No stress,

Let plants be your success!

'A spatial suitability analysis for agricultural systems that could be promising for salinity, drought and waterlogging stress.'

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Glossary

Salt-Resilient Agricultural Systems (SRAS) = Defined for this study as agricultural systems that have a specific crop selection and crop management to increase the resilience against salinity. Water and soil management are not taken into account for these systems.

Salinity, Drought and Waterlogging (SDAW) = The three environmental stressors which are increased by climate change and are assessed in this study.

Spatial Suitability framework = This is a framework developed to assess the spatial suitability of the SRAS based on the SDAW stressors and soil type.

Climate scenario 'High 2050' = The projected future climate scenario based on the KNMI that assumes the highest predicted values for the SDAW stressors.

Summary

Global food security is under increasing pressure due to climate change-induced environmental stressors: salinization, droughts, and waterlogging (SDAW). These stressors are already causing economic losses, environmental degradation, and societal problems. One promising adaptation strategy involves the transition to more resilient agricultural systems based on crop selection and management, referred to in this study as Salt-Resilient Agricultural Systems (SRAS). However, current knowledge about SRAS transitions is often based on single aspects, limited in scope, and mostly focused on global scales.

What is needed is a practical spatial approach that combines SRAS knowledge with local data, helping decision-makers understand which SRAS options are feasible, where they are suitable, and what their implementation implies for key stakeholders. This study supports such a transition by integrating multiple aspects of SRAS systems and using a holistic approach that includes environmental, technical, and societal perspectives.

This was achieved by answering the question: '*Which salt-resilient agricultural systems are potentially suitable for areas increasingly affected by salinization, drought, and waterlogging, and how can their spatial suitability be assessed and interpreted based on soil types and climate projections?*'

To address this question, the case study Schouwen-Duiveland was investigated, because this region is already exposed to SDAW stressors. Both current conditions and a high 2050 climate scenario were assessed. This desk study developed a spatial suitability framework to evaluate the potential of SRAS based on four key factors: salinity levels, drought stress, waterlogging stress, and soil type.

Through a combination of literature review and geospatial analysing in QGIS, three promising SRAS approaches were identified for Schouwen-Duiveland. These include: 1.) Salt-tolerant crop rotation, which adapts conventional agricultural practices to include crops with higher salinity tolerance. 2.) Halophyte (plants that thrive on saline soils) intercropping or rotation, which can improve soil health by taking up salt from the soil while enabling cultivation of conventional crops. 3.) Agroforestry, a system based on trees or shrubs, which provides a higher tolerance to both drought and waterlogging, while also increasing biodiversity and potentially total yields.

Due to several data and knowledge gaps, assumptions had to be made, which reduce the robustness of the outcomes. Therefore, this study should be seen as an exploratory assessment rather than a set of definitive guidelines. Nevertheless, the results highlight the potential of these systems and emphasize the need for sustainable water management and location-specific guidelines, considering the local variability of stressors.

The spatial suitability maps were interpreted from both scientific and societal perspectives and are recognized as a tool to initiate social dialogue around the SRAS transition. These spatial guidelines can serve as practical tools for both policymakers and farmers.

Achieving a full transition requires increasing the readiness for change, starting with small-scale field experiments initiated by farmers, supported by policymakers who share the risks. Other key aspects include collaboration and knowledge sharing between stakeholders, which are essential for gaining further insights and improving spatial suitability assessment.

Despite its limitations, this study provides a foundation for a practical tool to assess local SRAS suitability. It contributes to informed discussions for SRAS transitions and ultimately supports the development of climate-resilient agriculture that strengthens long-term food security.

1. Introduction

1.1 Global food security stressors

Global food security is increasingly under pressure due to two major factors: a growing global population and climate change (Panta et al., 2014). Population growth is driving up food demand, while climate change is putting stress on agricultural systems through irregular rainfall, land subsidence, and sea level rise. These changes increase the environmental stressors: **S**alinization, **D**roughts **A**nd **W**aterlogging (**SDAW**) (Eswar et al., 2021).

Salinization, the process of increasing salt concentrations in soils and freshwater, is becoming a bigger threat to food security over time and is gradually gaining more attention in both scientific and political contexts (Mukhopadhyay et al., 2021; Tarolli et al., 2024). An increase in salt concentrations in agricultural soils can limit crop growth and yield, resulting in significant food production losses (Zörb et al., 2019). The current global agriculture system is vulnerable to salinity, as the thirty crop species providing 90% of the global food supply show already substantial yield losses under moderate salinity levels (Snethlage et al., 2023). Globally, it is estimated to cause annual losses of €21.3 billion (Snethlage et al., 2023). Thus, from a societal perspective, salinization is contributing to food supply reduction and economic losses. Environmentally, it is a major cause of soil degradation and desertification, potentially leading to land abandonment and migration to other areas, which is associated with increased deforestation and biodiversity loss (Dagar & Gupta, 2020; Panta et al., 2014; Van Den Burg et al., 2024). Salinization occurs in arid, semi-arid, coastal, and delta regions through natural processes and is intensified by unsustainable irrigation practices and climate change (Meena et al., 2019; Mukhopadhyay et al., 2021; van Dijk et al., 2021). With the progression of climate change, it is predicted that 50% of all arable land will be affected by salinity by 2050 (Wang et al., 2003).

In addition, climate change is expected to increase both the frequency and the severity of droughts, further threatening global crop production (Panta et al., 2014). It has been estimated that droughts and heat reduce cereal yields by 9-10% (Lesk et al., 2016). Waterlogging stress, the saturation of water at the root zone of plants leading to oxygen stress and root rot, is expected to worsen due to changing rainfall patterns (Khan, 2003; Rijkswaterstaat, n.d.; Tyagi et al., 2024). Currently, waterlogging is estimated to cause yield reductions of approximately 20% on about 12% of the world's arable land (Setter & Waters, 2003; Tian et al., 2021).

The combined impact of salinization with either drought or waterlogging amplifies total stress and poses a serious threat to food security (*KWR, 2023*). Salinization often occurs simultaneously with drought. Without interventions, these SDAW stressors represent a significant danger to the future of global food security.

1.2 Salt-Resilient Agricultural Systems

To ensure long-term food security and adapt to the increasing pressures from SDAW stressors, it is essential to develop a climate-resilient agricultural system. Currently, multiple mitigation strategies, which aim to reduce the impact of these stressors, and adaptation strategies, which adjust agricultural systems to better cope with them, are available (Shahid et al., 2018). While mitigation measures such as sustainable water management and soil amendments currently play a key role in reducing stressors, crop-based adaptation offers the potential to transform salt-affected lands from environmental burdens into economic opportunities (Qadir et al., 2008). This form of adaptation can enhance soil health and productivity through plant-soil-microbe interactions that help restore degraded land and improve soil structure (Ma et al., 2024; Qadir et al., 2008; Tang et al., 2024). Therefore, crop-based adaptation methods are a nature-based, low-impact solution to SDAW stressors and promotes both sustainable food production and soil health (Tarolli et al., 2024). This approach is particularly valuable in regions where mitigation through freshwater flushing is not feasible, either due to water scarcity or the low-lying nature of areas where salt intrusion is inevitable (Negacz et al., 2021; Vellinga & Barrett-Lennard, 2021; Wit et al., 2021).

In this study, these crop-based management practices, characterized by specific species selection and tailored cropping strategies to enhance SDAW resilience, are referred to as **S**alt-**R**esilient **A**gricultural **S**ystems (**SRAS**). SRAS places a strong emphasis on salinity management, since controlling soil salinity is essential for maintaining arable land and even moderate salinity can reduce yields of sensitive crops by up to 50% (Singh, 2022). These systems combine crop selection, including salt-tolerant crops, halophytic plants (salt-loving species), or trees, with adaptive cropping strategies such as intercropping and crop rotation, which help enhance soil health and limit salt accumulation.

SRAS offers unique opportunities for areas affected by SDAW stressors. However, due to the complexity of the challenges, there is no single SRAS model suitable for all regions (Shahid et al., 2018). Moreover, because salinity is often invisible and highly location-specific, it is critical to know where it occurs and how to best adapt (Delsman et al., 2018; FAO, 2021; Utset & Borroto, 2001). Therefore, site-specific assessments are necessary to evaluate the suitability of multiple SRAS for local SDAW conditions. With these site-specific suitability guidelines, a targeted and effective transition towards specific SRAS can be achieved in regions vulnerable to SDAW stressors.

However, achieving this transition requires evaluating this suitability through both technical, environmental and societal perspectives of the transition. Figure 1.1. shows these perspectives and key aspects that must be addressed for a full transition. The first step remains to develop site-specific SRAS suitability guidelines, which can then be interpreted from the societal perspective.

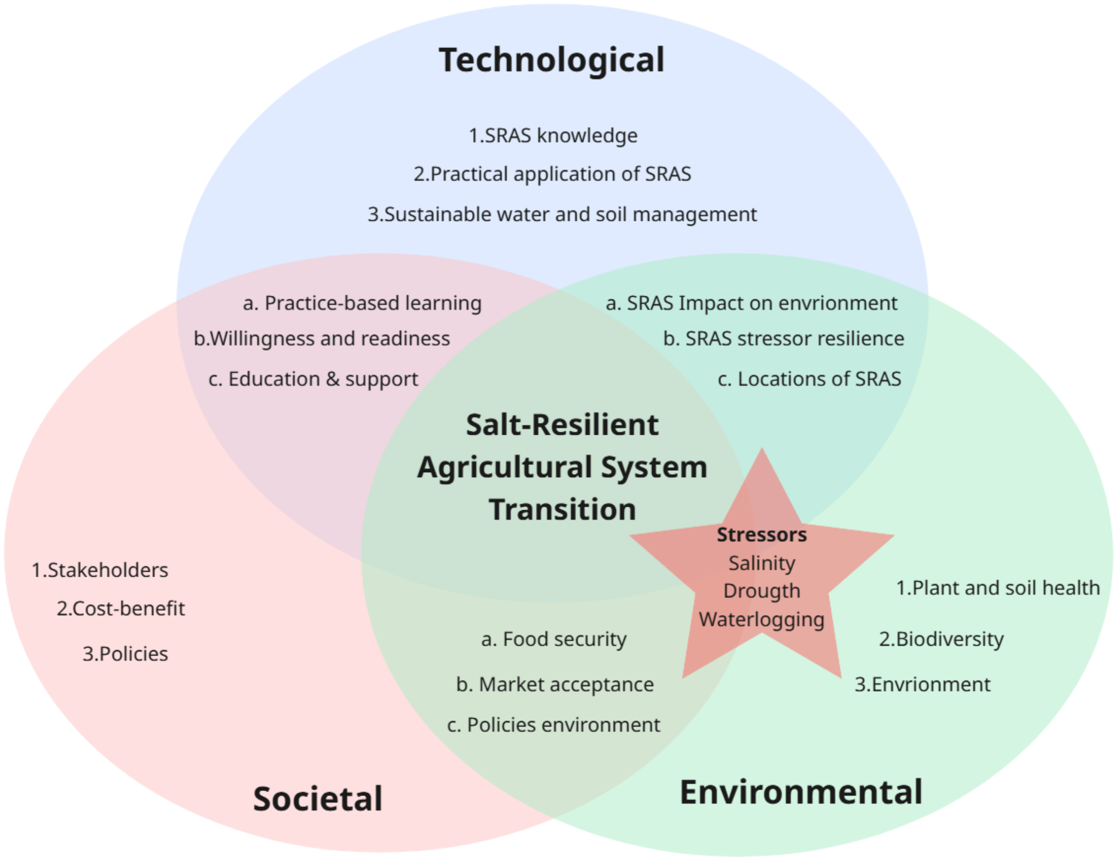


Figure 1.1: *Identified key aspects for Salt-Resilient Agricultural Systems from a societal, technical and environmental perspective. The SDAW stressors are depicted in the environmental site and influence both technological and social aspects indirectly.*

1.3 Current knowledge SRAS transition

For these site-specific suitability guidelines for SRAS transition research has progressed along five complementary research areas:

1. Mapping SDAW stressors

A lot of research has been dedicated to identifying the extent and locations of SDAW stressors. For salinization, which is not easily visible, mapping severity is a crucial first step in identifying the stressor. Several projects have produced detailed maps of salinity in agricultural soils, based on field measurements and remote sensing (*Boeren Meten Water*, 2020; Delsman et al., 2018; FAO, 2021). These maps can be used to support decision making (Utset & Borroto, 2001). Databases like Climate Impact Atlas (2024) provide spatial projections for salinity, drought and oxygen stress for both current and future scenarios. Here, oxygen stress refers to the effects of waterlogging.

2. Plant tolerance mechanisms and values

Research has also explored the cellular mechanisms and tolerance responses of plants to SDAW stressors (dos Santos et al., 2022; Lin & Chao, 2021; Pan et al., 2021; Shannon & Grieve, 1998; Wang et al., 2003). In addition, several studies have identified tolerance thresholds for varieties of conventional crops to these stressors (Bao et al., 2023; Stuyt et al., 2016; Zilt Perspectief, 2015). A widely adopted model for crop salt tolerance was introduced by Hoffmann and Maas (1977). Breeding efforts for SDAW-tolerant crops are ongoing, but practical applications remains complex due to the multigenic nature of tolerance mechanisms (Shannon & Grieve, 1998).

3. Field assessments of cropping strategies

Experiments have focused on the impacts of crop choice and strategy on soil health and yields. Halophytes have shown potential to remove salts from the soil (dos Santos et al., 2022; Litalien & Zeeb, 2020). Trees have been found useful for soil reclamation and improving water infiltration (Dagar, 2014; Fuchs et al., 2022; P. Kumar & Sharma, 2020; Mathur & Mathur, 2024; Singh, 2015). Other studies highlighted the importance of proper guidelines for intercropping or crop rotations, although these are still under development (*Blom-Zandstra et al., 2014*, n.d.; Cammerino et al., 2025; Simpson et al., 2018).

4. Spatial suitability analysis

To generate spatial suitability guidelines, several studies have integrated geospatial data with SRAS knowledge. Negacz et al. (2022) and Wen et al. (2023) conducted global suitability analysis of potential locations for saline agriculture under current and future scenarios. Wen et al. (2023) used salt-tolerant potatoes as a proxy to determine where saline agriculture is possible. Both studies considered soil salinity and fertility as criteria, and the study by Negacz et al. (2022) also included water availability. Region-specific studies, such as Kumar et al. (2019), incorporated salinity and water availability for agroforestry planning.

5. Societal evaluations

Some studies have evaluated the societal dimension of SRAS transition. Fotakis et al. (2024) included labor, population density, and access to funding in an agroforestry suitability assessment, though the impact on society was less explored. Wit et al. (2021) examined shifts Dutch policy, showing a change from salinization prevention to mitigation, and ultimately to adaptation if mitigation is no longer feasible. Additionally, Winkel et al. (2021) evaluated the viability of halophytic farming in the Netherlands and identified economic feasibility as a main constraint. These findings emphasize the importance of addressing societal factors alongside technical and environmental aspects in SRAS transitions.

1.4 Research gap

Although numerous studies have addressed aspects of SRAS transition, most remain limited in scope, focusing on single stressors or one specific SRAS method. Additionally, most studies apply on a global or regional scale. This leaves a gap in integrated, local-scale research that can serve as a practical tool for implementation. Moreover, many studies overlook the societal dimension of SRAS transition. For an effective transition towards SRAS all three perspectives need to be taken into account to make it possible to move from theoretical potential to practical application (Figure 1.1).

A holistic approach is needed, which integrates multiple SDAW stressors, includes future climate projections, and assesses various SRAS strategies at a local level. As noted by Winkel et al. (2021), the next step is to connect current knowledge to be able to make choices per geographical location in collaboration with agricultural entrepreneurs.

1.5 Thesis Objective and questions

This research aims to support the transition to SRAS by identifying suitable systems for areas affected by SDAW stressors and developing spatial suitability guidelines, interpreted from a societal perspective. In doing so, the study contributes to both the practical implementation of SRAS and the theoretical framework of sustainable agricultural transition, bridging technical feasibility with societal relevance.

Research question:

"Which salt-resilient agricultural systems are potentially suitable for areas increasingly affected by salinization, drought, and waterlogging, and how can their spatial suitability be assessed and interpreted based on soil types and climate projections?"

To address this question, a case study was conducted on Schouwen-Duiveland, a low-lying island in Zeeland, the Netherlands. This site was selected due to its exposure to SDAW stressors and the availability of relevant data. The analysis focuses on the current situation and the 2050 high-emissions climate scenario. In addition to SDAW stressors, soil type is considered because it influences the severity of these stressors (Appendix A.1). Although water and soil management strategies are important for mitigating the stressors, they are excluded from the scope of this study due to the limited freshwater availability in Schouwen-Duiveland. While the societal implications of implementing SRAS are analyzed, aspects such as market acceptance and detailed cost-benefit analysis fall outside the scope of this research.

To answer the main research question the following sub questions will be addressed:

1. How are the SDAW stressors and soil types incorporated into a spatial suitability framework for SRAS?
2. Which SRAS are suitable for the Netherlands, and what levels of each SDAW stressors and soil types can they tolerate?
3. What is the current and projected spatial distribution of SDAW stressors and soil types across existing agricultural fields in Schouwen-Duiveland?
4. Which existing agricultural fields in Schouwen-Duiveland are suitable for SRAS implementation, now and under future climate projections?
5. What are the societal interpretations of the spatial suitability guidelines for local farmers and policymakers, and what are the main bottlenecks for SRAS transition?

This desk study first developed a suitability framework, based on existing studies, which was then used to spatially assess the suitability of multiple SRAS systems. Data on SRAS and the SDAW stressors were collected through a literature review of a publicly available database. Quantitative spatial data was analyzed using QGIS spatial mapping, with calculations carried out in Excel. This was followed by a qualitative discussion of the results.

Reading guide

Chapter 2 outlines the methodology, beginning with more details of the case study and then describing the development of the suitability framework. It also explains how sub-questions 1 through 4 are addressed to ultimately develop the spatial suitability maps.

Chapter 3 presents the results, including identified suitable SRAS and their potential suitable areas in Schouwen-Duiveland. Based on these maps, key findings are identified and discussed in **chapter 4**. This chapter also evaluates the validity of the findings, discusses the limitations of the framework, and addresses sub-question 5, which focuses on the societal interpretations of the results. This leads to practical recommendations. Afterwards, scientific interpretations are discussed, along with suggestions for future research.

Finally, **chapter 5** provides a concise summary of the main findings of the study. The **appendices** and **supplementary material** provide additional methodological and background information.

2. Methodology

To assess potentially suitable SRAS and their spatial suitability, this research uses a mixed-methods approach to answer the sub-questions, focusing on the case study of Schouwen-Duiveland. The goal is to provide local suitability maps for different identified SRAS, based on existing knowledge of these systems and future spatial projections of SDAW stressors and soil types.

To create the suitability maps, a spatial suitability framework was developed. This framework allows the identification of suitable areas for SRAS based on threshold values that reflect the tolerance to the SDAW stressors. Potential SRAS and their associated threshold values were identified through a literature review and by selecting model species that serve as proxies for the full SRAS. Using spatial SDAW stressor data from Climate Impact Atlas (2024), spatial suitability maps for SRAS were generated in QGIS, with additional calculations conducted in Excel.

To allow for comparison, threshold values were also defined for conventional agricultural. Additionally, a suitability map was developed to be able to evaluate the SRAS performance in relation to conventional agriculture. The resulting maps were qualitatively interpreted from both scientific and societal perspective to derive key findings and insight.

The research is structured into four phases aligned with the sub-questions:

- **Phase 1 - Framework development:** A spatial suitability framework is developed by structuring thresholds of suitability for the SDAW stressors and soil types. This framework sets the foundation for assessing spatial suitability.
- **Phase 2 - SRAS selection:** Potential SRAS options are identified through a literature review. Additionally, their tolerance to identify SDAW stressors and soil types are assessed based on model species used as a proxy to determine suitability parameters.
- **Phase 3 - Spatial stressor analysis:** Spatial SDAW stressors and soil type datasets are collected and processed in QGIS to create maps of the current and projected levels of SDAW stressors for existing agricultural fields in Schouwen-Duiveland.
- **Phase 4 - Integration & mapping:** The suitability framework is applied by using QGIS with additional calculations in excel to generate spatial suitability maps for each SRAS and conventional agriculture.
- **Phase 5 – Interpretation of suitability maps:** In the discussion the spatial suitability maps will be interpreted qualitatively from a scientific and societal perspective. To formulate key findings of the research.

Phase 1 focuses on the development of a spatial suitability framework. Phases 2 and 3 involve collecting the data for the input of the framework. Phase 4 applies the framework to produce spatial suitability maps, and Phase 5 interpretates these maps. This research flow is depicted in Figure 2.1.

This chapter begins with background information on the cast study area, Schouwen-Duiveland. It then describes Phase 1, the development of p the framework, as part of the methodology, followed by the methods used in Phases 2 till 4. Phase 5, the interpretation of the results, is addressed in chapter 4, the discussion.

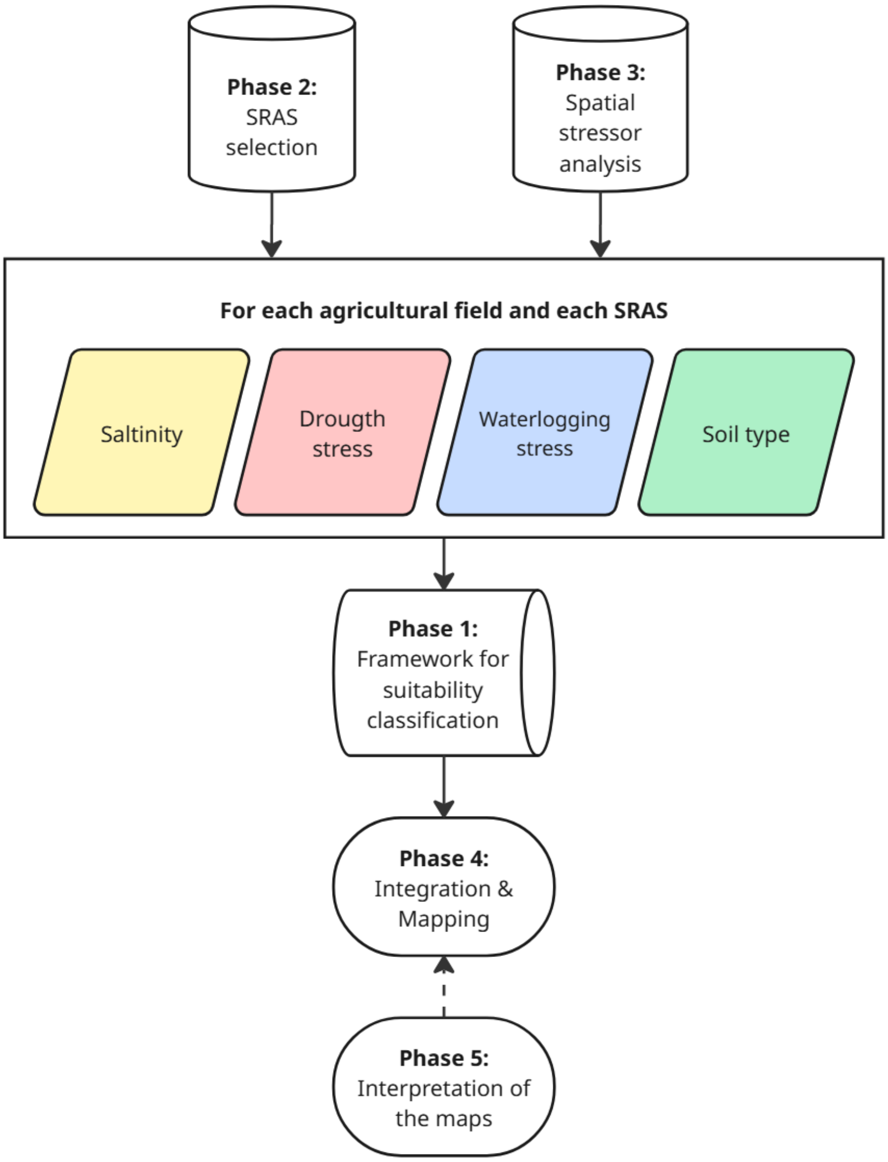


Figure 2.1: *Research flow diagram of the five phases.*

2.1 Case study and scenarios

Case study: the Netherlands, Schouwen-Duiveland

The Netherlands is especially vulnerable to salinization due to its position below sea level and increasing land subsidence, which together with sea level rise increases saltwater intrusion (Deolu-Ajayi et al., 2024). Once agricultural fields levels drop below sea level, it becomes increasingly difficult to prevent saline water from infiltrating the soil (Wit et al., 2021; Vellinga & Barrett-Lennard, 2021). The estimated annual economic losses due to salinization in the Netherlands may reach up to €600 Millon yearly (Deolu-Ajayi et al., 2024).

Schouwen-Duiveland is an example of an area in the Netherlands that is below sea level and is highly susceptible to salinization. In addition, Schouwen-Duiveland mainly relies on rainfall as freshwater resource, with limited additional reserves in dune and creek ridges (Figure 2.2) (Kaandorp et al., 2021). However, rainfall is expected to become more irregular, and increased periods of drought are anticipated (Eswar et al., 2021).

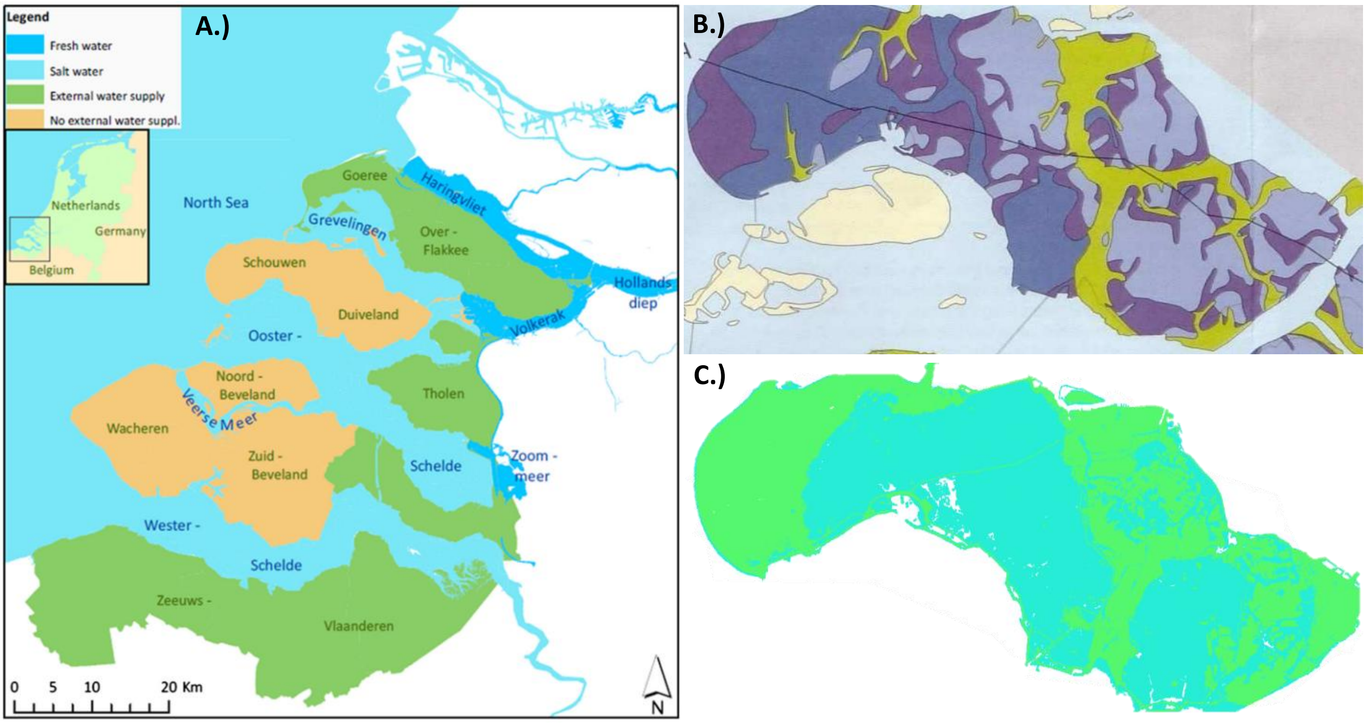


Figure 2.2: A.) *Schouwen-Duiveland with no external (fresh) water supply (van Duinen et al., 2015).* ***B.)*** *Creek ridges in Schouwen-Duiveland marked green (BAAC, 2011).* ***C.)*** *The elevation of Schouwen-Duiveland in which green shows area above sea level and blue below sea level (PDOK, n.d.).*

From both, social and environmental perspectives, concerns are growing in Schouwen-Duiveland. Some agricultural fields have become too saline for some conventional crops (Winkel et al., 2021). The combination of salinization and limited freshwater availability resulted into halved pea yields and 15% to 20% reduced fruit yields ('Ondernemerskring Schouwen-Duiveland', 2023). The dry years of 2018, 2019, and 2020 showed the island's vulnerability to drought and salinization (Kaandorp et al., 2021). Furthermore, waterlogging remains a major concern for local farmers, as it can rapidly destroy crops (*KWR, 2023*). Without measures, the increasing threats of SDAW will continue to reduce crop yields and soil health impacting both food security and the socio-economic conditions for farmers on Schouwen-Duiveland.

Currently, mitigation measures on Schouwen-Duiveland has primarily been focused on water management, including large-scale planning to freshen the Grevelingenmeer (Figure 2.2) (*onswater.nl*, n.d.). If converted into a freshwater body, the lake could help reduce soil salinity in the surrounding areas and serve as a valuable freshwater resource. However, this approach is costly and faces resistance due to the unique saline ecosystem the lake provides (Bert, 2018; *onswater.nl*, n.d.). In addition, a spatial suitability model was developed for several novel, self-sufficient, climate-adaptive (ground)water management systems designed to store the surplus fresh rainwater from winter for use during summer (Kaandorp et al., 2021). However, the effectiveness of these innovative systems remains uncertain, as they have not yet been tested under the specific environmental conditions of Schouwen-Duiveland.

The Rijksoverheid and regional water boards have stated that they cannot guarantee a reliable freshwater supply to mitigate the effects of drought and sanitation during prolonged dry periods (Rijksoverheid, 2023). This underscores the urgent need for Schouwen-Duiveland to adapt towards a more resilient agricultural system to these stressors.

Given the limited freshwater resources and the significant challenges currently faced by local farmers, there is a clear window of opportunity for a transition towards SRAS. Furthermore, the availability of relevant data makes Schouwen-Duiveland a valuable case study for exploring such a transition.

Scenarios

Two scenarios were explored: the current and the future climate scenario, of High 2050 based on The Royal Netherlands Meteorological Institute (K.N.M.I., 2020). This future climate scenario was selected based on the data availability for the stressors provided by Climate Impact Atlas (2024), and to explore potential stress under high predicted climate conditions, to assess robustness of the system during the highest predicted possible stress

2.2 **Phase 1**: Framework Development

How are the SDAW stressors and soil types incorporated into a spatial suitability framework for SRAS?

To assess the spatial suitability of SRAS based on the SDAW stressors and soil type a framework had to be developed that compares the values of the SDAW stressors with the suitability of the different SRAS. Therefore, the main criteria of this framework were to incorporate the three SDAW stressors and soil types to generate a suitability score.

Similar scoring frameworks were already applied in spatial suitability studies. These include the study by Wen (2023) which identified suitable locations for saline agriculture based on the proxy of salt-tolerant potato cultivation, and the research conducted by Deltares, which evaluated suitable locations for sustainable ground water management on a local scale (Kaandorp et al., 2021; Wen et al., 2023). Both studies used a scoring framework that combines multiple stressors by assigning values to the different criteria, typically ranging from 2 to 0. Wen applied a method where the criteria scores were multiplied to generate a final suitability score. Deltares used for each method a tailed decision framework resulting into four suitability classes.

This study adopts a similar approach by combining the multiplication method from Wen to assess the multiple stressors simultaneously and the class-based evaluation method used by Deltares which allows for qualitative interpretation. These two studies were selected as foundation because, like Wen, this research uses proxies to asses' agricultural systems, and like Deltares, it focusses on a local scale. The resulting adaptations form a framework tailored to evaluate SDAW stressors and soil types in Schouwen-Duiveland. The full framework development is explained by addressing the criteria, underlying logic, and associated assumptions.

2.2.1 Criteria and logic

The spatial suitability framework is based on four key criteria, each classified into three categories:

- **Salinity & soil type:** 0 = Not Suitable, 2 = Moderately suitable, 3 = Highly suitable (Adapted from Wen (2023); values increased by 1 to match the weight of the other stressors)
- **Drought & waterlogging:** 1 = High stress, 2 = Medium stress, 3 = Low stress (Based on classifications from Climate Impact Atlas (2024))

To integrate these criteria, a simplified suitability model was developed, consisting of three steps (Figure 2.3). Each step results in a suitability level, corresponding to the following categories: Not Promising (scores: 0-2), Potential Promising (scores: 3-4), Promising (score: 6), and Highly Promising (score: 9).

The three steps are:

Step 1: Multiply salinity and soil scores.
Step 2: Multiply drought and waterlogging scores.
Step 3: The final suitability level is equal to the lowest suitability category of step 1 and 2.

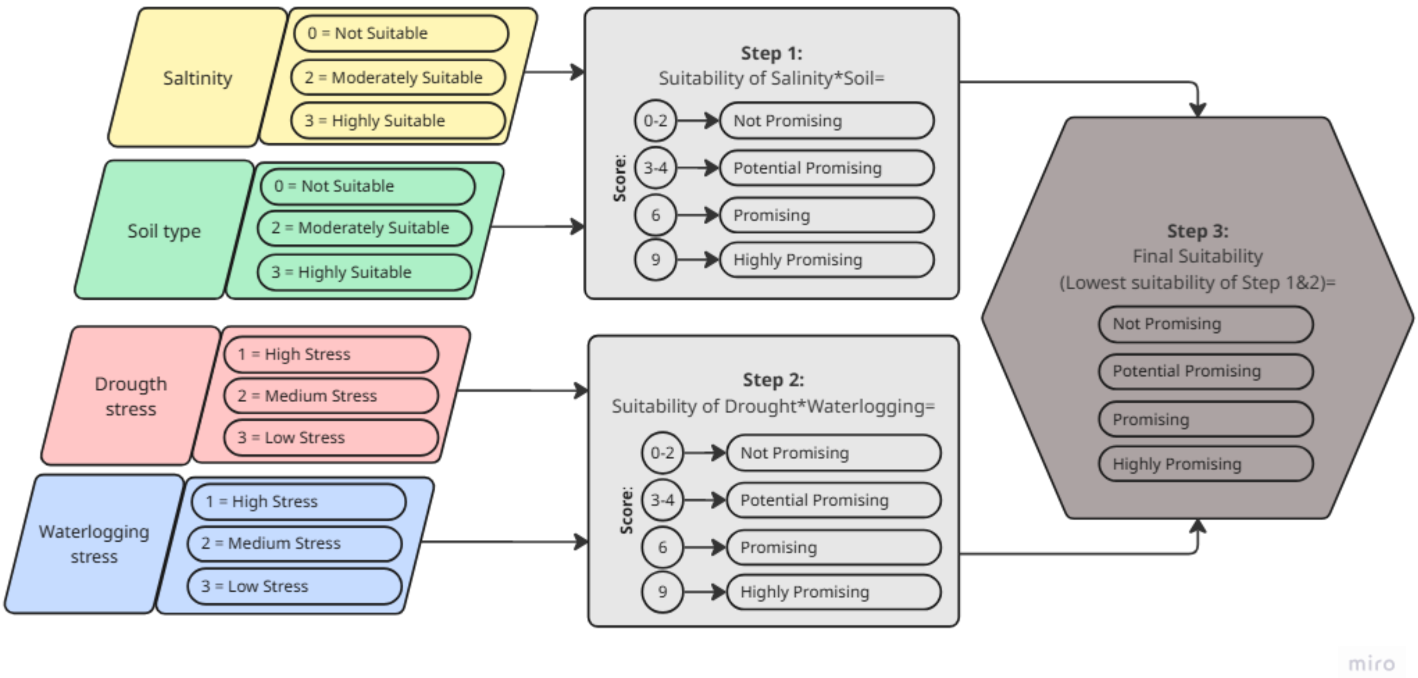


Figure 2.3: *The three steps of the framework to access spatial suitability for the SRAS.*

This three-step multiplication structure differs from Wen's single-step approach, where all criteria are multiplied at once. The reasoning behind this choice is that the combination of stressors increases the total stress and should not be averaged in the suitability selection process (*KWR, 2023*). In comparison with Wen (2023) this method ranks seven combinations of input criteria more strictly, which are highlighted in Appendix B.1. The final suitability assigned in step 3 shows the suitability for each agricultural field. All 81 possible input combinations and their outcomes are shown in Table 2.1.

Table 2.1: *All possible input combinations and their final suitability classification. Abbreviations in the table are representable for the suitability classification: Not Promising (-), Potential Promising (PP), Promising (P), and Highly Promising (HP).*

			Salinity								
			3.Highly Suitable			2.Moderatly Suitable			0.Not Suitable		
Soil	Drought	Waterlogging	3.Low Stress	2.Medium Stress	1.High Stress	3.Low Stress	2.Medium Stress	1.High Stress	3.Low Stress	2.Medium Stress	1.High Stress
3.Highly Suitable	3.Low Stress		HP	P	PP	P	P	PP	-	-	-
	2.Medium Stress		P	PP	-	P	PP	-	-	-	-
	1.High Stress		PP	-	-	PP	-	-	-	-	-
2.Moderatly Suitable	3.Low Stress		P	P	PP	PP	PP	PP	-	-	-
	2.Medium Stress		P	PP	-	PP	PP	-	-	-	-
	1.High Stress		PP	-	-	PP	-	-	-	-	-
0.Not Suitable	3.Low Stress		-	-	-	-	-	-	-	-	-
	2.Medium Stress		-	-	-	-	-	-	-	-	-
	1.High Stress		-	-	-	-	-	-	-	-	-

2.2.2 Assumptions

The framework builds on the underlying assumption that there are different threshold values specific for each SDAW stressors. However, in reality these threshold values can vary widely dependent on local conditions (Stuyt et al., 2016). Furthermore, values are categorized into discrete classes, which may over- or underestimate values near category boundaries, especially if other mitigation or adaptation measures are applied.

This framework simplifies complex biophysical interactions into four criteria. Other factors such as water and soil management, fertilization, pests and diseases, or crop growth stages, are not included, even though they also influence how crops are affected by stressors.

Despite the assumptions and simplifications of real-world systems, the frameworks still serve as a useful tool to assess spatial suitability of SRAS based on the SDAW stressors. This provides a starting point for identifying promising locations, under the assumption that real-world agricultural systems will be more complex.

2.3 **Phase 2:** SRAS selection

Which SRAS are suitable for the Netherlands, and what levels of each SDAW stressor and soil types can they tolerate?

To answer this sub question, a semi-structured literature review was conducted. This approach consisted of an exploratory and iterative search, allowing refinement in the search strategies by using new information. The review consisted of two stages:

Stage 1: Identifying SRAS for the Netherlands

This first stage, focused on identifying SRAS options suitable for the Netherlands. A semi-structured literature search was conducted using the scientific databases Scopus and Web of Science, combing multiple combinations of keywords related to SDAW stressors and crop-based agricultural systems or management methods. Boolean operators were used to create different search strings (see Appendix B.2 for the full list of keywords).

Eight different search queries yielded approximately 920 articles, filtered by the criteria that they were published after 2000, written in English, peer-reviewed, and duplicates were removed. Due to the exploratory nature of this semi-structured review, not all articles were screened in detail. Instead, a targeted selection approach was applied. First, articles were ranked by citation count to prioritize influential studies. The top-cited articles were scanned for relevance. Of all searches combined approximately the top 100 articles were screened based on titles and abstracts, and scanning. These articles were assessed for SRAS that reported salinity tolerance levels with a minimum threshold value of 2 dS/m. This threshold is recognized as the general upper boundary for conventional agriculture (Wen et al., 2023). Studies focusing solely on soil or water management, integrated livestock systems, or breeding were excluded, because the focus is on crop species selection and management.

Following this screening process, three different SRAS were selected for further assessment in this study. After selecting these SRAS, all 920 articles titles were searched using Ctrl+F with specific keywords related to each SRAS to identify articles with direct relevance. This yielded approximately 15-20 papers for each SRAS which were read thoroughly.

Although this semi-structured approach does not guarantee complete coverage of all available SRAS-related studies, it provided a relevant selection of scientific based evidence.

Stage 2: Threshold identification

In the second stage, the three selected SRAS were analyzed for their tolerance levels to the four criteria: salinity, drought, waterlogging, and soil type. Salt tolerance is described with a certain threshold value after which the plant shows significant damage (Maas & Hoffman, 1977) (see Appendix A.2.2 for additional theoretical details). An in-depth search resulted in scientific literature, and publicly available case study reports that were assessed. To compensate for data limitations model species with more accessible data were used as proxies for SRAS, and spatial data was used to derive thresholds.

When necessary, data of criteria tolerance values was converted into the right units the suitability framework:

- **Salinity tolerance:** Values expressed in electrical conductivity (EC) were converted to chloride concentrations (mg Cl^-/L), using the formula from van Dam et al. (2007). Van Dam et al. (2007) provided a conversion formula for open field crops from EC to mg Cl^-/L. The calculation is done in two steps. First the chloride concentration in saturated paste (C_{sp}) is determined by the formula: $C_{sp}=151EC^{1,31}$. This value is multiplied by 2 to obtain the chloride concentration in the soil at field capacity (C_{fc}). This value is assumed to be valid for the salt tolerance thresholds that are found in scientific literature. The full calculations can be found in *Supplementary Material - Excel: Calculations: 'EC to Cl L-1'.*

- **Drought and waterlogging tolerance:** For the drought and waterlogging tolerance only qualitative tolerance data was available. Therefore, this qualitative information about the drought and waterlogging tolerance values of the SRAS had to be converted to the values from Climate Impact Atlas (2024) which are given in % yield decrease for grasses per year.

Because tolerance is dependent on multiple factors it is impossible to find one perfect conversion factor. Even so, this study compares the tolerance for drought and waterlogging between different SRAS by applying a factor of *0.75 for sensitive systems and factor of *1.25 for tolerant species. This allows taking the tolerance of the systems to these two stressors into account. Additionally, a sensitivity analysis was conducted to assess the influence of this value.

2.4 **Phase 3:** Spatial stressor analysis

What is the current and projected spatial distribution of SDAW stressors and soil types across existing agricultural fields in Schouwen-Duiveland?

In this phase the SDAW stressors, and soil type are combined to agricultural fields on Schouwen-Duiveland using QGIS, which is in line with the method used by Wen (2023). This is an appropriate approach as salinity maps that assessed with GIS can support decision making (Utset & Borroto, 2001).

1.The agricultural fields

The agricultural fields were obtained from Nationaal Georegister (Basisregistratie Gewaspercelen (WFS)) (Nationaal Georegister, 2024). Only the fields that were currently used for agricultural practices were included in this study. This included the fields that were used for cropland, grassland: temporary, and other: food forest. All other agricultural fields were excluded due to other assigned purposes than agriculture or not deemed suitable for agricultural practices. This method assumes no land-use change is required, as it combines SDAW data with existing agricultural fields.

2.The Soil map

For soil type, the geomorphologic map from Bodemdata.nl was used, based on research by Wageningen Environmental Research (WENR) (*Bodemdata*, n.d.). The scale of this map is 1:50.000 and provides information up to a depth of one meter.

The soil map was combined with the agricultural fields using the “Vector General: Join Attributes by Location (Summary)” tool in QGIS. Features were intersected, and the result was based on the majority soil type within each field. All NULL values were removed. This resulted in one dominant soil type per agricultural field.

The Dutch soil classifications were then translated into five categories of the USDA classification system: Sandy, Sandy Loam, Loam, Clay, and Clay Loam (*NutriNorm*, n.d.). The exact division of soil types is provided in Supplementary material – Excel: Calculations: ‘Soil types’.

3.The salinity map

The salinity map was obtained from Climate Impact Atlas (*Climate Impact Atlas*, 2024) and shows salt load (in NaCl kg/ha/year), which is the amount of salt transported from groundwater to surface water. The data is available for the current situation and for projected sea-level rise scenarios (0.5m, 1m, and 3m). The 0.5m absolute sea-level rise scenario was selected, as it corresponds to the High 2050 climate scenario.

The maps were combined with agricultural fields using the "Zonal Statistics" tool to calculate the mean salt load per field. All NULL values were removed. For future projections, the salt load difference was added to the current values to calculate the total future salt load.

Salt load values (NaCl kg/ha/year) were converted to mg Cl^-/L. Because Climate Impact Atlas provides the salt load as the amount of salt transported from groundwater to surface water, it is assumed that all this salt will be dissolved in the total surface water available. Furthermore, it is assumed that only rainfall and evaporation contribute to the total surface water as rain is the main freshwater source for Schouwen-Duiveland. For the conversion to mg Cl^-/L it assumed that the fraction Na^+ and Cl^- are similar to their molar weight. Median values for rainfall and evaporation were used for Schouwen-Duiveland (Rougoor et al., 2016) (see Appendix B.3 for additional information).

4.The drought map

The drought map was also obtained from the Climate Impact Atlas (*Climate Impact Atlas*, 2024) and presents drought in terms of % yield loss for grass species per year. It assumes a uniform coverage of grass across the Netherlands and is based on water shortages over a time period of 10 days per year. Data is available for both the current situation and the High 2050 scenario and is provided with a resolution of 1:250.

The maps were linked to agricultural fields using Zonal Statistics to calculate the mean drought per field. NULL values were removed. A difference map was created by subtracting the current values from the future scenario. The original classification from the Climate Impact Atlas were used.

5.The waterlogging map

For waterlogging, the oxygen stress map from the Climate Impact Atlas was used (*Climate Impact Atlas*, 2024) as oxygen stress is the result of waterlogging. Similar to the drought map, this map shows % yield loss for grass per year and is based on oxygen stress that occurs after a period of 10 days. Data is available for the current situation and the High 2050 scenario and is provided with a resolution is 1:250.

The maps were linked to agricultural fields using Zonal Statistics to calculate the mean oxygen stress per field. NULL values were removed. A difference map was created by subtracting the current values from the future scenario. The original classification from the Climate Impact Atlas were used.

2.5 **Phase 4:** Integration & mapping

Which existing agricultural fields locations in Schouwen-Duiveland are suitable for SRAS implementation, now and under future climate projections?

This final phase integrates the results from Phase 1 (framework), Phase 2 (SRAS tolerance), and Phase 3 (spatial data). The classification rules derived from the framework were implemented in Excel and the results were linked back to QGIS to produce the spatial suitability maps (Supplementary Material – Excel: Calculations: 'All values of current situation' & 'All values of high_2050 situ', provides the full calculation).

The maps were produced for both current and future climate scenario for each SRAS and conventional agriculture. Additionally, a composite map was developed to visualize the highest suitable SRAS per agricultural field. For each category, the total percentage of land areas was calculated to support comparative analysis. Furthermore, additional maps were created to assess data sensitivity and explore discussion points, which are addressed in the discussion section.

This approach allows location-specific assessment of SRAS suitability in Schouwen-Duiveland both under current conditions and projected future scenarios, providing guidelines for agricultural planning.

3. Results

The results are structured according to Phases 2 through 4. Phase 2 presents the identified SRAS and summarizes the current knowledge about these systems, together with the defined threshold values based on the proxies of the systems. Phase 3 shows the spatial distribution of the stressors, while Phase 4 provides the spatial suitability maps of the SRAS and conventional agriculture. Following this, the main research question will be answered. However, the interpretation of the suitability maps will be assessed in the discussion.

3.1 **Phase 2:** Identify SRAS and criteria thresholds

This phase provides three SRAS for the Netherlands, which each are discussed shortly together with the identified criteria which are all summarized in Table 3.1 (further details are provided in Appendix C). In addition to this the threshold values for conventional agriculture, based on Wen (2023), are also included to allow for comparison with the SRAS.

The three identified SRAS are:

1. Salt-tolerant crop rotation
2. Halophytic intercropping or ration
3. Agroforestry

It should be noted that the literature review identified additional potential SRAS options, including inland saline aquaculture, which uses saline water to farm aquatic animals or plants (Singh, 2015). However, this option was excluded from the study because this system focusses on a full land function change with a total new saline water management. Similarly, other systems that only partially involve crop selection and management, such as climate-smart agriculture, regenerative agriculture, and permaculture, were also excluded from the study (Dimkpa et al., 2009).

3.1.1 Salt-tolerant crop rotation

Salt-tolerant varieties of conventional crop species are widely recognized as an important adaptation strategy and a promising solution for maintain productivity in salt-affected regions (Flowers, 2008; Mukhopadhyay et al., 2021; Wen et al., 2023). These crops enable continued production in saline environments without substantial loss of yield or quality, helping to adapt towards the irreversible salinization of freshwater and soils (Stowa, n.d.). Additionally, Singh et al. (2015) emphasized that salt-tolerant crops serve as a cost-effective adaptation strategy to combat salinization in India, making it an economically feasible solution.

A particularly promising approach is the development of crop rotation systems based on the annual salination patterns of the soil, as drought and salinization occur more frequently in summer than in winter. A well-designed rotation system could help align the cultivation of salt-tolerant varieties with periods when they are most needed (Blom-Zandstra et al., 2014). However, such salt-tolerant crop rotation plans are not fully developed yet, although Winkel et al. (2021) emphasized the need for a salt-tolerant crop rotation plan for potatoes (Winkel et al., 2021).

Because these rotation systems are not yet developed, this study applied a simplified approach by using a salt-tolerant variety of potatoes (Potato '927') and sugar beets as proxies to access the spatial suitability for this SRAS (Dutch Scientists Introduce an Improved Method to Identify Salt Tolerant Crops, 2018). These species were chosen due to their demonstrated salt resilience in the Salt Farm Texel field experiments, as well as their societal importance and already established markets (Alavilli et al., 2023; Blom-Zandstra et al., 2014).

The threshold values for these two proxies are shown in Table 3.1 and more details about these values can be found in Appendix C.1 & C.2. The main assumptions for obtaining the thresholds values are:

- Potato '927' is a cultivar of *Solanum tuberosum* L. and is assumed to have the same general tolerance values (*The European Cultivated Potato Database*, 2005).
- Clay and clay loam soils were assumed to be not suitable for both proxies, as salts can permanently damage clay or clay loam soils (*SalFar*, n.d.) (Appendix A.1).

3.1.2 Halophytic rotation and intercropping

The second identified SRAS focusses on using halophytes, which are plant species that thrive in saline environments and can play a crucial role in mitigating salinity stress (Flowers, 2008; Geissler et al., 2014; Mukhopadhyay et al., 2021). Integrating halophytes into agricultural systems could reduce the pressure on land and water resources, offering a sustainable adaptation to salinization while repurposing affected land (Panta et al., 2014). Additionally, halophytes contribute to soil restoration by either accumulating salts within their tissues or secreting them through specialized glands (dos Santos et al., 2022; Litalien & Zeeb, 2020) (See Appendix A.2.1 for more details about these mechanisms). This soil restoration by using plants, is called phytoremediation, and is an environmentally friendly cost-effective method currently used in various context to restore soil health and reclaim salt-affected land (Hasanuzzaman et al., 2014; Litalien & Zeeb, 2020; Mukhopadhyay et al., 2021). Furthermore, halophytes offer economic potential as source of food, animal fodder, bioenergy, fiber, and oilseeds (Geissler et al., 2014; A. Kumar et al., 2023; Luković et al., 2021). Lastly, halophytes allow brackish or salt irrigation water, reducing reliance on freshwater sources (Luković et al., 2021). However, saline irrigation is unsuitable for clay and loam soils, as high salt concentrations can degrade the soil structure (*SalFar*, n.d.)(Appenidx A.1).

Currently halophytes are not widely adapted in large-scale agriculture yet, due to challenges such as market limitations, yield optimization, cost-benefits considerations, and support of governmental policies (Panta et al., 2014). In the Netherlands, halophytic cultivation is currently often limited to small-scale production, mainly due to a lack of market demand (Wit et al., 2021). However, if salinization pressures continue to rise, the resulting economic losses in conventional agriculture may create a window of opportunity for halophyte cultivation (Wit et al., 2021). To (partly) overcome the lack of market demand, a transition to large-scale markets is needed, or halophytic cultivation need to be combined with glycophytic cultivation trough intercropping or crop ration (Stowa, n.d.).

Studies show the potential of intercropping of halophytes with conventional crops to mitigate salt stress while maintaining crop yields for both crop types (Cammerino et al., 2025; Simpson et al., 2018). This promotes sustainable research management and food security. However, practical knowledge for intercropping with halophytes is limited (Simpson et al., 2018). Therefore, the glasswort was selected as a model species for this study. Because it has been effectively used in intercropping experiments and is already produced in a nice market in the Netherlands with a high economic value (Acharya et al., 2024; Cammerino et al., 2025; Mathur & Mathur, 2024; Simpson et al., 2018).

For rotational cropping systems, it was suggested that a promising strategy combines the rotation of salt-sensitive potato varieties with the halophyte quinoa (Sun, 2013; *Zilt Perspectief, 2015*). Furthermore, quinoa may contribute to improve soil health and has a market potential due to its statues as superfood (Dehghanian et al., 2024). Therefore, quinoa is used in this study as a proxy crop for halophyte-based rotation systems.

The threshold values for these two proxies are shown in Table 3.1 and more details about these values can be found in Appendix C.3 & C.4. The main assumptions for obtaining the thresholds values are:

- For intercropping systems with glasswort, drought and waterlogging tolerances are assumed to range from moderately sensitive to tolerant. This is based on the known resilience of glasswort and assumptions that the intercropped species will be selected with a similar tolerance.
- For quinoa a range of 5 dS/m is used around the optimal salinity tolerance to define moderately suitable salinity levels (*Biondi et Al.,* n.d.; Sarwar Qureshi & Worku Daba, 2020).

3.1.3 Agroforestry

The final identified SRAS is agroforestry, which is an agricultural system that cultivates perennial trees and shrubs possibly integrated with conventional crops on the same field, offering both environmental and economic benefits (Fuchs et al., 2021; Mathur & Mathur, 2024). Agroforestry has been frequently mentioned as potential promising solution against salinization (Jianfeng et al., 2004; Singh, 2015). Furthermore, several case studies showed in India have demonstrated successful reclamation and remediation of abandoned salinized soils through agroforestry (Dagar, 2014; P. Kumar & Sharma, 2020; Mathur & Mathur, 2024).

Although the specific effects are not yet fully understood and quantified, several mechanisms have been identified that influence salinity levels in the soil. Firstly, trees and shrubs enhance the soil's infiltration capacity, due to the extensive root systems, allowing water to gradually seep in and be retained. The extent to which this occurs depends on the soil type (Fuchs et al., 2022; Singh, 2015). Secondly, trees can create microclimates by reducing wind speed and providing shade, which can potentially decreases evaporation and increases water availability within these microclimates (Mathur & Mathur, 2024). This helps maintaining a higher freshwater lens in the topsoil, thereby reducing salinity concentrations in the microclimate (Fuchs et al., 2022).

Other advantages of a properly designed agroforestry system include, increases in soil organic matter, carbon storage, biodiversity, preventing soil erosion and top soil cracking, enhancing crop growth due to lower wind stress, and providing economic products as food, fodder, timber, construction materials or biomass (Fuchs et al., 2021; Mathur & Mathur, 2024; Singh, 2015). Furthermore, integrating trees with crops can lead to an increase in total output per unit area (Mathur & Mathur, 2024). However, improper placement, can lead to total yield reductions due to nutrient competition (Fuchs et al., 2021).

While agroforestry systems can enhance resilience against stressors such as sanitization, drought, waterlogging, and wind, these same challenges can complicate the implementation of agroforestry, particularly in regions with limited freshwater availability, such as Schouwen-Duiveland (Fuchs et al., 2021). Aadditionally, increased humidity within the microclimate can elevate the risk of fungal diseases (Fuchs et al., 2021).

The success of agroforestry systems depends on careful design choices, including species selection and spatial arrangement, making knowledge about these factors crucial (Fuchs et al., 2022). However, a standardized crop selection and agroforestry guidelines for saline soils in the Netherlands remains currently absent.

Although research is still ongoing, some agroforestry practices have already been implemented in Zeeland, primarily for windbreaking purposes. For example, hedgerows are used to protect fruit trees from strong winds (Fuchs et al., 2021). Additionally, a food forest is being developed on Schouwen-Duiveland (Beheerlyckheid, n.d.).

Current agroforestry practices and monocropping of trees on Schouwen-Duiveland were used as the basis for determining salinity tolerance and soil suitability for the agroforestry system assessed in this study (Appendix C.5). Therefore, it is assumed that the current values of the salinity levels and soil types are representative of the total potential of agroforestry. Furthermore, agroforestry is assumed to be tolerant to drought and waterlogging, as summarized in Table 3.1.

Table 3.1: *Threshold values for each SRAS and conventional agriculture for all SDAW stressors and soil type.*

Tolerance levels	Potato 927	Sources:	Sugar Beet	Sources:	Glasswort intercropping	Sources:	Quinoa rotation	Sources:	Agroforestry	Sources:	Conventional Agriculture
Salinity mg Cl^-/L (dS/m)	**Highly suitable:** 374-928 (2-4) **Moderately suitable:** 928-2302 (4-8) **Not suitable:** <374 or >2302 (<2 or >8)	(*De Vos et al., 2016*; Oosterbaan, n.d.; Wen et al., 2023)	**Highly suitable:** 374-3915 **Moderately suitable:** 3915-5000 **Not suitable:** <374 or >5000	(Stuyt et al., 2016; *Zilt Perspectief, 2015*) (*SalFar, 2022*).	**Highly suitable:** 928-1473 (4-6) **Moderately suitable**: 374-928 (2-4) & 1473-2302 (6-8) **Not suitable:** <374 or >2302 (<2 or >8)	(Acharya et al., 2024; Cammerino et al., 2025).	**Highly suitable:** 6166-15288 (10-20) **Moderately suitable:** 2487-6166 (5-10) & 15288-20479 (20-25) **Not suitable:** <2487 or >20479 (<5 or >25)	(*Biondi et Al.*, n.d.; Sarwar Qureshi & Worku Daba, 2020)	**Highly suitable:** 749-4500 **Moderately suitable**: 4500-5500 **Not suitable:** <749 or >5500	(Appendix C.5)	**Highly suitable:** 0-749 (0-2) **Not suitable:** >749 (>2) (Wen et al., 2023)
Drought	Sensitive	(Obidiegwu et al., 2015; Orsák et al., 2020)	Tolerant	(Alavilli et al., 2023)	Moderately Sensitive	(Calone et al., 2022).	Tolerant	(Bouras et al., 2022; Lin & Chao, 2021; Nguyen et al., 2024)	Tolerant	(Fuchs et al., 2022; N. Kumar et al., 2019; Zhang et al., 2024)	Sensitive
Waterlogging	Sensitive	(Obidiegwu et al., 2015; Orsák et al., 2020; Sela, 2024)	Sensitive	(Sha et al., 2024)	Moderately Tolerant	(Jordine et al., 2024).	Moderately Sensitive	(Bouras et al., 2022; González et al., n.d.; Nguyen et al., 2024)	Tolerant	(Fuchs et al., 2021; Kumud Dubey, 2022; Singh, 2015).	Sensitive
Soil type	**Highly suitable:** Sandy, Sandy Loam **Moderately suitable:** Loam **Not suitable:** Clay, Clay Loam	(*De Vos et al., 2016*; Sela, 2024).	**Highly suitable:** Sandy, Sandy Loam **Moderately suitable:** Loam **Not suitable:** Clay, Clay Loam	(*Yara UK*, 2019)	**Highly suitable:** Sandy, Sandy Loam, Clay **Moderately suitable:** Loam, Clay Loam	(Cammerino et al., 2025; El-Maboud, 2021; *PFAF Plant Database*, n.d.-a)	**Highly suitable:** Sandy, Sandy Loam **Moderately suitable:** Loam, Clay Loam, Clay	(Bouras et al., 2022; S. Lv et al., 2024; Rankel, 2024)	**Highly suitable:** Loam **Moderately suitable:** Sandy, Sandy Loam, Clay **Not suitable:** Clay Loam	(Appendix C.5)	**Highly suitable:** Sandy, Sandy Loam, Loam, Clay Loam, Clay

3.2.Phase 3: Spatial data analysis

In this phase, the spatial analysis was conducted to assess the current and future exposure of Schouwen-Duiveland's agricultural fields to the key SDAW stressors. This forms the basis for the suitability analysis. Since soil types influence the SDAW stressors this phase will start with assessing the soil types before moving to the SDAW stressors.

3.2.1 Soil type

The soil map of Schouwen-Duiveland (Figure 3.1) reveals that the island's agricultural landscape is mainly composed of loamy soils, which covers approximately 67% of the land area. The second most common soil type is clay, accounting for 24%. While the other 9% consists of sandy, sandy loam and clay loam soils. It is assumed that these soil types are also representable for the futures projections. This distribution of soil types forms an important basis to be able to assess the SDAW stressors, as the soil type varying in capacities to drain or hold water (Appenidx A.1).

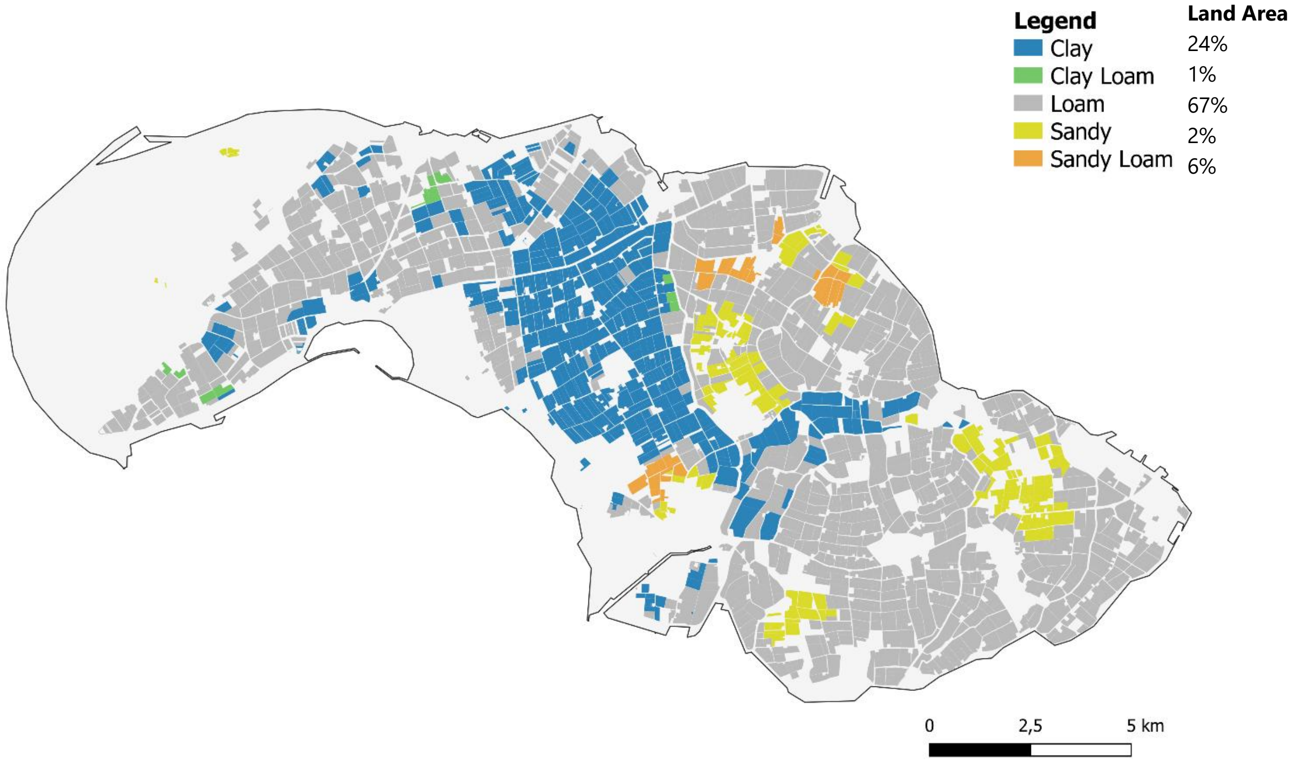


Figure 3.1: *The soil type distribution map of Schouwen-Duiveland.*

3.2.2 Salinization

Current and future salinity levels are mapped in Figure 3.2 in combination with the projected change. These maps show that even under current conditions, Schouwen-Duiveland is facing substantial salinization. One notable pattern can be observed along the creek ridges (highlighted in Figure 1.2), which shows relatively fresh groundwater conditions in the current situation and is projected to become even fresher in the future.

This freshening can be partly assigned to the fact that the creek ridges have a higher elevation above sea level, making them less susceptible to salinization (Figure 2.2C). However, the eastern part of Schouwen-Duiveland is also elevated, yet this area is still expected to have an increase in salinization. This could be explained by the smaller distance to sea and possibly a higher infiltration into the land. The southern parts of the island are expected to experience the most severe increase in salinization.

When comparing the total surface area affected by different salinity classes, a clear shift towards higher salinity is evident. Notably, the highest salinity category of 8464 (approximately 32 dS/m) or higher increases by 5% of the total land area. Additionally, nearly one-third of the island is projected to experience an increase of at least 700 mg Cl^-/L (approximately 4 dS/m). These changes indicate a growing challenge for conventional agriculture on Schouwen-Duiveland.

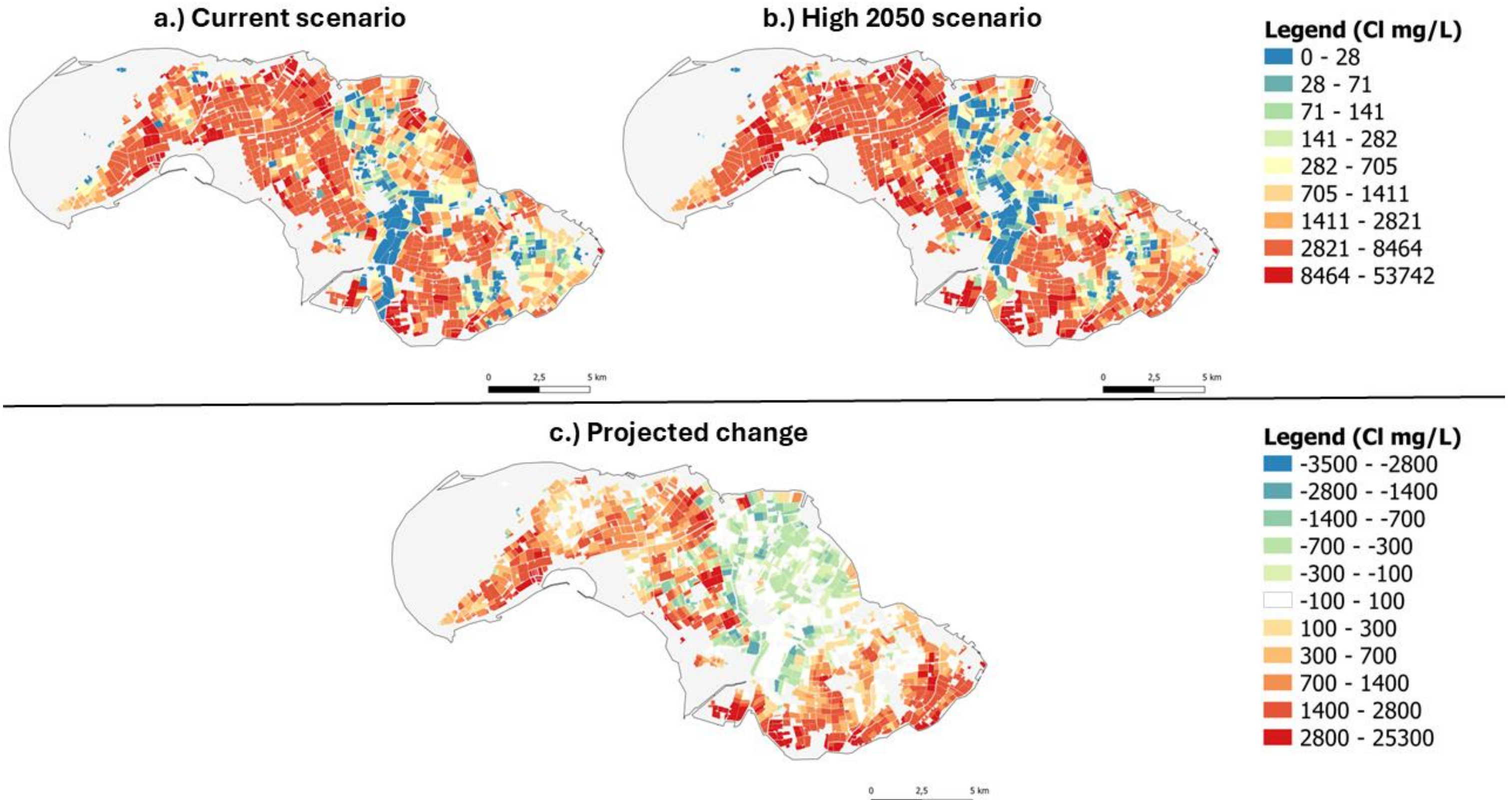


Figure 3.2: *The salinity distribution map for a.) Current Scenario, b.) High 2050 scenario, and c.) Projected change for Schouwen-Duiveland.*

3.2.3 Drought stress

Drought stress is already a concern in the central parts of the island, particularly in areas with clay soils (*KWR, 2023*). As shown in Figure 3.3, projections suggest that drought conditions will intensify across Schouwen-Duiveland, resulting in a significant increase of areas that shift from low stress to medium stress. The medium drought stress category is expected to grow by 35%, and high drought stress will affect an additional 9% of land area. A spatial correlation can be observed between the clay-dominated areas and the zones that are most vulnerable to drought, this emphasizes the sensitivity of clay soils to prolonged dry periods.

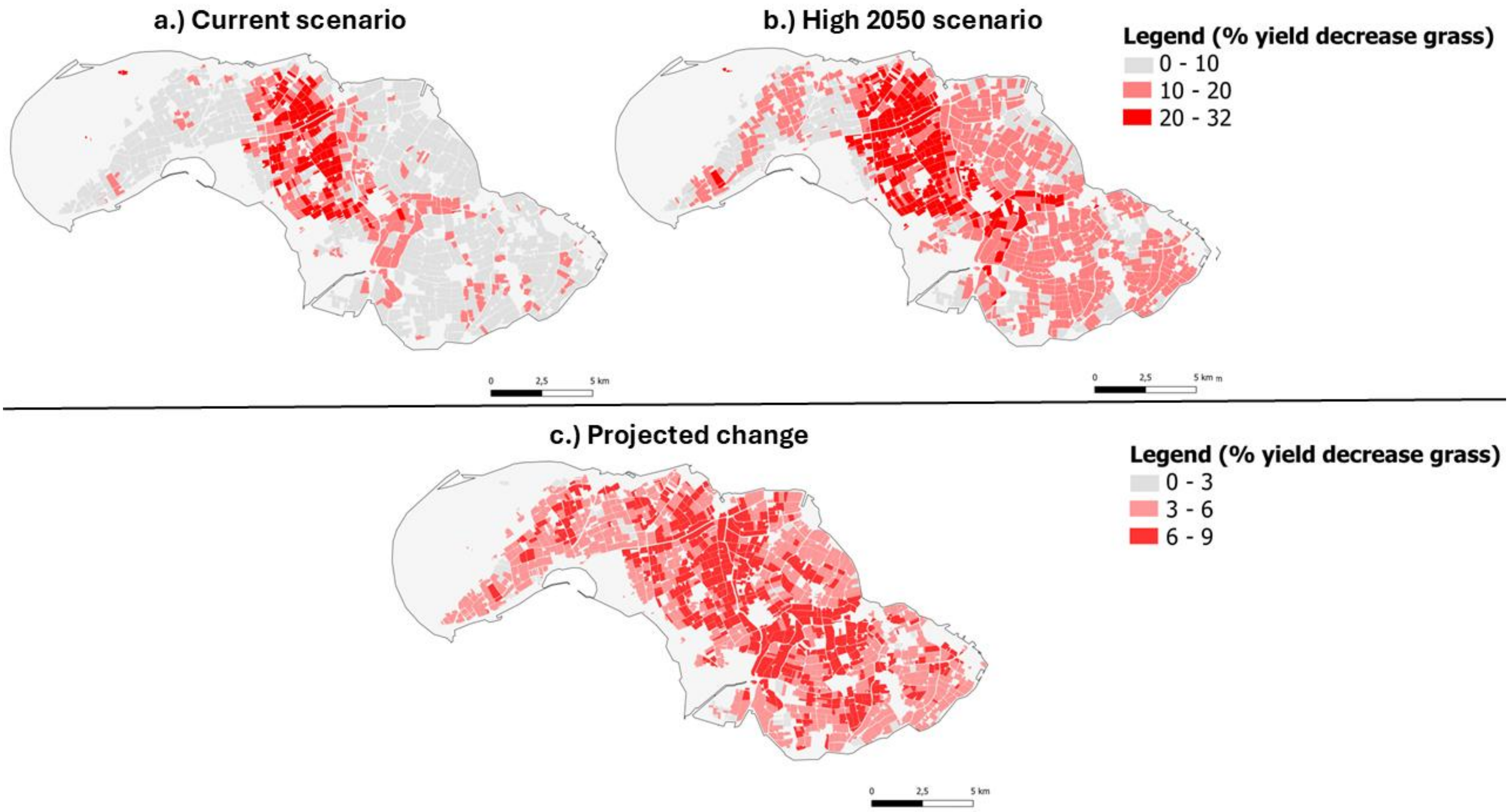


Figure 3.3: *The drought stress distribution map for a.) Current Scenario, b.) High 2050 scenario, and c.) Projected change for Schouwen-Duiveland. The legend for a.) & b.) shows the classification of Climate Impact Atlas: low, medium and high.*

Salinity and drought stress often occur simultaneously, which is clearly highlight by these maps for the central area that is expected to experience high drought and salinity levels. Notably, this is not the case for the creek ridges that will experience high drought stress, likely due to their higher elevation.

3.2.4 Waterlogging stress

The maps in Figure 3.4 illustrate yield reductions resulting from oxygen stress, which is the result of waterlogging. For this analysis, oxygen stress is assumed to reflect the total impact of waterlogging. The current situation already indicates that the majority of the land is affected by mild waterlogging stress, and the stressor is projected to become even more widespread. By 2050, the share of land experiencing mild waterlogging stress increases from 63% to 91%. Interestingly, areas along the creek ridges (Figure 1.2) once again demonstrate greater resilience, consistently showing lower levels of waterlogging stress, likely due to their higher drainage capacity.

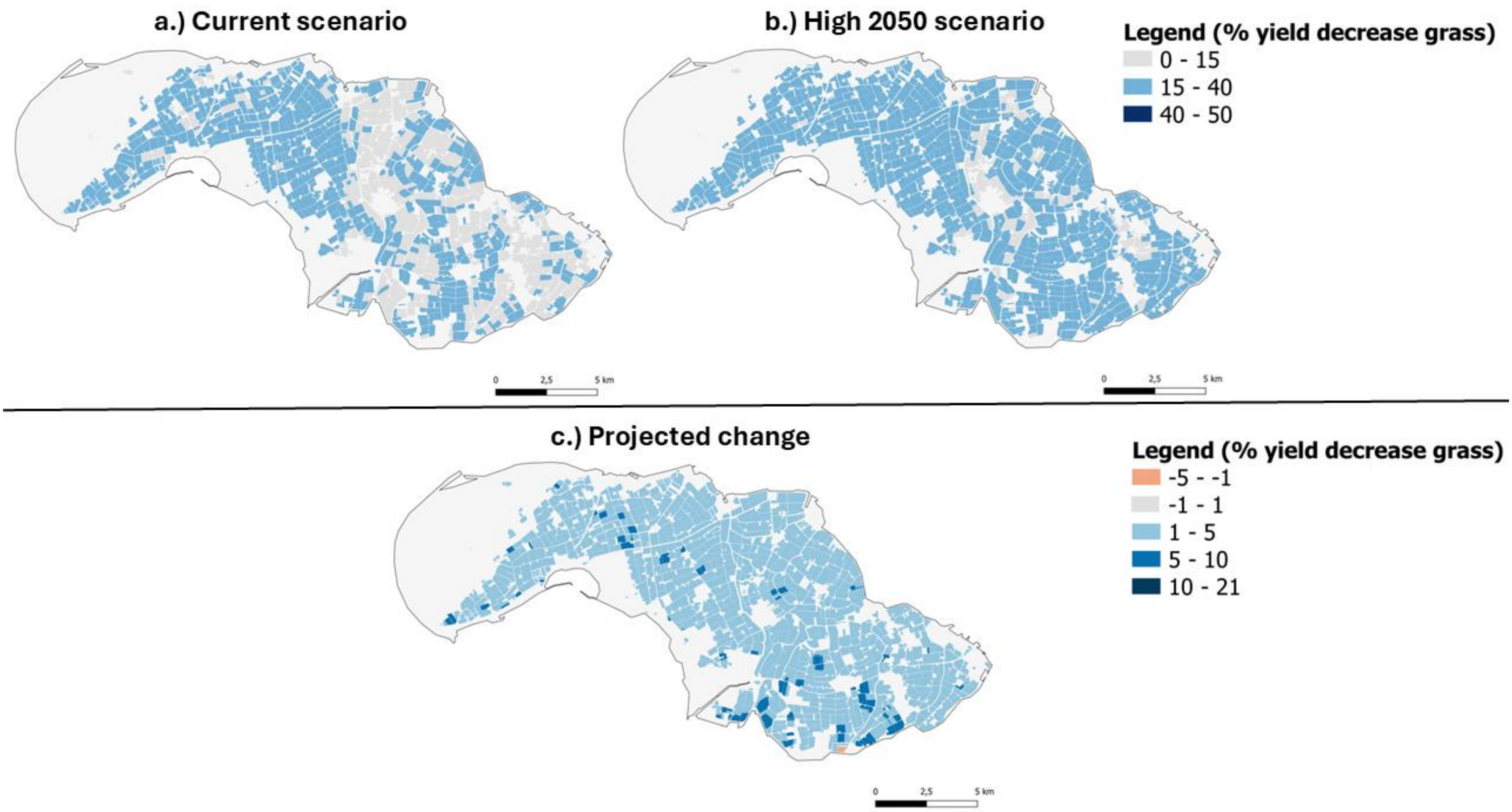


Figure 3.4: *The waterlogging stress distribution map for a.) Current Scenario, b.) High 2050 scenario, and c.) Projected change for Schouwen-Duiveland. The legend for a.) & b.) shows the classification of Climate Impact Atlas: low, medium and high.*

3.3 Phase 4: Integration & mapping

This phase applied the developed framework in combination with the stressor thresholds for the SRAS and the stressors maps to create spatial suitability maps for each SRAS. Additionally, the framework was applied to the thresholds for conventional agriculture to allow comparison. The analysis begins with an overview of the total land suitability per system expressed as percentage of land area, followed by a more detailed presentation of the spatial maps to explore and compare geographic patterns.

3.3.1 Overview suitability based on % land area

The results from all spatial suitability maps are summarized in Figure 3.5, which shows the suitability areas based on % land area. Under current conditions, conventional cropping is considered promising on approximately 25% of the land. However, this is projected to decrease significantly to only 9% in the future, highlighting the growing pressure from SDAW stressors for conventional agriculture. It is important to note that this analysis considers conventional agriculture viable only on land with salinity levels below 2 dS/m. In addition, these areas are assumed to be unsuitable for the SRAS systems, although this assumption may underestimate certain systems' total coverage.

In contrast to conventional agriculture, the SRAS systems offer broader and more resilient agricultural options. Although all systems show a decline in overall suitability under future stress scenarios. System 2 stands out for its wide geographic spread, which is based on its high range of salinity tolerance. System 3 shows the highest promising values due to the system's high tolerance to drought and waterlogging. System 1, which is the most similar to conventional agriculture, remains at least potentially promising for 45% of the area in the future scenario.

Combining all systems the total area suitable for agriculture compiles to 99% in the current situation, and to 76% under future projection. This shows a substantial potential for SRAS systems as it provides significantly higher suitability than if only conventional agriculture would be applied.

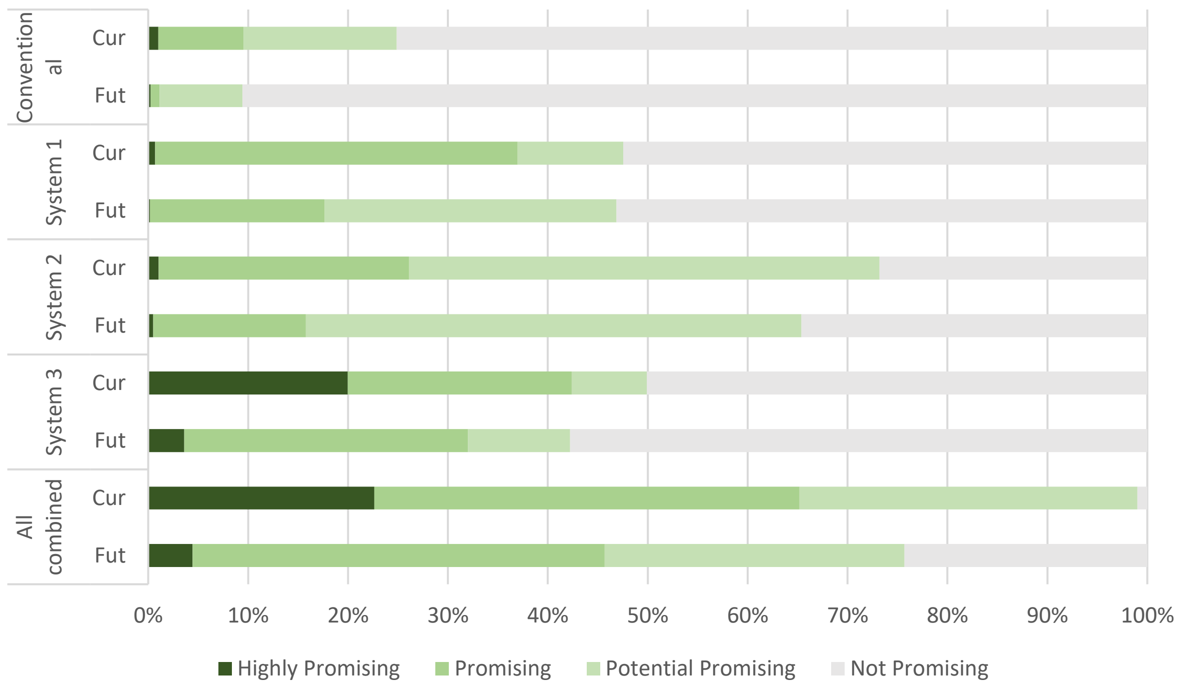


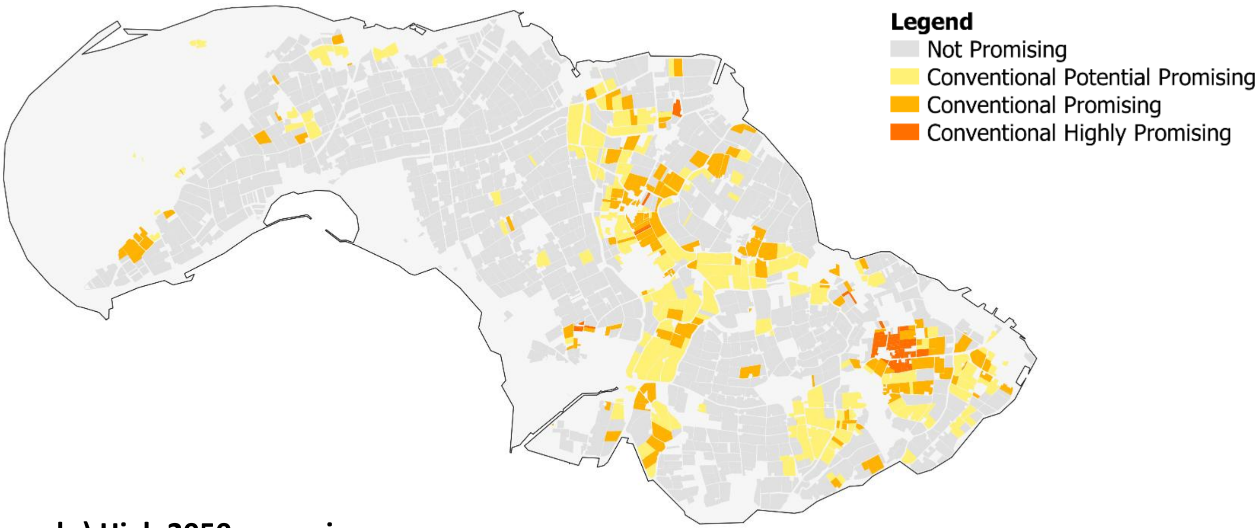
Figure 3.5: *The potential suitability of conventional agriculture, all three SRAS and the combination of all these three systems based on % land area.*

3.3.2 Conventional agriculture

Figure 3.6 illustrates the potential suitability for conventional agriculture based on the assumptions to be viable below 2 dS/m and with a sensitive to drought and waterlogging. Currently, suitable areas are primarily concentrated around the creek ridges, where the soil is fresher, and drainage is more effective. However, projections for 2050 indicate a significant decrease in suitability, from 25% land area to just 9%, due to the increase of the SDAW stressors.

Although conventional agriculture is still widely practiced across Schouwen-Duiveland today, this assessment identifies only the most promising areas, assuming no additional mitigation or adaptation measures are conducted.

a.) Current scenario



b.) High 2050 scenario

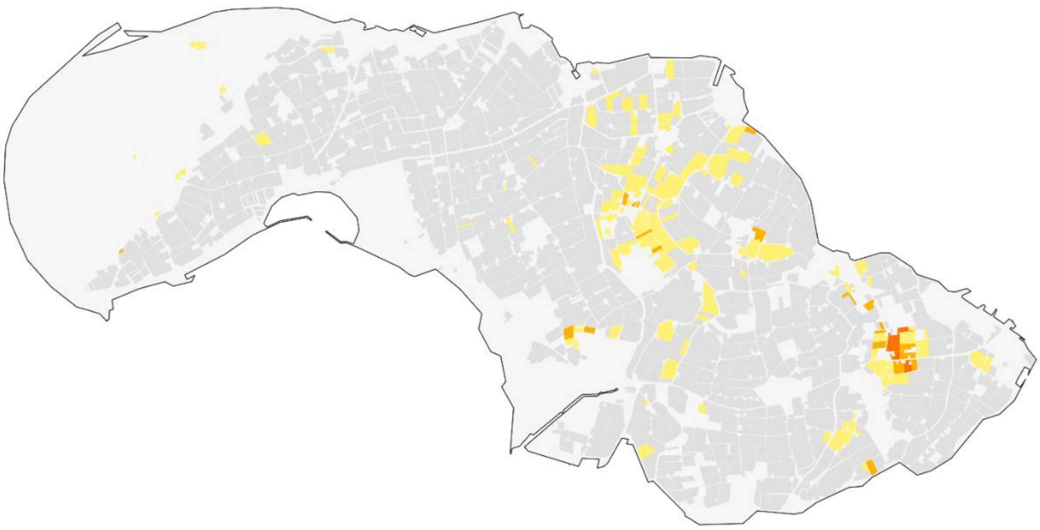


Figure 3.6: *The potential suitable locations of conventional agriculture for a.) current scenario and b.) future scenario.*

3.3.3 System 1: Salt-tolerant crop rotation

System 1, which is based on salt-tolerant potato and sugar beet crops, currently shows a coverage of 48% of at least potentially promising areas, which decreases to just 47% under future projections. As shown in Figure 3.7, there are no zones where only salt-tolerant potato is suitable, because the stressor thresholds for potato completely overlap with that of sugar beet. Therefore, the overlapping areas increase the confidence in these zones for system 1.

Notably, the creek ridge zones are not covered by this system, as these areas have a salinity level of below 2 dS/m. The suitability threshold is defined as areas with salinity levels above 2 dS/m, consistent with the approach used by Wen et al. (2023). Therefore, areas with salinity levels below 2 dS/m will be considered unsuitable for this system. Additionally, the clay region in the center of the island is not suitable, as the salt-tolerant crops were assigned not suitable for clay soils due to the negative interaction between salt and these soils. Both assumptions may underestimate the system's true potential if the salt concentrations are low.

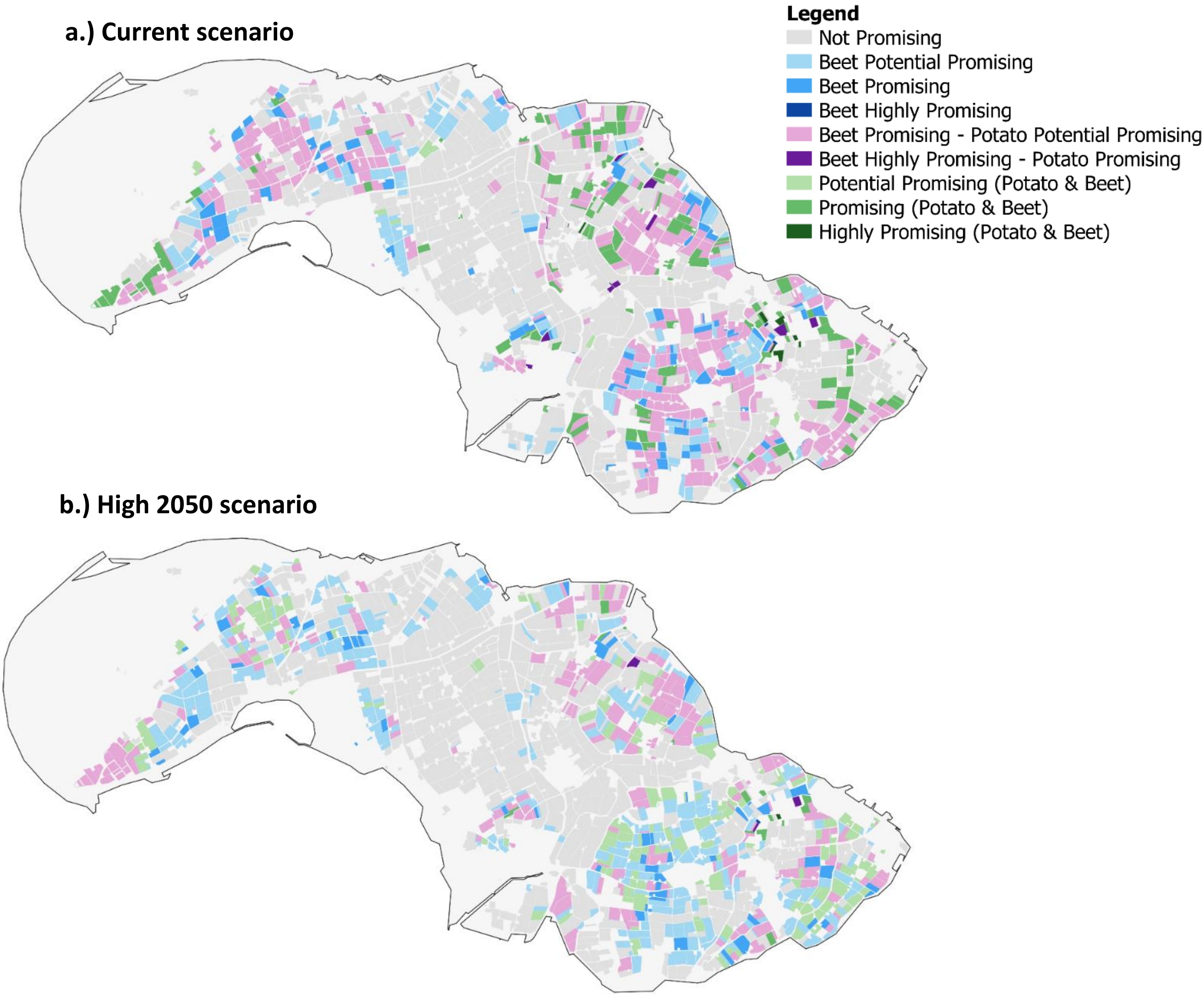


Figure 3.7: *The potential suitable locations for salt-tolerant crop rotation systems for a.) current scenario and b.) future scenario. If only one crop is shown in the legend, the other crop is not promising.*

3.3.4 System 2: Halophytic intercropping or rotation

System 2 includes intercropping with glasswort and rotating with quinoa and resulted in the most widespread suitability. Covering 73%, land area under current conditions and 65% in the future, as seen in Figure 3.8. This widespread potential is derived from the system's high spread in salinity threshold, and suitability for all soil types.

It should be noted that clay soils are more vulnerable to salt damage, but halophytes may offer additional benefits to restore soil health through phytoremediation. Furthermore, the systems offer the potential to use brackish water for irrigation (not suitable for clay soils), which could offer an extra possibility to mitigate drought stress. This advantage is not taken into account in this spatial assessment.

Although system 2 is currently assessed to perform well in the middle of the island on the clay and drought sensitive areas, in the futures scenario the suitability lowers in these regions. Moreover, the creek ridge areas are again excluded, because halophytes are assumed not suitable in fresh zones.

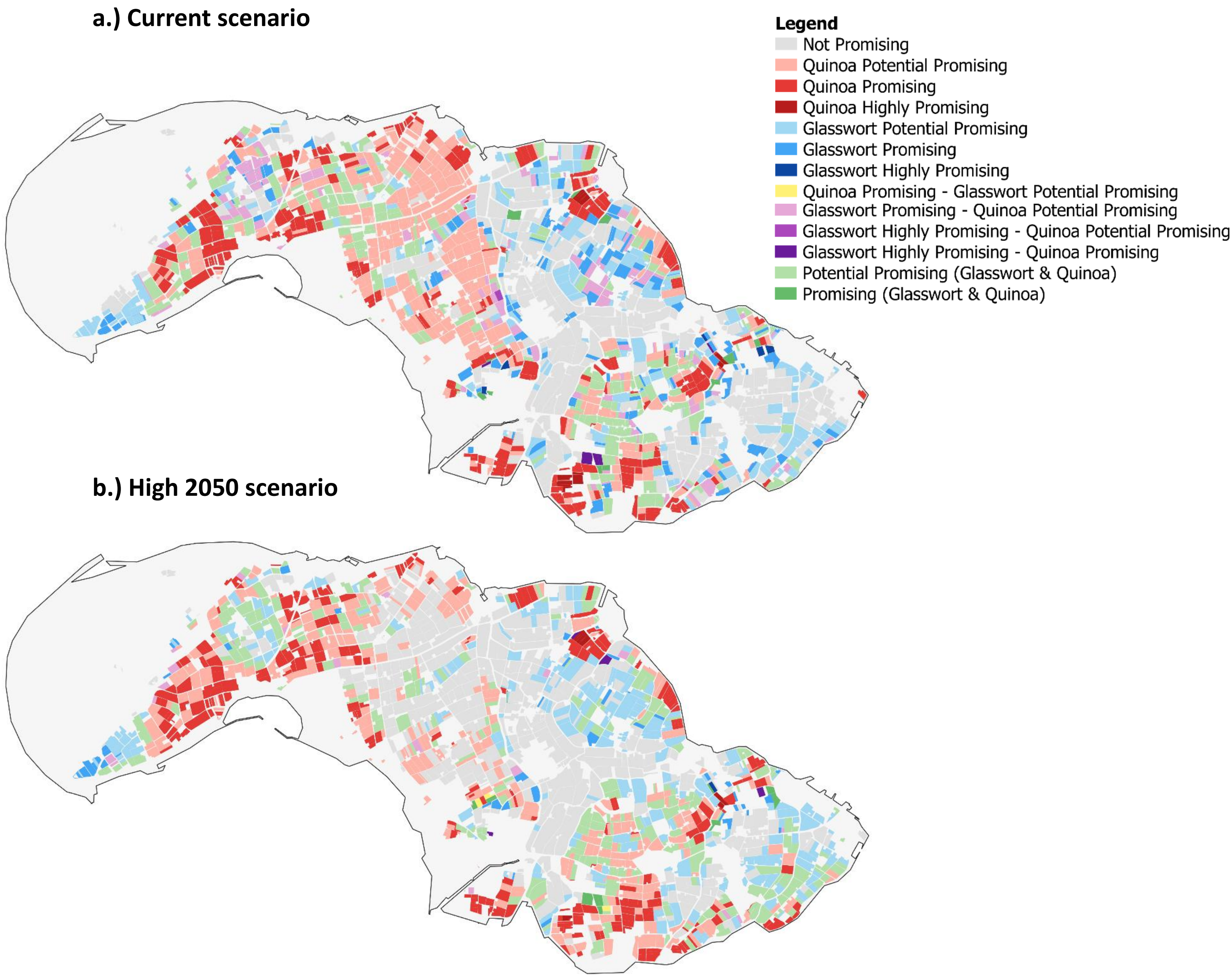


Figure 3.8: *The potential suitable locations for halophytic intercropping or rotation systems for a.) current scenario and b.) future scenario. If only one crop is shown in the legend, the other crop is not promising.*

3.3.5 System 3: Agroforestry

Agroforestry stands out as the most resilient and promising option to the SDAW stressors, particularly due to its tolerance to drought and waterlogging. This is under the assumption that the agroforestry system is properly designed.

Currently, 50% of the island is suitable for agroforestry and will decrease to 42% under future projections. This decline is most noticeable in the central clay region, seen in Figure 3.9, and can be explained by the increasing salinity in that area. Nevertheless, approximately 32% of the land area remains classified as promising or highly promising. This has the highest long-term potential of agroforestry.

Again, the creek ridges are not suitable, because these areas have a salinity level of below 2 dS/m and based on Wen et al. (2023) only areas above 2 dS/m are taken into account for agroforestry. However, excluding agroforestry from these areas may underestimate its potential, particularly given its tolerance to the drought and waterlogging stressors.

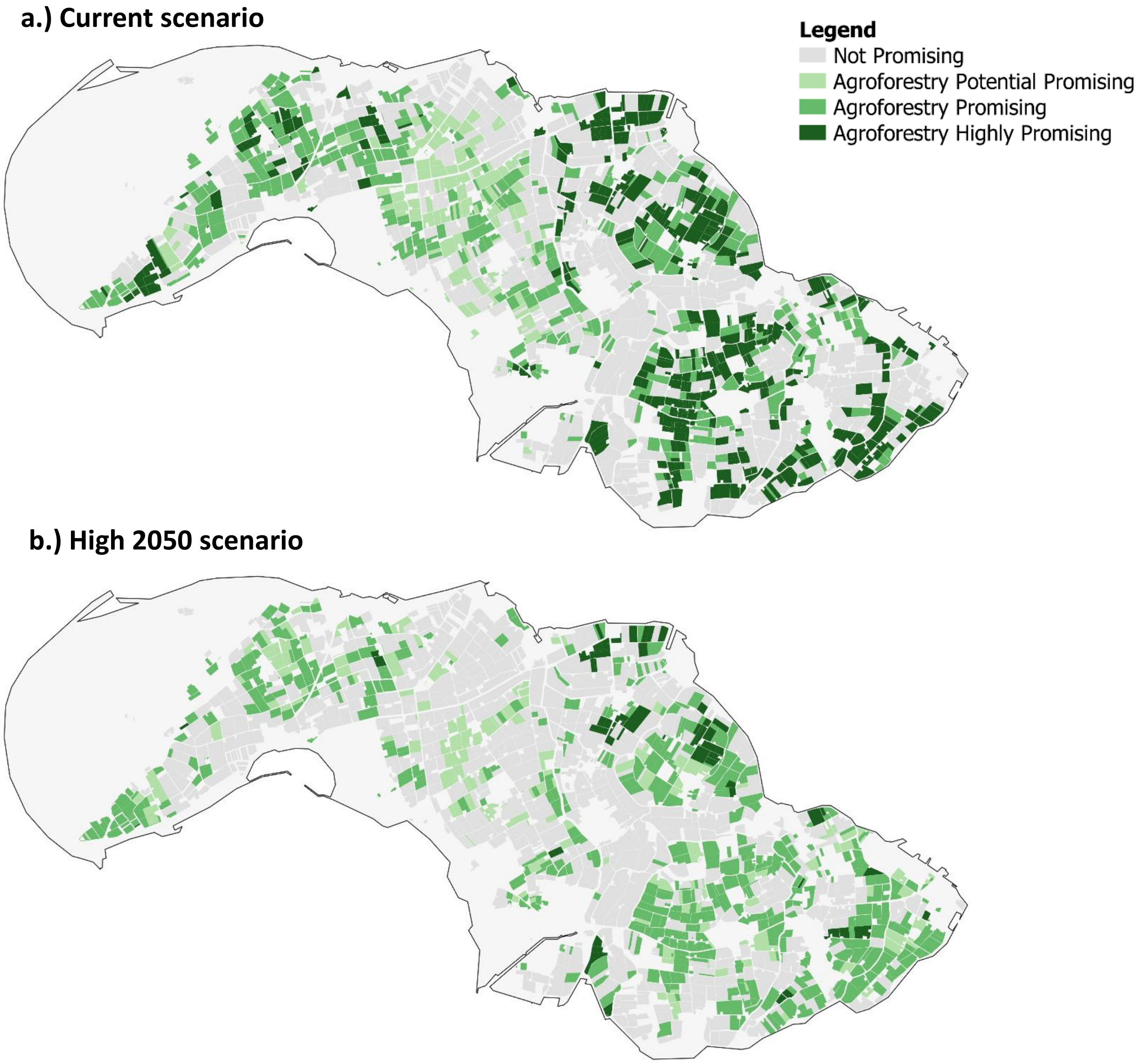


Figure 3.9: *The potential suitable locations for agroforestry systems for a.) current scenario and b.) future scenario.*

3.3.6 Integration of SRAS and conventional agriculture

The final integration of all systems provides a comprehensive overview of the agricultural potential across Schouwen-Duiveland based on the SRAS. As seen in Figure 3.11, conventional agriculture remains located around the creek ridges, but its suitability decreases in the future scenario due to the increasing stressors. In contrast, systems 2 and 3 offer promising alternatives for the central clay areas. The northern part of the island shows more highly potential zones in future projections, because the southern regions are more heavily affected by salinization.

An additional analysis was conducted to identify which SRAS contributes highest to the integration of the most suitable options (Figure 3.10). This shows that system 1 is best suitable for 10% in current situation and 12% in future, system 2 for 29% and 26%, and system 3 for 36% and 29% in the future. These findings suggest that halophytic intercropping and agroforestry offer the highest overall potential, now and into the future. The slight increase for system 1 may reflect the decrease of conventional agriculture.

The only major areas where none of the systems show strong suitability are the clay area in the middle with high drought and salinity stress and the creek ridges. For the creek ridges, the assumption that SRAS are not suitable for area's below 2 dS/m, results that these systems are not suitable for the creek ridges that experience freshening of the soils. The clay area in the middle is not suitable for the SRAS systems due to increased drought stress, which could be mitigated though additional sustainable water management.

This final suitability map in Figure 3.12 provides a clear visual summary of where agriculture can continue in the coming decades, and which system offers the best potential. Notably, even the most extreme future scenario shows that SRAS are for 45% land are classified as promising or highly promising, indicating the potential of SRAS for sustainable farming in the future.

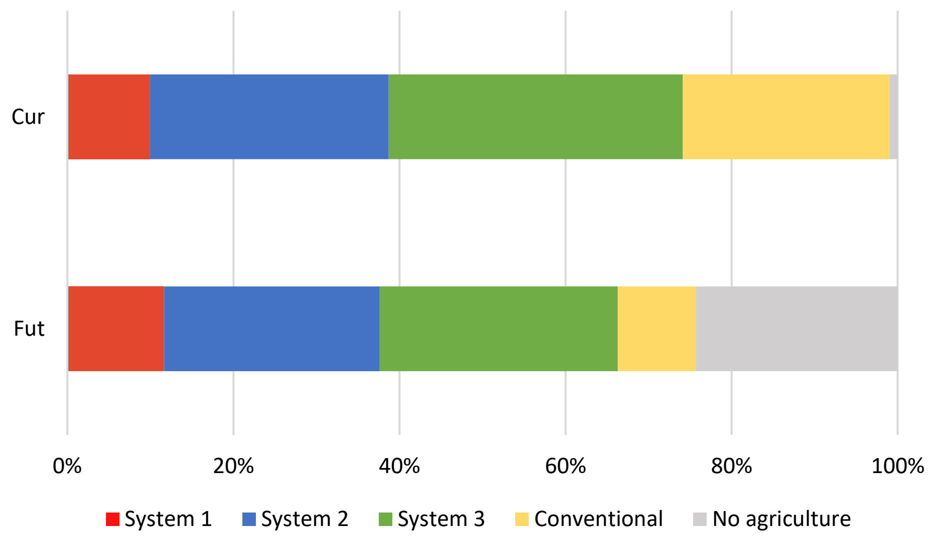


Figure 3.10: *Percentage of land area contributions to the spatial suitability map for all the systems combined. If multiple systems had the same suitability for an area, the area was equally divided for those systems.*

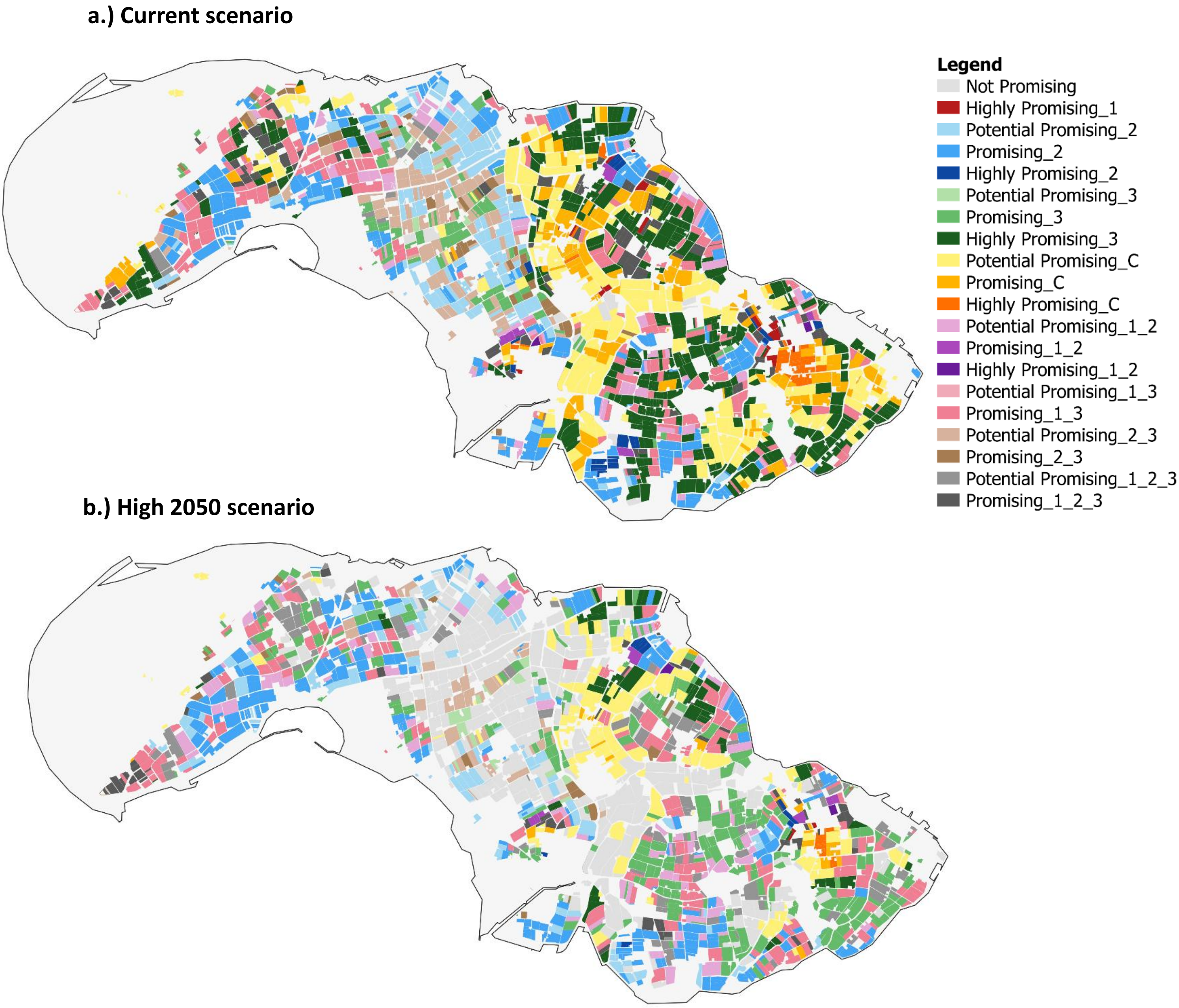
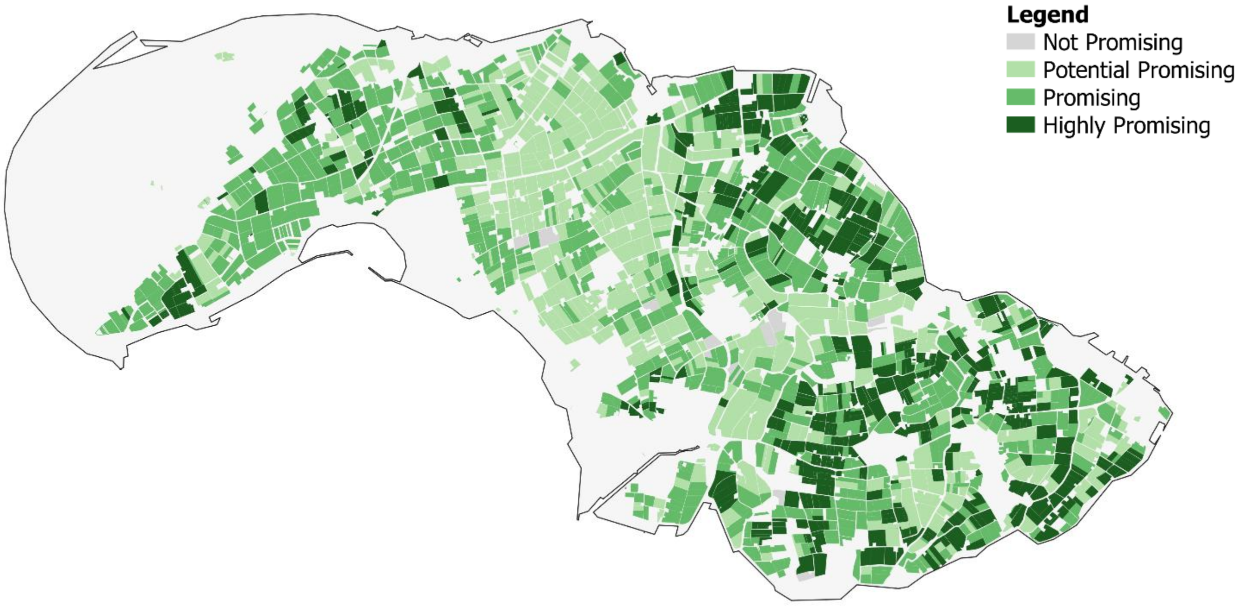


Figure 3.11: *The spatial suitability map for all systems combined for a.) current scenario and b.) future scenario.*

a.) Current scenario



b.) High 2050 scenario

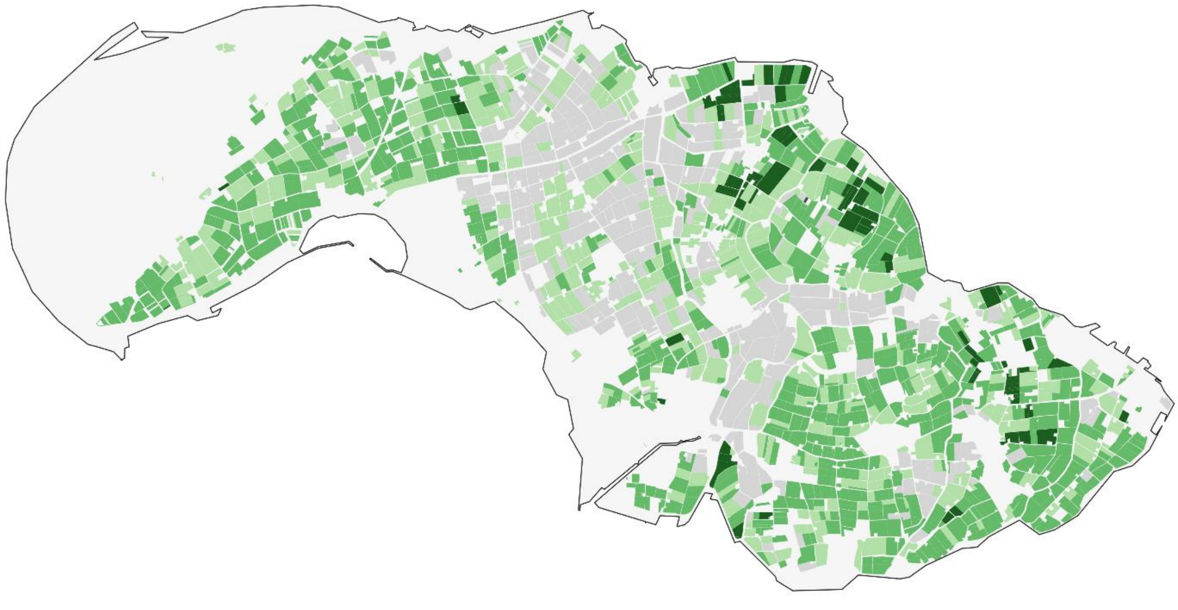


Figure 3.12: *The simplified version of the spatial suitability map of 3.11 for all systems combined for a) current scenario and b.) future scenario, which allows easier comparison for the categories of suitability.*

3.4 Overall result

The central research question of this study was:

"Which salt-resilient agricultural systems are potentially suitable for areas increasingly affected by salinization, drought, and waterlogging, and how can their spatial suitability be assessed and interpreted based on soil types and climate projections?"

This study addressed the main research question using a case study approach focused on Schouwen-Duiveland. At least three different SRAS options are identified as potentially suitable for Schouwen-Duiveland. However, not all systems show equal suitability. Among them, system 2 (halophytic intercropping or rotation) and system 3 (agroforestry) showed the largest suitable area under both the current situation and the future scenario. Overall, all three SRAS outperform conventional agriculture in terms of resilience to SDAW stressors both in the current situation and future scenario. This suggests that SRAS offer promising strategies for enhancing food security in vulnerable areas like Schouwen-Duiveland

The suitability of these systems was assessed spatially by combining their threshold values for SDAW stressors with both current and projected levels. Using a suitability framework, GIS-based suitability maps were generated. However, several key assumptions had to be made to enable this assessment.

The interpretation of these results and the final sub-question are discussed in the next chapter.

4. Discussion

This section begins by assessing the findings. Their validity and sensitivity are then analyzed. Following this, the final phase and sub-question of the study are discussed by highlighting the societal interpretation of the results and the resulting practical recommendations. The section concludes with a scientific interpretation of the findings and suggestions for future research.

4.1 Key findings

1.) SRAS show greater suitability than conventional agriculture

The spatial analysis indicates that all three SRAS options outperform conventional agriculture in areas already affected by SDAW stressors and even more under the future projections if these stressors increase. This suggests that in regions currently experiencing high levels of salinity along with certain amounts of drought or waterlogging, it could already be promising to focus on SRAS to enhance food security. These findings algin with existing literature, which highlights the potentials of these systems (Dagar, 2014; Flowers, 2008; Mathur & Mathur, 2024; Mukhopadhyay et al., 2021; Wen et al., 2023). However, it should be noted that in this study assumes that these systems show optimal performance to the stressors, which may not always reflect real-world conditions.

2.) No universal SRAS solution

Another key insight is that there is no SRAS best suited for all conditions. Suitability dependents on site-specific factors and each system have different tolerance thresholds. For instance, halophytic systems have the highest tolerance to salinity, while the agroforestry systems show greater resilience to drought and waterlogging. There are other possible SRAS options with varying tolerance values, however these were excluded from this study due to the scope (Singh, 2015). It should also be noted that that if additional mitigation measures are taken the tolerance thresholds of these systems may change, potentially altering their spatial suitability.

3.) The importance of location-specific guidelines

Shahid et al. (2018) emphasized the need for location specific agricultural guidelines due to variability of local stressors. This study applied a local, agricultural field level approach, which revealed that site-specific differences can significantly influence SRAS suitability outcomes. Developing tailored guidelines at this scale helps farmers identify the most appropriate SRAS options for their specific field conditions.

4.) Addressing drought stress is critical

The spatial suitability analysis reveals that in regions projected to face severe droughts, SRAS alone will not be sufficient without complementary water management strategies. This supports findings by Wen et al. (2022), who used remote sensing to show that drought stress has a higher impact than salinity stress for farmers. While SRAS inherently offer resilience, sustainable water management remains critical for creating a climate-resilient agricultural system.

5.) Knowledge gaps remain, limiting the reliability of the suitability maps

This study encountered limitations due to data gaps, particularly concerning the thresholds values of the systems. These gaps are partly the results of the complexity of SRAS, which had to be simplified for the purpose of this study. As a result, the spatial suitability analysis could only be partly conducted with the current publicly available data, and necessary assumptions had to be made. It is likely that more practical knowledge of these systems exists but is not publicly assessable. Therefore, this study emphasizes the importance of knowledge sharing. While the assumptions were supported by logical reasoning, the lack of comprehensive data prevents the development of fully practical and reliable guidelines. This highlights the need for practical and accessible data on the SRAS.

4.2 Validity, sensitivity & Limitations

To assess the robustness of the results, multiple sensitivity and validity checks were conducted.

4.2.1. Validity of the results

The results shown in Figure 4.1 indicate that, under current conditions, only 25% of the land is considered suitable for conventional agriculture. However, in practice, agriculture cultivation occurs in nearly all of these fields, suggesting that the model likely underestimates the actual stability of conventional agriculture. This can be partly explained by the models focusing on only the most promising areas, assuming no additional mitigation or adaptation measures applied. It is possible that the areas that are deemed unsuitable are, in reality, using such measures or are coping with reduced yields (*KWR, 2023*). Another possible explanation is that the applied threshold value of 2 dS/m for salinity tolerance based on Wen et al. (2023) is too strict for the situation on Schouwen-Duiveland and may underestimates the total suitable area. This highlights the importance of using locally validated threshold values in spatial assessments. While the key finding that SRAS outperforms conventional agriculture is still supported by literature on which it is based, the extent of this might be overestimated.

To further investigate this issue, a validity analysis was conducted by comparing the current cultivation of potatoes and sugar beet with the modelled suitability for both conventional agriculture and SRAS 1. Figure 4.1 presents soil types together with black outlined fields, representing fields currently used for potato and sugar beet cultivation but were assessed as too saline and therefore classified as unsuitable in the suitability analysis. Some of these outlined fields are located on blue clay fields that were excluded from SRAS 1 based on the statement that salt-tolerant crops should not be grown on clay soils due to the adverse effects of salinity on the soil. However, this assumption may be too strict, as clay soils with low salinity levels might still support salt-tolerant crops without causing long-term soil degradation. The remaining black outlined fields fall within areas considered too saline for cultivation based on the model, yet they are currently used for growing potatoes or sugar beet. This again emphasizes the need for refining suitability criteria based on local conditions and crop-specific tolerances.

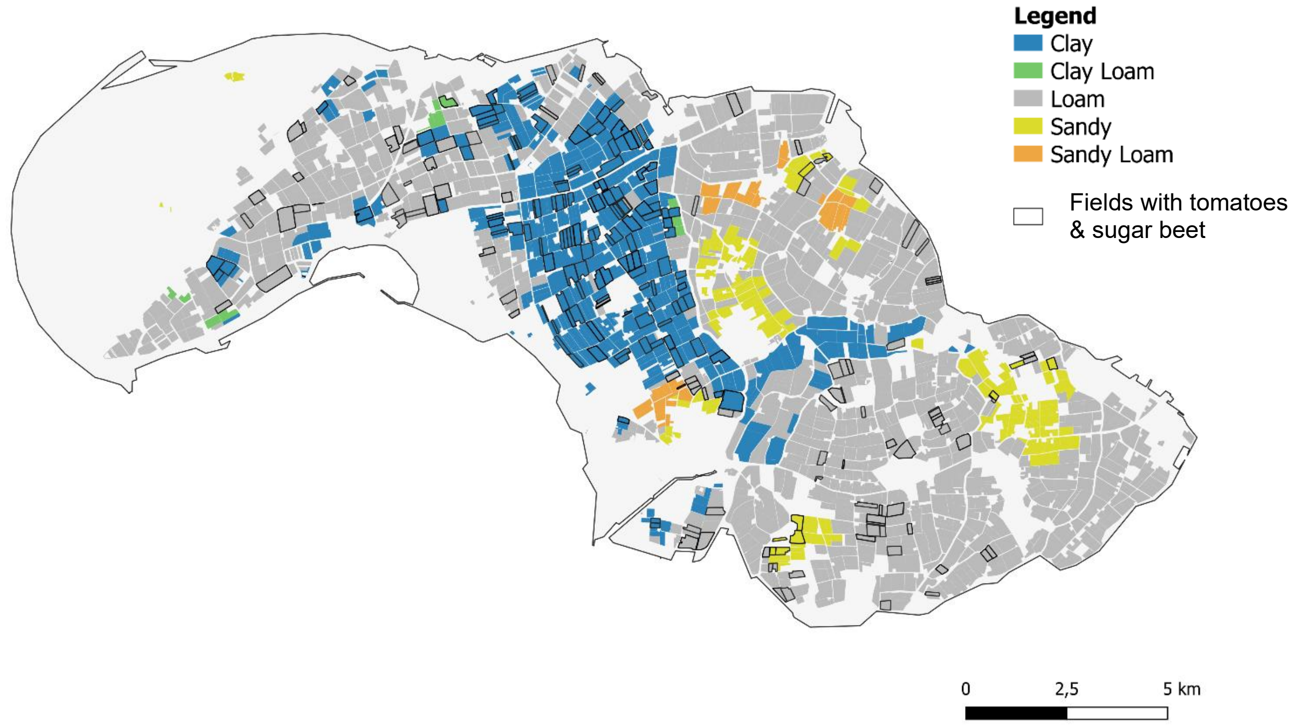


Figure 4.1*: The soil type distribution map in combination with agricultural fields of potatoes and sugar beet that are currently cultivated on fields which are seen as unsuitable for these crops based on the high salinity levels.*

4.2.2. Sensitivity of the model

A. Drought and waterlogging stressors

The tolerance for drought and waterlogging depends on many complex variables. Assigning a single standardized factor for tolerance is therefore challenging. Still to account for the tolerance of drought and waterlogging, a factor of 1.25 or 0.75 was applied in this study. A sensitivity analysis was performed to test the impact of the drought and waterlogging stressors on the outcome. This was done by excluding the drought and waterlogging stressors from the model, leaving only the criteria of salinity and soil type. The results showed significant changes in the spatial distribution of suitable areas (see Figures 4.2 and 4.3), leading to two insights:

1. **Accurate stressor values are critical:** Drought and waterlogging stressors significantly affect spatial suitability. Future studies should aim to obtain data for drought and waterlogging tolerance based on empirical crop-specific data rather than assumptions derived from grass yield losses.
2. **Mitigation drought and waterlogging could increase potential of SRAS**: If additional mitigation or adaptation methods are implemented together with SRAS, the total suitable area may be even larger than resulted from this study.

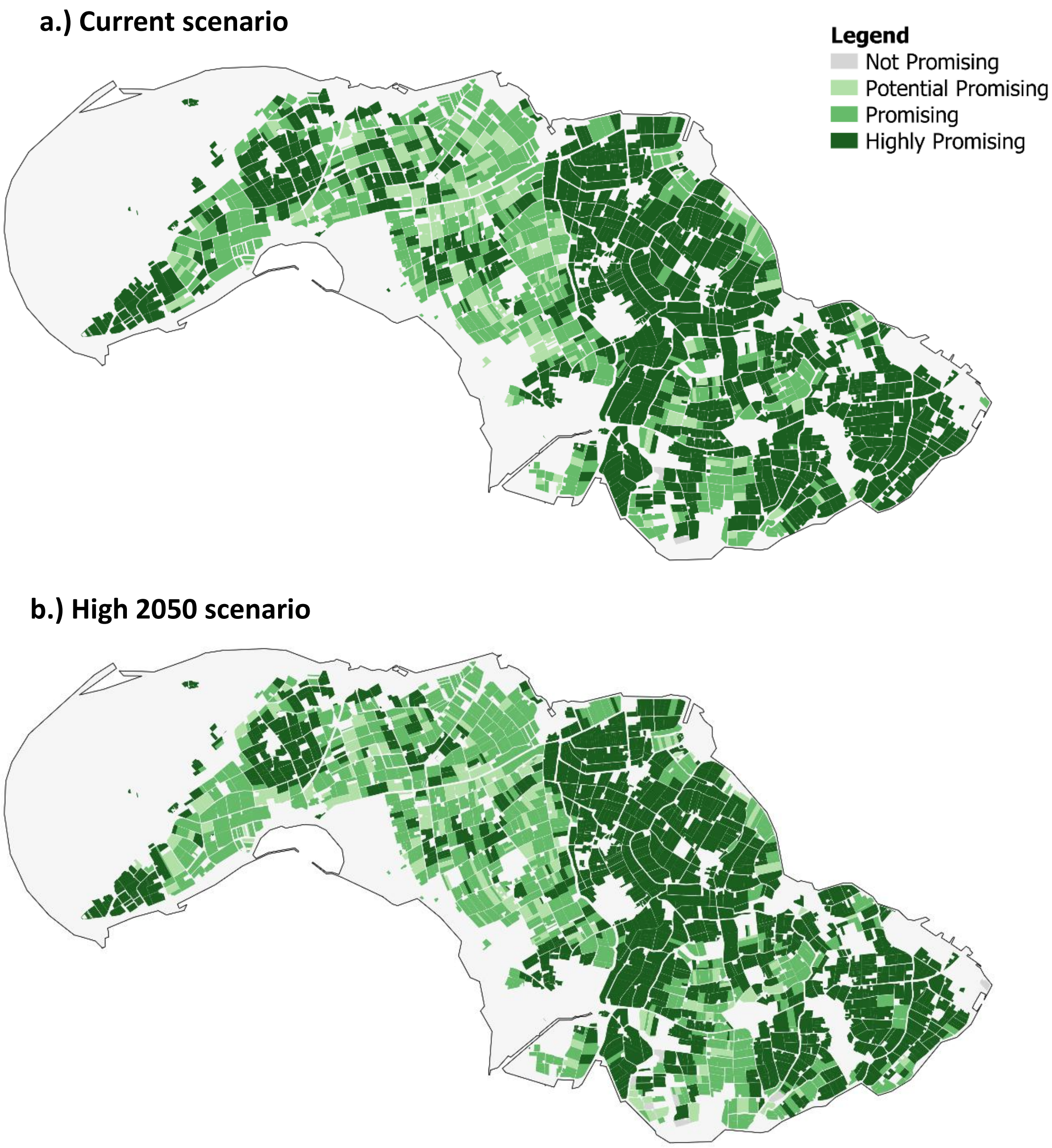


***Figure 4.2**: The simplified version of the spatial suitability map for all systems combined for a.) current scenario and b.) future scenario, without accounting for the drought and waterlogging stressors.*

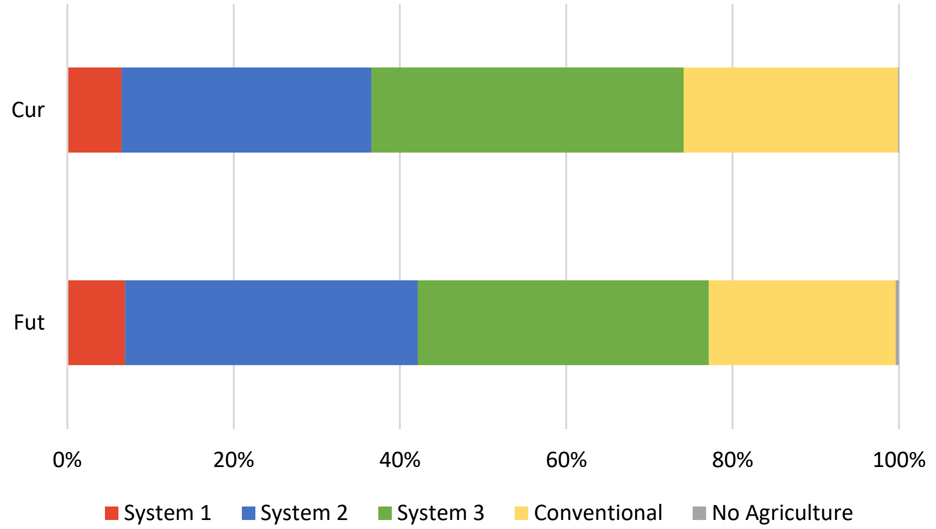


***Figure 4.3**: Percentage of land area contributions to the spatial suitability map for all the systems combined without accounting for the drought and waterlogging stressors. If multiple systems had the same suitability for an area, the area was equally divided for those systems.*

B. Conversion factors

Conversion factors for the spatial salinity data and from salt tolerance threshold needed to be converted to mg Cl^-/L, based on assumptions. A sensitivity test was conducted in Excel using different calculation methods based on multiple sources to see how much the outcomes varied.

For converting salinity threshold values from EC to Cl^-/L, two sources were used. EC is not only influenced by chloride, which results is no general formula that can be used. In total five different methods were used to convert EC to Cl^-/L (Supplementary Material - Excel: Calculations: 'EC to Cl L-1'). The conversions differed significantly, thus the decision which formula was used has a noticeable impact on the results. The CFC formula by Van Dam et al. (2007) was chosen because it estimates chloride concentrations in soil moisture at field capacity, which is likely the basis in most tolerance studies.

For the salt load conversion from NaCl kg/hec/year, it was assumed that only rainfall and evaporation influence surface water on Schouwen-Duiveland. Median values were used. An alternative method used by Daan Heeling (2024), based on total ground- and surface water use in agriculture, was tested for comparison. This showed significant differences. However, because Schouwen-Duiveland mainly relies on rainfall as fresh water source, the first approach was deemed suitable.

Both sensitivity analysis revealed significant differences in the results, highlighting the sensitivity of this analysis.

4.2.3 Limitations of the model

This study faced several limitations arising from data availability and necessary simplification for the model. These limitations include that the framework uses only four criteria to assess suitability of SRAS, while actually it depends on many interacting environmental, technical, and socio-economic factors. Furthermore, missing data resulted into multiple assumptions (Appenidx D), which should be validated and researched for future studies. One of these assumptions include that the SRAS were assessed based on two different model species, which may not fully reflect the diversity or adaptability of the actual systems in practice. Additionally, the study assumed that salinity levels below 2 dS/m were not suitable for the SRAS because conventional agriculture can then be adopted. However, this may have overlooked areas where SRAS could be beneficial even at lower salinity levels. This could have resulted in an underestimation of the total suitable area for the SRAS.

A limitation arose from the spatial resolution of the soil map provided by (Wageningen Environmental Research (WENR)). As this map had a lower spatial resolution (1:50.000) than the SDAW stressors from Climate Impact Atlas (1:250). As shown in Figure 4.4 agricultural fields often contain mixed soil types. For this study, the majority soil type per agricultural field was used, but this reduced spatial accuracy.

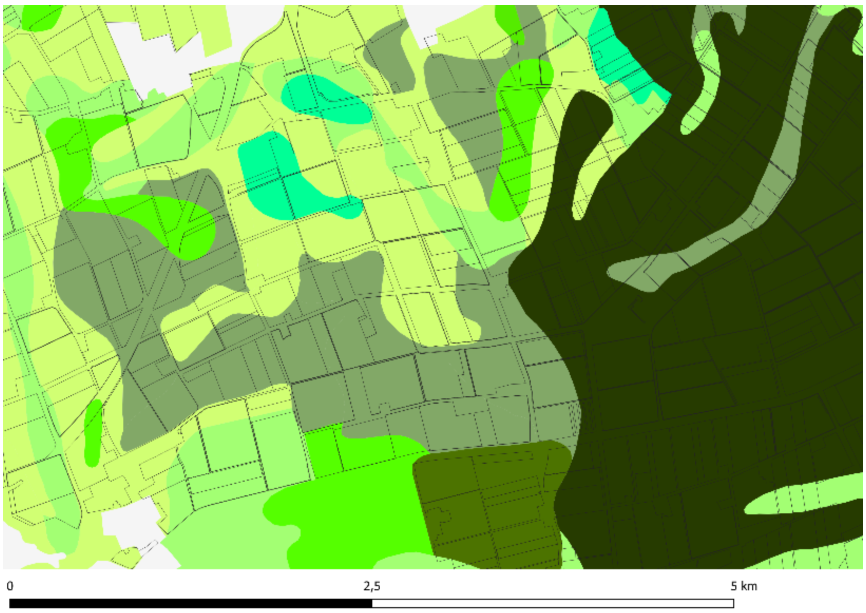


Figure 4.4: *Shows agricultural fields on top of the soil map provided by Wageningen Environmental Research and shows the low spatial resolution of this map.*

4.3 Societal interpretations of the results

This study presented the spatial suitability results for three different SRAS options. But what do these results mean for a broader transition to SRAS? To explore this, the final sub-question is addressed:

What are the societal interpretations of the spatial suitability guidelines for local farmers and policymakers, and what are the main bottlenecks for SRAS transition?

The interpretations of the key findings are assessed from the perspectives of local farmers, policymakers and additional aspects for society, and consumers. Practical recommendations are provided for local farmers and policymakers for the transition toward SRAS. In addition, the main challenges and areas of focus are identified, along with key knowledge gaps (see Table 4.1). These factors correspond to the key aspects illustrated in Figure 1.1. Finally, a conclusion is presented how to move from spatial suitability guidelines to a social transition.

4.3.1 Local farmer

Interpretation key findings

The key findings suggest that for local farmers already coping with yield losses and the negative impacts of SDAW stressors, transitioning to SRAS could be a beneficial strategy. To do so effectively, farmers should assess which SRAS options are feasible for their specific location and, where possible, measure local SDAW stressors to obtain accurate, site-specific data. Besides looking at SRAS, investing in sustainable water management is essential to be able to cope with prolonged periods of drought. Although remaining knowledge gaps introduce uncertainty, small-scale low-risk steps can help farmers begin the transition and gradually build practical knowledge.

Consequences transition

Farmers are the core of the transition (Negacz et al., 2021). Shifting towards SRAS involves more than just changing crops. It requires adapting cultivation techniques, land and water management, machinery, and long-term planning. This transition is not a simple step change and incorporates risks. To overcome this risk, support is needed both economically and in terms of knowledge to enable a feasible transition for farmers.

Another key factor is the willingness of farmers to transition. Many have practiced the same techniques for generations, which are deeply rooted in traditions. Shifting to a new system requires time, energy, investment, new skills, and a change in mindset and identity (van Sommeren, 2019). Therefore, this process should be seen as a gradual transition rather than an immediate change. It is important to note that not all SRAS involve the same scale of change, especially for farms that are already applying similar cropping strategies.

Practical recommendations

1.) Start with small-scale, practice-based learning

To help close existing knowledge gaps, practice-based learning through small-scale field trials is essential (Kaandorp et al., 2021). Although fully standardized protocols for SRAS are not yet established, many system components, including salt-tolerant crops, halophytes, and tree cultivation, are already practiced even on Schouwen-Duiveland. This allows small step practical experimental.

Examples of small-scale recommendations include:

- **Salt-tolerant crop rotations:** Test salt-tolerant beet or potato on the most stress-prone area of the agricultural field and compare the yield data to conventional crops.
- **Halophytic intercropping:** In areas where glasswort is already cultivated, establish a test field by intercropping lettuce, tomatoes, or Swiss chard between two rows of glasswort and measure the salinity levels and crop productivity (Acharya et al., 2024; Cammerino et al., 2025; Simpson et al., 2018).

- **Halophytic rotation:** Rotate fields currently cultivated with glasswort with other crops in the same year or over a two-year time period and assess the impact on soil salinity and crop productivity.
- **Agroforestry adaptation:** Where trees are already cultivated, plant crops between two rows of trees. If spacing is limited, remove one row of trees to create space for the crops (Fuchs et al., 2021).
  Windbreak introduction: Windbreaks can be introduced to protect crops from strong winds (Fuchs et al., 2021).

2.) Engage in knowledge sharing

Sharing knowledge and experiences is essential for enlarging the knowledge of SRAS and increases the transition readiness. Collaboration organs such as the Living Lab on Schouwen-Duiveland promote sustainable development by encouraging collaboration between farmers, researchers, and policymakers (Living Lab Schouwen Duiveland, n.d.).

3.) Focus on sustainable water management

Even with SRAS prolonged periods of drought need to be mitigated by sustainable water management. Especially in areas like Schouwen-Duiveland, which are dependent on rainwater, it is important that farmers have a sustainable water management strategy. A spatial suitability analysis for sustainable water management was conducted Schouwen-Duiveland, which can be used as guidelines for decision making (Kaandorp et al., 2021).

4.3.2 Policymakers

Interpretation key findings

The findings of this study highlight the growing challenges for conventional agriculture in areas affected by SDAW stressors and howe these threaten long-term food security. Therefore, policymakers have a critical role in supporting farmers in the transition towards multiple different SRAS. Policymakers should prioritize filling knowledge gaps, supporting sustainable water management, assessing the economic feasibility of SRAS, and facilitating development of new markets.

Tools and recommendations

The primary responsibilities of policymakers are to ensure food security, achieve environmental goals and support local farmers in sustainable transitions. The shift to SRAS cannot be achieved without policy support. Policymakers can help reduce risks for farmers through three key mechanisms:

1.) Share risks through funding and enable policy support

Farmers need risk-sharing mechanisms to initiate the transition. These include subsidies, insurance schemes, and flexible regulations. Policy support should not focus on a single SRAS approach, but instead cover a wide range of options, since the suitability of each system varies locally.

Currently, policy-related barriers remain a significant issue in the Netherlands. Yield losses are not compensated when farmers change crop species, which poses economic risk for implementing crop changes (Stowa, n.d.). Additionally, agroforestry is currently not recognized as an official agricultural system in the Netherlands, which creates financial risks for its implementation (*CRA, 2020*). It is therefore recommended to remove policies that act as a barrier.

Despite these challenges, there are signs of progress. The European Union does recognizes agroforestry as a valid agricultural system, creating opportunities for support (*CRA, 2020*). While halophytes are not explicitly mentioned in EU frameworks, there are still policies that support their use (Bazihizina et al., 2024). Vellinga et al. (2025) have proposed to acknowledge saline agriculture as an agricultural system to simplify targeted funding and policy support, while also encouraging pilot projects through fundings.

At this moment, the Common Agricultural Policy (CAP) funds can be used for SRAS transitions. (*CAP 2023-27 - European Commission*, 2025). A recommendation is to create additional, dedicated funding streams specifically for SRAS, and to actively encourage their use.

2.) Support knowledge acquisition and market development

Policy support should also focus on building knowledge. This includes enabling the development of the spatial suitability guidelines, which will serve as practical tools for both long-term planning and short-term decision-making.

A key priority should be supporting economic cost-benefit analysis. In addition, developing markets for new crops is an important factor, as economic feasibility remains a limiting factor for the adoption of certain SRAS options (Winkel et al., 2021).

3.) Collaborating with stakeholders

SRAS have the potential to outperform conventional agriculture in the long term. However, current evidence is incomplete. Therefore, collaboration between policymakers and stakeholders is necessary to be able to create tailored policies based on the needs of the stakeholders. Living labs offer a valuable tool in this process by bringing different stakeholders together. This helps to accelerate the transition and has already contributed to transitions in water management in Schouwen-Duiveland (Living Lab Schouwen Duiveland, n.d.).

4.3.3 Society

The transition to SRAS impacts not only farmers and policymakers but society as a whole. It is essential to provide equal opportunities for all farmers that are willing to transition towards SRAS. Large scale farms often have greater financial flexibility and can tolerate risks more easily than smaller farms. Furthermore, farms located in regions with severe SDAW stressors face greater urgency and have fewer viable options. To ensure a fair transition, targeted and location-specific support must be made available to all types of farms (ActionAid, 2020).

4.3.4 Consumers

If the agricultural system transitions towards SRAS, consumers will experience changes as well. This may include the appearance of new products on the market or changes in taste and quality of conventional crops. For example, tomatoes grown in saline conditions can become sweeter (Blom, 2017). Consumer acceptance is essential for making SRAS viable. Without a market for alternative crops, the transition becomes economically unfeasible (Winkel et al., 2021). Therefore, raising awareness about the benefits of local, climate-resilient, and sustainable produce is essential to increase the acceptance of these products.

In addition, SRAS may bring visible changes to the landscape. Agroforestry and halophytic crops transform the rural environments, potentially affecting how people value these landscapes (CRA, 2020; KWR, 2023; Fuchs et al., 2021).

4.3.5 Conclusions societal interpretations

To conclude: *What are the societal interpretations of the spatial suitability guidelines for local farmers and policymakers, and what are the main bottlenecks for SRAS transition?*

The spatial suitability analysis can serve as a starting point for initiating social dialogue for the SRAS transition, of which the key implications are shown in Table 4.1. A key limiting factor is the current readiness of the transition. This readiness can be increased by identifying the key knowledgebase and initiating practice-based small-step innovation by farmers which need to be supported by policymakers. In addition, collaboration is required between different stakeholders and active knowledge sharing is essential.

This study provides a foundation for integrating spatial insights with social strategies. Although specific outcomes will vary between locations, due to differences in local policies, subsidies, and stakeholder networks, the key enabling factors remain consistent across regions.

Table 4.1: *The societal interpretation of the key findings for farmers, policymakers, society, and consumers. Additionally, the main areas of focus or change are identified for each stakeholder group. The final column presents the key knowledge gaps derived from the findings. The focus areas and knowledge gaps correspond to the key aspects from the three perspectives shown in Figure 1.1.*

Key findings	Farmers	Policymakers	Society	Consumer	Key knowledge gaps
1.SRAS show greater suitability than conventional agriculture	-Transition towards SRAS	-Support transition in SDAW sensitive areas	-Equal possibilities for farmers	- Accept possible new or products	- Cost-benefit analysis
2.No universal SRAS solution	-Choose the best suited or preferred system	-Support multiple alternatives	-Equal possibilities for different systems	- Accept possible landscape changes	- Specific practical details of the systems
3.Location specific guidelines needed	-Measure local SDAW values	-Invest in spatial planning to create location specific guidelines	X	X	- Expand the spatial suitability framework
4.Sustainable water management needed	-Invest in sustainable water management	-Support regional sustainable water management, especially in areas prone to drought	-Equal fresh water accessibility	X	- Incorporate water management in the assessment
5.Knowledge gaps remain	-Small scale practice-based learning -Active knowledge sharing	-Support knowledge gathering and sharing (e.g. fieldlabs) -Share risk through subsidies	X	X	- Analyze long term effects on the environment, biodiversity and soil health
Main focus or change	-Willingness to change -Practice based learning -Knowledge sharing	- Ensure food security - Support transition by legislation - Share risk through subsiding - Support market creation - Support education and knowledge sharing	- Equal possibilities needed	- Accept new market	- Assess the readiness of the transition

4.4 Scientific interpretation of the results

This study contributes to the scientific understanding of SRAS by being among the first to adopt an interdisciplinary approach that emphasizes the practical applicability of spatial suitability. It integrates multiple environmental stressors and compares several SRAS at the local scale. Although the maps are not yet robust enough for direct application at the farm level, they provide a valuable foundation for developing site-specific SRAS transition.

The maps confirm earlier findings that highlight the importance of local guidelines, as stressors show local variability (Shahid et al., 2018). Drought stress, in particular, was identified as a key limiting factor for SRAS, supporting the importance of water management to mitigate its impact (Wen et al., 2022). This underscores the need to account for both water management and local variability in spatial suitability assessments.

The study adds information by demonstrating the importance of combining different SRAS and concludes that no single system is universally optimal. Comparing multiple SRAS adds value by offering a wider range of options to both farmers and policymakers. Furthermore, the results show that all three SDAW stressors must be considered simultaneously to ensure resilient future-proof planning.

In addition to technical considerations, the study emphasizes that societal change is equally important. Social factors should not be overlooked, because farmers are at the core of the transition. This stresses the need for practical local guidelines that can be used for decision-making by both policymakers and farmers.

The methodology can be adapted to other regions affected by SDAW stressors, though it requires further development and careful SRAS selection based on local climate conditions. In addition, several knowledge gaps remain of which suggestions for future research are provided below.

4.4.1 Future research suggestions

Future research should expand the scope of the methodology to increase the validity of the results by including water management, and other biophysical aspects such as soil management.

To increase robustness, local threshold values and stressor levels should be based on field experiments. Small-scale trials are essential to provide trustworthy, location-specific data. Further research is also needed to identify appropriate crop rotation and intercropping schemes, and development of agroforestry models. Moreover, optimization for soil- and water management in combination with fertilizer use and new cultivation techniques are needed (Blom, 2017; Negacz et al., 2021). This insight should be translated into concreate guidelines for implementing SRAS.

Beyond technical and environmental aspects, futures research should also address the long-term impacts on the environment and biodiversity to ensure a truly sustainable transition. From a societal perspective, a priority should be given to cos-benefit analyses, including investment requirements, risk assessment and market potential because economic feasibility is a major concern (Wit et al., 2021).

5. Conclusion

This study provides an important first step in exploring the suitability of SRAS by spatially mapping their suitability on Schouwen-Duiveland. It highlights promising systems including salt-tolerant crop rotation, halophytic intercropping or rotation, and agroforestry to cope with SDAW stressors. Due to existing knowledge gaps, several assumptions were required, which affects the robustness of the outcomes. As such, this study should be viewed as an exploratory assessment of potential location and applications, rather than tailored guidelines that can be directly implemented.

Nevertheless, the finding highlights the potential of these systems and underscores the need for location-specific guidelines, given the local variability of stressors. The importance of sustainable water management is also emphasized. Spatial guidelines are highlighted to be a tool that initiate social dialogue around SRAS transition. These guidelines can serve as practical resources for policymakers and farmers. Achieving a full transition requires collaboration, shared risks, and gradual step by step changes. Small-scale field experiments and active knowledge exchange will be essential to gain further insight to improve the spatial suitability assessment.

In summary, the main research question is only partly answered, primarily due to limited publicly available data needed to develop robust, location-specific suitability guidelines for SRAS. Nevertheless, this study identifies promising SRAS opportunities and emphasizes the importance of collaboration, knowledge sharing, and practical knowledge acquiring. In doing so, it lays the foundation for a practical tool to assess local suitability for SRAS, helping to initiate informed discussion around SRAS transition. Ultimately, this contributes to the development of climate-resilient agricultural that supports long-term food security.

6. Supplementary materials

All calculations performed for the suitability assessment, as well as the stressor values for each agricultural field, are included in the supplementary Excel file *"Calculations.xlsx"*.

7. References

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Appendix A: Additional theoretical information

A.1 Soil type and salinity

Soils consist of inorganic and organic components. The inorganic part is classified based on the percentage of clay, silt and sand (Figure A.1). Clay particles have a diameter of less than 0.002 mm, silt particles range from 0.002 to 0.05 mm, and sand particles measure between 0.05 and 2 mm (Soil Texture, 2016). The size of these soil particles influences the drainage and the capillary rise.

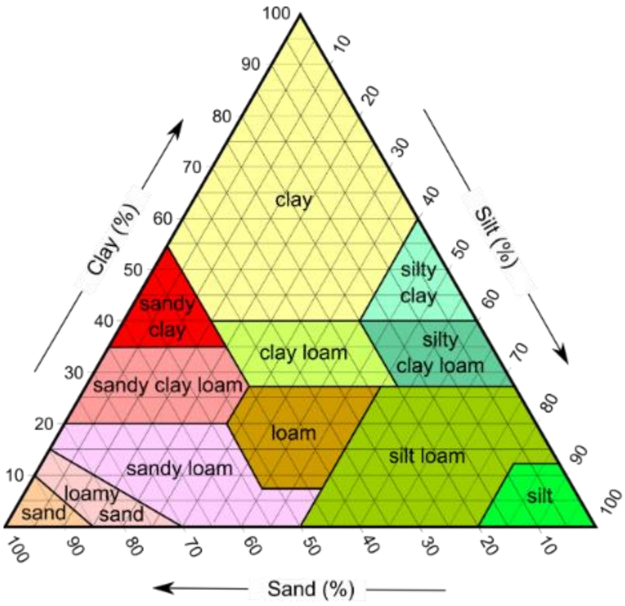

Figure A.1: *Soil classification based on percentage of clay, silt and sand* (*Soil Texture*, 2016).

Sandy soils have better drainage due to their larger pores, which reduces the chance for waterlogging. Moreover, they are less prone to salinization, as accumulated salts are leached away by rainwater. Nevertheless, due to the high permeability, sandy soils are more susceptible to drought (*SalFar*, n.d.). In contrast, clay soils have much smaller pores, reducing the drainage capacity. This increases the risk of waterlogging but decreases the risk of drought, as moisture is retained more effectively. However, this also means that salt remains in the root zone longer, increasing the risk of salinization. Additionally, clay soils have stronger capillary forces, allowing water from deeper, potentially saline layers to rise (*SalFar*, n.d.).

While soil composition plays a key role in salinization, accumulated salts can also impact soil structure. In particular, salts can permanently degrade the soil structure of clay and loam soils. This occurs because clay soils consist of negatively charged clay colloids, which are bound together with double positively charged elements such as Mg^{2+} and Ca^{2+} (*SalFar*, n.d.). Since these elements have a double positive charge, they can bind two negatively charged colloids together, forming aggregates that create a stable soil structure with well-developed pores. However, in saline soil, Na^{+} is more prevalent and replaces Mg^{2+} and Ca^{2+}, breaking the aggregates apart (Figure A.2). This results into a denser soil structure with fewer pores, reducing water infiltrating and degrading soil quality (*SalFar*, n.d.). In general, this effect occurs only when soils are exposed to high salinity levels, such as sea water which contains around 24-30 g NaCl/L (Geissler et al., 2014; Stowa, n.d.; van Dam et al., 2007). The conventional mitigation strategy of adding gypsum to the soils (3 to 10 tons per hectare) introduces extra Ca^{2+} to the soil, which helps to mitigate the soil degradation effect (van Dam et al., 2007).

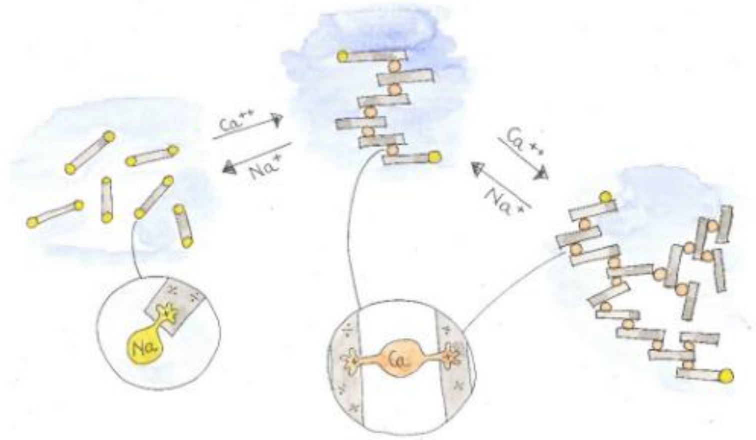

Figure A.2: *Na^+ is replacing Ca^{2+} resulting in breaking of the clay aggregates* (*SalFar*, n.d.).

Because of this soil degradation effect, it is frequently highlighted that irrigation with brackish or saltwater is not recommended for clay soils, as it can permanently damage the soil (*SalFar*, n.d.). Irrigating with brackish or saline water could be an option for sandy soil if the plant species tolerate the salinity levels.

A.2 Salt tolerance of plants

In this part the salt tolerance of plants is described, by addressing the mechanisms of salt tolerance, describing how salt tolerance levels of plants are measured, and evaluating the salt tolerance of some agricultural crops.

A.2.1 Salt tolerance mechanisms

The salt tolerance of plants refers to the ability to withstand the negative effects of salts and is regulated by complex mechanisms controlled by many genes (Shannon & Grieve, 1998). Multiple plant species have naturally developed defense mechanisms against salt stress. These mechanisms can be classified into three main categories (Stowa, n.d.):

1.) **Na^+ exclusion, is a mechanism used t**o prevent toxic sodium concentrations. This can occur through two different strategies: either **Na^+ uptake is blocked at the root level, or** Na^+ and Cl^- ions are actively secreted from leaf surfaces via salt glands or bladders (Blom-Zandstra et al., 2014, n.d.; dos Santos et al., 2022; Stowa, n.d.).
2.) **Accumulation of Na^+ and Cl^- ions** occurs either within the cel or in intercellular spaces to prevent toxic concentrations in the cytoplasm (dos Santos et al., 2022; Mukhopadhyay et al., 2021; Stowa, n.d.)
3.) **Osmotic adaptation** refers to the ability of plants to adjust their osmotic potential in response to the osmotic value of the soil. Some plants can increase their osmotic potential by absorbing inorganic ions like K^+ form the soil, or they can synthesize new soluble organic compounds. In hypersaline soils, the synthesis of organic solutes can consume a significant amount of the plant's energy, resulting in a decreased growth rate (Blom-Zandstra et al., 2014, n.d.; dos Santos et al., 2022).

A.2.2 Measuring salt tolerance of plants

Salt tolerance in plants is influenced not only by their genes and defense mechanisms but also by environmental factors. These factors include the salinity concentration specifically in the root zone, soil type, weather conditions and the exposure duration (Stuyt et al., 2016). Salt tolerance can be determined by linking observed negative effects of salinity on the plant to the corresponding salinity level. These effects can be assessed through various factors, including yield, germination success, root development, and the quantity and quality of shoots, leaves, flowers, seeds, and fruits (Blom-Zandstra et al., 2014). A simplified model for assessing salt tolerance was developed by Maas and Hoffmann (1977). They proposed that all plants have a specific salt tolerance threshold after which yield begins to decrease linearly. This model consists of two parameters: (1) the threshold, expressed in ECt, which represents the salinity level at which the first significant reduction in maximum yield occurs, and (2) the slope (S), that indicates the rate at which the yield declines as salinity increases beyond the threshold reached (Figure A.3) (Maas and Hoffmann, 1977). This relationship can be expressed as an equation, where Y represents the relative crop yield as a function of ECe, the salinity of the soil: Y=100-S(ECe-ECt) (Maas and Hoffmann, 1977). Due to its simplicity and practical application, this model is now widely used (Shannon & Grieve, 1998). It should be noted that the salt tolerance threshold is not a specific value but a range.

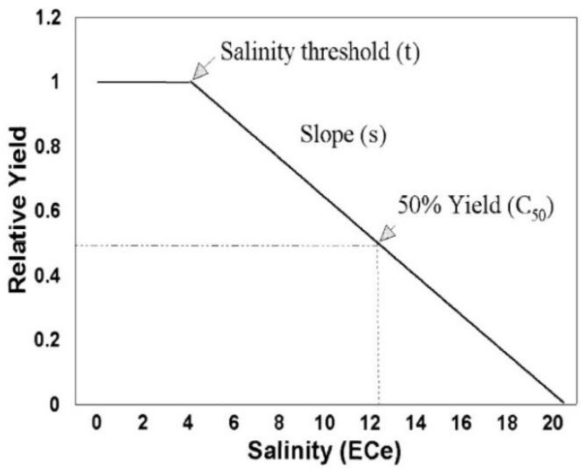

Figure A.3: *The Maas and Hoffman model for salt tolerance* (*Blom-Zandstra et al., 2014*, n.d.; Maas & Hoffman, 1977).

In 2019, van Straten et al. refined this model by using the ECe value at which the yield is reduced to 90%, rather than using the absolute threshold after which the first significant yield losses occur (van Straten et al., 2019). Additionally, the function representing yield decrease does not use a linear decrease but instead uses a logistic S-curve model. These adjustment were made based on field observation of yield and soil salinity levels from the Salt Farm on Texel (van Straten et al., 2019).

Appendix B: Additional information Methodology

B.1 Framework result comparison

In Table B.1 there are the seven combinations of input criteria that would have ranked differently if the single-step approach of Wen (2023) had been used highlighted in orange. All values are currently ranked one level lower, to account for the fact that multiple stressors combined can increase total stress.

Table B.1: *All possible input combinations and their final suitability classification according to the single step approach. Abbreviations in the table are representable for the suitability classification: Not Promising (-), Potential Promising (PP), Promising (P), and Highly Promising (HP).*

			Salinity								
			3.Highly Suitable			2.Moderatly Suitable			0.Not Suitable		
Soil	Drought	Waterlogging	3.Low Stress	2.Medium Stress	1.High Stress	3.Low Stress	2.Medium Stress	1.High Stress	3.Low Stress	2.Medium Stress	1.High Stress
3.Highly Suitable	3.Low Stress		HP	P	PP	P	P	PP	-	-	-
	2.Medium Stress		P	P	PP	P	PP	PP	-	-	-
	1.High Stress		PP	PP	-	PP	PP	-	-	-	-
2.Moderatly Suitable	3.Low Stress		P	P	PP	PP	PP	PP	-	-	-
	2.Medium Stress		P	PP	PP	PP	PP	-	-	-	-
	1.High Stress		PP	PP	-	PP	-	-	-	-	-
0.Not Suitable	3.Low Stress		-	-	-	-	-	-	-	-	-
	2.Medium Stress		-	-	-	-	-	-	-	-	-
	1.High Stress		-	-	-	-	-	-	-	-	-

B.2: Literature search key words

During the semi-structured literature review, eight distinct search strings were developed by combining one or more stressor categories with agricultural system-related terms, each consisting of a subset of the following keywords:

Salinity:

salinization* OR salt stress* OR salinity stress* OR salt accumulation* OR soil salinity* OR saline intrusion* OR sodium ions* OR brackish water irrigation* OR saline soil* OR saltwater contamination* OR salinity management* OR salt remediation* OR saltwater intrusion* OR high salinity* OR salinized soil* OR sodic soil* OR salt crusting* OR halophyte farming* OR biosaline agriculture* OR salt tolerance* OR sal* tolerant* OR sal* resilient* OR sal* resistant* OR sal* adapt* OR sal* acclimat* OR sal* stress tolerance* OR sal* endurance* OR halotolerant* OR salt-loving plants* OR salinity-adapted species* OR alkali* tolerant* OR alkali* resilient* OR alkali* resistant* OR sal* acclimat* OR alkali* acclimat* OR alkali* endurance*

Drought stress:

drought* OR dry period* OR soil moisture deficit* OR rainfall deficit* OR desertification* OR hydrological drought* OR meteorological drought* OR agricultural drought* OR water scarcity* OR extended drought* OR soil moisture stress* OR climate-induced drought* OR rainfall shortage* OR water stress* OR crop yield reduction* OR lack of precipitation* OR desertification risk* OR reduced rainfall* OR water deficit* OR hydroclimatic drought* OR arid conditions* OR prolonged dry periods* OR rainfall extremes* OR water shortage* OR arid land* OR drought* tolerant* OR drought* resilient* OR drought* resistant* OR drought* adapt* OR arid* tolerant* OR arid* resilient* OR arid* resistant* OR arid* adapt*

Waterlogging:

waterlogging* OR soil saturation* OR water excess* OR excess soil moisture* OR subsurface water accumulation* OR drainage problems* OR flash floods* OR heavy rainfall* OR intense rain events* OR pluvial flooding* OR stormwater runoff* OR torrential rain* OR flood risk* OR surface runoff* OR waterlogging events* OR storm events* OR excessive precipitation* OR rainfall extremes* OR water retention issues* OR flooding events* OR anaerobic soil conditions* OR surface runoff issues* OR extreme precipitation*

Agricultural systems:

Agricul* OR intercrop* OR multicropping* OR polyculture* OR crop* rotation* OR agroforest* OR forest gardening* OR food forest* OR phytoremediat* OR climate smart agricul* OR circular agricul* OR biosaline* OR farming* OR

B.3: Salt load calculations

The conversion of salt load from NaCl in kg/ha/year to mg Cl^-/L was done in three steps.

1.) First kg NaCl was converted to Cl^- by using the molar weight. This results in a conversion factor of:
    Conversion factor = NaCl/Cl^- = 58.44/35.45 = 0.607
2.) Secondly, it was assumed that only rainfall and evaporation influence the amount of surface water on Schouwen-Duiveland. The median values of annual rainfall and evaporation were used from (Rougoor et al., 2016)
    Surface water = rainfall - evaporation
3.) This allowed the chloride concentrations to be calculated:
    Chloride concentration = (Salt load * conversion factor) / surface water

The full calculations can be found in the Supplementary Material – Excel: Calculations: ‘Salt load calculations’.

Appendix C: SRAS additional information and assumptions

C.1 Salt-tolerant potato '927'

Salt tolerance

At Salt Farm Texel, Potato 927 maintained 90% at a salinity level of 5.5 dS/m (*De Vos et al., 2016*, n.d.). Its salinity threshold was later defined as 5.9 dS/m (*De Vos et al., 2016*; Oosterbaan, n.d.). Based on these findings, Wen (2023) conducted a global planning analysis for potato 927 and introduced suitability classifications based on the salinity level (Wen et al., 2023). According to this classification, salinity levels between 0-2 dS/m are low enough for conventional cropping, thus not suited for salt-tolerant potatoes. Salinity levels between 2-6 dS/m are considered viable for potato 927. Additionally, Wen incorporated the FAO guidelines, which classify the soils with a salinity between 4-8 dS/m as severely limited for plants. As a result, Wen divided the salinity levels of 2-4 dS/m as highly suitable for potato 927 and 4-8 dS/m as moderately suitable.

Drought tolerance

Potatoes are the stable crop with the lowest water foodprint (Blom-Zandstra et al., 2014). Nevertheless, drought stress can impact the yield. The level of drought tolerance varies among potato lines. A study researched the drought tolerance of eighteen potato lines and found that six lines were tolerant, seven moderately tolerant, and five were sensitive (Albiski et al., 2012). However, in general potatoes are assumed to be sensitive to drought stress, as it reduces yield significantly (Obidiegwu et al., 2015; Orsák et al., 2020).

Waterlogging tolerance

Potatoes are sensitive to waterlogging stress (Obidiegwu et al., 2015). It can reduce both the yield and quality of the potatoes, and furthermore, waterlogging can increase the change for diseases (Orsák et al., 2020; Sela, 2024).

Soil type

In the field experiment of Salt Farm Texel, potato 927 was cultivated on a sandy soil (*De Vos et al., 2016*). Therefore, sandy soil is suitable for this cultivation. Additionally, potatoes perform well on sandy loam soils (Sela, 2024). Clay soils are not recommend for salt-tolerant potatoes, as the salts can affect the soil structure, and the low drainage capacity form clay soils are not ideal (Sela, 2024).

Salt tolerance mechanisms

Research has been conducted to analyze the salt tolerance mechanisms of potatoes. Of the three classification of salt tolerance mechanisms, the potato uses osmotic regulation, and Na+ transport plays an important role (Jaarsma & de Boer, 2018; Li et al., 2022).

C.2 Sugar beet

Salt tolerance

The salt tolerance of sugar beet has been reported to range from moderately sensitive to tolerant (Stuyt et al., 2016; *Zilt Perspectief, 2015*). The threshold values for chloride concentrations are identified as 600 mg Cl/L for the lower limit and 5000 mg Cl/L for the upper limit (Stuyt et al., 2016). Additionally, a study by SalFar reported that sugar beet maintained 90% yield at salinity levels of 12-14 dS/m (*SalFar, 2022*). Using the calculation of van Dam et. all (n.d.), this corresponds to an estimated chloride concentration of 3915-4791 mg Cl^-/L. To classify the suitability of sugar beet cultivation under different salinity levels, it is assumed that chloride concentrations below 374 mg Cl^-/L (2 dS/m) are unsuitable, as this range is viable for conventional agriculture. Concentrations between 374-3915 mg Cl^-/L are considered highly suitable, while levels between 3915-5000 mg Cl^-/L are classified as moderately suitable. Concentrations above 5000 mg Cl^-/L are deemed unsuitable.

Drought tolerance

Sugar beet is classified as a drought tolerant crop and can withstand short periods of drought. However, after prolonged drought stress a significant yield reduction will occur (Alavilli et al., 2023).

Waterlogging tolerance

Sugar beet experiences negative effects on development and production when it endures waterlogging stress during the seedling stage. Some beet species are more tolerant to waterlogging than others, but in general waterlogging poses a threat to sugar beet cultivation (Sha et al., 2024).

Soil types

Suitable soils for sugar beet cultivation include sandy loam and sandy soils (*Yara UK*, 2019). Clay soils are not recommended for salt-tolerant yield.

Salt tolerance mechanisms

Sugar beet has multiple adaptations to mitigate salt stress. It combines the mechanism of osmotic adaptation and Na^+ exclusion, and employes various strategies to combat Na^+ toxicity (X. Lv et al., 2019).

C.3 Intercropping– Glasswort

Salt tolerance

Swiss chard has been shown to benefit from intercropping with glasswort under moderately saline conditions. Research indicates that Swiss chard can still gain advantages from this intercropping system even when soil salinity reaches 6.9 dS/m (Cammerino et al., 2025). Similarly, lettuce has been found to benefit from glasswort intercropping up to approximately 5 dS/m (Acharya et al., 2024). Based on these findings, a moderate salinity level of 4-6 dS/m is considered highly suitable for the intercropping system with glasswort. Salinity levels between 2-4 dS/m and 6-8 dS/m are classified as moderately suitable, as glasswort grows less optimally at lower salinity levels, while glycophytes experience reduced growth at higher salinity levels. Salinity levels below 2 dS/m and above 8 dS/m, are considered unsuitable. It should be noted that while glasswort can tolerate higher salinity levels, with optimal growth occurring between 20 and 40 dS/m, these levels are not suitable for the intercropped glycophytes (Cárdenas-Pérez et al., 2022; *PlantStress*, n.d.).

Drought tolerance

Glasswort is assumed to be moderately sensitive to drought. Research indicates that during drought periods, a reduction in shoot fresh weight occurs (Calone et al., 2022). The drought tolerance of the system is dependent on the intercropped glycophytes. As freshwater irrigation is limited in Schouwen-Duiveland, glycophytes should not be highly sensitive to drought stress. Therefore, the system is classified as moderately sensitive to drought, as selecting an extremely drought-sensitive intercrop would not be a viable option.

Waterlogging tolerance

Glassworts natural habitat includes coastal areas where periodic flooding occurs, indicating a high tolerance to waterlogging. Research has shown that glasswort can transport oxygen into waterlogged soils, enhancing its resilience (Jordine et al., 2024). However, in an intercropping system, the companion crop also influences the overall tolerance to waterlogging. Since glasswort has the ability to transport oxygen into the soil, with a properly selected companion crop, it is assumed that the system has a moderate tolerance to waterlogging.

Soil suitability

Glasswort is highly suitable for sandy and sandy loam soils (El-Maboud, 2021). For example, intercropping with Swiss chard was conducted on sandy loam soil (Cammerino et al., 2025). Furthermore, clay soils are also suitable, as glasswort is currently being cultivated on clay soils in Zeeland (*PFAF Plant Database*, n.d.). Because glasswort accumulates salts form the soil in its tissue, it plays an important role in soil phytoremediation.

Salt tolerance mechanisms

Glasswort employs multiple mechanisms to enhance salt tolerance. These include accumulation of Na^+ in vacuoles and the production of proline within cells to mitigate osmotic stress (Cárdenas-Pérez et al., 2022; Jordine et al., 2024). By absorbing and storing salts within its tissues, glasswort contributes to reducing soil salinity (*PFAF Plant Database*, n.d.)

C4. Crop rotation- quinoa

Salt tolerance

Quinoa can survive in soils with a salinity level up to 40 dS/m, which exceeds the salinity of seawater. This shows the possibility of irrigating quinoa with brackish water (Bouras et al., 2022). However, salt tolerance varies among quinoa cultivars. For this research, a salt-tolerant cultivar was chosen, with an optimal yield recorded at salinity levels of 10-20 dS/m . The cultivar showed significantly reduced yields at salinity levels of 30 dS/m. For this study, a range of 5 dS/m is used around the optimal to select the moderately suitable salinity levels. This range of 5 dS/m is chosen because a salinity level of 30 dS/m significantly reduces the yield and 5 dS/m showed to less stability than 10-20 dS/m .

Drought tolerance

Quinoas drought tolerance varies among cultivars, though quinoa is generally seen as tolerant to drought (Bouras et al., 2022). Quinoa uses multiple drought adaptation mechanisms to cope with water scarcity (Lin & Chao, 2021). Even so, excessive drought stress results into reduced plant growth (Nguyen et al., 2024).

Waterlogging tolerance

Although quinoa is resilient to many stressors, waterlogging significantly affects its growth, leading to reduced plant growth and fewer leaves and branches (Bouras et al., 2022; Nguyen et al., 2024). Quinoa is more sensitive to waterlogging than drought stress (González et al., n.d.), and is therefore classified as moderately sensitive to waterlogging.

Soil types

Sandy loam and loam soils are seen as the most suitable option for quinoa, as it provides a proper drainage (Bouras et al., 2022; Rankel, 2024). Quinoa can also grow on clay and clay loam soils (S. Lv et al., 2024).

Salt tolerance mechanisms

Quinoa employs several mechanisms to increase salinity tolerance. For example, quinoa retains water within its leaves, reducing the effects of dehydration. Additionally, quinoa can sequester and secret salts from the leaves through epidermal bladder cells (Cai & Gao, 2020; Moog et al., 2022; Terletskaya et al., 2023). Furthermore, salts can accumulate in older leaves, which eventually fall off, reducing the overall salt load of the plant (Cai & Gao, 2020; Moog et al., 2022).

C5. Agroforestry

Salinity tolerance

The salinity tolerance was obtained from selecting existing agroforestry agricultural fields where trees are currently cultivated. The selection of agricultural fields based on the tree species is described in the Supplementary Material – Excel: Calculations: 'Selection of species'. The corresponding salinity levels were divided into categories of 250 mg Cl^{-}/L generating a histogram (Figure C.1). Based on the distribution, the salinity levels were assigned as: highly tolerant 749-4500 Cl^{-}/L (because below 749 is reserved for conventional agriculture), moderately tolerant: 4500-5500 Cl^{-}/L and not tolerant above 5500 Cl^{-}/L or below 749 Cl^{-}/L. The data points with higher salinity levels were consider outliers and excluded from the decision for salt tolerance levels.

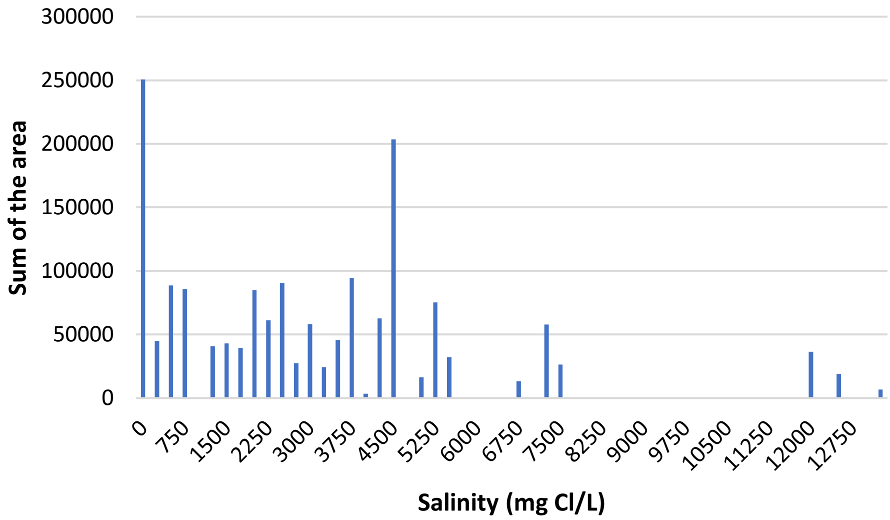

Figure C.1: *Distribution of salinity levels of current fields that cultivate trees.*

Drought tolerance

Some tree species are able to use saline groundwater more efficiently, and when properly selected and spaced, they can improve water efficiency within agroforestry systems (N. Kumar et al., 2019; Zhang et al., 2024). However, not all studies support this claim. One report found no significant reduction in overall water usage in agroforestry systems compared to monocropping (Fuchs et al., 2022a). Nonetheless, it concluded that agroforestry systems could reduce drought and salinity stress during critical dry periods (Fuchs et al., 2022a). Therefore, agroforestry is assumed to be drought tolerant.

Waterlogging tolerance

Besides salt- and drought-tolerant species, there are also some bio drainage species identified that can mitigate waterlogging stress through rapid transpiration (Kumud Dubey, 2022; Singh, 2015). Therefore, a well-designed agroforestry systems has the potential to be tolerant to salinization, drought, and waterlogging (Fuchs et al., 2021; Singh, 2015).

Soil type

Soil suitability was also determined using the same set of agricultural fields. A histogram was created to show the frequency of each soil type associated with agroforestry (Figure C.2). Clay loam soils were not represented based on the current fields and therefore accounted as not suitable. Loam was identified as highly suitable, and the other soil types were classified as moderately suitable.

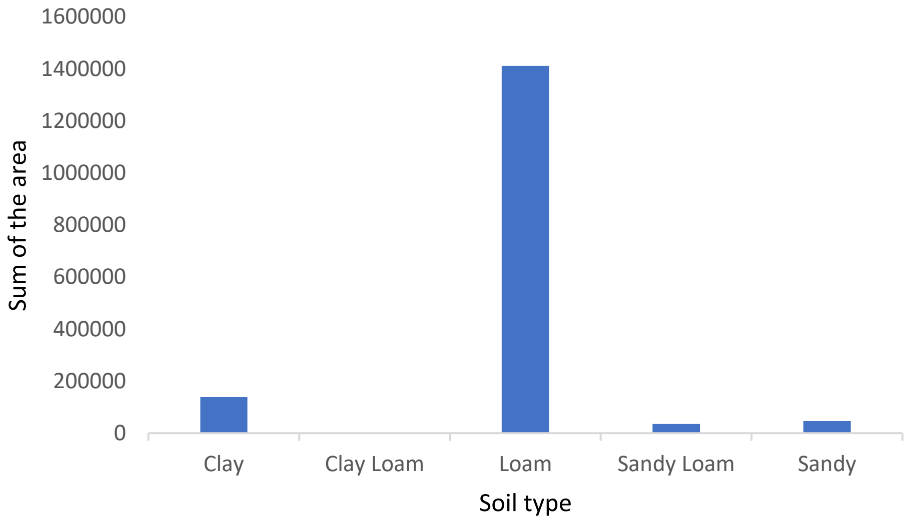

Figure C.2: *Distribution of soil types of current fields that cultivate tees.*

Appendix D: Overview of all assumptions

This study is based on the following assumptions:

- **Phase 1 - Framework development**
    - Criteria classifications identified for the stressors.
    - The ranking for the suitability (Appendix B.1).
- **Phase 2 - SRAS selection**
    - Assuming the model species have appropriate values for the systems itself.
    - Valus for the tolerance thresholds (Appendix C).
        - Below 2 dS/m is suitable for only conventional agriculture and not for SRAS.
        - Salt tolerant crops not on clay soils due to damage on soils.
        - Assumed the general tolerance values of *Solanum tuberosum L.* can be applied for Potato 927.
        - Agroforestry based on current values which are assumed to be equivalent to the full potential. And assumed the system is designed properly so that the system is tolerant to drought and waterlogging.
    - The conversion to proper units.
- **Phase 3 - Spatial stressor analysis:**
    - Soil classification (Supplementary Material - Excel: Calculations: 'Soil types').
    - Conversion for salt load (Appendix B.3).
    - Oxygen stress is equivalent to waterlogging.