degradation. Moreover, highly productive monoculture farming resulted in the loss of biodiversity in and around our agricultural production and forestry systems. Challenges are further exacerbated by climate change. Dutch and European policies now ask for a transition towards more sustainable, circular and resilient food and forestry systems.
Literature	• https://edepot.wur.nl/579316 • https://edepot.wur.nl/575252 • Choudhury, A., Berentsen, P., Slingerland, M., & Vos, J. (2021). Tailor-made solutions for regenerative agriculture in the Netherlands. ScienceDirect. https://doi.org/10.1016/j.apenergy.2020.114147 • De Boer, I. J. M., & van Ittersum, M. K. (2019). Prospects from agroecology and industrial ecology for animal production in the 21st century. ScienceDirect, 105, 107-122. https://doi.org/10.1016/j.agee.2019.02.008 • Food and Agriculture Organization of the United Nations. (n.d.). Agro Ecology - TAPE - Food and Agriculture Organization of the United Nations - Webcast. Retrieved from http://www.fao.org • Hauggaard-Nielsen, H., & Jensen, E. S. (2005). The productive performance of intercropping. Proceedings of the National Academy of Sciences, 102(21), 7574-7579. https://doi.org/10.1073/pnas.0502296102 • Nieuwe Oogst. (n.d.). Dan Saladino: 'We hebben meer genetische diversiteit in de landbouw nodig'. https://www.nieuweoogst.nl • The Agroforestry Research Trust. Forest Gardening | Fruit Trees | Nut Trees | Perennial Vegetables. https://www.agroforestry.co.uk
Confidential	**NO**
Relevant expertise & keywords	Relevant keywords are: • Communication • (Agro)ecology • Genetic diversity • Plant/animal breeding • Socio-economic factors • Resilience • Food system transition Suggested Master programs are: MCH, MPS, MID, MAS, MPB, MAM, MBI
Case recruiter email	
Case recruiter name	
Period available	