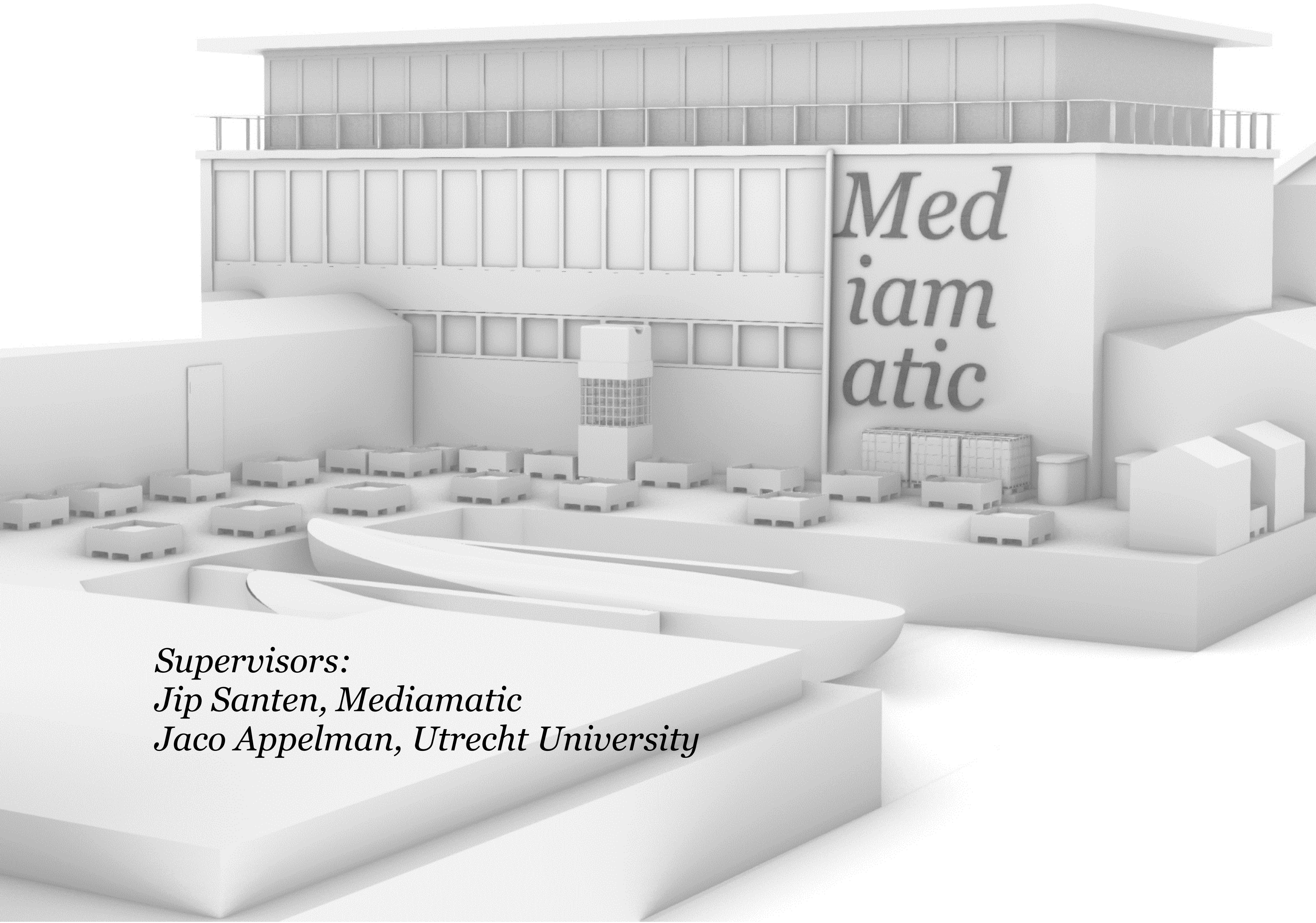
Korreltje Zout

A Literature Review of Saline Irrigation

By Max Ciaglo



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Cover photo by Jishuang Zheng.

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Abstract

Globally, soil salinity and the salinization of water resources is increasing. For plants in particular, this trend could be troubling as saline water and soil can cause ion toxicity, osmotic stress, and nutrient imbalances. However, responses to salinity vary greatly across the Plantae kingdom. In general, three strategies—adaptation, mitigation, and desalinization—can be applied to address these issues. Mediamatic is an arts, science, and cultural organization that is exploring the use of saline water for myriad irrigation projects in Amsterdam, the Netherlands. Their goal is to stop using any tap water to irrigate outdoor gardens and supply an aquaponics greenhouse. Within this context I review the current literature discussing the first two strategies of adaptation and mitigation and make recommendations for adapting Mediamatic to a sustainable and salty future. Overall, while some species of plants, and halophytes in particular, show remarkable resilience to saline conditions, others are very sensitive to salt stress and require special attention. Therefore, plant selection is vitally important to adapting to a saline irrigation system. However, current literature also describes many potential strategies to mitigate these responses to salt stress, allowing a broader range of plants to tolerate high levels of salinity. Most literature focuses on using different soil treatments, such as potassium, gypsum, and bio-organic amendments to alter ion imbalances in the soil and promote uptake of vital nutrients. Further research suggests different irrigation strategies, such as mulched drip irrigation and freshwater flushing of the soil to control the salt levels in the soil. Taken together, I recommend that Mediamatic employ a mulched drip irrigation system that is supplemented with bio-organic soil amendments, while also choosing plants that can tolerate the moderate salinity level of the brackish water in the Dijksgracht with an EC of ~2-5 dS m^{-1}. I also recommend that they increase their rainwater storage capacity for use in the aquaponics system and for flushing outdoor irrigated areas. Finally, I outline the design of a potential integrated system of all irrigated areas within Mediamatic, where I propose to implement a stage-based halophyte filter.

Layman's Summary

As the climate changes, land all over the world is becoming more salty. Sea level rise and runoff from different industries is making our water more saline. Where this water is used to irrigate agricultural crops, the soil accumulates salt. Additionally, as temperatures rise, more water evaporates from the soil and the plants, leaving more salt behind in the soil. Together, these dynamics build on each other and create issues for plants that struggle in saline environments. More salts in the soil and water make plants lose water and nutrients, causing drought like responses, and general issues with growth and development. Mediamatic is an arts, science, and cultural organization that is exploring ways to use saline canal water to irrigate different gardens and greenhouses in Amsterdam, the Netherlands. Their goal is to stop using any tap water in these systems. Here I review the current literature on how to adapt these systems to irrigation with saline water, and how to manage the systems to avoid negative responses in the plants. In general, many species of plants are very resilient to saline conditions, even simple crops like potatoes. However, other plants are very sensitive to salt stress and require special attention. Therefore, plant selection is important to consider for Mediamatic when adapting to a saline irrigation system. However, the literature also describes many strategies to avoid salt stress and help even sensitive species grow in a saltier environment. Most literature focuses on adding different fertilizers to the soil, such as potassium, gypsum, and bio-organic composts. These additions change the nutrients in the soil so there is relatively less salt in the environment, which helps plants uptake important nutrients. Further research suggests different irrigation strategies, such as using mulch on top of the soil, and using drip irrigation to deliver the saline irrigation water. Another strategy involves using freshwater to flush the salts out of the soil. Taken together, I recommend that Mediamatic use a layer of mulch on their soil along with drip irrigation. They should also supplement the soil with bio-organic soil amendments. I also recommend that they pay particular attention to choosing plants that can tolerate the moderate salinity level of the brackish water in the canal. It is also recommended that they increase their rainwater storage capacity to use more freshwater in the aquaponics system and for flushing outdoor irrigated areas. Finally, I outline the design of a potential integrated system of all irrigated areas within Mediamatic, where I propose to use particular plants to physically filter salt out of the water.

1. Introduction

Worldwide, the salinization of soil and water resources is increasingly destabilizing ecological, agricultural, and urban systems. Anywhere that plant transpiration exceeds average rainfall or irrigation, soil salinity will naturally increase. However, sea level rise, saltwater intrusion into groundwater, and increased urban and industrial runoff can also lead to salinization of freshwater resources in coastal temperate regions. As freshwater salinization increases, and drought and high temperatures become increasingly common, it is obvious that we are facing a saltier future.

For plants in particular this trend may be troubling. High levels of salt in the soil and water can create an osmotic imbalance between the internal and external environment, making it more difficult for plants to take up water. This can quickly lead to water stress. Further, an increase of salt ions in the soil can lead to an ion imbalance in the plants, where salt ions, such as sodium (Na+) and chloride (Cl-), can compete with and replace the uptake of important mineral nutrients like potassium (K+), calcium (Ca2+), and magnesium (Mg2+). If these salt ions accumulate in plant tissues, it can disrupt cellular processes and damage cell membranes, potentially causing symptoms like leaf burn, necrosis, and reduced rates of photosynthesis.

While this is by no means a new problem, and peoples have been farming even using seawater for centuries, there is renewed interest in finding ways to combat increased salinity of land and water. Generally speaking, three main strategies exist to manage these issues:

1. Adaptation:

   This strategy requires that we adapt anthropogenic systems to be more salt tolerant. Globally, many plant species exist that either tolerate saline environments, or prefer them (halophytes). Additionally, techniques have been developed and are being improved every day to genetically modify plants to be more tolerant of saline environments.

2. Mitigation:

   Mitigation requires adopting and adapting new strategies to reduce the salinity of the environment. These strategies typically require leaching salts from the soil by improving irrigation and drainage techniques. Other strategies include directly altering the ion profile of the soil through proper soil amendments.

3. Desalinization:

   Finally, and potentially the most technically difficult, is directly changing the salinity of the soil and water. This strategy typically requires intricate systems to desalinate the water before using it for irrigation.

The Netherlands serves as an exemplary case study when it comes to saline agriculture, primarily due to its unique geographical, historical, and environmental challenges. The country's low-lying landscape, with a significant portion of its territory below sea level, makes it particularly vulnerable to saltwater intrusion and soil salinity. Within the past century the Netherlands has conducted extensive research and experiments to deal with these issues.

Mediamatic is a cultural center dedicated to emerging topics in art, science, and culture located in Amsterdam, the Netherlands. They have a functioning aquaponics system and extensive outdoor gardens that are currently predominantly irrigated using fresh water from the municipal drinking water system. However, they are also located on the Dijksgracht, a brackish canal that is distantly connected to the North Sea through a series of other canals, dikes, and inland seas. Due to recent droughts, and an interest in finding sustainable solutions, Mediamatic has begun the Korreltje Zout project, where they use this canal water to replenish their aquaponics system and irrigate their gardens. Therefore, they are interested in understanding the current techniques available to sustainably change from fresh to saline irrigation.

Within this context I will conduct a literature review to discuss the current state of research into saline irrigation. However, I will focus the research within the Dutch context, particularly on urban areas and urban green space to avoid an over-selection of research on the agriculture of food. I will also focus this literature review on low-cost techniques (e.g. not including genetic engineering) to make it more useful for local and applied organizations such as Mediamatic. Therefore, this review will focus on the first two strategies, adaptation and mitigation, where desalinization is typically costly and technologically advanced. I will conclude with a final suggestion for a system, and detail specific recommendations taken from the literature that Mediamatic can integrate into their Korreltje Zout project and change entirely to saline irrigation.

Overall, this literature review will aim to answer the question:

What is the state of the art of saline irrigation in the urban and Dutch contexts?

2. Methods

To conduct this literature review I used the Google Scholar search engine to find relevant and current peer-reviewed research. To review current literature for Section 3.1, “Adaptation” I searched for the terms “saline irrigation urban green space Netherlands” in the search engine and I restricted my search to articles published during or after 2010. While this allows for older articles to be reviewed, it also made it possible to include more research specific to the Dutch context. For Section 3.2, “Mitigation” I searched for the terms “saline irrigation urban green space” in the search engine and I restricted my search to articles published during or after 2020, to focus solely on the most current management techniques. For both searches I reviewed the available summaries or abstracts of the first 100 most relevant articles (according to Google Scholar). From these I chose the ten articles most relevant to each of the strategies (adaptation, mitigation), specifically aiming to include articles relevant to the Dutch context, and excluding articles focused on high-tech or costly solutions.

Note on measuring salinity: Across the literature there are many ways to measure salinity. Salinity itself as a term refers to the concentration of all salts, either precipitated in the soil, or dissolved in water. When referring to seawater, measurements of salinity will be dominated by Na^+ and Cl^- ions. However, as this field of research also encompasses topics of urban runoff and industrial effluent, we must note that these are not the only elements to which salinity refers. Therefore, it is important to caveat that different measurements of salinity exist, and they can point to different trends or ideas. Measuring the concentration of a single ion in water will not be comparable to measuring the total salinity of the soil or water. Here I attempt to always be specific about measurements of salinity, and specifically denote what type of measurement was used in the literature, however, the research is not always consistent. So, where the exact measurement is not specified, it is important to only use the measurement to compare results within the same paper (i.e. how salinity changed within the study) and not compare it between studies or to practical contexts. So yes, please take these measurements with een korreltje zout.

Here is a list of the common salinity measurements reported here and their meaning. Again, where there is no specific denotation (usually a subscript) it was not reported in the literature and should not be assumed.

EC – *Electrical conductivity*. Measured in dS m^{-1} is a measure of the ability of a material to conduct electricity. Used in water it is an accurate measurement of the total salts. However, as it can only measure the total salts in water, to measure the EC of soil, different methods are used.

EC_e – *Soil paste electrical conductivity*. Also measured in dS m^{-1}, this is a method of dissolving the salts from soil into the water for measurement. While this measurement is generally agreed to better represent the true salinity of the soil it is more technical than other measurements.

$EC_{1:x}$ – *Soil electrical conductivity in ratio*. This is a simpler method of dissolving the soil salts and is cheaper, but less accurate. In this method EC is measured for a soil:water extract, where soil is mixed with water in a ratio of 1:x where x is typically 2 or 5.

ppm – *Parts per million*. This will only measure the parts per million of a specific ion or single salt in an extract. Therefore while it gives interesting information about the response of a specific element, it does not give the full picture of salinity.

(m)g L^{-1} – *(Mili)grams per liter*. Similar to ppm, this is the measurement of the concentration of a single ion or salt.

mM – Millimolar. Similar to ppm and (m)g L^{-1} this is a measurement of the concentration of a single ion or salt.

3. Literature Review

3.1 Adaptation

This section of the literature review synthesizes findings from ten papers to provide a perspective on the current understanding of plant adaptations to salinity, with a particular focus on the Dutch context.

3.1.1 Mechanisms of Salt Tolerance

In a current literature review**,** van Zelm et al. (2020) explored cellular responses to salt stress in plants. They detail the very earliest stages of response to salt (even within the first five minutes), although they note that early cellular responses are "arguably the least understood, and they remain a black box." After this early signaling, the growth rate changes through different growth phases, starting with quiescence where growth temporarily halts followed by a recovery phase where the growth rate partially recovers. During these phases, plants accumulate osmolytes like proline and sugar alcohols in order to maintain the cell volume under osmotic pressure in a saltier environment. However, this process distinctly redirects energy from growth and other vital functions toward osmotic adjustment. Salt stress can also directly impact photosynthesis through stomatal closure reducing endogenously available CO_2, reduction in the activity of CO_2-fixing enzymes, and by the positively charged Na^+ ions disrupting the proton-motive force necessary for energy synthesis in chloroplasts.

Overall, it is well reported that salt stress reduces both below- and above-ground biomass growth, however, van Zelm et al. (2020) also reports on the adaptations of halophytic plants as a model for salt tolerance mechanisms. In general, halophytes are able to withstand saltier environments because of a few different mechanisms, (1) halophytes have a greater capacity for osmotic adjustment, potentially due to having higher pre-stress levels of metabolites such as proline and sugar alcohols, (2) different mechanisms for ion transport such that halophytes accumulate more Na^+ in their shoots instead of their roots, but can still maintain higher levels of K^+, and (3) some halophytes (such as quinoa) have developed epidermal bladder cells (EBCs) where they can secrete salt.

3.1.2 Historical Perspective and Management

The Netherlands has a unique relationship with issues surrounding saline agriculture and soil salinity. Raats (2015) provided a historical perspective on salinity management in the Netherlands, discussing the geographic, climatic, and political causes of salinization and sodification of the country's soil, as well as historic soil and crop management strategies. According to Raats (2015), soil salinity in the Netherlands has been influenced by factors such as rising sea levels during the Holocene, storm floods, strategic inundations during wartime, and various engineering projects like the Zuiderzee and Delta works. Some of these events, especially the anthropogenic events and storm floods, offered unique opportunities to study the effects of salt water and soil salinization on native plant communities. For example, David Jacobus Hissink (1874-1956) started his career studying the dynamics of soil salinity after a storm flood in 1906, and studied the salinity of Dutch polders from 6 to 400 years old.

Of particular interest to this review is the work of Willem Feekes (1907-1979) who studied the ecosystem dynamics of the Zuiderzee polders after they were drained of brackish water, detailing the successional phases of plant growth on saline soils. In this study Feekes observed the dominant vegetation type change, from algae to 261 different species of plants, of which 50 became established. They also observed halophytic species eventually being replaced by glycophytes as NaCl was quickly leached from the soil. Works by other researchers at the time, such as Dr. Klaas Zijlstra also demonstrate the natural ability of plants to colonize these saline soils. In one greenhouse experiment using solutions of 2, 3.27, 8.36, 14.73, 21.10, and 34.87 g of salt per liter, Raats (2015) describes that the results of Zijlstra demonstrate that "varieties (of crops) adapted to the tidal flat environment were found to be much less sensitive to salinity" (Figure 1).

While the historical context provided by Raats (2015) illuminates trends in research into saline agriculture, and provides important context for the research, they also concede that while "the early literature pays much attention to response of crops and vegetations to salinity... much of it is rather qualitative." Therefore, it is important to also consider more recent sources on the subject.

3.1.3 Plant Tolerance to Salinity

As described by Raats (2015) and many other researchers, while there is a long history of research, soil salinization is becoming a bigger and bigger challenge worldwide. As different ecosystems and crop lands become more saline, and saline water may need to replace freshwater for irrigation in different contexts, it is imperative to understand how plants will respond, and which species are able to tolerate saltier environments. Therefore, there is currently extensive research focused on the sensitivity of various plants to salinity.

Still within the Dutch context, Stofberg (2016) conducted a controlled greenhouse experiment on five naturally occurring Dutch freshwater fen plant species. He chose species that were not known to be salt tolerant, although their ecosystem faces the threat of salinization from rising sea levels. In the experiment, the different species were exposed to salt concentrations of 200, 500, 1000, 1500, 3000 mg $Cl^- L^{-1}$. The study found that the total biomass of all five species was significantly reduced when the salinity levels reached 200 mg $Cl^- L^{-1}$.

Four out of the five species—*Succisa pratensis*, *Thelypteris palustris*, *Viola palustris,* and *Myosotis scorpioides* — were sensitive to the salinity treatments and showed a reduction of

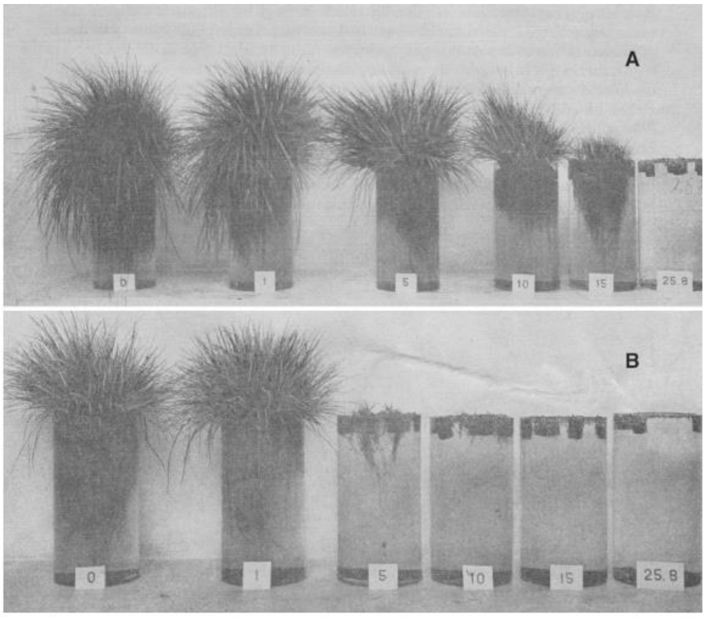


Figure 1. From Raats (2015) and adapted from Zijlstra (1946) showing red fescue grown from (A) seeds collected from a tidal flat and (B) commercial seed grown in solutions of 2 (0), 3.27 (1), 8.36 (5), 14.73 (10), 21.10 (15), and 34.87 (25.8) g NaCL L^{-1}.

biomass within just seven weeks at the lowest salinity levels. The first three species exhibited leaf death and a reduction in relative growth rate at salinity levels of 1000 mg Cl^- L^{-1}, while *M. scorpioides* was affected at a higher salinity level of 3000 mg Cl^- L^{-1}. For these four species, the highest salinity treatment reduced growth by an average of 60-73%. In the experiment, *Comarum palustre* was the exception, showing no significant sensitivity to even the most saline treatment.

While this paper focused on the tolerance levels of native plants not typically associated with saline environments, other research has focused on more halophytic species. These are species that are known to tolerate or prefer highly saline environments. A few of these studies have focused on native or ornamental varieties of plants that may be found in urban spaces.

Loconsole et al. (2019) reviewed the salt tolerance of the common ice plant (*Mesembryanthemum crystallinum L.*), an edible halophyte known to switch from C3 photosynthesis to crassulacean acid metabolism (CAM) under saline or drought conditions. In one experiment conducted by Atzori et al. (2017) the plants were irrigated using subsurface irrigation with water with an EC ranging from 2 to 35 dS m^{-1}. They obtained the "best results" with irrigation water from 20 to 35 dS m^{-1}. Loconsole et al. (2019) details two more studies that report similar findings, one that reports that *M. crystallinum* performed best between 50-250 mM NaCl, and another that reports maximum growth in a 100 mM NaCl solution. However, the article fails to define "best results" or other growth parameters.

Cirillo et al. (2016) conducted a greenhouse experiment to explore the effects of salinity on *Viburnum lucidum L.* (arrow-wood) and *Callistemon citrinus* (red bottlebrush), two ornamental shrubs common throughout Europe. The experiment also investigated whether the addition of two osmolytes (glycine betaine (GB) or Proline (Pro)) could mitigate the negative impacts of salinity (osmolytes will be discussed in more depth in Section 3.2). In this experiment Cirillo et al. (2016) used two concentrations of NaCl (1 mM and 200 mM) to water two-year-old rooted cuttings. The experiment showed that the high salinity significantly affected plant growth. Apical shoot length was reduced up to 81% in *V. lucidum* and up to 91% in *C. citrinus*. Lateral shoot length was also reduced by 77% and 98% for the two species, respectively. The study aimed to illuminate the cause of these negative effects as well. They determined that under saline treatment the concentration of Na^+ and Cl^- ions in the leaves were five- and two-fold higher and were linked with 70% reduction in the net photosynthetic rate.

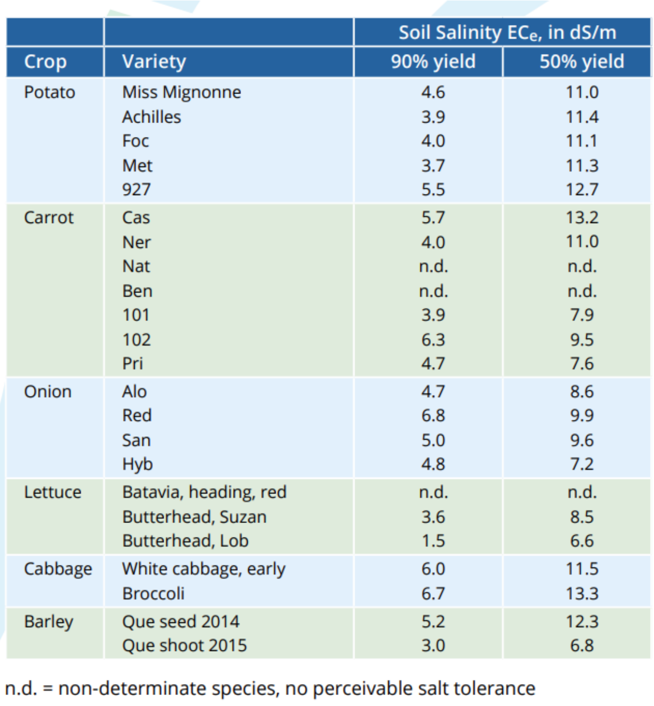
While these studies focus on native or ornamental vegetation, many more focus on species specifically used for agriculture. Much work on this topic has been conducted in the Netherlands, and here I will focus on the Dutch context again. Within this field, the studies focus on both traditional, glycophytic crop species, as well as examining the potential for cultivating halophytic species for agriculture.

De Vos et al. (2016) conducted an extensive field study at Salt Farm Texel in the Netherlands. The study tested the salt tolerance of various crop varieties, including five types of potatoes, seven types of carrots, four types of onions, three types of lettuce, two types of cabbage, and one type of barley on an open-air farm. Here the soil consisted of about 93% sand, 3% loam, 2% clay and 2% organic matter. All crops were grown using drip irrigation with saline water at seven different concentrations, from 1.7 to 35 dS m^{-1}, and measured the root zone salinity of each plot. Overall, measures of the root zone salinity were consistent with the salinity of the irrigation water, and there was little seasonal variation in soil salinity or salt accumulation in the root zone. The root zone salinity was then correlated to growth parameters to determine EC thresholds for 90% and 50% crop yields. Surprisingly, the study found that some crop varieties showed salt tolerance up to a salinity level of 4-6 dS/m (EC_e) in the soil and 5-7 dS/m in the irrigation water without a loss in yield. Threshold values for all crops can be found in Table 1.

The "Inspiration Guide on Saline Farming", produced by SalFar (2022), a project funded by the

European Regional Development Fund Interreg North Sea Region similarly reports on the salt tolerance agricultural crops, with a special attention to the potential of growing halophytic crops from around Europe. For typical agricultural crops, they report that varieties of potatoes, beets, brassica, carrots, onions, wheat, and pasture grass all show potential for cultivation using brackish or moderately saline water. In particular, they report that sugar beets (*Beta vulgaris vulgaris var. Altissima*), red beets (*Beta vulgaris vulgaris var. Conditiva*), and Brussels sprouts (*Brassica oleracea gemmifera*) showed surprisingly high tolerance, with little to no reduction in yield at water salinities around 11-14 dS m^{-1} when compared to the control.

The guide also reports on 19 different halophytic species that have medium to high salt tolerance (see Appendix Table I for full list). Of particular interest to this review are five species that were tested on the Dutch island of Terschelling and include sea lavenders (*Limonium*), sea aster or seashore aster (*Tripolium pannonicum*), sea banana or beach banana (*Carpobrotus rossii*), samphire (*Crithmum maritimum*), and common glasswort (*Salicornia europea*). These crops were grown in sea clay instead of sandy soils, the former being more typically prone to salt accumulation due to reduced leaching capabilities and increased capillary action form groundwater. The soil salinity at this site varied between 4.2 and 10.2 dS m^{-1}, and all plants performed well in these conditions.



		Soil Salinity EC_e, in dS/m	
Crop	**Variety**	**90% yield**	**50% yield**
Potato	Miss Mignonne	4.6	11.0
	Achilles	3.9	11.4
	Foc	4.0	11.1
	Met	3.7	11.3
	927	5.5	12.7
Carrot	Cas	5.7	13.2
	Ner	4.0	11.0
	Nat	n.d.	n.d.
	Ben	n.d.	n.d.
	101	3.9	7.9
	102	6.3	9.5
	Pri	4.7	7.6
Onion	Alo	4.7	8.6
	Red	6.8	9.9
	San	5.0	9.6
	Hyb	4.8	7.2
Lettuce	Batavia, heading, red	n.d.	n.d.
	Butterhead, Suzan	3.6	8.5
	Butterhead, Lob	1.5	6.6
Cabbage	White cabbage, early	6.0	11.5
	Broccoli	6.7	13.3
Barley	Que seed 2014	5.2	12.3
	Que shoot 2015	3.0	6.8

n.d. = non-determinate species, no perceivable salt tolerance

Table 1. From de Vos et al. (2016) reporting the soil salinity tolerance of various species of crops for 90% and 50% production levels from experiments conducted at Salt Farm Texel.

Liu and Wang (2021) also report on the potential for halophytes in agricultural production, however they focus on their cultivation in China. They define halophytes as plants that can complete their full life cycle in media containing 200 mM NaCl or more. They highlight eight different categories of use for these halophytic species, including as food crops such, medicinal crops, and for greening saline affected areas (Figure 2). Liu and Wang (2021) especially highlight quinoa (*Chenopodium quinoa var. Willd*) as a halophytic grain. For the potential use of halophytes as agents of ecological protection and sustainable development (greening and coastal protection) they also note the ability of halophytes to “promote the growth of rhizobacteria which can stimulate plant growth and increase the salt tolerance of non-saline crops.” Which provides a unique insight into the potential use of combining halophytes and glycophytes in saline affected soils.

Within the Dutch context, but focused on cultivating grass species for cattle, Kroes and Supit (2011) used models to quantify the impact of various groundwater salinity levels. The study used the results of three different field experiments (a total of 13 years of data) to model the effect of the groundwater levels and salinity on permanent agricultural grasslands and combined this with regional data of the yields from 2121 other grassland units based on groundwater salinity levels and historical weather data from 1971-2000. This model is then used to predict the future yields of these grasslands under different climate scenarios in 2050, including temperature increase, saline intrusion into ground water, and increased atmospheric CO_2. Interestingly, the study found

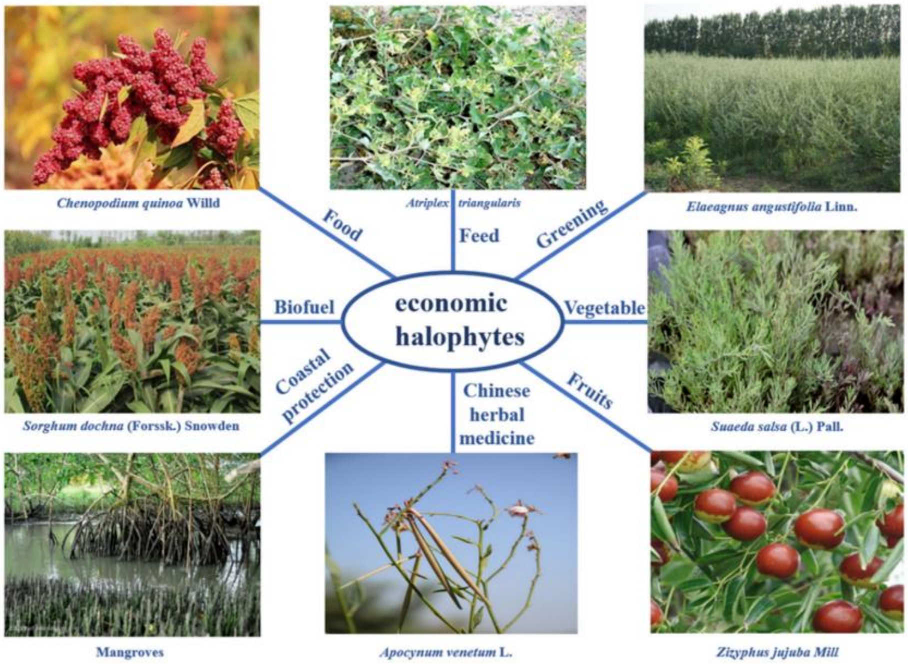


Figure 2. From Liu and Wang (2021) demonstrating halophytes representative of different uses in China.

that groundwater salinity did not have a significant effect on grassland yields under the different climate scenarios. These results were corroborated even when tested in low-lying areas where Cl$^-$ concentrations in the subsoil are expected to exceed 2000 mg L^{-1}. These findings show that grass species will likely be tolerant to saline conditions in the soil, now and in the future.

Petretto et al. (2019) investigated the impact of salinity on six rocket genotypes. The study examines the effects of different NaCl concentrations (0, 65, and 130 mM) on various plant parameters, including shoot biomass, plant height, and leaf area. All genotypes showed high variability in leaves, roots, total plant biomass, and the biometric parameters evaluated. Saline irrigation led to a significant reduction in shoot dry weight and total biomass at both NaCl concentrations. A reduction in plant height was also observed in the saline treatments. However, the study notes that root growth was not significantly affected by salinity, and thus the root to shoot ratio increased under saline irrigation. The negative effects on plant growth could mostly be attributed to salt-induced stress responses, such as reduced photosynthetic rate, altered stomatal conductance, and nutritional imbalance. Salinity also induced the presence of yellow leaves and increased the flowering percentage, both of which are symptoms of a plant stress response. Additionally, the study found that increasing salinity levels significantly affected the sodium content in all genotypes, with an increase of Na$^+$ ions in roots and leaves directly proportional to the increase in salinity levels.

Overall, understanding plant adaptations to salinity is crucial for developing strategies to cope with increasing salinity pressures, or adapting current agricultural lands or urban green spaces to irrigation with saline water. While some species, especially halophytes, show remarkable resilience to saline environments, others are very sensitive to salt stress and require special attention, and potentially targeted interventions. The following chapter of this literature review will focus on these management strategies and examine the current techniques in the literature to mitigate soil salinization and reduce salt-induced stress in plants.

3.2 Mitigation

Here we discuss research focused on various strategies to manage the salinity of the soil and reduce the toxic and osmotic effects of salinity to plants. These strategies focus on both reducing the salinity of already saline soils, as well as mitigating the effects of irrigation with saline or brackish water. Overall, a number of studies have been conducted to explore innovative strategies and management practices focused on various aspects such as irrigation methods, soil amendments, increasing plant tolerance to salt, and sustainable agricultural practices. Here we review ten of the most relevant papers to this research context.

In a general review on the topic, Etikala et al. (2021) delves into various management strategies to mitigate salinity problems but focuses primarily on arid and semi-arid regions. While these environments present a specific set of salinity issues due to high transpiration and evaporation, many of the solutions are still applicable to humid and low-lying environments such as the Netherlands. In particular, the study highlights different water management strategies such as increasing the frequency of irrigation through drip irrigation or mulching to keep the root zone hydrated and maintain low salt levels. Additionally, Etikala et al. (2021) discusses using organic fertilizers that can increase the amount of vital elements in the soil (such as Ca^{2+}, Mg^{2+}, K^{+}, and P^{3-}) leading to improved soil structure, and a reduction of Na^{+} toxicity. In this section of the literature review I will first examine the current literature on using soil amendments and organic fertilizers to increase salt tolerance in plants. I will then follow this with a discussion of various irrigation methods to manage soil salinity.

3.2.1 Soil amendments

Bello et al. (2021) reviews the role of gypsum and bio-organic amendments in mitigating the effects of ion toxicity and osmotic stress in saline soil and enhancing plant productivity. Applying gypsum ($CaSO_4 \cdot 2H_2O$) to saline soil has been shown to increase available sulfur in the soil which reduces the uptake of other toxic ions, while also increasing the amount of Ca^{2+} which replaces Na^{+} ions in the soil, and makes more Ca^{2+} available for uptake by the plants. Importantly, Ca^{2+} is involved in salt signaling pathways to help plants respond quickly to salt stress and helps maintain cell membrane integrity under salt stress. However, gypsum needs to be applied in large quantities and be well mixed within the soil, followed by the application of water to be effective.

The study also describes various bio-organic soil amendments, such as plant growth-promoting microorganisms, arbuscular mycorrhizal fungi, cellulose-decomposing bacteria, P-solubilizing bacteria, and N-fixing bacteria, as well as organic materials such as compost, straw, manures, and biochar. The fungi and bacteria are able to form symbiotic relationships with the plants and can increase the uptake of water and facilitate the transport of essential nutrients in stressful conditions, such as saline environments. One striking example described by Bello et al. (2021) is an experiment conducted by Leithy et al. (2009) where, under irrigation with saline water at an Na^{+} concentration of 3000 ppm the colonization of compost amendments by *Azospirillum* bacteria increased plant growth and reduced the accumulation of Na^{+} in geraniums (*Pelargonium graveolens L.)*. Further, regardless of the plant response, organic soil amendments are able to positively impact soil salinity. In another experiment described by Bello et al. (2021), they remark that Khatun et al. (2019) were able to show that adding vermicompost and cow dung to soil with a salinity of 10.6 dS m^{-1} and irrigating it with brackish water at a salinity of 4.28 dS m^{-1} reduced the soil salinity to 3.37 dS m^{-1} , remarkably below both the original soil salinity and that of the irrigation water. This is likely due to the fact that organic soil amendments can reduce soil evaporation, improve porosity, soil stability, and permeability. It can also increase the Ca^{2+}, Mg^{2+}, N, and K available in the soil for uptake by the plants and compete with the high levels of Na^{+}.

Ultimately, Bello et al. (2021) describe multiple studies that report that a combination of both gypsum and bio-organic amendments can have a greater positive effect on plant responses to salinity stress than either of them used on their own. These soil amendment management strategies, alone and together, show much promise that simple interventions can have a great impact on plant responses to soil salinity.

In a review focused on mitigating salinity stress in wheat (*Triticum aestivum* L.), Sabagh et al. (2021) describe three main strategies to improve salt tolerance. The first is by using osmoprotectants (also used by Cirllo et al. (2016) described in section 3.1.3), which are organic molecules produced by plants that help to maintain osmotic balance and cell turgor pressure by stabilizing proteins and cell membranes. These osmoprotectants include proline, glycine betaine, salicylic acid, and sugar alcohols like trehalose, sorbitol, and mannitol. Applying concentrations of these osmoprotectants to the plants externally has been shown to effectively increase the concentration of osmoprotectants in the plants and confers increased salinity tolerance. Second, the review highlights the use of plant hormones, including abscisic acid, auxins, cytokinin, and ethylene to increase salt tolerance in wheat. Research has shown that these hormones are involved in regulating the response of wheat and other plants to salinity stress. Subsequent studies have shown that exogenous application of these plant hormones can therefore improve the response of plants in saline conditions, increasing their salt tolerance. Finally, the authors discuss the application of other vital plant nutrients such as potassium, gypsum, zinc, and silicon. In particular, they highlight research that showed that foliar application of potassium can improve many different aspects of plant growth under salinity stress.

Kumari et al. (2021) explores the topic of potassium amendments further, specifically reviewing the relationship between salinity stress and potassium in plants. As described in Section 3.1.3, Na^+ influx into plants under salinity stress can lead to K^+ efflux, leaving plants devoid of potassium. The authors highlight how this dynamic can compound salinity stress as potassium is vital for photosynthesis, alleviating oxidative stress, maintaining osmotic homeostasis, and maintaining membrane stability. Therefore, mitigating the loss of potassium can be an important step increasing salt tolerance. Kumari et al. (2021) highlights over 15 studies that demonstrated an increase in salinity tolerance using potassium supplementation. These studies applied potassium in various forms, including K_2O, KNO_3, sulphate of potash, KCl, KH_2PO_4, and K_2SO_4 either through supplementing the irrigation water, or applying the nutrients through a foliar spray. The studies observed a wide range of positive responses by the plants including increased osmolyte production, increased antioxidant activities, increased plant growth (particularly root and shoot height), improved rates of photosynthesis, and decreased Na^+ uptake.

Phogat et al. (2020) examined the effects of gypsum application on tomato, cucumber, capsicum, and eggplant in an unheated greenhouse scenario. They used modeling techniques to assess potential long-term effects from 2018-2050. The study showed that applications of gypsum to the soil alone reduced the pH of the soil. When this was combined with an increased leaching fraction, there was no increase in soil salinity. This result is in agreement with other research on the topic that highlight the need to apply sufficient water alongside the gypsum treatments.

This points to the necessity of examining the second area of mitigation techniques recommended by Etikala et al. (2021), irrigation management techniques, which will be described in the next section.

3.2.2 Irrigation management

Wang et al. (2022) conducted field experiments in China to study the long-term effects of mulched drip irrigation (MDI) with brackish water in arid regions over an 11 year period. The study revealed that this method was actually able to significantly reduce the soil salinity and concentration of soluble salt ions. In general, the study observed that over time salts moved downwards in the soil column (Figure 3). This method of irrigation was

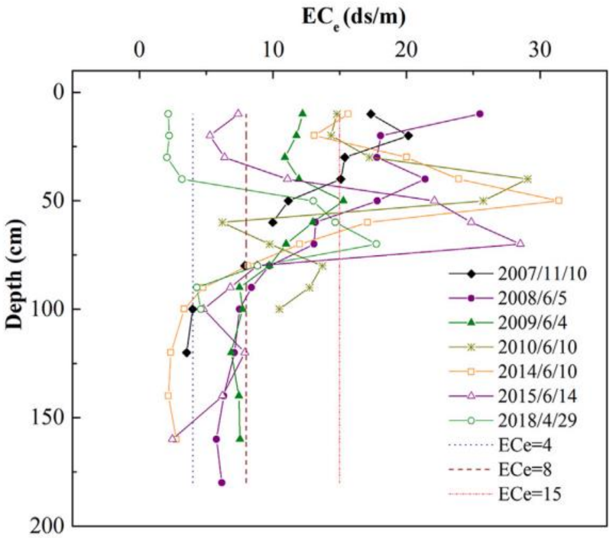


Figure 3. Figure from Wang et al. (2022) showing the observed downward migration of the maximum EC$_e$ in the soil from 2007 to 2018.

able to reclaim the top layer of soil from an initial EC$_e$ of 17.8-25.5 dS m^{-1} in 2008 to 2.1-3.2 dS m^{-1} in 2018. However, the salts did eventually accumulate around 40-80 cm in the soil, with a maximum EC$_e$ of 7.9 dS m^{-1} at 70-80 cm in depth. The authors also observed that soluble salt ions in the soil (Cl^-, Na^+ and K^+) decreased after MDI from leaching, and that Ca^{2+} and SO_4^{2-} increased as they were absorbed by the soil particles and precipitated as $CaSO_4$. However, the accumulation of these ions was much greater in bare soil compared to mulched soil. The accumulation of Ca^{2+} and SO_4^{2-} in bare soil was more serious than that in the mulched land. After brackish MDI, K^+ did decrease, but not as much as the other ions.

It is important here to emphasize some differences between this study and others. Here, while the soil was predominantly sand (65.67-89.00%) it did have significant amounts of silt (6.00-25.33%) and clay (2.00-6.33%). Thus, there was significant interaction between the soil and the groundwater through pore capillary action. Additionally, over the study period, the ground water table decreased from ~1-2 m in 2008 to ~13 m in 2019. Therefore, EC$_e$ also decreased with the declining groundwater level. Another important caveat is that the study fails to report the EC of the irrigation water itself, so while the general trend that salinity decreased with increased time and irrigation does hold, it is difficult to understand how the specific salinity levels will translate to other contexts. Especially to Mediamatic where they have sandy soils, a high groundwater table, and high humidity. However, aside from these differences, the results are still convincing that MDI with brackish water has the potential to reduce soil salinity and effectively irrigate crops.

Another management strategy is to change the irrigation schedule instead of changing the type of irrigation, and alternately irrigate with fresh and saline water. Sang et al. (2020) explored the effects of alternating irrigation with fresh and saline water on soil salinity and the growth and yield of summer maize. In particular, they focused the schedule on different phenological periods where they used either saline or freshwater to irrigate the maize at the jointing, heading, and filling stages (i.e. they had five treatments alternating saline (S) or fresh (F) water FFF, SFS, FSS, SSF, SSS). In this study the saline water had a concentration of 4.0-4.4 g L^{-1} NaCl. Overall, they found that alternating fresh and saline water irrigation always resulted in a smaller increase in soil salinity compared to irrigation with saline water alone. For the maize itself, plant growth was most inhibited by saline irrigation at the jointing stage where the ion imbalance from salt stress lead to a decrease in absorption of other vital ions. However, the authors did observe that if this stress was followed by irrigation with freshwater at the heading stage (SFS), it was sufficient for the plants to recover. The crop yield was also significantly affected by the salinity of water at the heading stage. When the maize was irrigated with saline water first, then freshwater at the heading stage, followed again by saline water (SFS), the yield was only reduced from 11.35 to 8.53 tons ha^{-1}. This was the smallest reduction in yield of all other treatments. Overall, Sang et al. (2020) demonstrate the strategic use of fresh and saline water, especially prioritizing the application of fresh water at crucial growth stages (like the heading period for summer maize), can be used to optimize soil salinity and plant growth.

Similarly, Paraskevopoulou et al. (2022) investigated the growth of *Arthrocnemum macrostachyum* (a native Mediterranean halophyte) under various irrigation treatments alternating seawater and tap water in a simulated green roof system. In the study they applied tap water or seawater every four or eight days to the plants, with the EC of the seawater being 57.6 dS m^{-1}. In the end the experiment consisted of six different treatments, (i) tap water every four days, (ii) tap water every eight days, (iii) seawater every four days, (iv) seawater every eight days, (v) seawater alternated with tap water every four days, (vi) seawater alternated with tap water every eight days. The experiment was set up such that the leachate from the simulated green roof could be analyzed. The EC of the leachate, as well as various plant growth metrics were analyzed at regular intervals. After only 13 and 17, the leachate of the seawater every four and eight days exceeded the EC of the seawater alone. The leachate of the plots where seawater and freshwater were alternated every four or eight days also exceeded the EC of pure seawater, albeit slower, after 25 and 29 days respectively. However, the EC more or less stabilized after 41 days in both experiments, around a mean of 85.9 dS m^{-1} (four days) and 79.9 dS m^{-1} (eight days) compared to pure seawater at 129.3 dS m^{-1} (four days) and 118.5 dS m^{-1} (eight days). Overall, alternating freshwater with seawater was effective in reducing the EC below that of the seawater only plot, but not below that of the seawater itself. However, as the leachate would be concentrated from evaporation out of the green roof system, it is not clear what the relationship is between the EC of the leachate and the actual EC of the soil.

As for plant growth metrics, there were surprisingly few significant differences in plant heights between the different treatments. Only plants grown in seawater irrigated every eight days had significantly lower height than all other treatments. The ground cover of the plants in different treatments showed some more variation. By the end of the 97 days, while plants exposed to freshwater irrigation every four days had the most extensive growth, plants grown with alternating seawater and freshwater every four days outperformed all other experiments. Overall, this study demonstrates that not only can the salinity of the growth medium can be well managed with proper irrigation scheduling, with the correct choice of halophytic plants, urban greenery can be unaffected by saline irrigation.

Zhang et al. (2021) conducted a field experiment assessing the integrated use of saline drip irrigation for reclaiming saline soil in China. The study used various soil matric potentials (a measure of the total soil water potential which determines the movement and availability of water in the soil) to trigger irrigation with five different water salinities (0.8, 3.1, 4.7, 6.3, and 7.8 dS m^{-1}). Over four years, the study reported that all of the drip irrigation treatments were able to reclaim the extremely saline soil from an EC_e of 27.8 dS m-1 to 4.1-7.2 dS m^{-1} for the top 1 m of soil. In particular, the study notes that, after the initiation of treatments, a low-salt zone was established beneath the drip irrigation head and expanded downwards over the years. The survival, plant height, ground diameter, and short dry mass of the shrub used in the experiment, *Caryopteris clandonensis*, was inversely proportional to irrigation salinity. Here, while the authors did describe the ability to reclaim highly saline soils using saline drip irrigation, and demonstrated the ability for even saline drip irrigation to move salts lower in the soil column, they also show that plants are affected directly by the salinity of the irrigation water, emphasizing the need for proper plant selection when using these management techniques.

Chandel et al. (2022) investigated the effects of alternating applications of saline and fresh water on soil salinity and salinity build-up under four seed spices (*Anethum graveolens L.* (Dill), *Nigella sativa L.* (nigella), *Pimpinella anisum L.* (anise), and *Trachyspermum ammi L.* (ajwain)) grown in pots. It is important to note that the pots did not have any drainage in this experiment, so leaching from the 14kg of soil was not allowed. The experiment applied saline water (6.0 dS m^{-1}) to the spices at various times throughout their growth cycle based on 30-day periods from sowing seeds to harvest at 150 days. The findings suggest that alternating applications of saline and fresh water are as effective as continuous fresh-water application. The EC_e and $EC_{1:2}$ of a number of treatments were not statistically greater than continuous freshwater irrigation. These treatments included: saline irrigation for the first 30 days followed by freshwater irrigation until harvest; freshwater irrigation for the first 30 days, followed by saline irrigation for 30 days, followed by freshwater irrigation until harvest; and freshwater irrigation for the first 60 days, followed by 30 days of saline irrigation, followed by freshwater irrigation until harvest. Surprisingly, under the various treatments, the research showed that plant height and seed yield was highest for some spices under alternative application of fresh and saline water compared to freshwater alone. Dill and anise both had the most growth when freshwater was applied until physiological maturity (120 days), but then was followed by saline irrigation until harvesting. Similarly, all spices showed the greatest seed yields under this same irrigation treatment. Therefore, Chandel et al. (2022) was able to show that using alternative irrigation methods can simultaneously manage soil salinity and improve growth of non-halophytic plants.

4. Conclusions and Recommendations

The goal of the Korreltje Zout project, from the beginning, has been to shut off the tap – stop using fresh drinking water for garden irrigation and the aquaponics system. Here I recommend specific steps and considerations to realize this goal. TO start, I will treat the aquaponics and the garden separately, because, currently, they are separate systems each with unique challenges.

4.1 Outdoor gardens

4.1.1 Salinity prognosis

The gardens at Mediamatic are currently in raised beds, however the intent is to change this so that the gardens are directly in the soil. Research shows that the soil composition fundamentally changes the dynamics of soil salinity. While we believe that the soil composition at Mediamatic is predominantly sand, the exact ratio is unclear. A first step in this process may be testing the soil to understand the exact ratio of sand to other soil components. However, in the case that the soil is almost entirely sand, similar to experiments by de Vos et al. (2016) where the soil consisted of ~93% sand, it is likely that the salinity of the soil will not change significantly and will maintain the same EC as the brackish water used for irrigation. Especially because, as shown by other research conducted in the Netherlands (De Vos et al., 2016; Kroes and Supit, 2011; Raats, 2015; SalFar, 2022; Stofberg, 2016), the Amsterdam climate is sufficiently humid and provides enough rainfall for plant evapotranspiration to be low, and for the soil to receive sufficient rainwater to control salinity levels.

Measurements conducted by Mediamatic show that the EC of the Dijksgracht typically ranges between an EC of 2-5 dS m^{-1}. Thus, this window is a reasonable prediction for the future salinity of the soil. Therefore, following de Vos et al. (2016) and SalFar (2022), I would suggest that the garden be planted with plants that can tolerate this range of salinity in the irrigation water (See Appendix Table I for a list of potential plants). As reviewed in the literature above, many plants can tolerate these levels (even glycophytic crops) so this will not greatly restrict the diversity of potential plants.

4.1.2 Management recommendations

If plants are chosen that can tolerate the above-mentioned salinity levels, then no other saline mitigation is needed. However, it may still be advisable to implement a drip irrigation system, with a mulched surface. As described by Etikala et al. (2021), Wang et al. (2022), and Zhang et al. (2021), implementing this system will further ensure that there will be low accumulation of salts in the soil, less than that of the brackish irrigation water.

Overall, it would also be advisable to monitor the salinity levels over time. Conducting EC measurements of the soil (where $EC_{1:2}$ is the most simple) will allow monitoring of the soil salinity to ensure that it is not rising significantly. In the case that it does rise above the tolerance levels of the plants, it will be important to mitigate this by either irrigating with the canal water at a higher leaching fraction (Etikala et al., 2021; Phogat et al. 2020, Wang et al. 2022, Zhang et al., 2021) or flushing with fresh water (Chandel et al., 2022; Paraskevopoulou et al., 2022; Sang et al., 2020). Efforts to collect rainwater at Mediamatic are already underway, to allow freshwater flushing without tap water. However, it is not yet clear how large the outdoor gardens will be. When this is known, it will be important to calculate the exact amount of freshwater needed to flush out the salts and be determined if the rainwater collection will be sufficient, and the tap can indeed be turned off.

Finally, I recommend using bio-organic soil amendments. According to the literature (Bello et al., 2021; Etikala et al., 2021; Kumari et al., 2021; Phogat et al., 2020; Sabagh et al., 2021) these amendments can provide a wide range of benefits. Not only can they reduce soil salinity on their own through chemical and microbial action, they also greatly benefit plant growth. Applying bio-char, or compost from the gardens and/or restaurant may be greatly beneficial to the gardens. Another interesting option may be to add the nitrogenous effluent from the aquaponics system, however this may be concentrated with salt, which I will discuss in the next section.

Recommendations:

1. Sample the soil to understand it's current composition.
2. Choose plants tolerant of 2-5 dS m^{-1}.
3. Implement mulched drip irrigation.
4. Monitor soil salinity and flush with rain water or fresh water if needed.
5. Monitor plants for signs of nutrient deficiencies (especially potassium) and add soil amendments if needed. Especially bio-organic fertilizers.

4.2 Aquaponics system

4.2.1 Salinity prognosis

The aquaponics system at Mediamatic is a closed system, where the only water that leaves is through evaporation. Therefore, any salts in the system will naturally accumulate. The entire system consists of approximately 5000 L of water, where 1000 L need to be added to the system weekly to account for evaporation losses. Assuming an average EC of the canal, simplistic predictions conducted by Mediamatic indicate that the concentration of Na^+ will rise above 1500 ppm within 9 weeks. Currently, this is the level that is understood to be tolerable for the fish in the system. Therefore, for the long-term sustainability of integrating canal water into the aquaponics, the system would need to be flushed every time it meets this threshold. While some strategies can be employed to extend this time frame, such as monitoring the fluctuating EC of the canal and only replenishing after rainfall events when the EC is lowest, this number can serve as a conservative estimate for the freshwater requirements of the system. Therefore, in this scenario, it would be necessary to add 5,000 L of freshwater to the system once every 9 weeks. Yearly, this would require about 29,000 L of freshwater.

The current rainwater collection capacity at Mediamatic is around 30-40 L per mm of rainfall. Very roughly, based on various sources, and disregarding important factors such as seasonality, the annual rainfall in Amsterdam is between 700-900 mm per year. The expected yield of rainwater is therefore expected to be somewhere between 21,000 and 36,000 L. Therefore, in some years the rainwater will be sufficient to flush salts from aquaponics, with some leftover for other uses such as the outdoor gardens, but in others it might be difficult. Further, in years when rainfall is lowest, the EC of the canal will also be higher on average, making the system more saline, and less water available for flushing. However, as stated above, these predictions are imprecise, and other factors need to be considered such as seasonal requirements of the aquaponics system, exact dynamics of salts in the system, seasonality of rainfall and the changing EC of the canal. However, as it stands under these estimations the sustainability of this system is not guaranteed.

4.2.2 Management recommendations

With the shortfall of rainwater collection, a few options exist. The first is to change the system to be more adaptable to a higher saline environment. To adjust to the lowest estimate of rainwater collection, if only 21,000 L of rainwater can be collected, this will amount to only flushing the system four times over the course of a year, or once every 13 weeks. According to the current estimations this would lead to an upper Na^+ concentration of ~2200 ppm. While many of the current plants can tolerate this level of salinity, the African Catfish currently in the system have a low salt tolerance and may not be able to survive. Therefore, if the tap is to be turned off, it would be advisable to either find an alternative species of fish that can tolerate these higher salinity levels, or to remove fish from the system and find an alternative method of introducing beneficial nutrients (e.g. compost teas).

However, this is still assuming complete use of the rainwater in the system, with no potential to use it for other gardens. Therefore, a second option to consider is to expand the current amount of rainwater collection. Currently, only one drainpipe from the main Mediamatic roof is planned for rainwater collection, but more pipes, or other roofs could be used. If, say, the rainwater storage capacity was doubled, then the low estimate of rainwater collection would be 42,000 L per year, which would significantly put estimates outside of the margins for error, and leave freshwater for other applications. However, it will again be necessary to calculate the seasonal availability of rainwater to ensure that the needs can be met year-round. For example, according to the Royal Dutch Meteorological Institute (KNMI), there was only 106 mm of rainfall in the spring 2022. This would only provide 8,480 L of rainwater (assuming the high end of 80 L collected per mm of rain), which could flush the system once fully in 13 weeks, even at double capacity. However, this does not account for potential storage from previous months, and more sophisticated predictions should be made. Regardless, it is important to either substantially increase the rainwater collection capacity or consider other options in combination.

A final low-cost, low-tech method to consider is implementing methods of bio-filtration of salts. As described in the literature review, many halophytic plants not only tolerate salts but actively remove salt ions from their environment and accumulate them in their tissues. Focusing on integrating these plants directly into the aquaponics system, or implementing a halophytic biofilter in between the canal and the aquaponics system has the potential to desalinate the water. By using the natural biology of plants, it would reduce the need for other interventions in the system. Further, it would reduce the salinity of the aquaponics runoff, allowing the nutrient rich effluent to potentially be used in the gardens outdoors.

Recommendations:

1. Investigate alternative options for the African catfish to increase the low threshold of the system. Either replacing them with other fish, or with another method of nutrient supplementation entirely.
2. Increase the rainwater collection capacity. Under simplistic calculations, the current system should at least be doubled to mitigate seasonal and yearly variations in rainfall.
3. Introduce halophytic plants into the system that can actively remove salt. Incorporate them directly into the aquaponics grow beds, or as an intermediary step before adding canal water to the system.

4.3 Suggestions for a system: Future outlooks

Currently, the aquaponics greenhouse and the outdoor gardens act as two separate entities. Additionally, plans are in place to add another irrigated area (potentially a greenhouse or green roof) to the roof of the Mediamatic building and to shut off the tap for other gardens at Mediamatic that are currently irrigated with fresh water. In this final chapter I make suggestions to integrate these separate components into a system.

As it stands, if the tap is shut off, there is not sufficient freshwater to sustain the current system, and especially not to supply any additional irrigated areas. However, I propose that integrating these separate pieces into a system will provide myriad benefits and allow the tap to truly be shut off.

In Figure 4 I provide a rough schematic of this system. I will refer to the figure, and its labelled elements in the following section to illustrate the potential system. Overall, the system can be viewed like a living machine, that provides a slow cascade of salt filtration throughout the system. It will slowly move water across Mediamatic and provide canal water of gradually decreasing salinities to the various gardens which can be adapted to these varying levels of salinity.

First, I propose to install a permanent pump (1) connected to a holding tank for brackish canal water (2). Currently, there is no pump permanently installed to add canal water to the system. Using a hydraulic ram pump, which is low-tech, low-cost, low-maintenance, and does not require power to operate (Practical Engineering, 2019), a slow intake of water could be provided to a holding tank. This holding tank could be designed to be transparent and as a display for the public to demonstrate what is in their canal water. This could be integrated with some amount of data presentation to display current salinity levels of the canal and communicate about salinity problems and salinization of the canal to the public. This would be especially useful to educate and inspire

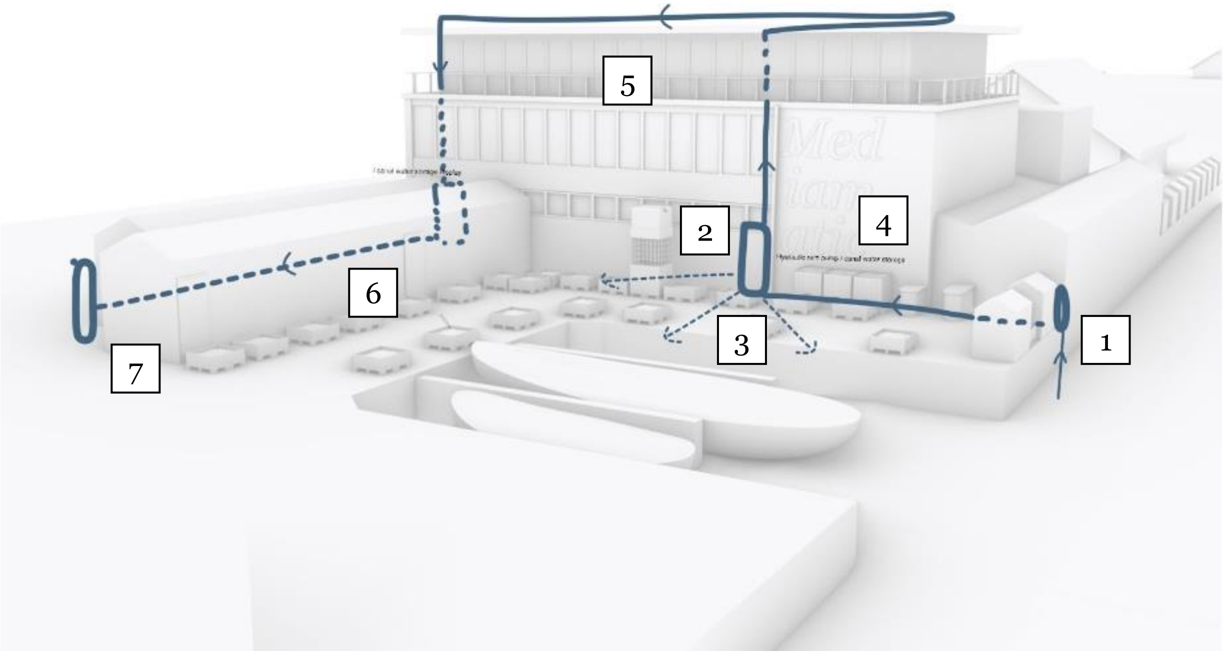


Figure 4. Draft sketch of water flow in proposed integrated irrigation system at Mediamatic. By Jishuang Zheng and Max Ciaglo.

more people to use the canal water themselves. I would propose it also be integrated with artwork such as the "Growing Connections" project of Marjolijn Boterenbrood to demonstrate what is alive and living in the canals of Amsterdam. This initial holding tank could also be used as the first step of a halophytic filter by adding algae to the tank. In one study, Sahle-Demessie et al. (2019) demonstrated that some species of algae could reduce the salinity levels of water by 30%. By integrating this into the holding tank we achieve the first step of salt filtration.

Next, I propose to add a drip irrigation system leading from the holding tank (3). This system will provide mostly brackish water to the terrace garden, which, as described in Section 4.1.2, should be designed to tolerate brackish conditions. This garden will act as a garden to demonstrate the possibilities of growing plants and maintaining urban green space directly from brackish canal water in Amsterdam. When necessary, this system can be connected to the rainwater collection system which is already installed nearby (4).

Water from the holding tank can then flow to the roof garden system (5). At this stage in the system the water will still be saline. If the roof component is installed as an open-air green roof instead of a green house, water will likely evaporate as it moves across the roof and can concentrate salts. Therefore, the system on the roof should also contain halophytes, and can act as another stage in the filter. However, if the roof component is open-air, it will also act as another rain catchment system, potentially lowering the salinity of the system.

This water can then flow down from the roof and into the aquaponics green house (6), as well into other green spaces around Mediamatic. At this point, the aim would be for the water to have been at least slightly desalinated. However, it is hard to say at this very early stage what salinity levels to reasonably expect, and it will take some research and modelling. If the water is expected to still be saline, with an EC similar the brackish canal water, I propose adding a specific halophyte filter at this stage. Especially within the aquaponics greenhouse, plants such as mangroves which specifically remove salt into their leaves (Parida & Jha, 2010), or tanks of halophytic algae (Sahle-Demessie et al., 2019), could be grown. The water could then be fed directly into the aquaponics system, without needing to implement major changes to the system or the other green spaces.

Ultimately, I propose adding a final display to the system (7). This final display would be another holding tank, either with the outflow of the halophyte filter, before adding it to aquaponics, or the effluent from aquaponics itself. This tank would be designed to display the quality of the water after it has gone through the system, to contrast with the initial holding tank. Alternatively, if the water is still saline at this stage, and salts are accumulating in aquaponics, this could also act as a holding tank for a flush of the aquaponics system. And it could display the nutrients and salts that accumulate during the closed cycle process of aquaponic farming. At this stage, if the salt-levels are high, the display could even run off of electricity generated by a saltwater circuit (TeachEngineering, 2018).

This would ultimately demonstrate that every part of a system, the inflow, throughflow, and outflow, can be used in creative and effective ways.

Overall, this proposed system would demonstrate multiple approaches to utilizing the brackish canal water that is within the reach of Amsterdammers and people throughout the Netherlands. In the end, this multifaceted, system-based approach, would inspire innovative, circular and sustainable thinking.

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Appendix

Scientific name	Common name	Annual, perennial, hardy annual	Salt tolerance	Usage tested	Notes
Salicornia europaea	Glasswort	A	High	Vegetable, salad, raw or cooked, pesto, jam, spirit	Salt treatment necessary for the characteristic taste
Mesembryanthemum cordifolium	Heart-leaf	P (N)	High	Salad, raw, leaves and flowers	Salt treatment necessary for the characteristic taste
Carpobrotus rossii	Karkalla	P (N)	High	Salad, fresh or dried	Rich in anti-oxidants
Limbarda crithmoides	Golden samphire	P (?)	High	Salad, raw, cooked as leaf vegetable, spirit	Sea-fennel-like taste
Crithmum maritimum	Sea fennel	P (Y)	Medium	Herb, raw and cooked food, spirit	Rich in vitamins and omega-3 fatty acid
Arthro-cnemum glaucum	Perennial salicornia	P (Y)	High	Similar to Salicornia europaea	Taste turns woody in autumn
Mesembrya-nthemum crystallinum	Ice plant	A	High	Salad, raw or cooked	Fresh and salty
Lepidium latifolium	Pepperweed	P (Y)	Medium	Salad, less bitter after cooking	Bitter and sharp taste like cress
Crambe maritima	Sea kale	P (Y)	High	Vegetable, cooked	Preparation like asparagus
Mertensia maritima	Oyster plant	P (Y)	Medium	Salad, raw	Taste like crab chips
Cochlearia officinalis	Scurvy grass	A	High	Salad & soap	Bitter, nice smell, high Vitamin C
Cochleria danica	Danish scurvy grass	P (Y)	High	See above	See above
Cochlearia glastifolia	Perennial Scurvy grass	P (Y)	High	See above	See above
Salsola soda	Opposite-leaved saltwort	A	High	Raw or cooked	Taste resembles spinach
Plantago coronopus	Buck's-horn plantain	P (Y)	Medium	Salad, raw or cooked	Rich in calcium & vitamins
Portulaca oleracea subsp. sativa	Golden purslane	A	Medium	Herb, salad	Similar to parsley or celery. High in vitamin C
Foeniculum vulgare	Fennel	P (Y)	Medium	Herb, raw & cooked	Bulb, seeds, and flowers are edible
Atriplex halimus	Mediterranean saltbush	P (?)	Medium	Salad or vegetable, raw or cooked	Forage plant in arid areas
Triglochin maritim	Seaside arrowgrass	A or P (Y)	High	"Röhrkohl" is a traditional spring dish in some northern regions of Germany	Cooking removes alkaloids

Table I. From Salfar (2022), a table of halophytic plants grown in Terschelling, the Netherlands under spray irrigation with saline water of 15 dS m^{-1}.