

Conference

# Saline Futures

Addressing climate change  
and food security

## Book of Abstracts

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## Table of Contents

<b>Policy and Management</b> .....	6
I Addressing Climate Change and Food Security, time, place.....	6
1. Freshwater salinisation and its drivers: A critical water quality challenge with implications for agricultural development - Josefin Thorslund, Michelle van Vliet .....	6
2. Understanding Farmers' Perceptions of and Livelihoods Adaptation to Climate Change: Insights from the Coastal Bangladesh - Md. Jahangir Kabir, Donald H Gaydon, Mohammad Mainuddin, Mohammad Moniruzzaman .....	10
3. Delta environments: landscapes at major threat from salinity - Edward G Barrett-Lennard ..	13
4. The Effect of Climate Change Adaptation on Rural Community Livelihoods - Nakasaga Halima, Kabagenyi Hilder, Lukyamuzi Grace, Mbidde Robertson (presenting author: Nalubega Rose) .....	15
II Awareness raising and capacity building for saline farming.....	16
5. A Legal Perspective on the Effects and Prevention of Salinization - Annalies Outhuijse, Ida Helene Groninga, Tatia Brunings .....	16
6. Is saline farming a shape shifter? Review of the debate on and policies for climate adaptation at the Flemish coast (2005-2017) - Jeroen De Waegemaeker.....	20
7. A vision and a strategy for mitigating and adapting to salinization of highly productive clay soils in the Netherlands - Mindert de Vries .....	23
8. Adaptive Management Strategies to Alleviate the Impacts of Saltwater Inundation on Agricultural Lands - Christopher F. Miller .....	24
9. Salinization of the coastal zone as driver for innovation in flood risk management strategy - Jantsje M. van Loon-Steensma .....	26
10. Salinization and agriculture in the Netherlands: benchmarking stakeholder perspectives - Isa Camara Beauchampet .....	29
III Food-water-energy nexus .....	32
11. Salinity dynamics in river water, canal water, pond water and groundwater over the dry season in Ganges Delta - Afrin Jahan Mila, Richard Bell, Edward Barrett-Lennard, Enamul Kabir and Yingying Yu .....	32
12. What if it becomes too saline? - Reinier Nauta .....	33
13. The impacts of North Sea flooding to UK agriculture - Iain Gould, Isobel Wright, Gary Bosworth, Eric Ruto, Martin Collison, Simon Pearson .....	34
14. Sustainable saline agriculture in Iran: Turning Threats into Opportunities - Raheleh Malekian .....	37
15. Potentials of saline agriculture for subsistence and livelihoods of local poor communities in the Jordan Valley - Ziad Al-Ghazawi.....	38
IV Fresh and brackish water management in potentially saline soils.....	40
16. Managing salinization under climate change: using degraded irrigation waters and new technologies - Francisco Pedrero Salcedoa, Juan José Alarcón Cabañeroa, Margo Robbenb, Huub Rijnaartsb , Pedro Javier Guillermo Lópezza .....	40

17.	Nine steps towards a sustainable climate-proof fresh groundwater supply: the case of Zeeland, the Netherlands - Oude Essink, Gualbert.....	41
18.	Saline groundwater seepage increase with sea level rise - Johan Medenblik.....	48
19.	The Water Farm: collaborative water system measures and governance approach to increase self-sufficiency of freshwater availability for agriculture - Rozema, J.; Pauw, P.; Arts, M.; van Baaren, E; Nikkels, M.; Moermans, T. ....	50
<b>Innovations</b> .....		52
V Experiments and promising crops .....		52
20.	Quinoa, a Promising Halophyte with Modified Planting Date and Minimum Water and Pesticide Requirements for Fars province, Iran - Rezvan Talebnejad .....	52
21.	The study of quinoa at high salinity in the field conditions - Muhammad Shahid .....	54
22.	Screening of Sorghum genotypes in the coastal saline region of Bangladesh - M.H. Rashid, M. K. Shahadat, M. Amiruzzaman and M. Akkas Ali .....	58
23.	Multi-year evaluation field trials of <i>Salicornia bigelovii</i> in United Arab Emirates: prospects & challenges - Dionysia Lyra, Hifzur Rahman, Hamza Khan and R.K. Singh.....	59
VI Promising crops for saline farming .....		60
24.	Physiological growth and gas exchange of saffron ( <i>Crocus sativus</i> L) in saline and deficit irrigation condition under different planting methods - Maryam Dastranj, Alireza Sepaskhah, Seyed Mohammad Mirsafi.....	60
25.	<i>Tetragonia tetragonoides</i> as a salt-tolerant crop in a saline agriculture context - Giulia Atzori	62
26.	Investigations of soils and plants from farms and field trials in South-East Norway, can make the local farmer better prepared from future episodes of sea water flooding - Åsgeir R. Almås and Susanne Eich-Greatorex .....	65
VII Salinity adapted cultivation strategies .....		66
27.	Reducing Salinity Effect On Alfalfa ( <i>Medicago Sativa</i> ) Production Using Soil Conditioner- Case Of Lahbab Farm In Dubai - Khalil Ur Rahman, Mohammed Khalifa Bin Thaleth and Khalfan Al Suwaidi.....	66
28.	Crop Intensification option through zero tillage potato cultivation using mulch that improves soil properties in the south-western saline soil of Bangladesh - Mustafa Kamal Shahadat, Md. Harunor Rashid, Farzana Jahan Juthi and Munmun Ahmed .....	67
29.	Performance Of Intercropping Short Duration Leafy Vegetables With Elephant Foot Yam In The Coastal Area Of Bangladesh - M.H. Rashid, M. K. Shahadat and M. Akkas Ali .....	68
30.	Spaarwater: sustainable and profitable usage of fresh water for agriculture in the Wadden Sea Region - J. Velstra, T. te Winkel, A. Oord, S. Burger, B. de la Loma Gonzalez .....	69
31.	Desalinization of greenhouse floors - Stephan Jung.....	74
VIII Innovation and practical experience at farm level .....		77
32.	Putting Saline Agriculture into Practise - a showcase from Bangladesh - Arjen de Vos.....	77
33.	Climate resilient agricultural practices in the saline prone areas of Bangladesh - Muhammad Abdur Rahaman Rana.....	79

34.	Modular farming approach utilizing saline water resources to enhance food and nutrition security in desert environments: two case studies in United Arab Emirates - Dionysia Lyra and Stathis Lampakis .....	83
35.	Saline Agriculture, Smart Water Management and Agroforestry - B. Bruning, R. van Opstal, E. van Zandwijk .....	84
36.	Sustainable Saline Soils Use System for Food Security and Poverty Alleviation in Ghana - Rosemary Nunoo .....	86
<b>Geography and Biology .....</b>		<b>87</b>
<b>IX Revitalization of saline degraded soils.....</b>		<b>87</b>
37.	The monitoring of soil salinity using remote sensing data on agricultural lands of Central Asia - Konyushkova M.V., Pankova Ye.I., Kontonoytseva A.A.....	87
38.	A Simplified Model for Soil Salinity and Sodicty in Drylands - Isaac Kramer, Yair Mau .....	91
39.	Droughts impacts on surface salinity levels and implications for irrigation water scarcity in the United States - Edward Jones, Michelle T.H. van Vliet.....	95
40.	Soil salinity in Denmark - Laurids Siig Christensen.....	99
41.	Recovery opportunities and prospects for the use of degraded land in the context of structural economic and technological changes - Mikhail Kislitskii.....	102
42.	Revitalisation of degraded lands – Ties van der Hoeven .....	105
<b>X Traits affecting salinity tolerance.....</b>		<b>106</b>
43.	Development and characterization of an EMS mutated wheat population and identification of salt tolerant wheat lines - Lethin Johanna, Shakil Shahriar S.M., Hassan Sameer, Sirijovski Nick, Töpel Mats, Olsson Olof, Aronsson Henrik .....	107
44.	OsHAK9, a potassium transporter, is essential for seed germination in rice under salt stress - Peng Zeng, Luofeng Qian, Ting Xie, Xumei Qian, Yuqian Jiang, Zhoufei Wang, Henrik Aronsson, Jinping Cheng, Hongsheng Zhang .....	107
45.	Genome Wide Analysis Of WRKY Transcription Factors In The Wheat Genome With Emphasis On Regulating Salt Tolerance - Hassan Sameer, Lethin Johanna, Blomberg Rasmus, Mousavi Hesam, Aronsson Henrik .....	108
46.	Molecular breeding of Triticum aestivum in abiotic stress - Esteri Viitanen, Sameer Hassan, Henrik Aronsson.....	109
47.	Effects of elevated salinity on agronomic and physiological parameters of different mutated wheat lines - Hesam Mousavi, Johanna Lethin, Nupur Naik, Olof Olsson, Henrik Aronsson	110
<b>XI Interactions among salinity, roots and microbial communities .....</b>		<b>111</b>
48.	Rhizobiome of resurrection plants-potential source of plant growth promoting bacteria - Zivko Jovanovic, Svetlana Radovic, Tamara Rakic, Jelena Lozo, Djordje Fira .....	111
49.	Endophytic fungi-mediated salinity stress tolerance in Solanum dulcamara (Bittersweet) - Sasirekha Munikumar, J. Theo M. Elzenga, J. Dick van Elsas, N. Nataraja Karaba.....	112
50.	Elucidation of root traits that contribute to yield stabilisation in potato under climate change - Jan Henk Venema and J. Theo M. Elzenga .....	115

51.	Root system architecture and grass productivity under salt stress - L. Wang, J. Theo M. Elzenga .....	116
XII	Alternative use of salt-tolerant plants .....	117
52.	Evaluating crop salt tolerance from field trials at Salt Farm Texel – a new venue - G. van Straten, A. de Vos, J. Rozema, B. Bruning, P.M. van Bodegom .....	117
53.	Saline plant molecular factory for production of pharmaceuticals, functional feed, and biofuels using biorefinery technologies - Mette Hedegaard Thomsen, Tanmay Chaturvedi, Iwona Cybulska .....	122
54.	Bio-fractionation of <i>Salicornia bigelovii</i> to increase the value of the green biomass - Aslak Christiansen, Henning Jørgensen, Dionysia Lyra .....	123
	<b>Additional extended abstracts</b> .....	127
55.	Genetic characterization of salinity tolerance traits to increase salinity tolerance in crops - Mark Tester .....	127
56.	Identifying crop-varieties suitable to grow under saline conditions - Andrés Parra González, Bas Bruning, Arjen de Vos.....	127
57.	Constraint-level excess water in coastal soil can be a resource for cropping during winter in the southwestern region of Bangladesh - Md. Enamul Kabir, Bidhan Chandro Sarker .....	129
58.	Cropping System Based Irrigation for Improving Crop and Water Productivity in the Coastal Zone of Bangladesh - Khokan Kumer Sarker, S.S.A. Kamar, M.A. Hossain, M. Mainuddin, R. Bell, E.G. Barrett-Lennard, D. Gaydon, M. Glover, R.R. Saha, M.S.I. Khan and M. Maniruzaman.....	131
59.	Effects of Fresh and Saline Water for Irrigation of Sunflower in the Salt-Affected Coastal Zone of Bangladesh - Khokan Kumer Sarker, S.S.A. Kamar, M. Mainuddin, R. Bell, E.G. Barrett-Lennard, D. Gaydon, M. Glover, M.A. Hossain, K.F.I. Murad, M.H. Rashid, M.S.I. Khan, M.M.K. Shadat and M. Maniruzzaman .....	134
60.	Mycologically Synthesized Nanoparticles for Prevention of Soil Salinity - K. Harish Kumar, Dr. V. P. Savalgi, .....	137
61.	Building small farmers’ capacities on climate-resilience farming in saline affected regions of Haryana, India - Pawan Kumar.....	140
62.	Effect of irrigation water alkalinity on performance of some wheat cultivars in a semi-arid region of northwest India - Pawitar Singh, O P Choudhary and Pritpal Singh.....	142
63.	Kale forage ( <i>Brassica napus</i> ) solution for use, phytoremediation and preservation of salty soil - Benbessis Yamina, Halilat Med Taher & Salhinasrine .....	144
64.	Halophytes: Alternative applications for saline plants - Yanik Nyberg.....	145



# Policy and Management

## I Addressing Climate Change and Food Security, time, place

1. Freshwater salinisation and its drivers: A critical water quality challenge with implications for agricultural development - Josefin Thorslund, Michelle van Vliet

### **Freshwater salinisation and its drivers: A critical water quality challenge with implications for agricultural development**

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Freshwater salinisation, irrigation, agricultural water use, climate change, drivers

#### **Introduction**

Salinity impacts on freshwater resources is becoming a widespread water quality issue, particularly in dryland and coastal regions, with large socio-economic and environmental effects (Pereira et al., 2019; Sietz et al., 2011). The causes of freshwater salinisation can be manifold, arising from both natural processes (i.e. primary salinisation) and human activities (i.e. secondary salinisation) (Cañedo-Argüelles et al., 2013). Two main drivers of freshwater salinisation are climate change and agricultural development (Olson 2018; Scanlon et al., 2007). Both these drivers are projected to increase evapotranspiration and decrease water availability, causing salinity to increase due to limited dilution capacity and evapo-concentration effects (Thorslund et al., 2018). Well-known examples of freshwater salinisation due to these drivers include the drying of the Aral Sea, where agricultural water diversions for cotton production reduced the freshwater inflow to the lake. Such irrigation expansion led to a drastic volume reduction, with associated salinity increase, and ecosystem collapse (Jarsjö et al., 2008). Lake Urmia, in Iran, is another on-going severe example of freshwater salinisation. Here, irrigation, in combination with climate change, have already driven the lake region towards severe salinisation and water scarcity issues, with huge negative socio-economic and environmental consequences (Shadkam et al., 2016).

In addition to being a driver of freshwater salinisation, the agriculture water use sector is also very sensitive to high salinity, mainly in terms of irrigation water quality requirements, but also for livestock water use (Alam et al., 2017). Although saline agriculture has been discussed as a potential management strategy for coping with salinized water use (Qadir and Oster 2004), the global crop production is adversely impacted by high salinity. Salinity issues may severely constrain agricultural development due to its negative effects on crop yields and soil structure (Zörb et al., 2018). Since irrigated agriculture accounts for over 30% of global food production, salinisation of freshwater resources could thus have large impact on food security (Kadiresan and Khanal 2018).

Although individual case studies have targeted freshwater salinisation, limited knowledge exist about freshwater salinisation in different basins globally and its impact for agricultural water use.

This project aims to address these knowledge gaps by assessing, at cross-regional scales: (1) the spatial and temporal patterns of freshwater salinisation, (2) its impact on agricultural water use and development and (3) the relative contribution of both anthropogenic and hydroclimatic drivers to freshwater salinisation.

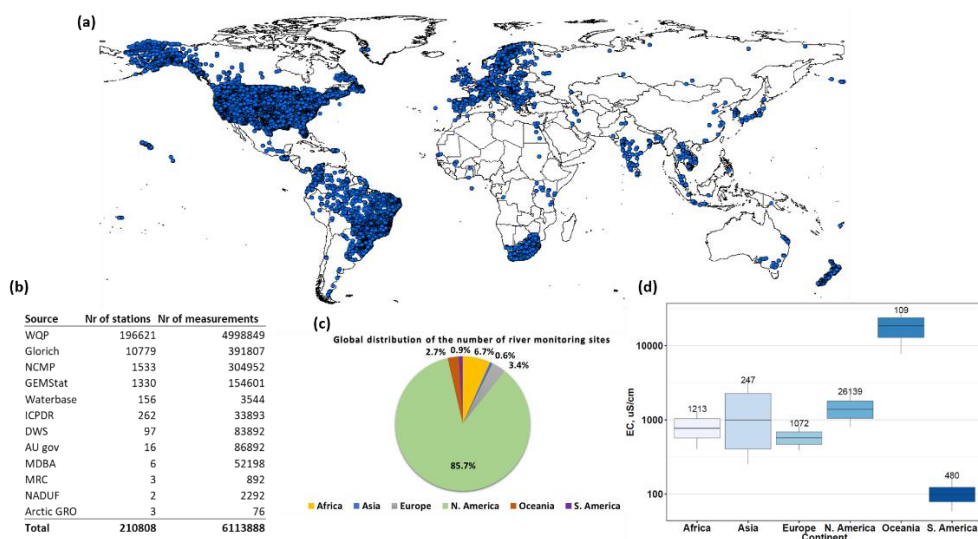
## Methods

To address knowledge gaps on the salinity status of water resources at large spatial scales, we synthesized and combined observation-based salinity data from different data products and sources. We used both cross-regional and global datasets, including for instance the USGS National Water Information System (NWIS) (<https://www.usgs.gov/nwis-national-water-information-system>), the GEMStat water quality database from the International Centre for Water Resources and Global Change (GEMS/Water. <http://www.gemstat.org/>), as well as data from individual river basin management commissions and other more local sources. If electrical conductivity (EC), which is the most commonly monitored parameter of salinity, was not available, other parameters (e.g. total dissolved solids) were synthesized and converted to EC.

For reasons of comparability and for evaluating long term trends, station data was selected for the period 1980 until present (up to 2018). For the analyses, a data selection criterion of at least 30 measurements for each station (only results for rivers are included here) was used. Stations that fulfilled the data criteria were then aggregated to various scales (basin, country, continent) and further analyzed in terms of spatial and temporal trends. For evaluating salinity impacts on agricultural water use, salinity levels were also related to water quality guideline levels for irrigation water use, using data from FAO ([www.fao.org](http://www.fao.org)).

## Preliminary results and future outlook

The new salinity dataset for river monitoring stations across the world are shown graphically in Fig. 1a and its individual data sources are given in Fig. 1b. The dataset comprises over 210 000 individual stations and a total of more than 6 million salinity measurements. The overall highest station density is found in North America (comprising a total 86% of all monitoring stations; Fig. 1c), whereas the lowest station density is found in Asia (0.6 %), closely followed by South America (0.9 %). Surprisingly, Africa has a higher total amount of stations compared to Europe (6.7 % vs. 3.4 %), however the stations in Europe are more evenly distributed across the continent compared to Africa, where the majority of salinity monitoring stations are located in South Africa.

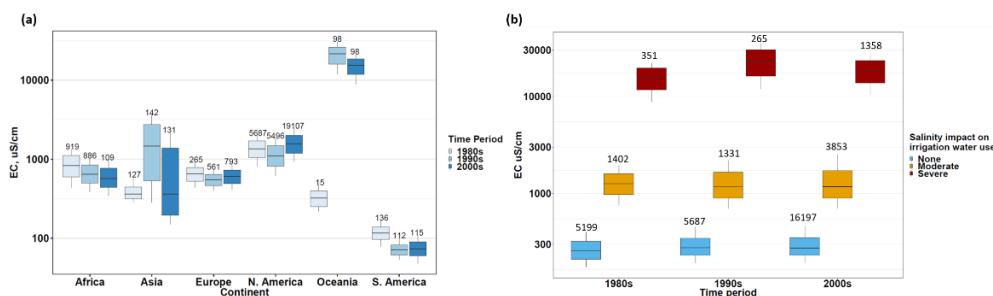


**Figure 1.** Figure showing (a) the global distribution of the combined salinity (EC) dataset for river monitoring stations. The table in (b) shows the individual data sources, their number of stations and measurements, as well as the total number of stations and measurements of the combined dataset. The pie chart in (c) shows the comparative continental distribution of monitoring sites, and (d) shows a boxplot of long-term salinity levels (from 1980-most recent) in river basins, grouped over continents. The number on top of each boxplot represents the total number of included monitoring stations (i.e. that fulfill the selection criteria) per continent.

Fig. 1d shows long-term salinity levels of river basin aggregated to the continental scale. Salinity levels are highest for river basins in Oceania, with a median EC of 18525  $\mu\text{s/cm}$  (number of stations,  $n = 109$ ). The overall lowest salinity is found in river basins in South America, with a long-term median of 100  $\mu\text{s/cm}$  ( $n = 480$ ). River basins in North America has the overall highest number of sampled stations ( $n = 26\ 139$ ), and a long-term median salinity of 1388  $\mu\text{s/cm}$ . In terms of impacts for agricultural water use, these salinity levels were compared to water quality guidelines for irrigation. A salinity level below 700  $\mu\text{s/cm}$  for EC has no impact on irrigation water use, whereas levels up to 3000  $\mu\text{s/cm}$  has moderate impacts and values above 3000  $\mu\text{s/cm}$  are considered to have a severe impact (FAO). For all continents over the studied time period, only river basins in South America (100  $\mu\text{s/cm}$ ) and Europe (574  $\mu\text{s/cm}$ ) have salinity levels which are below any threshold guideline values for irrigation water use. These results highlight that the geographical spread of salinity water quality issues for irrigation water use are widespread throughout the world, with the highest overall impact in Oceania.

Fig. 2a further shows salinity changes across continents over time, from the 1980s up until today. Oceania is the only continent with a substantial increase in salinity over time, from 322 to over 15000  $\mu\text{s/cm}$  from the 1980s up until today. In contrast, salinity levels in river basins in Africa and South America have decreased over time, whereas river basins in Europe, North America and Asia only show a slight increasing trend from the 1980s up until today. However, Asia shows a large increase in salinity in the 1990s compared to the other time periods. Overall, no consistent pattern of salinity changes occurs across the continental scale.

Grouping the river basins instead according to their different salinity impact level for irrigation water use (Fig. 2b), there is an overall increasing trend for the most saline rivers over time, whereas the lower salinity river basins show no increasing trend. This suggests that rivers that had a higher salinity from the earlier period increase more over time than those without salinity issues. Reasons for increasing salinity may include flow alterations, both through lower average flows and less high flow events, which brings less dilution capacity and less flushing out of salts over time. Salt entering rivers from runoff from the landscape may also increase over time due to land-use changes and increasing anthropogenic inputs (Diamantini et al., 2018; Kaushal et al., 2018).





**Figure 2.** Boxplot (a) showing salinity trends over decadal scales (from the 1980s until today), grouped over continents and (b) showing salinity changes over the same time periods, but here grouped according to salinity classifications of river basins, according to restriction on irrigation water use due to guideline threshold values.

These preliminary results give some first indications of large-scale patterns and changes of freshwater salinity and its potential impact for irrigation water use. Sources of uncertainty include flow dependence of salinity levels, sample sizes and the possibility of different monitoring stations in different sample groups (no selection criteria of choosing only the same stations for all time periods were used). To decrease such uncertainties, further uncertainty and trend analyses at both individual stations and larger scales will be conducted, to get a deeper understanding about historic to current salinisation of freshwater and its impact for agricultural water use. Further outcomes of this project are also to bring new knowledge on the future trajectories of salinisation of water resources (including main drivers) and its impacts on water scarcity and agricultural water use. In addition to novel scientific insights of these dynamics, this knowledge is critical for sustainable management of vulnerable freshwater resources under the influence of global change.

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## 2. Understanding Farmers' Perceptions of and Livelihoods Adaptation to Climate Change: Insights from the Coastal Bangladesh - Md. Jahangir Kabir, Donald H Gaydon, Mohammad Mainuddin, Mohammad Moniruzzaman

### **Understanding Farmers' Perceptions of and Livelihoods Adaptation to Climate Change: Insights from Coastal Bangladesh**

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Coastal Bangladesh, climate change, salinity, adaptation strategies, Risk and economic viability

#### **1. Introduction**

The coastal zone of Bangladesh covers about 32% of the total country area (47,551 sq. km), of which 1.7 million ha is cultivated land (BBS, 2017). Of this cultivated coastal land, about 63% has already been affected by various degrees of salinity, while 26.7% of previously non-saline area has become affected by salinity during the period 1973-2009 (SRDI, 2012). The cropping intensity in the coastal areas is about 174% - below the average in the traditional rice-growing areas of 207% (BBS, 2017).

This is due to the scarcity of fresh water for irrigation, higher soil salinity levels, moisture stress, increased erraticness of rainfall and extreme weather events (cyclones, droughts, heavy rainfall events and tidal surge) because of climate change and even the lack of access to saline tidal water for shrimp culture (Saleque et al., 2010, Kabir et al., 2016, Kabir et al., 2017b). Despite that, rice is main crop in the coastal zone, occupying about 95% of the total area of major crops (rice, wheat, maize, and jute) (BBS, 2017). Land with high soil salinity levels and adequate access to tidal saline water is used for brackish water shrimp culture in the dry season. The area under integrated fresh-water shrimp–fish–rice farming has been increasing in coastal land with low levels of salinity as a means of reducing farming risks and environmental hazards and increasing farm income (Ahmed et al., 2008). The studies performed in the coastal zone in Bangladesh mainly focused on biophysical ecological sustainability of the shrimp farming areas (Ali, 2006, Azad et al., 2009, Karim, 2006). Other studies assessed sustainability of rice/non-rice cropping system in the south-west coastal zone (Kabir et al., 2016, Kabir et al., 2018, Kabir et al., 2017a). However, none of the studies evaluated sustainability of main staple (rice cropping) under farmers' current practice and recommended management in the trial plots. Thus, the aim of this study was to understand farmers' perception of climate change and its impact on farming, delineate their adaptation options and assess the economic viability of wet season (WS) rice under different treatments (farmers current vs recommended practice).

## **2. Methodology**

### **2.1 Study location and method of data collection**

Farm level data for the study was collected through reconnaissance surveys, village censuses, farmers' group discussions and 18 case studies with key informant farmers from two villages of Dacope, Khulna and one village from Amtali, Barguna. Data on farmers' climate change perception and their responses were collected through 'group discussions' with key informant farmers. Inputs and labour use patterns, performance of the crops and prices of outputs under different seasonal conditions were collected through 18 case studies households for developing representative budgets.

### **2.3 Enterprise budget**

The gross benefit (GB) of an enterprise was defined as the value of the produced output (including by-products) at the actual farm-gate selling prices (Dillon and Hardaker 1993). The GB of rice was measured as the value of rice grain and straw at farm-gate prices after one month of harvesting, as farmers sell rice grain and straw over a period. Following (Herd, 1978), the gross income (GI) of an enterprise was defined as the GB less Total Paid-out Cost (TPC) and the net income (NI) was defined as GI less Total Imputed Cost (TIC). Hence,  $NI = GB - Total\ Cost\ (TC)$ . These were expressed on a Bangladesh Taka (BDT) per-hectare basis. A proxy measure for the return to family labour was used, namely, the ratio of GI per ha to the number of days of family labour per ha for each enterprise.

### **2.4 Risk accounting:**

A stochastic efficiency analysis was performed to evaluate the risk-return trade-offs by comparing the cumulative probability distributions of the alternative enterprise choices (Anderson et al., 1988, Dillon and Hardaker, 1993). The program @RISK Version 7.5 was used along with MSExcel to derive cumulative probability distribution functions for gross income, net income, and gross income per work day of family labour. Farmers' perceived typical, best-case, and worst-case yields and prices for each enterprise were applied for determining risk. The best-case yield was that obtained under favourable weather conditions and the worst-case yield under unfavourable weather conditions, but extreme events such as cyclones and storm surges causing complete crop loss were not included. Monte Carlo simulation was applied to triangular probability distributions, with the lower limit as the estimated worst case, the mode as the perceived most likely outcome, and the upper limit as the best case (Hardaker et al., 2004).

## **3. Results**

Farmers observed increased temperature, erratic rainfall patterns and decreased rainfall days over the year. Dry season (DS) and early wet season (EWS) crops, livestock and aquaculture were

frequently affected substantially because of climate change in post monsoon months and during the DS. However, decreased heavy rainfall events in post monsoon months alleviate adverse consequences of extreme weather events on WS rice, as well as create a favourable environment for harvesting WS rice and planting DS crops on time. Farming adaptation strategies included adoption of modern short-season rice varieties (MVs), changes in agronomic management, decreased area of EWS rice and stress vulnerable DS crops, intensification of rice/fish/crab/shrimp farming, homestead cropping (vegetables, fruits and timber) and the rearing of livestock. Other livelihood adaptation options included participation in off/non-farm wage work, temporary migration, plus catching fish and crabs in the Sundarban estuaries. Gross income (GI) of WS rice is highly variable due to seasonal fluctuations in yield and market uncertainty. Modern variety (MVs) WS rice is the most viable economically (highest profit and least risk) under researcher management, followed by MVs and LVs under farmers' practice. The findings suggest that the adoption of modern technologies (variety and agronomic management) is not only likely to increase food grain production and farm income but also to reduce risks in rainfed crop cultivation. Major constraints to cropping system intensification in the area included inadequate access to fresh-water for irrigation, stress management technologies, a shortage of stress tolerant varieties and extension support, as well as high soil salinity, excess and scarcity of soil moisture at sowing time of DS crops and EWS rice, respectively, and finally price volatility. Therefore, farmers suggested that re-examination of canals, repair and/or establishment of new sluice gates between canal and rivers, farming friendly sluice gate management, increased extension support, dissemination of stress tolerant varieties and stress management technologies, together with ensuring access to a fair price for farm outputs, soft credit, and quality inputs may jointly facilitate increased cropping intensity and ensure agricultural sustainability in the coastal areas of Bangladesh.

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### 3. Delta environments: landscapes at major threat from salinity - Edward G Barrett-Lennard

#### **Delta environments: landscapes at major threat from salinity**

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Saline agriculture, climate change, inundation, salinity, drought

The world's coastlines and mega-deltas are homes to hundreds of millions of people. These are at extreme risk of environmental degradation due to: (a) sea-level rise, (b) the decreased flushing of rivers (associated with increased river water use by uplanders at the expense of the lowlanders), and (c) increased land subsidence due to increased groundwater pumping. It is also predicted that there will be an increase in major tropical storms that have the power to destroy local defences, like polders, and inundate with sea-water hundreds of thousands of hectares of land of low elevation.

The IPCC has developed future climate change scenarios based on four possible emissions trajectories into the future. Current emissions are presently tracking close to the worst-case scenario being modelled (RCP8.5): this scenario suggests that by 2081-2100 it is likely that there will be a temperature increase of 2.6-4.8°C, a sea level rise of 0.45-0.82 m and a large increase in extreme weather events (IPCC 2014).



All nations ('low' and 'high') will be affected either directly by sea level rise or as potential refugees to home the tens to hundreds of millions of people displaced as a result of sea-level rise. The flood of refugees may well damage the abilities of recipient nations to operate as civil societies.

Based on experience in the deltas of the Ganges/Bramaputra (in Bangladesh and West Bengal), the Mekong (Vietnam) and the Indus (Pakistan) this paper argues that the current settings for science, technology and community adaptation to this rising tide are grossly inadequate. Adaptations to the rising flood are being developed by communities, but there are no efficient international mechanisms for ensuring that these ideas can be disseminated between deltas, i.e. where communities can learn from each other. Trading houses of ideas need to be developed where community learnings and adaptations in one delta can be shared with others. There is presently no CGIAR world centre or world program for saline agriculture in its broadest sense. Researchers in saline agriculture, hydrology, meteorology and allied disciplines need to collaborate more effectively into the development of better solutions.

It can be argued that the impacts of climate change can already be seen in delta landscapes. In the upper Mekong in Vietnam, there is sufficient water and elevation to grow 4 rice crops a year; however, in the lower (1-2 m elevation lower) Mekong the growth of rice has given way to seawater inundation and shrimp-based aquaculture. Salinisation increases in the dry season. Seawater intrusion up the rivers of the delta was the worst on record in the dry season of 2016.

Delta landscapes need to be farmed in the most economically optimal manner possible. Tipping points where one form of agriculture best gives way to another need to be identified. Furthermore, this is not a story of adaptation to salinity alone. In wet seasons, salinity interacts with waterlogging. In dry seasons, salinity interacts with drought. Increased use of groundwater may expose crops to other hazards like boron.

Cropping systems need to be redesigned to optimise the use of available water of low salinity. In Bangladesh researchers are looking to insert another crop (like sunflowers or potatoes) into the start of the dry (rabi) season but achieving this will require finishing the prior wet season (amman) rice crop earlier so that sufficient water is still available in the soil profile to ripen the following rabi crop. The use of deep straw mulches is helping to ameliorate soils in Bangladesh, retaining moisture and decreasing salinity, thereby enabling the growth of relatively salt sensitive crops. These kinds of solutions may have valuable roles in supporting the growth of kitchen gardens in highly water-limited and saline areas in the Indus delta.

Many of the farms affected by future salinity will be quite small. How will small-holders learn about the new systems? To be acceptable to farming communities, new saline agricultural crops will need to not only be able to grow in defined landscapes: they will also need to be socially acceptable, be marketed into stable market chains, and be capable of offering farmers stable economic rewards. Innovative methods of extending information will be required that are accessible to poor, often illiterate farmers.

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Prof. Ed Barrett-Lennard works in the Western Australian Department of Primary Industries and Rural Development, at Murdoch University and at The University of Western Australia. His research and that of his students focuses on various aspects of saline agriculture in the disciplines of soil

science, plant physiology and agronomy. He has been involved in international projects in Pakistan, Iraq, Bangladesh, India and Vietnam.

#### 4. The Effect of Climate Change Adaptation on Rural Community Livelihoods - Nakasaga Halima, Kabagenyi Hilder, Lukyamuzi Grace, Mbidde Robertson (presenting author: Nalubega Rose)

##### **The Effect of Climate Change Adaptation on Rural Community Livelihoods**

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Effect, Climate Change Adaptation, Rural Community, Livelihoods

**Background:** Dependence on rain fed crop production means the impact of stresses and shocks are felt keenly by rural poor people, who depend directly on food system outcomes for their survival, with profound implications for the security of their livelihoods and welfare. This study explores the opportunities for linking social protection, CCA and DRR in the context of rain fed crop production, establishing whether these three approaches would help enhance resilience to shocks and stresses in rain fed crop production areas.

**Methods:** The study reviewed the conceptual and policy-related similarities and differences between the three disciplines. Case studies where climate change and resilient social protection approaches were collected and an adaptive social protection framework that highlighted opportunities were developed. The research design combined semi-structured and informal methods of data collection, including individual and focus group interviews with farmers, interviews with government employees, NGO staff and small business owners, recordings of farmer group discussions, and participant observation. Interviews and group discussions elicited information on farmers' expectations for the upcoming season, local forecasting knowledge, access to scientific forecasts and technical advice, and planting decisions for the previous and current season. Several open-ended interviews with district officials, community leaders, agricultural technicians, NGO field agents, and other resource persons were also conducted to obtain additional information on risk management in agricultural strategies. Respondents were selected purposively rather than randomly because of the difficulty of traveling to distant homesteads on poor roads and the challenges of mobilizing farmers at the onset of the rainy season, when they were busy planting their fields. Farmers were contacted through the extension service and through an NGO agent; some of them belonged to farmers' groups that intervened in agriculture, AIDS prevention, and community development, while others did not belong to such groups

**Results:** With climate change, the magnitude and frequency of stresses and shocks is changing and approaches such as social protection, disaster risk reduction (DRR) and climate change adaptation (CCA) will be needed to bolster local resilience and supplement people's experience. Social protection and DRR measures designed to limit damages from shocks and stresses may not be sufficient in the longer term. For social protection to be resilient to climate change impacts, it will

need to consider how reducing dependence on climate sensitive livelihood activities can be part of adaptive strategies. Several features of this indigenous climate knowledge system reflect characteristics common to local environmental knowledge in other contexts, such as practicality, complexity, and dynamism. This system has a strong practical emphasis, oriented towards agricultural planning. Individuals select the timing of agricultural activities and the specific crops that they will plant. It draws on multiple components that operate on a variety of spatial, temporal and social scales. It requires the integration of information from these different sources. It exhibits remarkable dynamism, which allows for the incorporation of new elements. Such dynamism is expressed in several ways.

**Conclusion:** Climate Change Adaptation and Disaster Risk Reduction cannot effectively address the root causes of poverty and vulnerability without taking a differentiated view of poverty, integration with social protection can solve the problem. We suggest that the openness to a variety of components of knowledge leads the farmers to be willing to integrate new information into their system of forecasting weather and climate. If they relied exclusively on one source, farmers might be less willing to adopt new sources. But they do, considering a variety of sources and evaluating them as each season arrives and unfolds. We have previously mentioned the integration of new elements, such as the flowering of coffee trees—a plant that was introduced into the region—as a forecasting sign, and the adoption of scientific terms for clouds learned in the schools. The readiness of farmers to discuss, assess and use modern scientific forecasts, provided by the Ugandan Department of Meteorology, is another example. In the conversations at group meetings, the farmers reviewed forecasts that they had heard in previous seasons on the radio or from agricultural extension agents, and commented that these usually proved to be accurate but on some occasions were incorrect. They also noted that their indigenous forecasts were generally reliable but sometimes failed to provide accurate predictions. This attention to multiple sources of information can also help farmers to be more aware of climate change. For example, they may comment when a season, or several seasons, departs from the historical patterns, and they will note when the forecasts based on established components, such as signs and weather observations, are not borne out. In reflecting on these deviations from established or expected patterns, they detect shifts that might be associated with climate change.

Rose Nalubega is a well-rounded research expert with wide span of experience in strategic program design and implementation. She has collaboratively worked with many research and academia institutions in the areas of applied research. Rose holds an MSc. in Environment & Natural Resources and she is a member of the Uganda Evaluation Association (UEA).

## II Awareness raising and capacity building for saline farming

### 5. A Legal Perspective on the Effects and Prevention of Salinization - Annalies Outhuijse, Ida Helene Groninga, Tatia Brunings

#### **A Legal Perspective on the Effects and Prevention of Salinization**

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Legal questions, effect, prevention, salinization

## **1. Introduction**

Salinization has become an issue of considerable importance for present and future generations alike. Salinization of land and water is increasing due to climate change alongside poor water and land management, and the effects are becoming more visible; threats to agriculture, the environment, and drinking water. Experts claim we are only in the starting phase of the problem, as salinization is linked to several other problems, including soil subsidence, rising sea levels, and a shortage of fresh water. Although many researchers from other disciplines are researching this problem, and asking how this problem can be dealt with, it has so far received minimal attention in legal scholarship - even while the role of the law in the context of salinization is undeniable.

Our contribution will highlight this essential role, and raise an array of legal questions in light of this problem. Using both European and non-European examples, the contribution will review the role of law, which can be an instrument to prevent or mitigate the effects of salinization, but can also form an impediment to preventing or solving the problem. Our contribution forms an explorative study in the role of the law in creating, addressing, and dealing with the problem of salinization.

## **2. The salinity process and its causes and consequences – presenting the case studies**

The salinity process depends on various factors and can occur both via ground and surface water, resulting in internal and external salinity, respectively. It is an increasing problem, particularly for the agricultural sector in many countries.

Just as there are various causes of salinization, there are also numerous potential actions to combat it. These include adaptations such as the modification of crops, and prevention, for example ensuring sufficient amount of fresh groundwater and limitation of activities which could further negatively affect the ground. Several private and public actors are involved in and influenced by this issue, adding to its complexity.

This contribution will discuss a few of those measures, and questions will be addressed, including:

- What are the options for the national and local governments to limit the effects of salinization?
- What are the legal possibilities and limitations in general?
- Are the options offered by current legislation and regulations optimally utilized?
- Are adjustments required to the current legislation and regulations?

Due to the limited word count of this extended abstract, one case study is presented, which focuses on the options in the Netherlands to secure sufficient quantities of fresh water (of sufficiently high quality). While the focus of this case study is limited, competition for scarce fresh water resources across the world is a worsening problem, especially for agricultural sectors.

## **3. Case study: storage of fresh water**

In the Netherlands, large areas of the country are situated below sea level and include historical tidal zones. In these areas saltwater is present in the subsoil. During summer droughts, the fresh

water present on top of this saltwater is depleted, leading to capillary rise of saltwater and damage to topsoil and crops.

In the Netherlands, existing crops are tested for their salt tolerance in order to minimize damage and genetically modified crops which are considered to have high salt-tolerance are assessed.<sup>1</sup> While these are suitable solutions, participation in water conservation programs is another option.<sup>2</sup> For example, rainwater can be harvested and collected and used across various sectors in society. This method is self-sufficient and is used in several countries across the globe.

This case study will examine whether, in the Netherlands, the law allows or prohibits the collection of rainwater. If it is prohibited, what can be done in order to limit losses during droughts? Additionally, if the government has hindered methods for individuals to be more self-sufficient, are those individuals entitled to compensation?

This paper will first make a comparison between various countries' approaches to legislation regarding rainwater collection and harvesting.

Currently, several states in the United States of America have enacted legislation that allows parties to harvest or collect rainwater. Several states including Ohio and Oregon, as well as the US territory of the US Virgin Islands, have adopted legislation covering the collection of rainwater for households and businesses. **The state of Colorado has a long history of legislation focusing on rainwater harvesting for household and its use.**

Also Belgium and Germany have legislated rainwater collection relating to households. In Flanders, rainwater collection is mandatory for owners of new-build homes. For single-family homes, the volume of the collection well must be at least 5,000 liters. For other buildings with a roof surface area greater than 100m<sup>2</sup>, the rule applies that the volume of the rainwater system must be 50 liters per square meter of roof surface area, with a maximum of 10,000 liters. In Germany rainwater collection is not mandatory, but households are encouraged to collect rainwater and can receive tax reductions as a consequence. Although these measures mainly relate to households, all savings of fresh water are beneficial, considering the shortages which are expected in the near future; both in general and as a result of considerable drought periods.

Within the Netherlands, there are ideas for the collection of rainwater not only by individuals and households, but also by companies and local governments.

For several years now, the municipalities have had an instrument in place to force citizens to process more rainwater on their own land. Since municipalities were given the opportunity in 2009 to oblige citizens to collect rainwater on their own property, more than forty municipalities have introduced rules on this. The municipality is responsible for the efficient collection and processing of run-off rainwater. This duty of care is laid down in Article 3.5 of the Water Act. The municipalities are obliged to elaborate rainwater treatment in the municipal sewage plan (GRP).

Again, however, these examples are limited to households and small-scale water storage. The question is: what can, for example, farmers do?

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<sup>1</sup> BART Timmermans and Monique Hospers-Brands, Soil and water salinization and the development of organic saline crops, Rahman & Aksoy (Eds.) (2014) Proceedings of the 4th ISOFAR Scientific Conference. 'Building Organic Bridges', at the Organic World Congress 2014, 13-15 Oct., Istanbul, Turkey (eprint ID 23952).

<sup>2</sup> Ibid.



Owners and operators of greenhouses are exploring the options of underground water storage. The operators of greenhouses are facing similar problems: excessive rainwater in some parts of the year, a shortage of water in case of drought, and being low on the priority list in case of water shortages. One idea being explored is the use of enormous water-banks, filled with rainwater.<sup>3</sup>

As the authors of the report describe, the water-bank is a dual concept: on the one hand, a physical water-bank, in which fresh water is stored in the subsurface, after which water can be extracted, and on the other hand a financial water-bank, making it possible for users to trade stored water.<sup>4</sup> The exact circumstances are still under consideration; for example, questions remain whether it should be:

- Public or private water banks (a government body, NGO or cooperation).
- Permanent or temporary water-banks or water-banks with option contracts. Permanent water-banks function in areas where there are frequent water shortages, while temporary ones are used mainly during the irrigation season. At water-banks with option contracts, users can purchase options that entitle them to purchase water in the event of a shortage, which reduces the risk of water shortage problems for the user.
- The purpose of the water-bank can vary between redistribution of raw materials, environmental objectives (where water rights are purchased for the benefit of nature), and risk management of water shortages.
- Active and passive water-banks. Active water-banks buy and sell water rights, with the aim of creating a balanced market. The bank is the only one that can buy and sell water rights and also determines the conditions for transactions. Passive water-banks bring users and suppliers of water rights into contact with each other, but do not influence the market.<sup>5</sup>

In realizing this, many legal questions are raised:

- Which laws and regulations and administrative responsibilities play a role in realizing a water-bank? For example, which permits are required, from which authorities, and is this currently possible?
- Is it desirable to make changes to the laws and regulations? Which parties can contribute to this?
- If collected, what rules are applied regarding water quality?

Farmers will face similar problems. Our contribution will show that the current administrative, legal, and organizational system can cause bottlenecks, hindering an innovative and sustainable approach to large water management projects.

#### **4. Conclusion**

While many researchers focus on the problem of salinization, this contribution reviews the role of law in seeking to provide a solution to the problem, mitigate the effects of the problem, adapt to the problem, or compensate the effects of the problem.

The case study considered in this abstract was the shortage of fresh water. Other case studies focus on the quantity and quality of groundwater and soil, the role of governmental actors and private actors pursuing public goals, the measures which farmers can take to guarantee certain levels of groundwater of sufficient quality, and how farmers could be compensated if the latter cannot be fulfilled. To a lesser extent, there is also a focus on modification of crops and the effects of salinization on natural areas.

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<sup>3</sup> See Sija Stofberg and Koen Zuurbier, Coastar. Verkenning waterbank Westland, 2018.

<sup>4</sup> Ibid.

<sup>5</sup> Ibid.

In general, it can be said that the institutional framework (legislation and regulations, planning procedures and administrative bodies) must be designed in such a way that the options, as formulated above, can easily be applied and encouraged in practice. This contribution can form a first step to this greater goal.

Annalies Outhuijse is currently a PhD researcher at the University of Groningen, focusing on competition law, and will soon be a junior associate at the law firm Stibbe in Amsterdam, focusing on environmental law.

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## 6. Is saline farming a shape shifter? Review of the debate on and policies for climate adaptation at the Flemish coast (2005-2017) - Jeroen De Waegemaeker

### **Is saline farming a shape shifter? A review of reports on and plans for climate adaptation at the Flemish coast (2005-2017)**

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Saline farming, Policy-oriented research, Flanders

#### *1. Introduction*

##### *1.1 Climate adaptation through saline farming*

As we have entered the age of global warming, coastal regions need to adapt to multiple climate challenges, including the salinization of low-lying areas. Both natural drivers, such as droughts and sea-level rise, and human drivers, for example an unsustainable management of surface water and groundwater, exacerbate the saline conditions at the coast (Oude Essink, 2001; Daliakopoulos et al., 2016; De Waegemaeker, 2019). Hence, the question rises how agricultural activities can be adapted to this saline future.

One pathway, amongst many others, is the cultivation of salt-tolerant crops in farmland that is subjected to salinization, a strategy known as saline farming. The international presence at this conference illustrates how saline farming is researched and debate throughout the world.

##### *1.2 The study of climate adaptation policies, a growing field of research*

The development and implementation of policies on climate adaptation are challenged by a wide array of constraints. At the start, research on climate adaptation focused primarily on biophysical and technical constraints. Today, there is a growing call for research on the societal and governmental constraints (Wolf 2011). This requires practice-oriented research that comprises an interactive engagement of policy makers in order to fully understand the complexity of policy work on climate adaptation (Moser 2010, O'Brien 2012).

#### *2. A review of the debate on climate adaptation at the Flemish coast*

As a first exploration of the complexity of policy work on saline farming, this paper studies the public debate on and the policy work for climate adaptation in the coastal area of Flanders, the northern region of Belgium. Since 2005 reports on climate challenges have questioned the coastal region's future development, including the local agricultural sector. Within the policy domain of spatial planning, more than twenty unique proposals for a 'climate-proof' coast have been developed by various design offices, policy departments and civil society organizations. Likewise, the agricultural community has drafted several reports on strategies for climate adaptation at the Flemish coast. This research lists and summarizes all proposals and analyzes their vision on climate adaptation in the agricultural sector at the Flemish coast.

### 3. Results

#### 3.1 Growing policy attention for salinization and saline farming in Flanders

In the coastal region of Flanders the salinization challenge is often forgotten, at least until recently. The aggravating storm surges and the resulting need to revise the coastal defense infrastructure dominated the local debate on climate adaptation. In contrast, the future freshwater floods, droughts and salinization were frequently overlooked. Recent shortages of freshwater resources, however, are gradually creating awareness about the need to revise water management in the low-lying coastal region. The case study showcases an alarm reflex (see Moser,2010) at the Flemish coast: the attention of policy makers is drawn to the most recent extreme weather event, and subsequently, they concentrate on a single climate challenge.

Whenever salinization is part of the equation, saline farming is often acknowledged as a possible climate-proof strategy for agricultural activities at the coast. The research found that a high number of reports on and plans for climate adaptation at the Flemish coast include sections on saline farming. There are, however, remarkable differences in the potential that is attributed to saline farming. In general those reports and plans that concentrate on climate adaptation at the long term, e.g. time horizons up to 2050 or 2100, accord greater importance to the strategy of saline farming than the policy work that focusses on the short or mid-term. Moreover, this case study research indicates that the agricultural community is less eager to develop saline farming than the policy workers in the domain of regional development and spatial planning. Reports and plans on climate adaptation drafted from an agriculture perspective are hesitant about the potential of saline farming.

To clarify, there are up-to-date no saline farming activities nor experiments with saline farming in the Flemish coastal region. In other words, the attention for saline farming in policy documents still needs to be transposed into actions on the ground.

#### 3.2 Saline farming as a 'shape shifter'

The review highlights that saline farming is a 'shape shifter': a concept that repeatedly emerges in policy work for climate adaptation, yet every time in a modified form. The research uncovers three types of differences.

Firstly, the acknowledgements of saline farming vary greatly with respect to the **agricultural crops**. Some reports and plans interpret saline farming rather narrowly: the cultivation of halophytes such as Sea Aster, Salicornia and Sea Lavender. Hence, saline farming is conceptualized as a radical alternative to conventional agriculture that produces a completely new type of food. On the other hand, this particular conceptualization *-inevitably-* classifies saline farming as a niche within the

agricultural sector since there is only limited demand for these halophytes. According to other reports and plans, however, saline farming entails the cultivation of salt-tolerant cultivars of conventional agricultural crops such as cabbages, tomatoes, potatoes and oats. Building on this conceptualization, saline farming is within reach and requires only small adjustments of the existing agricultural activities.

Secondly, there is a variation in the **types of agriculture** that are part of saline farming. Most reports and plans limit saline farming to horticulture and arable farming. As such saline farming is restricted to the production of plant-based food, used for direct human consumption. Other reports and plans, however, broaden the scope of saline farming. Here the acknowledgements of saline farming include the cultivation of mussels and oysters, the production of seaweeds for human consumption as well as animal feed, and sheep or cattle grazing on saline environments.

Thirdly, the **rationale for the development of saline farming** at the Flemish coast varies greatly. All reports and plans conceptualize saline farming as a strategy for climate adaptation at the coast, yet the underlying argumentations vary. Sometimes saline farming is seen as a way to reduce freshwater consumption by the farming community.

The development of saline farming allows for the use of brackish water as an alternative source of water for agricultural irrigation. Consequently, saline farming alleviates the pressure on the scarce freshwater resources at the coast. Building on this conception, saline farming competes with other water saving strategies such as drought-resistant farming and precision irrigation. Some reports and plans, on the other hand, underline that saline farming is a pathway to customize agriculture to the coastal hydrology, and the local presence of a saline groundwater layer to be precise. Within this perspective, saline farming opposes strategies that concentrate on the sustainable use of the phreatic freshwater aquifer at the coast. These opposing strategies include a wide range of interventions in the domains of surface water management and groundwater management (Oude Essink, 2001; De Louw et al., 2015). Finally, sometimes saline farming is seen as a way to use land where conventional farming is unviable due to flood risks. Building on the IPCC framework on adaptation responses at the coast (Dronkers et al. 1990, Nicholls et al. 2007), saline farming can be conceptualized as an accommodate strategy: rather than fighting against aggravating flood risks, local land uses are prepared for an occasional or even frequent flooding. Such embracement of the possible calamity sharply contrasts with protect strategies such as dyke reinforcement and dune nourishment.

#### *4. Discussion and conclusion*

As highlighted in section 3.1, saline farming in Flanders is currently limited to theoretical discussions about climate adaptation. With regards to the necessary transposition from theory into practice, we argue that the capacity of saline farming to shift its' shape is a barrier rather than an opportunity. As saline farming can take many shapes, there is a great risk for confusion about saline farming. Today there is no unequivocal answer to the questions 'What types of saline farming must be tested? And why?'. Consequently, there is no clear ownership of saline farming. Therefore we argue that in Flanders, and probably everywhere else, the strategy of saline farming needs to be specified. The agricultural activities need to be pinned down, and the area for saline farming needs to be pinpointed. We advocate that this process of specification involves all stakeholders, e.g. the agricultural community, the managers of surface and groundwater and the coastal safety engineers. Each of these stakeholders bring different sets of knowledge to the table. What is more, their engagement in the process of specification is important to spark the idea of ownership about the strategy of saline farming.

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Dr. Jeroen De Waegemaeker is a senior researcher at the Flemish Institute for Agriculture, Fisheries and Food Research (ILVO) and has a background in urban design, landscape planning and regional development. His research focuses on climate adaptation in peri-urban territories: how do we prepare these territories for climate challenges such as floods, droughts and heat stress? Today, he is working on the project SalFar, financed by Interreg North Sea Region. He is responsible for the participatory research; awareness raising about salinization of farmland, and capacity building for saline farming.

## 7. A vision and a strategy for mitigating and adapting to salinization of highly productive clay soils in the Netherlands - Mindert de Vries

**A well-structured multi partner program for mitigating and adapting agriculture of low-lying coastal areas to increasing salinization**



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Wadden sea region; clay soils; ground water; agriculture; salination

The deltaic Wadden region has a long and established tradition of water management, productive agriculture and flood protection by dikes. Starting from the twelfth century AD shallow and sediment rich branches, with natural salt marsh formation of the Wadden sea where diked step by step, resulting in steadily increasing areas suitable for highly productive agriculture. As a consequence, these diked areas have developed typically a freshwater lens on top of a deeper layer of saline groundwater. Through time, caused by active dewatering and compaction of the clay and peaty subsoils the diked areas have started to subside, resulting in a surface elevation often below present sea level. With respect to the highly productive agriculture, problems of salinization of the top soils start to cause impacts, exacerbated by climate change, for example more extreme droughts, and accelerating sea level rise. The aim of this study is to chart a structured way forward for agriculture, utilizing proven innovation methodologies, such as the ABCD-Roadmap concept and the quadruple helix living lab approach encompassing cooperation with citizens, government, enterprises, farmers collectives and knowledge organizations to discover viable business models for a future environment with increasing salinization and reducing availability of fresh water. As a first step a group of organizations has joined forces in 2017-2018 to create a vision on the way forward to protect the viability of agriculture in the region, in order to maintain a vital region, with a strong agricultural economy. The resulting approach consists of 1) the formulation a shared paradigm and vision, 2) the introduction of a coherent process of stimulating innovations, and 3) an analysis of the present situation as a starting point and 4) the definition of building blocks of a program that will help to implement the required transition to climate robust and salinization proof agriculture.

Mindert de Vries is program manager at the University of Applied Sciences Van Hall Larenstein, focusing on live in muddy coasts. He is an expert advisor on coastal safety, water management and nature based solutions at the Deltares foundation and is coordinating a Living Lab related to salination and agriculture on clay soils.

## 8. Adaptive Management Strategies to Alleviate the Impacts of Saltwater Inundation on Agricultural Lands - Christopher F. Miller

### **Adaptive Management Strategies to Minimize the Impacts of Salt Water Inundation on Agricultural Lands in the Eastern U.S.**

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Salinization, sea level rise, conservation plantings, ecosystem services, plant adaptability.

The USDA-Natural Resources Conservation Service (NRCS) Climate Change Vulnerability Adaptation Plan (2014) lists salinization of near coastal waters due to sea level rise, greater storm frequency and intensity as a significant future impact to agriculture in the United States. In the five years since this report was written, the issue of saltwater inundation due to sea level rise and more frequent and intense storm events has become increasingly problematic for agricultural producers, as predicted. The Mid-Atlantic States of the Eastern U.S. have been identified as especially vulnerable to coastal flooding because of both the increasing rates of sea level rise and land subsidence occurring simultaneously. The average rate of sea level rise for this geographic area is estimated at three times the global average.

Another impact of climate change will be increased temperature effects that result in changes in plant adaptability in specific geographic locations and local environments due to shifts in Plant Hardiness Zones. As time goes on, a new suite of plant species will need to be recommended for various cropping systems, cover crop applications, and conservation practices for a given geographic area. To compound the problem, potential water quality issues are also resulting from saltwater inundation. Researchers at the University of Maryland and George Washington University have found that on the lower eastern shore of Maryland (Delmarva Peninsula) this process mobilizes legacy phosphorus and nitrogen from the soil that eventually enters adjacent water bodies of the Chesapeake Bay.

The USDA-NRCS employs a host of conservation practice standards and specifications that are used to plan best management practices on farms to solve various natural resource problems. These practice standards in the Field Office Technical Guide (FOTG) are updated and revised periodically with new vegetative planting and engineering design recommendations. Many of the vegetation practices such as Herbaceous Riparian Buffers, Filter Strips, Streambank and Shoreline Protection, Cover Crop, Conservation Cover, and Critical Area Planting are planned to be updated to incorporate more salt tolerant species. In addition, due to potential nutrients released by saltwater flooding, plant species recommendations will need to include those species that provide for water quality improvement by plant nutrient removal.

This presentation will expose participants to alternative adaptation strategies and methods currently being studied to deal with this problem. Managing the impact of saltwater inundation will require producers to use more adaptive and innovative agricultural practices. With better site assessment tools and implementation of appropriate conservation practices, producers in these impacted areas may not need to completely abandon their affected fields. However, in some cases, wetland easements may be the best option. This would result in previous crop land being converted to wetlands either through natural regeneration or planned wetland creation. The benefit to the producer would be a one-time acreage payment for the land acquisition. The ecosystem benefit would be the additional floodwater storage that may help protect and buffer adjacent cropland. Another alternative strategy could be growing value-added, alternative niche conservation plants on these marginal lands that also provide valuable ecosystem services. The native salt meadow cordgrass (*Spartina patens*) or salt hay was historically harvested from the natural tidal marsh and used as feed hay and mulch. This mulch is highly valued as it is relatively weed free. However, most of these "farmed" wetland areas on the East Coast are no longer accessible due to sea level rise and storm damage to dikes and levees through the years. Opportunities exist for farmers to plant a crop of salt meadow cordgrass in the marginal, salt impacted transition zone between the wetland and the upland. These marginal lands were once traditionally farmed but are no longer economically productive due to periodic flooding and salt concentrations; the perfect conditions for salt meadow cordgrass to thrive. Another option where potential markets exist is to establish multifunctional buffers of deep rooted native warm season grasses and wetland forbs such as seashore mallow (*Kosteletzkya virginica*) to be harvested for biomass. These buffers will provide ecosystem services

for erosion control, water quality improvement and wildlife habitat. The chopped, dormant stems of the native grasses such as switchgrass (*Panicum virgatum*), coastal panicgrass (*Panicum amarulum*), prairie cordgrass (*Spartina pectinata*), Eastern gamagrass (*Tripsacum dactyloides*) and the seashore mallow are highly absorbent fibers. The poultry industry on the Delmarva Peninsula is very interested in expanding the production of these native plants for use as poultry house bedding material. Research has shown it is more adsorbent than sawdust which has been the industry standard for years. The use of native grass bedding results in less foot pad dermatitis on the birds. These materials are also being marketed as a cat litter product. Additionally, the chopped stems are used in the fabrication of various products associated with the erosion control industry and the natural gas extraction industry.

Specialty markets for products harvested from the tidal marsh are also being investigated in the Mid-Atlantic States. Some examples of these products include: fresh Salicornia for salads, pickles, and fried finger food, Atriplex burgers and seaside greens pasta. It may be slow to evolve in the U.S., but halophyte agriculture will eventually need to be adopted in localized geographic areas of the eastern U.S. for agriculture to remain viable and productive.

Chris is currently serving a yearlong detail assignment as an NRCS Project Liaison to the Northeast and Southeast USDA Climate Hubs. He has been the Manager of the USDA-NRCS Cape May, New Jersey Plant Materials Center for 12 years. Prior to that, he served for 18 years as a Plant Materials Specialist for the Northeastern and Mid-Atlantic states. Chris has a B.S Degree in Agronomy from Penn State and an M.S. in Plant Science from the South Dakota State University.

## 9. Salinization of the coastal zone as driver for innovation in flood risk management strategy - Jantsje M. van Loon-Steensma

### **Salinization of the coastal zone as driver for innovation in flood risk management strategy**

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Climate change, resilience, flood defences

Deltaic coastal zones – like the Wadden Sea region - are low-lying areas built from sediments that have been accumulated in the transition zone between the higher terrestrial and the marine environment. Their natural development is largely climate-driven, through combinations of terrestrial and marine processes (e.g. run-off, sediment transport, vegetation coverage, sea-level rise, tides, and storm, wave and currents action) (van der Meulen et al., 2007). Although these processes result in a dynamic, constantly reshaped coastal landscape, natural coastal lowlands essentially develop in an equilibrium between supply of sediment and the accommodation space for its deposition. Sediment input is thus of key-importance in such depositional systems. Within this dynamic environment, the transitions between land, fresh, brackish and saline water generate diverse habitats - such as salt marshes - hosting a rich variety in flora and fauna (Bakker, 2014) and offering a broad range of ecosystem services (Barbier et al, 2011). More than 2500 years ago, these Wadden Sea coastal salt marshes provided valuable hunting and fishing areas. The first inhabitants initially settled on natural heights, but the protection against flooding by building earth constructions started already more than 2000 years ago with the creation of artificial dwelling mounds (Van der Ven, 2014). The naturally formed salt marshes offered pasture for grazing cattle

and harvesting hay. From the Middle Ages onwards, parts of these fertile marshes were actively reclaimed in a step-by-step process of embanking the elevated marsh area (Bakker, 2014). This led to the formation of productive polders that were protected against flooding by dikes. Freshwater for agriculture was available due to freshwater lenses on top of saline groundwater (Acacia Water, 2019). Height and seepage of saline groundwater (and thus of fresh water) are influenced by sea level and patterns in the layers of soil resulting from historic geomorphological processes. Throughout history, agricultural production and flood risk management have both been evolved in an adaptive way in this coastal environment; that is, by experimentation, trial and error, and “learning by doing” (Kato and Ahern, 2008). Farmers selected the most productive and robust crops, and after extreme events, flood protection works were restored and improved to withstand the most recent extreme conditions. In addition, water management in the coastal zone was optimized for agricultural production by drainage canals and pumping facilities (Van der Ven, 2004). Furthermore, a sophisticated system ensured that internal salinization was prevented by flushing with external fresh water when needed. After adopting the Water Act in 1958, extensive dike reinforcements and proper maintenance and progressive water management resulted in a well-protected (Jorissen et al., 2016) and intensively water-managed, relatively densely populated, and high productive coastal zone. However, elevation differences between the sediment-starved hinterland and sea level will increase under sea level rise. This will result in increasing seepage of saline groundwater, aggravated by land subsidence. Although well-protected, these developments have made the low-lying Wadden Sea coastal area vulnerable to changing conditions, such as climate change related sea level rise, increasing salinization, and changing rainfall patterns.

Increasing international attention for climate change (IPCC, 2007) with its potential impacts and the near-flood disasters in the Dutch riverine area in 1993 and 1995, led in 2007 to the installation of an independent committee (the second 'Delta Committee') to prepare recommendations on how to improve protection of the coastal and low-lying parts of the Netherlands against the consequences of climate change and sea level rise. The challenge was to make the Netherlands climate proof in the future but at the same time keep the country an attractive place to live, reside, work, recreate and invest. Water safety was at the centre of their recommendations, and included both flood protection and securing fresh water supplies (Deltacommission, 2008).

In response to the advice of the Deltacommission, the Dutch national government adopted in 2008 a new Delta Plan and launched in 2010 the Delta Programme (<https://www.government.nl/topics/delta-programme>) to prepare for a sea level rise between 30-85 cm in 2100. This entailed for the Wadden Sea region a search for realistic adaptation options that use or enable natural processes to strengthen ecological resilience and facilitate sustainable human use in the Wadden region. In the Delta Programme 2015 (Delta Programme, 2014) eco-engineering concepts, as well as multifunctional dikes were advocated as the preferred approach to flood risk management along the Wadden Sea coast. In 2013 the new Dutch flood protection programme commenced with explorative studies (“Project Overstijgende Vekenningen”, (POVs)) on several eco-engineering solutions. These eco-engineering solutions, like the cyclic clay mining for wide green dikes and the integration of salt marshes in flood defences perfectly tied in the natural characteristics of and processes in the shallow Wadden Sea, with its sand and mudflats and coastal marshes. It are all sediment-based solutions, and grounded in the premises of abundant sediment availability under sea-level rise. Furthermore, they were framed as an opportunity to align climate adaptation strategies and measures with nature development and conservations goals (Van Loon-Steensma & Vellinga, 2019), which facilitated support from a broad range of stakeholders and to overcome legal hurdles.

Separately, studies have also been launched into the potential impact of climate change on the external supply of fresh water and increasing internal salinization, and subsequently on the agricultural production in the Wadden Sea. Pilot projects were initiated on fresh water retention,

adapting agricultural production to a reduced availability of fresh water, development of salt-tolerant crops, and boosting saline agriculture (Acacia Water, 2019).

Recent climate change projections warn for a strong sea level rise which may result in major challenges for flood risk management as well as for agricultural practices due to increasing salinization (Haasnoot et al. 2018). Furthermore, risks of heat-waves, droughts, and of extreme wet periods will increase under these more extreme climate scenario's, and affect the economic prospects of agricultural sector. It is therefore key to timely prepare for these climate related multi-hazards in a suitable and sustainable way, and to re-consider the current adaptation approach. The more so, because in the new extreme scenario's, with possible sea level rise up to 2 m in 2100 (Haasnoot et al., 2018), sedimentation of the Wadden Sea system may not be able to keep up with sea level rise (Baarse, 2014). Under such conditions deltaic landscapes will likely struggle to maintain their structural and functional dynamics (Day et al., 2016). It may be wise to widen the time and spatial perspective for both flood risk and water management and to search for sustainable, cost-effective and proportionate adaptation approaches, and to consider the wider costs and benefits of adaptation, business as usual, or of inaction. If management is directed at maximizing natural processes towards sustaining deltas, it will be much less expensive while at the same time be more effective (Day et al. 2016).

A first step could be to integrate the resilience of the hinterland in flood risk and water management strategy. Just because the hinterland is confronted with increasing salinization, it might be easier to accept some wetting of the most low-lying areas or a shift to new saline related functions and values along the coast that facilitate the preparation of the hinterland for occasional flooding with sea water. Managed flooding could even result in accretion of the hinterland through sedimentation. In the 'Weerbare Waddenkust' (*Resilient Wadden Coast*) project, we explore such innovative flood protection strategies – like parallel defences - that include adaptation of the hinterland to accommodate occasional flooding with sea water, managed sedimentation, and fresh water retention. Although biophysical and socioeconomic conditions do vary around the globe, these solutions might be also applicable for deltas elsewhere, because all deltas face similar challenges in responding effectively and timely to the impact of climate change.

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Jantsje van Loon-Steensma is a researcher and lecturer in climate adaptation. She has a background in environmental sciences, water quality and aquatic ecology. Her research focusses on the implementation of innovative green adaptation measures and on the co-benefits and trade-offs of integrating nature and landscape values with flood protection and its implications for management.

## 10. Salinization and agriculture in the Netherlands: benchmarking stakeholder perspectives - Isa Camara Beauchampet

### **Salinization and agriculture in the Netherlands: benchmarking stakeholder perspectives**

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climate change, mitigation, adaptation, resilience, water management

The salinization (i.e. increase in salt concentration) of fresh surface- and groundwater resources poses significant problems to farmers, industries, drinking water companies, and water managers in coastal areas all around the world. These problems include reduced crop yield, damaged infrastructure, adverse effects on vulnerable ecosystems, and the forced abandonment of extraction wells. Climatic and anthropogenic stresses like sea-level rise, changes in recharge and evaporation patterns, ground subsidence, population- and economic growth, increasing industrial and agricultural water demands, and contamination of surface water further intensify pressures on freshwater resources and competition between the different uses in these areas.

With regards to agriculture, salinization of freshwater resources and agricultural land is one of the biggest threats to food production worldwide, as higher salinity levels result in lower crop and as soil salinization is a global phenomenon, occurring in at least 75 countries around the world and on more than one billion hectares of total land. The issue is becoming increasingly problematic and widespread, particularly due to climate change effects like sea-level rise and more frequent and severe droughts. With a growing population and subsequent growing demand for agricultural products, progressing climate change, little new productive land without sacrificing valuable nature, and increasing competition for freshwater resources, salinization is a global issue that urgently requires a solution.

Salinization of soils is especially common in arid and semi-arid regions where rainfall is low and the rate of evapotranspiration is higher than the rate of percolation of rainwater through the soil. In more temperate regions, soil salinization is mainly caused by seawater intrusion in coastal aquifers and saltwater intrusion in inland aquifers from neighbouring saline aquifers, as a result of sea-level rise and over-extraction of groundwater. Annual precipitation in these regions is usually sufficient for plant transpiration demands and infiltrating water can form freshwater lenses on top of brackish or saline groundwater. However, if these lenses temporarily disappear in dry periods, this may lead to the capillary rise of saline water and in turn salinization of the root zone.

Although the Netherlands also has a temperate climate and saline aquifers due to past marine transgressions and seawater intrusion, it is rather unique because of two main reasons; firstly, about 25% of the land surface lies below mean sea level and without its dunes and dykes 65% of the country would be regularly flooded, and secondly, a significant amount of the land surface (600.000 ha) consists of polders, i.e. pieces of land that have been reclaimed from a body of water (i.e. a lake, floodplain, or a marsh) through the creation of artificial and autonomous hydrological systems of dykes and drainage canals. In areas that lie below mean sea level, saline groundwater may reach the surface by upward groundwater flow, a process which is commonly referred to as saline or brackish seepage. This results in the salinization of surface waters and shallow fresh groundwater bodies, making the water unfit for drinking water supply, industrial purposes, and irrigation. In addition, brackish seepage can also directly end up in the root zone and thereby cause salt stress in plants.

A future rise in sea level is expected to increase the seepage and the salt loads in surface waters and thereby reduce the availability of both fresh surface water and groundwater. Model simulations show that due to sea-level rise, salt loads from groundwater seepage will be doubled in several low-lying parts of the coastal zone of the Netherlands by 2100. Moreover, as the low elevation of polder systems requires perpetual drainage of water to avoid water logging from seepage, both direct salinization (by attracting saline water to the surface) and indirect salinization (through ground subsidence) are common. Therefore, most of the salinization prone areas are located near the coast, in reclaimed lands and in previous intertidal zones, where seawater is (historically) present in the groundwater and relatively close to the soil surface. Without the use of, often translocated, fresh water to regularly flush through the water systems and soils in these low-lying areas, the brackish groundwater would be a major limiting factor to agriculture in particular. However, the combination of increasing external intrusion of seawater in groundwater aquifers and (open) waterways, decreasing river discharge, decreasing precipitation and increasing evapotranspiration in the drier seasons is limiting the freshwater availability to do this, especially in 'end of the pipeline' regions.

However, as critical freshwater shortages have always been more of an exception to the rule – as evident from the national evaluations from water managers and users after the summer of 2018 which was the driest summer ever recorded in the Netherlands – the issue of salinization is relatively new to the Netherlands. Therefore, business-as-usual responses are rather unlikely to solve the problems ahead; new mitigative and adaptive measures are needed for 'climate-proofing' the



freshwater availability in the Dutch delta, as evident from the recently established Delta Decision and Delta Plan on Freshwater Supply, which aim to secure the availability of fresh water now and in the future.

Until now, the traditional measure of flushing to ensure that the surface water has the desired water quality has been rather effective. However, the availability of high-quality freshwater for flushing is decreasing while the demand for it is increasing due to several developments, mainly 1) increasing salt concentrations due to saline seepage, necessitating more flushing, 2) decreasing quantities of readily available good quality water due to decreasing river discharge and seawater intrusion in rivers, 3) increasing demand for more and higher quality water (e.g. due to the cultivation of high-quality, capital-intensive crops), 4) increasing salt concentration at the root zone when too little water is available to compensate evapotranspiration. Therefore, both changes to current land- and water management practices as well as alternative adaptive and mitigative measures can be considered. Such measures can be broadly categorized into securing the freshwater availability, more salt-tolerant agriculture, and spatial reclassification, and into different scales from parcel to the national level.

This research aimed to identify how the Dutch agricultural sector can be made more salinization-resilient, by reviewing the extent to which salinization is already perceived as an issue, how the dominant land- and water practices relate to the issue of salinization, the opportunities and barriers of different mitigative and adaptive measures in addressing the issue, and what is generally preventing a transition towards salinization-resilience and the opportunities to stimulate such a transition. Based on semi-structured interviews with experts, agricultural representatives, waterboards, provinces, and innovative farmers, it can be concluded that salinization is perceived as a large threat to agriculture in the low-lying regions of the Netherlands that should be addressed sooner rather than later, but that the urgency to do so is lacking due to low recognition and awareness of the issue amongst policy-makers and farmers, as well as the priority of other issues. Moreover, it can be concluded that current dominant land- and water management practices like the focus on disposing water instead of retaining it, the lacking efficiency in the use and supply of freshwater, and the paradigm of 'water follows function' in spatial planning and chloride norms are largely stimulating salinization and/or are expected to become unsustainable in light of salinization. Furthermore, the opportunities and barriers of different mitigative and adaptive measures like anti-salinization drainage, a higher water level, soil conservation, more efficient water use and supply is that they often have other positive side-effects and/or are not too different from current practices, thereby relatively attractive to implement, but that these are not expected to be effective on the long-term and that their (cost-)effectiveness is still rather unknown. For salt-tolerant agriculture, the opportunities lie with the selection of more salt-tolerant cash crops, and although this could be a more long-term solution, the salt-tolerance of these crops and common soils is currently under-researched. For spatial differentiation of water prices and in functions, the opportunities are that this can respectively increase efficiency in use and supply, as well as secure enough fresh water for certain areas. Nevertheless, such measures are politically challenging and might take a long time to become the standard. A lock-in of the status quo is that the diffuse burdens and responsibilities between farmers and water managers are resulting in virtually no-one having a strong incentive nor power to change the status quo. Moreover, short-sightedness amongst stakeholders and the uncertainty about the effectiveness and efficiency of different measures are preventing a transition to more salinization-resilience. On the other hand, especially more communication and collaboration between the stakeholders can create opportunities for such a transition. Furthermore, it is strongly advised that more research is done on the effectiveness of different mitigative and adaptive solutions, as this is currently lacking and thereby limiting the action-perspectives for both farmers as well as water managers. Finally, it is advised to supplement such research with a societal

cost-benefit analysis to identify the societal cost-effectiveness of different measures and the distributions of the costs and benefits, thereby informing decision-making on a preferred strategy.

- Master's in Environment and Resource Management at the Vrije Universiteit van Amsterdam
- Independently studied the issue of salinization for agriculture in the Netherlands for Master thesis
- Now pursuing a career in environmental management, project development, and/or consultancy

### III Food-water-energy nexus

#### 11. Salinity dynamics in river water, canal water, pond water and groundwater over the dry season in Ganges Delta - Afrin Jahan Mila, Richard Bell, Edward Barrett-Lennard, Enamul Kabir and Yingying Yu

##### **Salinity dynamics in river water, canal water, pond water and groundwater over the dry season in Ganges Delta: Implications for dry season cropping**

Afrin Jahan Mila, Murdoch University, Western Australia  
Richard Bell, Murdoch University, Western Australia  
Edward Barrett-Lennard, Murdoch University, Western Australia  
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Boro rice, fresh water, non-rice crop, Southern Bangladesh, water volume (From three to five keywords)

In the megadelta of the Ganges, Brahmaputra and Meghna rivers, the landscape has low elevation and is enormously vulnerable to changes in upstream flows, climate variability and sea-level rise. This increases the risk of salinity and requires adaptation in farming systems, impacting especially on the types of crops that can be grown. The lack of fresh water in the dry (rabi) season is a major impediment to agriculture. The dry season in southern Bangladesh generally extends from November to March. This study was conducted to assess the quality and quantity of water from river, canal, pond and groundwater sources during the dry season in a poldered test area at Dacope in Khulna District of Bangladesh. The survey was conducted at three points in a river, and in three water bodies (canal, pond and groundwater). For canals, at least three sections were selected for collecting data. Salinity of water bodies during high and low tide, and depth of water was measured once (March to May), twice (January to February) and thrice (December) in a week. We found that salinity in canals and ponds increased from 2 dS/m in February and reached a maximum of 2.6-3.8 dS/m in the middle of April. The construction of bunds between canals and saline rivers was able to delay the salinization of water resources within poldered areas compared to an area without bunds. Pond water salinity was suitable for rabi crop growth but the volume of stored water was not abundant. On the other hand, groundwater can be considered to be a prospective water source (with salinity ranges from 2.3 to 5.7 dS/m) if canal water is not available, but the impacts of the abstraction of groundwater on its salinity needs to be assessed. River water in this period was never

suitable for the growth of rabi crops due to its high salinity (1.3 to 25.3 dS/m). It is therefore recommended that the cultivation of boro (dry season) rice should be discontinued because of its requirement for substantial volumes of water of low salinity. Alternative crops need to be developed which are of short duration, and tolerant to salinity and drought at the end of the growing season. Another opportunity is to increase the storage capacity of existing water bodies (canal, and pond) so that water can be stored during the monsoon season from rainfall as well as from river sources when water salinity lies below 2 dS/m.

I have completed my graduate (2008) and post-graduate studies (2010) on Irrigation and Water Management. I am employed by the Bangladesh Agricultural Research Institute (BARI). Currently, I am a PhD candidate at Murdoch University, Australia conducting research on the conjunctive use of fresh and saline water to irrigate rabi crops.

## 12. What if it becomes too saline? - Reinier Nauta

### **What if it becomes too saline?**

*Seaweed cultivation; from knowledge to knowhow*

Reinier Nauta,

Seaweed researcher / Project manager

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Seaweed, Land-based, Value-chain

It is widely known that salinization of agricultural areas is a global and increasing problem. Solutions are now constructed for mild and moderate salinization, but groundwater salinities of over >35dS/m are commonly seen as too saline for agriculture. At The Saline Farming Group a step was made towards an answer for this gap in present knowledge. Next to testing agricultural crops for saline conditions on our open-air laboratory, knowledge was extended towards more aquatic options as an answer for the heaviest salinized areas. To our opinion this is to be found in seaweed.

With its ability to grow in saline waters of 25-60dS/m and its high diversity of potential usages, seaweed is nowadays gaining more and more interest for cultivation. By initiating marine aquaculture in areas where no standard nor saline agriculture can be exploited due to salinization a new commercial activity can in this way be developed. With seaweed being used for food, feed, fertilizer, pharmaceuticals and biofuel, it can be seen as the new green resource. Especially for (saline) agriculture one of the most interesting characteristics of seaweed is its potential as fertilizer. With the produced material, new local produced organic matter can be grown making it possible to revalue the surrounding agricultural lands.

By development of this new technology to fill in a major gap in our knowledge on dealing with salinization, a transition can be made from knowledge to knowhow by using land-based marine aquaculture as a stepping stone towards a solutions for (heavy) salinization, development of new commercial activities and a circular economy.

Reinier Nauta is a researcher on the topic of (land-based) seaweed cultivation. With his former job of being project manager at Saline Farming he is now continuing his work at the Royal Netherlands Institute for Sea Research (NIOZ). With his research he hopes to make the transition 'from knowledge to knowhow' and with that helping the world on dealing with heavy salinization.

## 13. The impacts of North Sea flooding to UK agriculture - Iain Gould, Isobel Wright, Gary Bosworth, Eric Ruto, Martin Collison, Simon Pearson

### The impacts of North Sea flooding to UK agriculture

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Coastal Flooding, Salinity, Economic Impact,

#### Introduction

Coastal flooding has devastating consequences for millions of people, properties and land worldwide<sup>1,2</sup>; incidence of which are only set to increase under future climate projections<sup>3</sup>. The UK's North Sea coast is one area at risk, having been subject to a history of coastal flooding. As recently as 2013, farmland was inundated across the east coast, impacting on farm outputs via soil salinity and structural degradation. Over the past 50 years, Shoreline Management plans have been implemented to protect the coast, often prioritising urban areas and leaving agricultural land exposed to a higher flood risk. However, much of the UK's prime agricultural land lies in these areas exposed to flooding; Lincolnshire alone is home to a quarter of England's Grade 1 Land, yet two thirds of this is exposed to some degree of coastal flood risk. The salt inundation following a coastal flood can impact on crop growth and soil physical structure, impairing soil function, and the salt can persist in the soil for several years<sup>4,5</sup>. This could lead farmers in productive areas to accept yield losses post-flood, or having to switch to less profitable crops.

This study aims to address this under-representation of agricultural value by assessing the damage of coastal flooding and soil salinity to UK agriculture. We do this in two stages: (i) measurement of post-flood soil salinity and impacts to soil function; (ii) developing a novel framework to assess the impact on agricultural outputs, using coastal Lincolnshire as a model system.

#### Methods

##### *Field Survey and Soil Analysis*

To investigate longer term soil damage, we visited a number of farms in 2017 which had been inundated with water in the 2013 Coastal floods. Following the floods, different farms adopted a range of post-management practices. These included gypsum applications, growing less tolerant crops, 'business as usual' cropping and putting in grass leys. Soil samples were taken and assessed for salt levels, alongside key physical properties such as bulk density, infiltration rates and aggregate stability.

##### *Economic Modelling*

We took a spatial mapping approach to obtain areas, and crops, at risk under a number of current and future flood scenarios, using field-by-field crop data, *Land Cover Plus*<sup>6</sup>. Crop data was overlain with Environment Agency coastal flood scenarios to determine total area, and crops, at risk along a 105 km stretch of the Lincolnshire Coast. The flood scenarios represented: (i) current breach risk; (ii) future breach risk under 2115 climate predictions; (iii) 'Big' flood event assuming no sea defences across the coastline.

For each of these scenarios, we compiled the total area of each crop under the flood map. We then calculated yield impacts based on from FAO crop salt tolerance data <sup>7,8</sup>. As no data is available on soil recovery from salts, we modelled a range of recovery yields for each crop from 1 year recovery up to 7 years for soil recovery and salt levels to reduce to pre-flood levels. We then converted yield impacts to financial losses using localised expected output data <sup>9</sup>. To accommodate for potential changes in farm management practices following a flood, we also simulated a further 3 recovery scenarios: (i) switching to more salt tolerant crops; (ii) putting down to grass; (iii) cost of gypsum application.

## **Results**

### *Field Survey*

Post-flood management had a significant impact on the levels of exchangeable sodium percentage (ESP) in the soil, even 3 years after a flood. Fields under gypsum application and grass had the lowest levels ( $4.6 \pm 1.6$  %), followed by those with moderately salt-tolerant crops ( $9.1 \pm 1.5$  %), with soils under the most salt- sensitive crops having the highest levels ( $14.2 \pm 0.9$  %). Further analysis found that high levels of ESP corresponded with reductions in log-transformed soil infiltration rates ( $R^2 = 0.35$ ), aggregate stability ( $R^2 = 0.60$ ), and increases in bulk density ( $R^2 = 0.70$ ).

### *Economic Modelling*

To assess whether there were variances between the relative salt tolerance of crops grown between the different coastal zones, we categorised each crop type into one of three salinity categories according to FAO crop salinity tolerance indices<sup>8</sup>, which were: moderately sensitive (field beans, maize, brassicas, potatoes); moderately tolerant (grass, wheat); or tolerant (beet, oilseed rape, barley). We found that the moderately salt tolerant and salt tolerant crops occupied a high proportion of the northern coastline, whereas in the other coastal zones further south the breach area contained moderately salt sensitive crops.

In the first (flood) year alone, a typical breach flood could deprive the inundated area of a total yield between 27,998 t in a low yielding scenario in the northern stretch up to 108,336 t in a high yielding scenario in the south. When yields were converted to potential outputs, this translates to between £1,074/ha and £1,368/ha in the north and £2,538/ha to £3,258/ha in the southern stretches of the coast. Beyond the flood year, different yield potential and recovery times of soils (2 to 7 years) could result in varying levels of yield and output losses in the longer term. As such, in the 'worst case scenario', assuming soils take 7 years to recover, flood damage could nearly double to up to £2,120/ha in the north and £7,511/ha further south.

Given more localised knowledge of the soil types and cropping in our specific case study areas, we can focus our damage estimates for each Coastal Zone. Grade 1 silt soils (Wisbech association), may expect output losses of between £4,719/ha and £5,376/ha, which equates to total flood losses per breach £21.7 million and £13.8 million. The heavier soils of northern reaches may expect poorer drainage and average yield conditions and thus output losses of £1,956/ha, equating to total losses of £3.8 million. In the 'big event' scenario, should the entire coastline be subjected to a flood, total output losses could range from £201 million (flood year and quick recovery) to £494 million (7 year recovery recovery). Switching to salt tolerant crops or grass systems could reduce output losses. Further up the agri-food chain, we estimate that potential job losses at the supplier and direct farm level range from 30-236 jobs per breach.

## **Discussion**

The impact of coastal flooding on agriculture has seen little attention in the literature; and no assessment has accommodated the multi-year and long term impacts of saline ingress on productivity following a flood, or the impacts on locally adapted production systems. We attribute this to a general lack of widespread salinity data in maritime climates <sup>10,11</sup>. Our framework differs from previous economic flood impact studies <sup>12,13</sup> in that it considers longer term impacts beyond one year. Factoring in a slow soil recovery, our model calculates likely losses in the region of 1.7 to 2.8 times higher than the conventional model estimates. This suggests that the potential damage caused to agriculture, particularly in high value areas, has been under estimated until now. Our loss

estimates are though conservative, they forecast similar single year losses to prior models but do reflect longer term impacts of saline ingression.

Our model shows that for agricultural output alone, a single sea wall breach could cost losses of up to £34 million in a high value, poor soil recovery area. However, natural hazard impact assessments rarely assess the cascading impacts on the food value chain<sup>10</sup>. Physical damage of a coastal flood will not only affect the farmland, but will have cascading negative consequences both backward (e.g. fertiliser, machinery suppliers) and forward (e.g. processing, distribution) along the chain. Based on the outputs of our wider agri-food economy assessment we could also expect significant job losses across the sector from a large flood.

The field survey highlighted the impact of sodium deposition on soil physical properties, and the importance of post-flood management in reducing sodium levels in soil. Nearly 3 years after the flood event, one of the management strategies still showed exchangeable sodium levels close to 15 % a threshold often referred to as that of 'sodium risk' to soil. The sodium risk was reflected in the reduction in the physical quality of the soil – lower infiltration rates and aggregate stability, and higher bulk density when compared to other managements. This reinforces the significance of the remediation steps a farmer may take to speed up recovery. Alternative management strategies may not just improve salt removal; they could also contribute to greater income in the long run. Our model found that substituting existing higher value, but salt sensitive, crops for more tolerant (albeit lower value) crops may reduce the total financial damage of a flood in our region by £0.7-10.2million, provided the alternative rotation is only in for a year or two.

### **Conclusion**

The results show that the economic threat to farmland may be much worse than previous assessments. Furthermore, 'agri-food hubs' of fresh produce, high value horticulture and shortened supply chains have built up around these fertile soils. Building on this, ongoing work on the SALFAR project with partners across the North Sea Region will help us understand how agriculture can adapt to these pressures.

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Iain Gould is a Soil Scientist at the University of Lincoln, UK. His research interests lie in plant-soil interaction, technological developments in soil mapping and coastal flooding and soil salinity. Recent work has looked at the economic impact to the agri-food sector of coastal flooding in the UK

#### 14. Sustainable saline agriculture in Iran: Turning Threats into Opportunities - Raheleh Malekian

##### **Sustainable saline agriculture in Iran: Turning Threats into Opportunities**

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Saline Agriculture, Saline Aquaculture, Quinoa, coastal area

##### **Abstract:**

Salinization of soil and water resources in Iran is increasing prominently which is posing a major challenge to national sustainable development and food security. Soil and water salinity in Iran is consequences of natural phenomenon but in many cases, these resources have become saline because of anthropogenic activities and mismanagement. According to the recent estimates in Iran, slightly to moderately salt-affected soils cover about 25.5 million ha and soils having severe salinity occupy 8.5 million ha. The annual economic loss in Iran due to the presence of salt-prone soils under irrigated agriculture in Iran is about 9 percent of the global value. Saline agriculture is a relatively new way of dealing with salinity in agriculture and turning threats into opportunities in Iran. Although crop-based management of saline soil and water has been practiced from many years ago in Iran, there has been a renewed interest in these approach because of the recent trends of soil and water salinization and an urgent need of these resources for producing more food and fiber for country's sustainable development. Here, some experiences of saline soil and water resources usage for salt- tolerant crops, oalgae and aquaculture crop production in Iran is described. Policies needed to implement and/or develop such practices are also outlined.

Raheleh Malekian has Ph. D in Irrigation and Drainage. She received a research scholarship from university of Guelph in Canada in 2011. Her researches have been mainly about environmental issues. She has published more than 9 peer-reviewed manuscripts and 12 conference papers. Now, she is working as a senior expert of the water studies section in the National Agriculture and Water Strategic Research Center.



## 15. Potentials of saline agriculture for subsistence and livelihoods of local poor communities in the Jordan Valley - Ziad Al-Ghazawi

### **Potentials of saline agriculture for subsistence and livelihoods of local poor communities in the Jordan Valley**

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Bio-saline, agriculture, treated, wastewater, Jordan

Jordan is a semi-arid country with limited renewable fresh water resources. Climate change and millions of refugees due to nearby conflicts have created increased pressure on Jordan's water resources and food production sectors. Irrigated Agriculture forms about 65 % of the total water budget in the Country. The chronic deficit between supply and demand caused a strategic decision to use non-conventional water resources namely treated wastewater as well as brackish groundwater to produce food especially in the Jordan Rift Valley (JV).

In 2020, it is projected that the total water requirement is 1647 MCM (million m<sup>3</sup>) with a deficit of 360 (MCM). 890 MCM of this total will go for agriculture. Projected amount of recycled wastewater is 232 MCM in 2020 with 137 MCM in the Jordan Valley alone.

This paper summarizes the results of a one-year research project to investigate biosaline agriculture potentials in the Jordan Valley and to understand the links between higher-salinity water resources and soil salinization in the Valley.

Jordan valley is a unique ecosystem characterized with very hot and dry summer as well as moderate temperatures and limited rainfall in the winter. JV has the most fertile soil in Jordan and depends on irrigated agriculture for citrus, palm, banana and vegetables. Irrigation water is imported from Yarmouk river and also from King Talal Reservoir (KTR) that is fed by Zarqa river which, in turn, carries most of the treated wastewater generated in the Country.

Fresh water from Yarmouk river is mixed with high-salinity water from KTR to irrigate lands in the middle JV. Limited rainfall has led over the years to salinization of precious fertile lands in the area due to limited leachability of salts and their accumulation in the top soil.

The main goal of this research was to develop soil salinity classification for lands in the JV and also to characterize levels of salinity in available sources of irrigation water to better manage salty lands for food production and to protect normal soils through flexible, alternating and site-specific irrigation schemes.

**Methods:** Develop soil classification maps and analyze salinity levels in irrigation waters, then propose irrigation and cultivation management scenarios including saline agriculture.

#### **Results:**

1. Classification and mapping of all lands in the JV based on level of salinization with help from JVA (see Figure below).

2. Classification of available water resources including the high-salinity level treated effluents in KTR. Levels of salinity in KTR range from 2000 to 2500 mg/L as TDS, while that for brackish groundwater range from 3000 to 6000 mg/L as TDS
3. Proposing an integrated strategy that combines the available water quality in KTR and soil classification in the Jordan Valley.

### Discussion and Conclusions:

It is understood from the JVA's average-salinity maps and the classification shown in the table below that the Valley has vast areas that are saltlands in the range of high, severe and even extreme salinity. Most of these are to the southern part of the Valley north of Dead Sea. However; there exist sizable areas of moderate salinity range where high salinity water can be used in biosaline agriculture scheme. This will form a win-win situation whereby these marginal quality waters can be used to produce income generating crops and in the same time reducing salinity level in these areas and recovering the high value land.

Table 1: Salinity classes for saltland suggested by Barrett-Lennard et al. (2008b)

Land salinity class	ECe range, dS/m
Non-saline	0-2
Low salinity	2-4
Moderate salinity	4-8
High salinity	8-16
Severe salinity	16-32
Extreme salinity	Greater than 32

A plan should be enacted to know the carrying capacity of each land zone as far as higher salinity water is concerned. For example, based on available rainfall (i.e salt leachability) in each land zone in the Figure, and the level of salinity in available water, the plan should predict how many years in the future the current/proposed irrigation practice can be sustained without irreversible impact on soil fertility and productivity.

For land zones where soil salinity is high or very high, bioreclamation with certain types of halophyte species should be considered. For example, the salt accumulator halophyte species, *Atriplexhallimus L.*, *Atriplexnumularia L.* and *Tamarixaphylla L.* were respectively found to lower the salinity as EC from 84 to 5.46, 5.04 and 6.3 mS/cm at the top layer (0-30 cm) and from 49.6 to 5.46, 13.45 and 7.14 mS/cm in the lower soil (30-60cm) in the salty soils of Ghor Safi at the southern tip of the Dead Sea.

Biosaline agriculture should be introduced and encouraged especially in those land zones of high salinity. Cash crop trees such as palm trees which are salt tolerant yet of high economic value should be considered. Vegetables such as salicornia which is known to be very salt tolerant should replace sensitive crops to soil/water salinity.

Clean Development Mechanism (CDM) which was an outcome of Kyoto Protocol on Climate change (2003) should provide an interesting option for Jordan. A closer attention should be paid to the available brackish water resources and to the cultivable saline lands in the JV.

Efforts are recommended to start by a pilot project where different varieties of salt-tolerant trees are planted on saline lands using reclaimed water and brackish water. This should form an income generating enterprise making use of this marginal quality water in a sustainable manner.

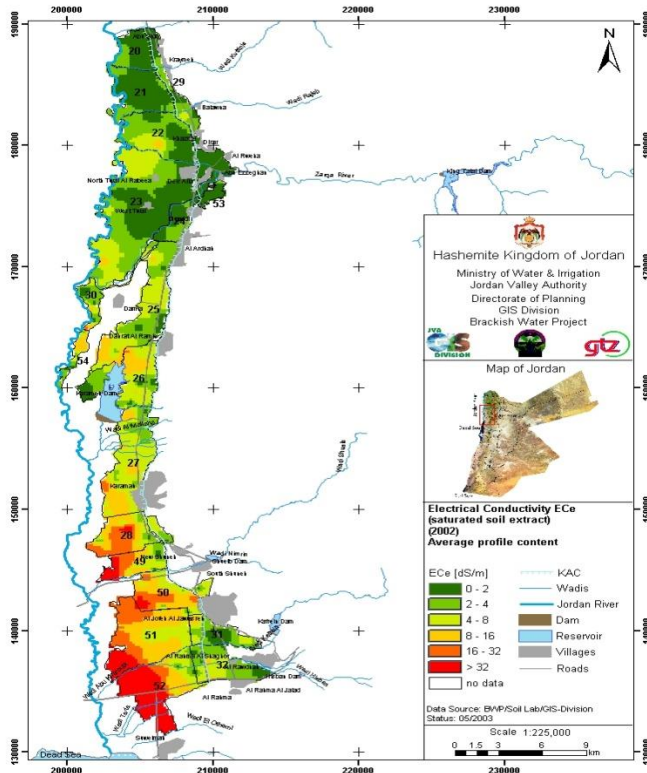


Figure: Soil salinity classification in the Jordan Valley (JVA, 2017)

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## IV Fresh and brackish water management in potentially saline soils

16. Managing salinization under climate change: using degraded irrigation waters and new technologies - Francisco Pedrero Salcedoa, Juan José Alarcón Cabañeroa, Margo Robbenb, Huub Rijnaartsb , Pedro Javier Guillermo Lópeza

### Salinization management using advanced information technologies and non-conventional water resources

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Reclaimed water, salinization, precision agriculture

In the Mediterranean Region, irrigated agriculture contributes 75% to the final production. The continued use of these water resources for irrigation will probably put the agro-systems and the environment at risk from salinization, soil compaction and undesirable ions toxicity. Soil secondary salinization affects an estimated 1 to 3 million hectares in the enlarged EU, mainly in the

Mediterranean countries (FAO, 2008). It is regarded as a major cause of desertification. A new strategy of water management it could be a key method for desertification prevention. Actually, there is a need for technologies that increase water use efficiency and make additional (non-conventional) water resources available for agriculture, thereby decreasing water scarcity and the discharge of water and nutrients to the environment.

The aim of the project is to lay the foundations of a novel integrated system for regional salinity assessment using advanced information technologies for an efficient crop production management by enabling the degraded water use for irrigation. Inside this project, a first-year experiment was developed in a broccoli and cauliflower cropping system in Campo de Cartagena (Murcia, Spain). The broccoli plot was irrigated with mixed water from different sources (brackish groundwater, transfer water or reclaimed water), while the cauliflower plot was irrigated only with reclaimed water.

In order to monitor broccoli and cauliflower growing systems, two drone flights were conducted for both fields and different indexes were calculated. The NDVI was selected because it gives information about the greenness and biomass of the vegetation and it is one of the most widely used remote sensing-based indexes. The EVI is an index which was formulated by the MODIS Science Team and it is an improvement on the NDVI. The EVI corrects for distortions in the reflected light caused by air particles as well as the ground cover below the vegetation, and the GARI was chosen because it can give an indication of crop coverage. Lastly, the CRSI was selected because it could provide more details about the plant health under saline stress.

First results showed that in both plots, there were no risk of soil infiltration reduction and a decrease in the E<sub>ce</sub> values, which was due to the salt leaching originated because of the high rainfall. Also, due to this reason occurred before the second flight, the salinity of the soil decreased and therefore the plant did not absorb a large concentration of salts and developed correctly, which is reflected in the high CRSI values obtained. In all the studied indexes, a very similar behavior to the one obtained in the CRSI was observed, reaching correlations between CRSI and EC of the same order ( $R^2 \leq 0.50$ ) for both the cauliflower and the broccoli plots.

In recent future research, and to avoid the absence of data in face of unusual weather events, it will be looked for more flights during the entire crop cycle to look for more accurate correlations and be able to select the indexes that provide more information, and to be able to relate in a fast and simple way, saline stresses in crops to environmental factors, to develop good agricultural practices in each specific plot.

I'm Dr. Agriculture Engineer, researcher at the Irrigation Department of CEBAS-CSIC, working during the last 10 years on precision irrigation and water reuse in agriculture, especially "sustainable reclaimed water use in agriculture".

## 17. Nine steps towards a sustainable climate-proof fresh groundwater supply: the case of Zeeland, the Netherlands - Oude Essink, Gualbert

### **Steps towards a sustainable climate-proof fresh groundwater supply: the case of Zeeland, the Netherlands**

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salinization; fresh water scarcity; agriculture, climate-proof groundwater supply; Zeeland

Salinization of fresh groundwater resources in coastal lowlands around the world is accelerated due to multiple causes such as increase of groundwater extractions (larger freshwater demands), groundwater recharge sealing (urban development), land subsidence, climate change and its associated sea-level rise.

Before successfully bring into practice water management strategies to mitigate and/or to adapt to this changing salinizing environment, we argue that first a number of conditions must be met. Based on the knowledge gained during the last 15 years in the province of Zeeland, The Netherlands, we learned there is no water management strategy fits all. We argue that tailor-made solutions are key, given different local varying circumstances. At the same time, we tried to keep in mind to bring fresh groundwater supply innovations to a Technical Readiness Level (e.g., Mankins, 2009) high enough to make it a feasible regional strategy.

Here, we demonstrate our nine steps towards a sustainable climate-proof fresh groundwater supply, for the case of Zeeland, the Netherlands.

**1) Sense of urgency on fresh ground water supply under climate and anthropogenic stress**

In the Southwestern delta, The Netherlands, the agricultural sector is confronted with growing impacts of water shortage and salinization (Van Baaren et al., 2016). The Province of Zeeland is aware of the negative influence on the socio-economic development (Deltaprogramma; Deelprogramma Zuidwestelijke Delta, 2011). The agricultural sector and municipalities consider a reliable freshwater supply as one of the key issues for future development and sustainable growth. This sense of urgency is necessary to start up initiatives such as funding applied research programmes, such as Salinization Processes Phreatic Groundwater in the Province of Zeeland (e.g. De Louw, 2013; Oude Essink et al., 2009), Knowledge for Climate (Jeuken et al., 2012; Pauw, 2015), GO-FRESH (Oude Essink et al., 2018, 2014).

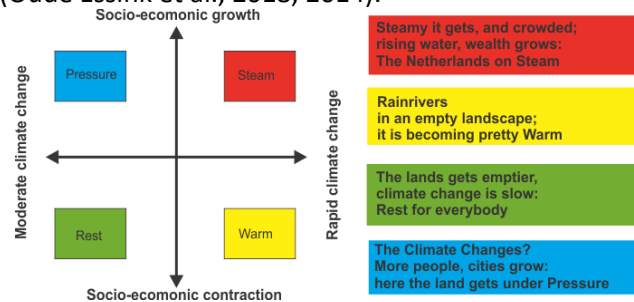


Figure 1: Climate and socio-economic scenarios for The Netherlands.

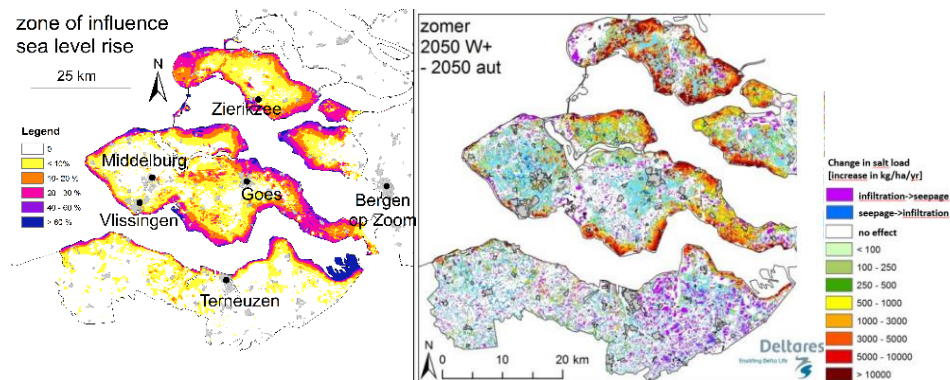


Figure 2: Zone of influence of sea-level rise and change in saline seepage.

## 2) Frontrunner stakeholders at every level

Stakeholders on different levels are needed who are aware of the pressing water related issues ahead. In Zeeland, the relevant stakeholder, viz. being the Province of Zeeland, sets the conditions, while The Water Board Scheldestromen, municipalities and the farmers organization ZLTO joining in with specific knowledge on hydrogeological processes, farmers interest and governance. The Deltaprogramme Fresh Water (national level) is important to link the local water demand and supply chain to the national water supply and demand programme where different water sector interests are weighed. Finally, farmers are crucial to bring in their experience on local hydrogeological processes, while their ideas on how to retrieve a sustainable climate-proof fresh groundwater supply are important for succesful showcases.

## 3) Analysis of the (ground)water system

Once the goals and ambitions of the stakeholders are acknowledged, the physical condition of the groundwater system must be understood in details (De Louw, 2013; De Louw et al., 2015, 2011). If necessary, addition scientific research must be executed; in this case the geological and hydro(geo)logical conditions of the water system (viz. sandy creek ridges, saline seepage area, effect groundwater extractions, fresh-brackish-saline groundwater distribution, etc.) using (innovative) monitoring and modeling techniques like FRESHEM (Delsman et al., 2018; Van Baaren et al., 2018) and 3D variable-density groundwater model Zeeland (Oude Essink and Pauw, 2018; Pauw et al., 2016; Van Baaren et al., 2016).

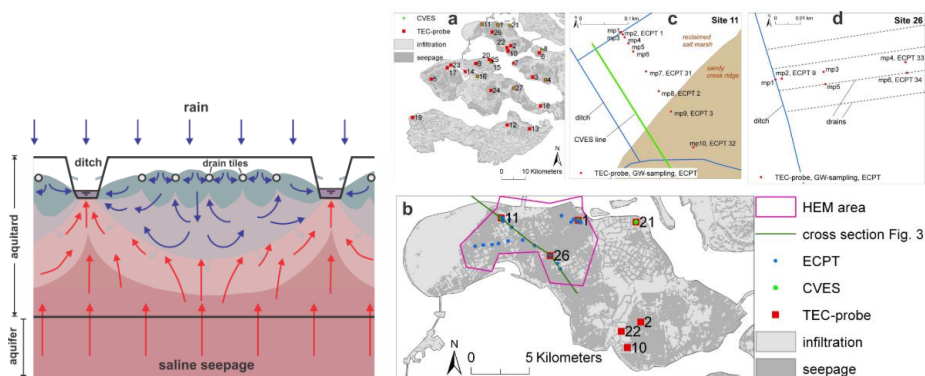


Figure 3: left: the working of a freshwater lens in a low-lying polder area under winter conditions; right: different field measurements at different scales in The Province of Zeeland (De Louw et al., 2011).

## 4) Open access to hydro(geo)logical data

Databases should be directly (preferably without costs) accessible via internet, to be used in the system analysis and the modeling. Examples are: geological data like GeoTop (dinoloket , <https://www.dinoloket.nl/>), fresh-brackish-saline groundwater salinities (<https://www.zeeland.nl/water/zoet-water/zoet-zoutverdeling-zeeuwse-ondergrond>, from project FRESHEM Zeeland (Delsman et al., 2018; Van Baaren et al., 2018), DEM and surface water system (<http://www.ahn.nl/>, <https://data.nhi.nu/>).



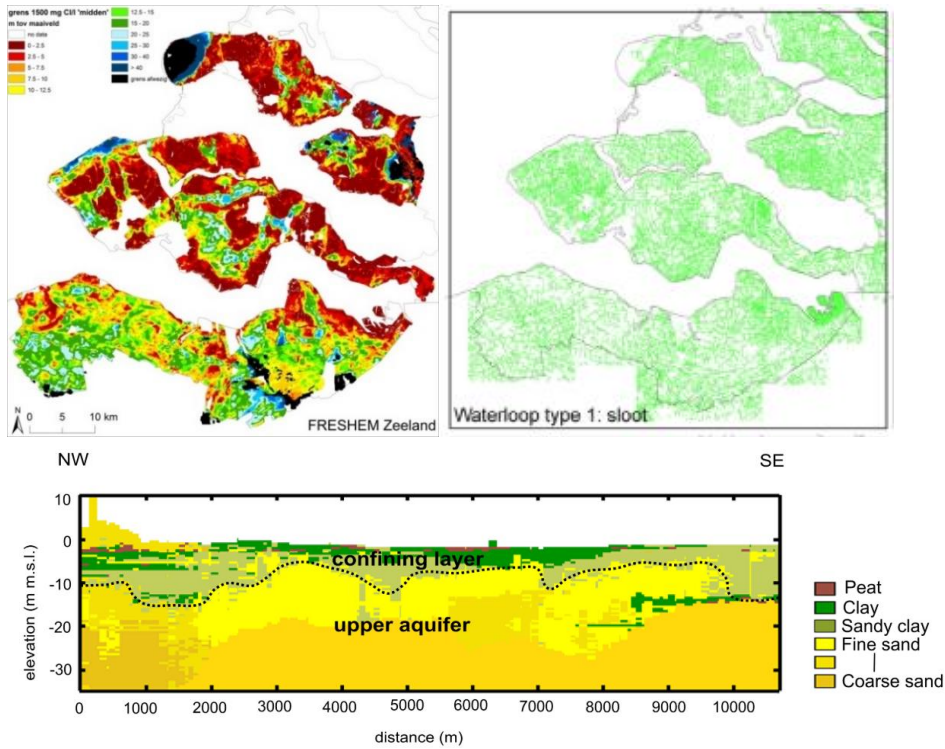


Figure 4: upperleft: depth of fresh-brackish groundwater interface below ground surface (FRESEHEM); upperright: : surface water network of water course level 1 (ditch level); below: distribution of so-called geological voxes (of sandy (yellow), clayey (green) and peaty (brown) composition) (De Louw et al., 2011).

### 5) Assessing the future water gap

With the collection of knowledge from the ground (and surface) water system analysis using modeling and monitoring techniques, the (ground)water supply and demand now and in the future can be assessed. If a serious water gap between supply and demand will occur and no reliable surface water source at the right moment of demand is available, future farming should be safeguarded using groundwater resources.

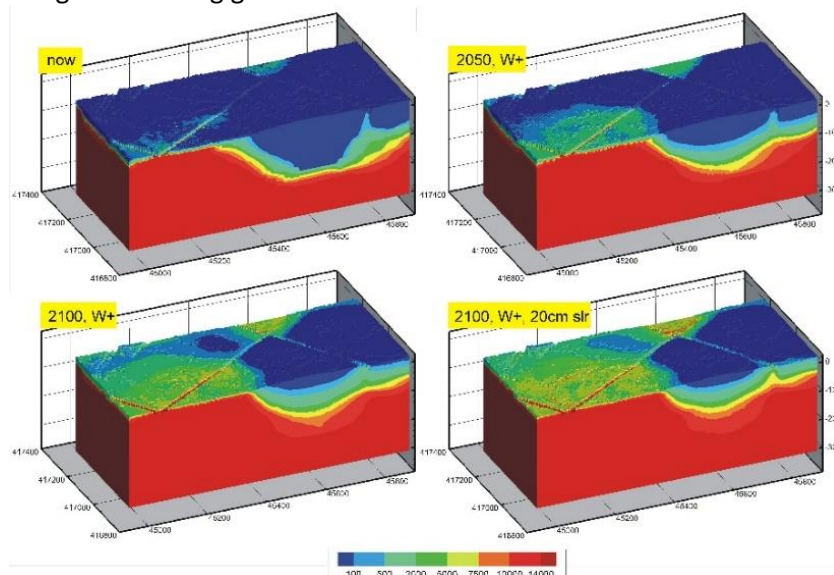


Figure 5: Modeled Cl-concentration: different climate change and sea-level scenarios over time (now, 2050 and 2100 with W+ scenario meaning less groundwater recharge, 2100, W+ plus a sea-level rise of 20cm), showing the change in groundwater salinity over time (from the legend label



'green' on (chloride concentration > 3000 mg Cl/L), the area is too salty for normal crops and serious salt damage will occur).

### 6) Setting up pilot on solutions and/or strategies

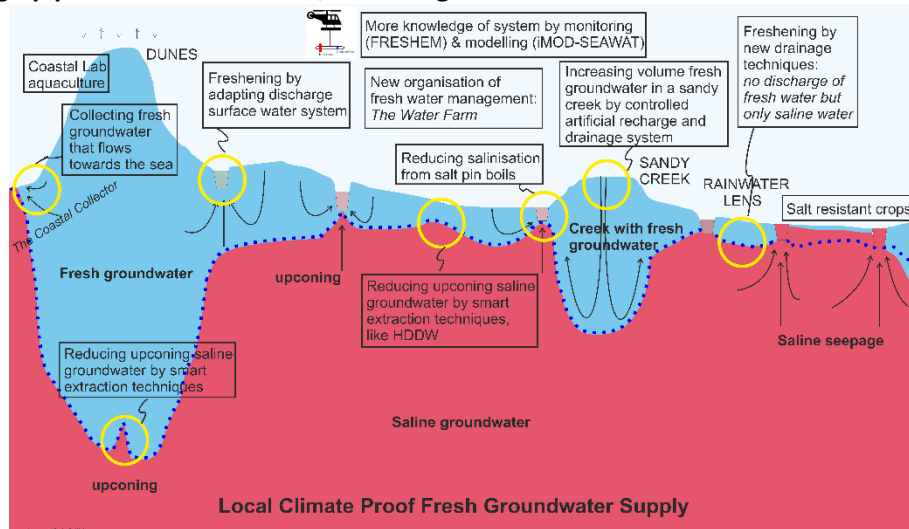


Figure 6: Combination of different strategies for improving local climate proof fresh groundwater supply.

Solutions are piloted on a local scale, to test their hydrogeologic and (socio) economic feasibility. Examples are:

- Aquifer storage and recovery underground freshwater storage (project GO-FRESH), especially at locations of sand-dune creek ridges.
- Salt resistant crops where needed in the future due to intense salinization
- Smarter water saving agriculture technologies
- Alternative water: waste water, desalinated brackish groundwater (COASTAR: 'Brackish Groundwater is the New Fresh')

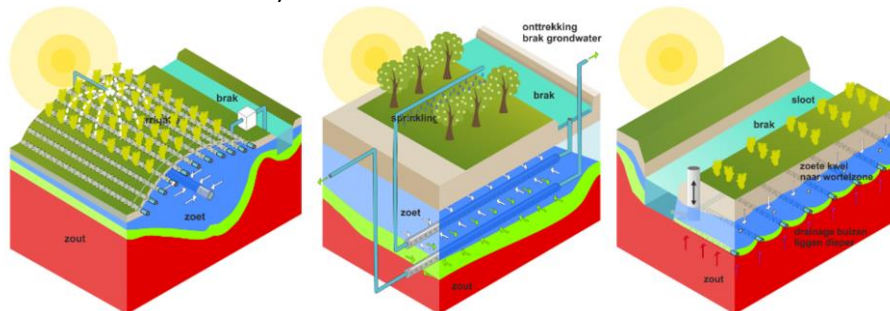


Figure 7: Local Aquifer Storage and Recovery Solutions: Left: Controlled artificial recharge and drainage system (CARD); middle: Freshmaker; right: DrainsBuffer.

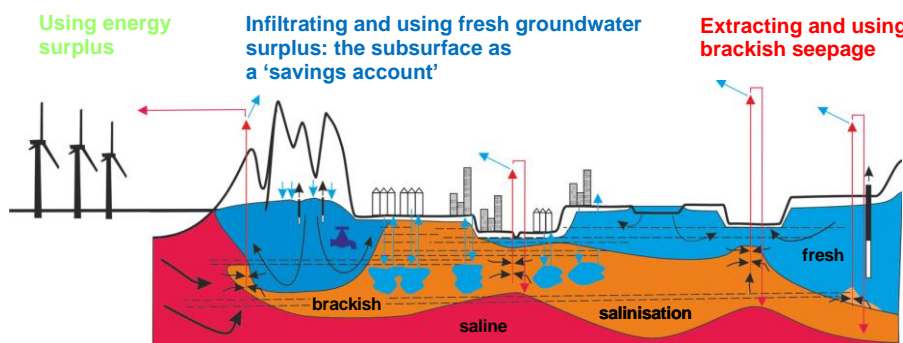


Figure 8: A conceptual schematization of COASTAR: Subsurface water solutions using brackish groundwater when possible.

**7) Procedure for scaling up solutions/strategies into the region**

Information provision on successful pilots for farmers and local government, e.g., via internet (wiki on possible solutions at farmers level, including a first assessment on economic feasibility), teaching experts farmers advisors, creating potential maps of solution in the region.

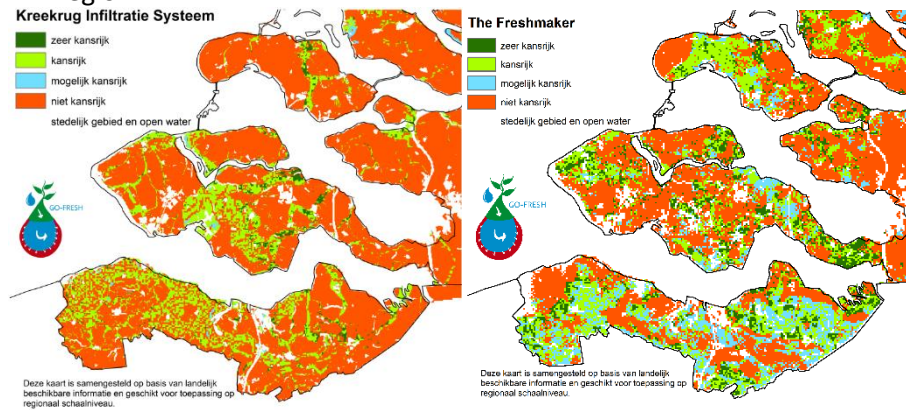


Figure 9: Examples of potential maps of two different aquifer Storage and Recovery techniques.

**8) Open up regulations/rules**

The Water Board, Province and national government should line up on facilitating solutions and strategies, e.g., regulating fresh surface water infiltration, brackish groundwater disposal to ditches and on sustainable groundwater extractions.



Figure 10: Regulations should be lined up to realize a sustainable climate-proof fresh groundwater supply (Zuurbier et al., 2015).

**9) Continuous communication and knowledge transfer**

All previous steps need to be communicated via websites (go-fresh.info), stakeholder meetings, reports (Oude Essink et al., 2018; Oude Essink and Pauw, 2018) and scientific articles (e.g., Pauw et al. (2015)), to keep the process ongoing.



*Figure 11: Stakeholder meetings GO-FRESH, with interested farmers, representatives of the Province, Water Board Scheldestromen, farmers organization ZLTO and the consortium (Deltares, WUR, Applied University of Zeeland and KWR).*

## **Conclusion**

A procedure including different steps must be followed before a sustainable climate-proof fresh groundwater supply in a coastal region under climate and anthropogenic stresses is accomplished. It takes serious time (>10 years) to go through all the steps, while during the whole process all stakeholders must be lined up.

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Gualbert Oude Essink is senior hydrogeologist at Deltares and associate professor at the Utrecht University. His expertise is on safeguarding fresh groundwater resources in the coastal zone under anthropogenic, climate change conditions. Gu participates in Aquifer Storage and Recovery solutions for fresh groundwater supply to reduce drought and salinity stresses in Zeeland (Netherlands), Vietnam and Egypt.

## 18. Saline groundwater seepage increase with sea level rise - Johan Medenblik

### Saline groundwater seepage increase with sea level rise

Johan Medenblik, Province Fryslân

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In the Dutch province of Fryslân groundwater is of great importance for agriculture, nature and drinking water supply. Because Fryslân borders the sea, salt water is never far away.

The land is well protected by dikes against seawater flooding. Behind the dikes, we find clay soils with water levels just below sealevel.

Further in the centre of the province, thick layers of peat has been formed since the last glacial period (that ended 10.000 years B.C). Already in Roman times, cultivation of the region required drainage which inevitably led to subsidence of the peat soils, over centuries adding up to several meters. The lowering of the ground levels and erosion of the banks led to the formation of the many lakes, of which the region is known for. Furthermore, from the 17th century until the late 19th century, large amounts of peat have been excavated on an industrial scale for fuel. Especially in the 19th century peat has been excavated in low-lying regions leaving wastelands behind, more water than land. These areas were (mandatory) reclaimed for agricultural use. This required the use of pumping stations for lowering water levels sufficiently. Water levels are now in some places more than three meter below sealevel.

Inevitably these changes in the landscape have had a major effect on the hydrology of the region. General groundwater flow is now directed to the lower regions in the heart of the province. In time, the effects of saline groundwater should be reckoned with. In several places there is still peat left. Low (ground) water levels cause peat degradation. As we react by further lowering the water levels, in combination with the rising seawater level, the inflow of salty groundwater will increase. How far will the salty groundwater reach into the province of Fryslân? How fast will it go? Will it get to the

drinking water wellfields, making it no longer suitable for drinking water? Can we influence the inflow of salty groundwater, or do we have to anticipate by defining strategic reserves for the drinking water supply? These questions require a thorough understanding of the hydrological system and the distribution of salty water in our aquifers.

Together with the waterboard Wetterskip Fryslân and the drinking water company Vitens, the province of Fryslân has executed a groundwater study for Fryslân. In this presentation the results of a 3D groundwater modelling study will be presented. Groundwater levels were calculated, taking the effects of the higher density of salty water into account, and were compared with measured values. The resulting groundwater flow has been simulated, both in the past and the future. Chlorine concentrations are assigned to the groundwater, giving us insight in the transport mechanisms. Calculated values were compared to a 3D-interpolation of all available chlorine measurements.

Groundwater flow processes appear to be very slow. Compared to these geological processes the influence of man is very dynamic. The hydrological system lags behind. Therefore: in order to explain the present chloride distribution, simulations had to start in the year 5500 B.C. The modelling showed that before the dikes protected the land, seawater flooding of the north-western part of the province caused intrusion of saline groundwater. This was following the last glacial period, for both from the surface and in the deeper aquifers. Recharge of rainfall in the southeast generated a fresh groundwater body which stopped this intrusion at a certain point.

After the Middle Ages, man-made dikes prevent seawater flooding and associated seawater infiltration. Peat degradation and lowering of the surface water levels in polder areas caused saline groundwater to migrate further east. The model shows that this is a very slow, but steadily ongoing process. Although the changes are not very prominent up to the year 2100, the model suggests more extended salinization of fresh groundwater resources in the following ages.

Rising of the sea level will increase the inflow of salty groundwater with around 20 percent at the end of our century. Salty groundwater will be found at lower depths in the coastal regions and surface waters will get more saline. Part of the effect will extend further land inwards. The flux of groundwater to the low-lying polder regions can increase with 50 percent. Until 2100 AD the changes in chlorine concentration do not seem very important. At the very long term however four of the seven drinking water wellfields are expected extract saline groundwater.

By increasing the water levels and fresh water infiltration in the coastal zone, we can delay this salinization, but we cannot stop it. Furthermore, we have to consider spatial effect, as increasing water levels can cause some increase in salt water seepage elsewhere. Still in the south and east of Fryslân, there are regions where the salty groundwater will not get to. We can give them the status of 'Strategic Reserve' groundwater, giving possibilities to protect them against forms of pollution and other undesirable activities (like drilling for geothermal energy).

The study has been reported not only in a scientific report, but also in a public-friendly 'Groundwater Atlas of Fryslân' in order to communicate the results with policy-makers and stakeholders and to create support by the residents of Fryslân. This Atlas will be presented at this Symposium.



19. The Water Farm: collaborative water system measures and governance approach to increase self-sufficiency of freshwater availability for agriculture - Rozema, J.; Pauw, P.; Arts, M.; van Baaren, E; Nikkels, M.; Moermans, T.

**The Water Farm of Walcheren: collaborative water system measures and governance approach to increase self-sufficiency of freshwater availability for agriculture**

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Pieter Pauw, Deltares

Marco Arts, Aequator Groen & Ruimte bv

Esther van Baaren, Deltares

Melle Nikkels, Aequator Groen & Ruimte / Wageningen University and Research

Tim Moermans, President of the 'Waterhouderij Walcheren' foundation, Manager of 'Boomgaard ter Linde'

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Groundwater, freshwater optimization, salinity, collaboration, agriculture

On the Walcheren peninsula (southwestern Netherlands) groundwater is the major source for irrigation. Fresh groundwater is present in the form of local water lenses. Unlike many other areas in the Netherlands, this part of Walcheren does not have access to external riverine freshwater and fresh surface water resources are not adequately available in times of irrigation demand (spring and summer). Walcheren is among the areas in the Netherlands with the lowest annual precipitation numbers. Hence, proper management of the freshwater lenses and optimization of the water system is of utmost importance to sustain irrigation. Promising measures to optimize the water system in this area are the buffering of freshwater from the dunes, coming mostly from precipitation in winter and redirecting saline ground- and surface water.

In 2010 a group of 7 farmers (managing over 300 hectares) in the northern part of Walcheren founded the 'Waterhouderij Walcheren' foundation. The foundation aims include the improvement of the freshwater availability, its governance in the area between Serooskerke, Vrouwenpolder, and Oostkapelle and enlargement of self-sufficiency in demand for irrigation water. In collaboration with consultancies, the local Waterboard, the Province of Zeeland, Farmers association and other stakeholders, the 'Waterhouderij Walcheren' has implemented pragmatic measures in the surface water system and subsurface over the last years, amongst others to buffer freshwater and to prevent the mixing of fresh and saline surface- and groundwater.

As the first implemented measures show positive results, the Waterhouderij Walcheren has been granted a EU agricultural development subsidy (POP3, non-productive measures) with the aim to further improve the fresh water system, to monitor and quantify the effects of various measures taken and to build towards a decision support structure on how the fresh water should be distributed between different or new users. In this presentation we shall present an overview of the results achieved so far and explain our strategy to answer remaining questions on how to monitor effects and how to build a discussion support system meeting farmers needs without conflicting conventional policy and other stakeholder?

Jouke Rozema is a field hydrologist working on optimisation of fresh (ground)water for agriculture and nature preservation at Aequator Groen & Ruimte. A consultancy firm bridging knowledge, governance and practice.



## Innovations

### V Experiments and promising crops

#### 20. Quinoa, a Promising Halophyte with Modified Planting Date and Minimum Water and Pesticide Requirements for Fars province, Iran - Rezvan Talebnejad

##### **Quinoa, a Promising Halophyte with Modified Planting Date and Minimum Water and Pesticide Requirements for Fars province, Iran**

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Quinoa (*Chenopodium quinoa* Willd.) is an Andean crop that was domesticated in southern Peru and Bolivia close to Titicaca Lake. The semi-cereals cultivar, quinoa, is adapted to a wide range of marginal agricultural soils, including those with high salinity and those prone to drought. Recently, several researches have primarily addressed salt and drought tolerance in quinoa (Jacobsen et al., 2003; Trognitz, et al., 2003; Talebnejad and Sepaskhah, 2015). Its salt tolerance is the result of osmotic adjustment, sodium exclusion and xylem loading and potassium retention (Adolf et al., 2013, Razzaghi et al., 2015). However, the presence of calcium oxalate crystals in leaf vesicles, reducing leaf transpiration, besides of having a thick plant cuticle and sunken stomata resulted in drought stress tolerance of quinoa (Jacobsen et al., 2009; Azurita-Silva et al., 2015, Isaa et al., 2019). Quinoa is a highly nutritional and gluten free crop, having a balanced composition of essential amino-acids sometimes scarce in legumes and cereals (Repo-Carrasco et al., 2003); and rich in Ca, Fe, and Mg, with high content of vitamins A, B2 and E (Ruales and Nair, 1992; Adolf et al., 2013; Nowak and Charrondière 2016). Therefore, this super grain is a promising halophyte in agricultural production, which can cope with growing food demand in semi-arid areas faced with drought and soil and water salinization. Although water scarcity generally associated with arid and semiarid climates, field and water resources management is essential to enhance the water productivity in all over the world in order to supply food for next generations. Quinoa is well adapted to grow under unfavorable soil and climatic conditions and is rapidly gaining interest throughout the world, even at non-native regions such as Iran, because of its high nutritional value and high resistance to negative impacts of climate change. Planting date is one of the most important challenges in non-native crop cultivation to develop effective integrated crop production, water management and environmental consideration. Air temperature and day length associated with different crop planting date was discussed by researches to gain economical yield from agricultural farms. Optimum planting date exhibited as a first step in crop production system and considered to be a base that leads to development of a proper production technology package especially for a new crop. High temperature during flowering and seed set can significantly reduce the yield and is one of the major barriers to the global expansion of quinoa (Pulvento et al., 2010; Hirich et al., 2014; Yang et al., 2016; Walters et al., 2016; Hinojosa et al., 2018). On the other hand, low temperature and frost during vegetative and flowering restricted quinoa cultivation in highlands (Jacobsen 2005; Rosa, 2009). Recently, quinoa has been introduced to leading farmers in Fars province, Iran as an alternative cultivation for high water consumptive crop cultivations such as rice or maize. (Talebnejad and Sepaskhah, 2018). Local farmers plant quinoa during March and April in spring cultivation, experimentally. For the first time a farm level experiment was conducted at the Drought

Research Center of Shiraz University, Fars province, Iran (29° 56' N, 52°02' E, 1810 m above sea level) to assess the possibility of Danish-bred quinoa cultivar (Titicaca, no. 5206) cultivation in September instead of usual planting date of March as, which has been practiced by leading farmers. The experiment was conducted at the same place with similar farm management but in two different planting date. First planting date was 3 March 2018 and the second one was 1 September 2018. The climatic condition of the study area is semi-arid and the soil texture is silty clay loam. Mean maximum and minimum daily temperature during two growing season is shown in table1. Soil phosphorous was enriched by applying triple superphosphate, at rate of 50 kg ha<sup>-1</sup> mixed with the soil at plowing. For soil nitrogen enrichment, urea was applied as 250 kg ha<sup>-1</sup> at vegetative and flowering quinoa crop development stages.

Table1. Mean maximum and minimum daily temperature during two growing season

Month	Mean daily temperature °C	
	Maximum	Minimum
March	15	1
April	23	4
May	24	8
June	33	13
July	35	15
August	36	14
September	32	10
October	28	6
November	19	-0.5

Quinoa was irrigated based on soil water balance. In full irrigation, the applied water provided by raising the soil water content in the root zone to the soil field capacity (0.33 cm<sup>3</sup> cm<sup>-3</sup>); therefore, the crop was kept under non-stressed conditions. Amount of irrigation water was 792 mm for spring planting in March while it was 465 mm for autumn planting in September. Total Rainfall amount was 104 mm during autumn planting while no rainfall accrued during spring planting. Harvesting date for spring and autumn planting were 3 July and 29 November 2018, respectively. Average quinoa seed yield was 4.6 Mg ha<sup>-1</sup> for spring planting in March while it increased to 5.06 Mg ha<sup>-1</sup> for autumn planting in September. Results indicated that quinoa planted in autumn completed its developmental growth, requiring significantly less irrigation water with no pesticide application as compared with the spring planting date quinoa. September planting date resulted in 40% reduction in irrigation water amount and 10% increase in seed yield as compared with March planting date. Furthermore, early autumn planting in September secured good flowering and seed set and avoided pest damage as opposed to spring planted quinoa, requiring pesticide treatment to overcome high temperatures occurring in June. Therefore, quinoa cultivation is recommended for development in Fars Province, Iran as a promising nutritious crop with high water productivity and low environmental impacts resulting from the autumn planting date.

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## 21. The study of quinoa at high salinity in the field conditions - Muhammad Shahid

### The study of quinoa at high salinity in the field conditions

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Quinoa, salt tolerant, morphological traits, marginal lands

#### 1. Introduction

Quinoa is a pseudo-cereal that belongs to the family Chenopodiaceae and is related to renowned crops like spinach and beet. It was domesticated in the Andean region of South America about 7,000 years (Kolata, 2009) from wild populations of *Chenopodium quinoa* (Pickersgill, 2007). It is an integral food grain source in the area. Peru and Bolivia are the main quinoa producing countries of the world. Quinoa is gluten-free, high in protein and one of the few plant foods that contain all nine essential amino acids. It is also rich in fiber, magnesium, B-vitamins, iron, potassium, calcium, phosphorus, vitamin E and different beneficial antioxidants (Vaughn and Geissler, 2009). Quinoa is considered to be a salt tolerant crop (Jacobsen et al. 2005; Koyro et al., 2008) that makes it ideal for cultivation in the marginal lands with salinity problem. To find the salinity-tolerance in it, experiments were conducted at low and high salinities, at the International Center for Biosaline Agriculture (ICBA), Dubai, UAE. The yield trials were done in RCBD with 3 reps and 2 treatments (low salinity, 0.3 dS/m and high salinity, 15 dS/m). Twelve quinoa cultivars were analyzed to detect their tolerance against high salinity. Different agronomic and morphological characteristics including days to flowering, days to maturity, plant height, number of primary branches per plant, number of panicles per plant, main panicle length, plant dry weight per plot, grain yield per plot, and thousand seeds weight were studied to find the impact of salt on the quinoa plant. The introduction of salinity-tolerant quinoa accessions to the salt-affected farmlands can help to rebuild the economy of the effected regions. It will also provide a healthy food to the local communities.

## 2. Materials and Methods:

Each set of accessions was sown in randomized complete block design (RCBD) in three replications. There were two water treatments: low salinity (0 dS/m) and high salinity 15 dS/m). The high salinity treatment was started after 2 weeks of sowing.

Plot size was 1 x 2 m. The seeds were sown manually by dibbling 3-4 seeds into the soil to a depth of 1-2 cm close to the dripper. After sowing, field was covered with acryl sheet. Both plant to plant and row to row distance was 25 cm.

Irrigation: Drip irrigation system was used for the experiment with drippers at 25cm distance. Irrigation twice a day for 5 minutes each time. Water release from each dripper was @ 4L/h. The plots were irrigated daily for both saline and no-saline treatments.

Table 1. Twelve different accessions were selected for the yield trails:

S.N.	Accessions	S.N.	Accessions
1	ICBA-Q1*	11	NSL-84449
2	ICBA-Q2*	12	Ames 13215
3	ICBA-Q3*	13	Puno
4	ICBA-Q4*	14	Titicaca
5	ICBA-Q5*	15	NSL-106399
6	Ames-13757	16	Zhang Li 3

\*The quinoa varieties were developed at International Center for Biosaline Agriculture (ICBA)

Table 2. Different agronomic and morphological characteristics studied for the experiment

S.N.	Traits
1	Days to flowering
2	Days to maturity
3	Plant height
4	Number of primary branches per plant
5	Number of panicles per plant
6	Length of main panicle
7	Plant dry weight m <sup>-1</sup>
8	Seed weight m <sup>-1</sup>
9	Thousand seed weight

### 3. Objectives:

- To understand the effect of salinity on different morphological and agronomic traits of quinoa
- To see how saltwater effect grain yield of different of quinoa cultivars developed at ICBA and other parts of the world

### 4. Results and Discussion:

#### 4.1. Days to flowering

For that trait, ICBA Q-1 and Ames-13757 were the earliest, as they flowered after 52 days followed by ICBA Q-4 and NSL-84449 (53 days). On the other hand, Zhang Li 3 flowered after 99 days making it the last in the category.

On average, high salinity hastens the days to flowering by 3 days in the studied quinoa cultivars. Zhang Li 3 was flowered 9 days earlier due to high salinity.

#### 4.2. Days to maturity

ICBA Q-1 matured after 103 days making it the earliest among the 12 quinoa varieties studied in the experiment. Zhang Li 3 took the longest period of time as it matured after 145 days.

In control plots, the median maturity time for the quinoa varieties was 113 days. While irrigation with high saline water decreased the maturity period by 5 days.

#### 4.3. Plant height

The maximum plant height was recorded in Zhang Li 3, which was more than 220 cm followed by ICBA Q-3 (117 CM), which has almost half of the height of the former. Whereas, Titicaca was less than 56 cm tall, the shortest among the 12 accessions.

The saline water lessens the plant height by 10 cm, which is more than 10% of the stature for the varieties grown using fresh water. The most effected accession for this trait was NSL-106399, which lost more than 34% of its height due to high salinity, while with only 6% decrease, ICBA Q-2 was the least affected cultivar.

#### 4.4. Number of primary branches per plant

The lowest number of primary branches was recorded in Zhang Li 3, which was about 1.1, while with 2.1, NSL-106399 was the second lowest. On the other hand, NSL-84449 had the highest number of branches, i.e., 9.4.

In response to high salinity, quinoa plants decrease branches. On average, 9% reduction in number of branches was recorded among the varieties.

#### 4.5. Number of panicles per plant

The highest number of panicles per plant of 9.3 was recorded in NSL-84449 and the second highest (6.2) in Ames 13215. While Zhang Li 3 had the lowest number of panicles among the 12 studied quinoa cultivars.

The irrigation with saline water decreases the panicle number in the quinoa plants by 15%. The most affected accessions were ICBA Q-1 and ICBA Q-3, which showed 34% reduction in panicle number, while no effect of salinity was recorded in Zhang Li 3.

#### 4.6. Length of main panicle

With more than 73 cm, Zhang Li 3 had the longest panicle followed by Ames 13215 (30 cm). The shortest panicle of around 14 cm was observed in the variety Titicaca.

The high salinity treatment reduced the panicle length in quinoa on average by 17%. The negative effect was most obvious in Zhang Li 3 that showed more than 21% decrease in panicle length.

#### 4.7. Plant dry weight per square meter

Zhang Li 3 has the heaviest plant dry weight  $m^{-1}$  of 1440 g, which was more than double than the second-best performing accession Ames-13757 (668 g). Because of high vegetative production, Zhang Li 3 can be used grown as a fodder quinoa variety.

Overall there was 18% decrease in plant dry weight due to high salinity among the 12 quinoa accessions. NSL-84449 with 7% reduction was the least affected accession, whereas maximum plant weight loss of 44% recorded in Titicaca.

#### 4.8. Seed weight per square meter

For that important trait, Ames-13757 and NSL-106399 performed better than other cultivars and produced 217 and 208 g of seed  $m^{-1}$ .

Averagely, the decline in seed yield in quinoa accessions because of high salinity was 25%. The maximum reduction of 50% was recorded in Puno, but NSL-84449 exhibited the least negative effect on its seed yield due to high saline water.

#### 4.9. Thousand seed weight

Both ICBA Q-2 and ICBA Q-3 had 1,000 seed weight of 3.6 g, which is the highest amongst the studied quinoa cultivars. The variety Chang Li 3 with just 1.1 g was at the bottom, which was more than 3 times lighter than topmost varieties for this seed trait.

Salinity on average reduced the thousand seed weight by 7% in the quinoa accessions. Chang Li 3 didn't show any change in its seed weight due to salinity, while other cultivars show some decline in their seed weight.

### 5. Conclusions:

- The identified salt tolerant quinoa varieties will help to introduce them in the marginal lands of different countries with salt effected large tracts of agricultural lands.

- High yielding salt tolerant quinoa varieties will help in improving life in the rural areas of many poor countries, where salinity is affecting the cultivation of other crops

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He holds a PhD in Genetics from Virginia Tech, USA. He is working as a geneticist in plant genetic resources program at ICBA. At ICBA he worked on different salt tolerant crops, including quinoa, barley, safflower, sorghum, pearl millet and a halophyte, *Salicornia*.

## 22. Screening of Sorghum genotypes in the coastal saline region of Bangladesh - M.H. Rashid, M. K. Shahadat, M. Amiruzzaman and M. Akkas Ali

### Screening of Sorghum genotypes in the coastal saline region of Bangladesh

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Sorghum, screening, yield

Sorghum is being cultivated all over the world mainly as feed for animals and in some areas it is used for human consumption. In addition it is also used in a variety of industrial applications like paper making and used as adhesives. This crop is of great help in conservation agriculture production system, promoting food security, minimizing input cost for farmers and protecting the soil. Now, it is essential to select sorghum varieties that are high yielding both in biomass and grain yield in Bangladesh. The experiment was conducted at the farmer's field at Multi Location Testing (MLT) site, Batiaghata upazila of Khulna district and On-station of On-Farm Research Division, Bangladesh Agricultural Research Institute, Daulatpur, Khulna during rabi season of 2017- 2018 to identify the suitable genotypes under coastal saline region of Bangladesh. Seven sorghum genotypes namely IS-29468, IS-19153, IS-2864, IS-9745, IS-21891, IS-24348 and IS-3158 were used in the experiment. Significant variation was observed regarding the yield and yield contributing characters among the genotypes. The soil salinity was ranged from 2.35 to 9.46 dS/m. The date of maturity was recorded



80.67 at IS 21891 and 92.33 at IS 2864. The shortest plant height was recorded at IS 24348 (86.33 cm) and tallest plant height was recorded at IS 3158 (227.00 cm). The plant height ranged from 86.33 – 299.00cm. The highest plant height was recorded in IS 2864 and the lowest plant height was recorded in IS 24348. The panicle length ranged from 16.33 to 32.33cm. The height panicle length was recorded the genotype IS 3158 and the lowest panicle length was recorded the genotype IS 9745. The grain yield per panicle ranged from 31.00-131.00g. The highest grain yield per panicle was recorded IS 3158 and the lowest was IS 21891. The thousand seed weight (TSW) ranged from 18.30-45.37. The height TSW was counted in IS 9745 and the lowest TSW was counted in the genotype IS 24348. The highest grain yield was recorded from sorghum genotype IS-3158 (5.60 t ha<sup>-1</sup>), may be due to its highest panicle length (32.33cm), grain yield per panicle (131.0 g). Also it's days to maturity was found highest (92 days). The second highest grain yield (5.32 t/ha) was recorded from genotype IS 9745. The lowest grain yield (1.78 t ha<sup>-1</sup>) was recorded with genotype IS-21891, may be due to its lowest length (121.33 cm) of panicle and grain yield (31.00 g) per panicle.

### 23. Multi-year evaluation field trials of *Salicornia bigelovii* in United Arab Emirates: prospects & challenges - Dionysia Lyra, Hifzur Rahman, Hamza Khan and R.K. Singh

#### **Multi-year evaluation field trials of *Salicornia bigelovii* in United Arab Emirates: prospects & challenges**

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*Salicornia bigelovii*; halophytes; salinity; marginal areas

*Freshwater scarcity is a global threat, especially in salt-affected areas where the communities are struggling to produce food and animal feed to sustain an increasing population. Salinity further exacerbates the problem by depleting productive lands and freshwater reserves leading to loss of biodiversity, soil fertility and organic matter. More halophytic crops that thrive in hostile saline conditions are needed to bring into production such degraded areas. *Salicornia bigelovii* is a halophyte that can be used as a vegetable, forage, and biofuel, and holds great potential to improve the livelihood of farmers in saline environments. Existing *S. bigelovii* germplasm originates from wild genetic varieties that need to be tested and developed through several generations and adapted to local conditions for large scale plantations. Since 2011, the International Center for Biosaline Agriculture (ICBA), along with local partners in United Arab Emirates (UAE) are actively looking into the potential for growing *S. bigelovii* under the hot and dry climate in UAE. The overall goal is to select the best performing *S. bigelovii* populations in terms of seed and biomass production for future breeding and commercial scale production. This could be achieved through evaluating *S. bigelovii* gene pool for various agronomic and growth parameters under field conditions. This would be followed by seed multiplication using saline groundwater and selecting the best populations each*

growing season for further investigation for pilot scale production systems. Results from multi-year trials will be presented with special focus on *S. bigelovii* germplasm evaluation, environmental sustainability of *S. bigelovii* - based systems and on the exploration of other innovative uses.

Dionysia Angeliki Lyra is a Halophyte Agronomist at ICBA leading projects on climate-resilient, sustainable modular farming systems customized for desert environments incorporating halophytes and utilizing marginal water and land resources, targeting to enhance the food security of underprivileged rural communities.

## VI Promising crops for saline farming

### 24. Physiological growth and gas exchange of saffron (*Crocus sativus* L) in saline and deficit irrigation condition under different planting methods - Maryam Dastranj, Alireza Sepaskhah, Seyed Mohammad Mirsafi

#### **Physiological growth and gas exchange of saffron (*Crocus sativus* L) in saline and deficit irrigation condition under different planting methods**

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Saline irrigation, deficit irrigation, field management

In the recent decades, water demand is increased due to climate change population growth, urbanization and economic development in addition to drought occurrence. Using saline water, especially in arid and semi-arid areas like Iran. Saffron (*Crocus sativus* L.) is a perennial and semi-tropical plant from Iridaceace family. Iran is the leading country in producing saffron and it is considered in sustainable crop production due to its low water requirement and high economical value. In the current study four salinity levels of irrigation water consisted of 0.45 dS m<sup>-1</sup> (well water, S<sub>1</sub>), 1.0 dS m<sup>-1</sup> (S<sub>2</sub>), 2.0 dS m<sup>-1</sup> (S<sub>3</sub>), 3.0 dS m<sup>-1</sup> (S<sub>4</sub>), three irrigation water levels including 100% (I<sub>1</sub>), 75% (I<sub>2</sub>) and 50% (I<sub>3</sub>) of saffron water requirement (WR) in two planting methods, basin (P<sub>1</sub>) and in-furrow (P<sub>2</sub>) planting, was considered to investigate the combination effects of irrigation water salinity, deficit irrigation and planting method on physiological growth and gas exchange of saffron. Leaf dry matter of saffron was taken from 30 cm of the middle row in each plot on different days after first irrigation both growing season. The samples were weighted after they were dried in 70 °C for 48 hours. Saffron corm samples were also taken from 30 cm of the middle row from each plot at the end of each growing season to determine the corm dry matter and analyze the corm growth. Also soil samples were taken from 0-60 cm of soil depth to determine soil salinity. LCi analyzer (Li-Cor Inc, Nebraska, USA) was used to measure leaf surface temperature (*T*<sub>l</sub>), net photosynthesis rate (*A*<sub>n</sub>), stomatal conductance (*g*<sub>s</sub>) and transpiration rate under fair weather condition at 11:30 in different days after first irrigation in both growing seasons. Saffron water potential in field was measured using pressure bomb in the same days that photosynthesis rate and stomatal conductance was measured during both growing seasons.

Mean E<sub>c</sub> of soil was lower than the used irrigation water salinity due to the fact that soil was not initially saline before applying the saline irrigation water and that rainfall provided a part of saffron water requirement and leached the salts in soil profile. The main and interaction effect of irrigation water salinity, deficit irrigation and planting method was significant on soil E<sub>c</sub>, saffron yield and dry matter and corm yield. The saffron dry matter was 59.6% higher in the second growing season which is due higher corm growth in the second growing season. Also, the main effects of irrigation water salinity, irrigation water level and planting method on yearly corm growth was analyzed. Results indicated that corm yield was increased in 2.0 dSm<sup>-1</sup> salinity level in in-furrow in planting method where it was decreased in 1.0 dSm<sup>-1</sup> salinity level in basin planting. Corm yield reduction was only significant in 50% WR irrigation method in comparison with 100%WR treatment. In-furrow planting method increased corm yield by 50.4% in comparison with basin planting method, on average in both growing seasons.

Leaf water potential was measured at the same dates that photosynthesis rate and stomatal conductance were measured. Results showed that irrigation water salinity decreased leaf water potential which is due to decreased soil water potential and decreased water uptake ability of saffron plant. The main effect of irrigation water level was not significant on leaf water potential. This is due to the fact that leaf water potential was measured the day before irrigation events when the soil was in it driest condition. Leaf water potential was higher in in-furrow planting method in comparison with that obtained in basin planting which represent the better condition in-furrow planting method for crop growth. Leaf water potential was decreased at the end of each growing season which is due to higher evapotranspiration rate due to higher air temperature. The comparison relationship between leaf dry matter and leaf water potential in basin and in-furrow planting methods showed that higher dry matter was produced in in-furrow planting method in comparison with the basin planting method in a particular leaf water potential due to better soil condition in in-furrow planting method

Leaf surface temperature was also measured during the growing season. Results showed that the interaction and main effect of irrigation water salinity, irrigation water level and planting method was statistically significant on leaf temperature.

Photosynthesis rate of saffron was significantly decreased with increase in irrigation water salinity especially in 2.0 and 3.0 dSm<sup>-1</sup> treatments and in deficit irrigation treatments. Photosynthesis rate of saffron was significantly higher in in-furrow planting method which led to higher saffron yield, dry matter and maximum LAI in in-furrow planting method regardless of irrigation water salinity and irrigation water level. Maximum leaf area index in the 3.0 dSm<sup>-1</sup> irrigation water salinity in in-furrow planting was higher than that obtained in 0.45 dSm<sup>-1</sup> irrigation water salinity and full irrigation in basin planting method.

Crop growth rate (CGR) was calculated for both growing seasons. Maximum CGR was occurred between 93-130 days after first irrigation in both growing season and maximum Leaf area index was occurred during the same days. CGR decline at the end of both growing seasons due to leaf senescence. Stomatal conductance was measured three times during each growing season. Main effect of irrigation water salinity on stomatal conductance was statistically significant in 2.0 and 3.0 dS m<sup>-1</sup> where it was reduced 20.3% and 34.1% in comparison with that obtained in 0.45 dS m<sup>-1</sup> salinity level, on average in both growing seasons. Stomatal conductance was 41.2% higher in in-furrow planting method in comparison with that obtained in basin planting method. The stomatal conductance in the second growing season was decreased due to higher air temperature in comparison with first growing season which resulted in 31.8% reduction in A<sub>n</sub>/g<sub>s</sub> ratio.

Leaf transpiration and leaf transpiration efficiency was reduced with increase in irrigation water salinity and in-furrow planting method increased transpiration efficiency 7.3% and 13.7% in comparison with that obtained in basin planting method in first and second growing seasons, respectively.

Finally, in-furrow planting method for saffron cultivation is suggested as an efficient field management strategy to mitigate the negative effects of irrigation water and deficit water on saffron

growth and its physiological parameters and gas exchange phenomena.. Basin planting method is not recommended even in favorable condition. In case of saline water, in-furrow planting method with irrigation level of 75% with  $1.0 \text{ dS m}^{-1}$  is recommended.

Maryam Dastranj was born in 1987 in Shiraz, Iran. She is a Ph.D. student in Shiraz University in water engineering- Irrigation and drainage.

## 25. *Tetragonia tetragonioides* as a salt-tolerant crop in a saline agriculture context - Giulia Atzori

### ***Tetragonia tetragonioides* as a salt-tolerant crop in a saline agriculture context**

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*Tetragonia tetragonioides*; salt-tolerant crop; saline agriculture; seawater farming.

Water counts on Earth about 1.4 billion cubic kilometers in total, as both surface or underground water (FAO, 1995). Of this amount, seawater represents about 97% while almost 2% is locked in ice. Accordingly, available freshwater represents less than 1%: among the different sectors, agriculture absorbs an average of 70% of overall freshwater (SDSN, 2013). Moreover, the increasing population rate is leading to 9.6 billion people by 2050 (FAO, 2009). Hence, the pressure on the Earth's natural resources will then further increase (FAO, 2017). Since the rhythm of freshwater withdrawal is faster than its regeneration, measures have to be taken in order to preserve such an important resource (Atzori et al., 2019) and alternative water sources for irrigation can represent a valid help for the preservation of the already overexploited freshwater. In particular, seawater is considered a realistic option in agriculture, either desalinated or blended with freshwater (Yermiyahu et al., 2007).

Seawater represents the most abundant water resource on Earth. Moreover, it is rich in most plant nutrients (Eyster, 1968), which are often the same nutrients representing limitations in human diets. Furthermore, it is found where around 40% of the world population currently resides. Thus, sea-water use in agriculture could represent a strategy to decrease the freshwater demand of the agricultural sector, exploiting, at the same time, the seawater nutrient content (Atzori et al., 2016). Seawater use in agriculture have been studied since the early sixties of the last century (Boyko, 1966): while a sustainable agriculture relying on pure seawater on a large scale is still utopian, in other cases (e.g. horticulture) small-scale seawater irrigation may be economically viable (Breckle, 2009). In particular, seawater could be used to irrigate salt-resistant crops in a saline agriculture context. In this sense, salt tolerant species allow the exploitation of the great availability of brackish and sea water, making coastal and salt affected areas productive (Atzori et al., 2017). Such salt-resistant crops must be found among the halophytes, species native from salt marshes and inland saline sites, that can grow and reproduce on saline soils on which 99% of the other species get deprived (Flowers and Colmer, 2008) and they are estimated to consist in 5000–6000 species, or 2% of total world angiosperm species (Glenn et al., 1999). Their adaptation to saline environments includes a wide range of morphological, physiological, and biochemical adaptations, varying widely in their degree of salt tolerance (Flowers and Colmer, 2008).

Because many of these salt tolerant plants are edible, their domestication and cultivation in a saline agriculture context could be an interesting approach to consider (Glenn et al., 1998; Rozema and Flowers, 2008; Rozema and Schat, 2013; Ventura et al., 2015). Saline agriculture may pursue relevant goals: an increased sustainable food production could be achieved exploiting resources which would not be used for conventional agriculture: seawater or brackish waters as

complementary irrigation waters and salt-affected soils (Glenn et al., 1999). Importantly, agricultural areas lost because of salinization would be regained for staple food production (Bruning and Rozema, 2013). With respect to this, irrigating with seawater on fertile and well structured soils would lead to a salt contamination occurring through  $\text{Ca}^{2+}/\text{Na}^{2+}$  exchange and consequent clay dispersion (Ventura et al., 2015), yet many soils are nowadays abandoned because of salinity conditions which cannot be removed, for economically or geographically reasons.

In the current trial, the New Zealand spinach (*Tetragonia tetragonioides* (Pallas) Kuntze) was grown in hydroponics with three seawater concentrations, i.e. 0% (control), 15% and 30% seawater (corresponding to electrical conductivity of 1.5, 9 and 18dS  $\text{m}^{-1}$ , respectively) under greenhouse conditions and respecting the tested species cycle length (60 days approx.). The species was chosen because already consumed in several world areas, including Southern Italy, as a vegetable crop. The trial aimed at identifying its salinity tolerance and evaluating possible mineral enrichments in the edible leaves related to salinity. Growth measurements were performed on a weekly basis, and at the end of the experiment the specific leaf area (SLA), leaf succulence, leaf dry matter content (LDMC) and leaf water content (LWC) were determined to investigate possible morphological adaptations to salinity treatments. The photosynthetic rate ( $A_n$ ) and the stomata conductance ( $g_s$ ) were obtained weekly through the open gas-exchange system Li-6400 XT (Li-Cor, Lincoln, NE, USA). At the end of the experimental period, total pigment concentration was calculated by reading the absorbance at 665, 652 and 470 nm of extracts obtained from randomly selected youngest fully expanded leaves. Crop evapotranspiration (ET) was recorded by measuring the volume of solutions for each treatment before the nutritive solution replacement, assuming zero losses for evaporation being the solution surface well covered by the polystyrene layer, and used to calculate the water use efficiency (WUE, total plant dry weight on water consumed) and water productivity (WP, plant fresh edible shoot on water consumed). Dry leaf samples were then used for the determination of ions and nitrates in plants tissue, by means of ICP OES (Inductively Coupled Plasma - Optical Emission Spectrometer) and UV-visible spectrophotometer (Bio-Rad SmartSpec™Plus), respectively. The relative phytodesalination rate (RPR) of the tested species was determined, according to Rabhi et al., (2015), as the measurement of shoots aptitude to accumulate sodium ions per unit of biomass per unit of time, thus of the species capability of desalinating the growing media.

Our findings showed that seawater did not affect the growth of the plants. This is true for both salinity treatments compared to the control, even if 30% seawater led to a slight growth decline. Regarding the morphological traits, increasing salinity increased the leaf succulence and decreased the specific leaf area, whereas LDMC and LWC were not affected. Pigments showed significant decreases at 30% seawater concentration, whereas 15% seawater treated plants chlorophyll a and carotenoids were in line with the control. Results on pigments concentration are consistent with those on the photosynthetic rate and the stomata conductance: in both cases, 15% seawater treated plants were comparable to the control, whereas the 30% seawater treated plants decreased both  $A_n$  and  $g_s$  parameters.

Results related to water consumption are very promising, especially the significantly increased WUE and WP obtained in seawater treated plants compared to the control. Such an augmentation is mostly related to the significant decrease in water consumption with increasing salinity levels, indicating that not only it is possible to save freshwater through irrigation with brackish waters, but also that the amount of salty water consumed by plants to produce the same biomass is lower compared to when using freshwater.

Regarding the nutritive characterization of the edible products (leaves), seawater treatments led to a mineral enrichment (i.e. Mg, Cu, Zn), accompanied by an increase in Na content too: the fortification in Mg, Cu and Zn represents a valid enrichment, as such elements play an important role in human nutrition (White and Broadley, 2009). Yet, the Na concentration in leaves could constitute a concern that may threaten its healthy use as food: nevertheless, monitoring its content or allowing this crop to act as a natural salt substitute would prevent possible health issues. Nitrates, moreover, do show a decreasing trend in salinity conditions, representing another asset: in fact, if

the food product high in nitrate content is ingested, it can be transformed into nitrite that, in combination with amines, may form carcinogenic compounds.

Finally, the results obtained calculating the relative phytodesalination rate (RPR) open to the possibility that such species has a double potential: from one side, it can be productive up to EC of 18 dS m<sup>-1</sup>; from the other, it could also be used as a crop with phytodesalination potential, thus capable of extracting salts out of a soil or an hydroponic system.

This experiment shows the high potential of *T. tetragonioides* to become a cultivated crop in a saline agriculture context, up to EC of 18 dS m<sup>-1</sup> or even higher, since a threshold for biomass reduction was not individuated. Also, the tested salinity conditions proved several crop enrichments achieved compared to freshwater irrigation conditions. Finally, *T. tetragonioides* also proved its potential in being considered as a phytodesalinating crop.

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Dr. Giulia Atzori, PhD in "Agricultural and Environmental Sciences" at the University of Florence, Italy, is currently a postdoctoral researcher studying seawater as an alternative water source for irrigation in agriculture. During her PhD she studied glycophytes and halophytes assessing different thresholds of salinity tolerance and analyzing the edible product nutritive characteristics in response to the seawater stress. Her major findings revealed that for the majority of the tested species salinity lead to the accumulation of mineral elements and enhanced the production of antioxidant compounds, thus enriching the final product

### 26. Investigations of soils and plants from farms and field trials in South-East Norway, can make the local farmer better prepared from future episodes of sea water flooding - Åsgeir R. Almås and Susanne Eich-Greatorex

#### **Investigations of soils and plants from a field trial in South-East Norway, can make the local farmer better prepared from future episodes of sea water flooding**

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Soil compaction, field trial, grass, changing climate, flooding

Norway's largest lowland plain, Jæren, on the southeastern coast has an important agricultural production both locally, regionally and nationally. Due to a high density of animal husbandry, including cattle, pigs and chicken, Jæren has a large amount of animal manure to dispose of. The soils are mostly sandy but in some areas also loamy and were originally not particularly rich in nutrients. Large parts of the area are used for grass production. Also due to high amounts of manure added over the years, organic matter contents are relatively high in the soils. The farming practise is intense with use of heavy machinery where grass is sown in rotation with potatoes, carrots or other field crops.

According to the report "Climate in Norway 2100 – a knowledge base for climate adaptation" commissioned by the Environmental Directorate in Norway (Hanssen-Bauer, 2015), western Norway, including the area of "Jæren" in the southwest, will experience slightly lower temperature



increases than other parts of Norway. “Jæren” and the coastal areas in the southwest already have a mild climate today with the longest growing season in Norway. The duration of the growing season is likely to continue to increase with one to two months during the 21<sup>st</sup> century, depending on the concentration pathway used. The south-western part of the Norwegian North Sea coast, may over the course of the 21st century experience slightly decreased precipitation in the summer but increased precipitation during the rest of the. Considering the generally relatively high precipitation, seawater is likely to be quickly washed out from the soil profile. However, with respect to salt-water intrusion, changes in precipitation but also changes in the frequency of storm events may be relevant. The former because it will wash excess sea salt out from the soil profiles, the latter because storm events at high sea levels may lead to considerable seawater flooding in coastal areas.

Due to the consequences of climate change, grasslands and other agricultural land close to the coast will experience more frequent flooding with seawater. A strong increase in sodium concentrations in the soil solution will lead to a replacement of other cations on binding sites in the soil, with consequences for nutrient cation availabilities and a potentially imbalanced uptake of nutrients into plants. This in turn can induce diseases particularly in cattle (e.g. milk fever). Soil samples have been collected during one year. The electric conductivity (EC) varies in response to management, being at its highest just after spring work (up to 1 dS/m) and lowest after heavy rains (down to 0.1 dS/m at same site).

A 500 m<sup>2</sup> field trial making use of ryegrass as test crop has been established close to the sea. The treatments are 0, 1 and 3 episodes/season of salt-water irrigations (50/50, sea water/fresh water, about 25 dS/m) in combination with compaction episodes. All treatments are established in 4 replicates, and executed just after harvests, which can be up to 3 times/year. We have designed and purchased a custom-made irrigation system, which is fitted on a tractor. The device is fitted with a pump and nozzles that control the amount of water added very precisely. Plant samples are collected at each harvest, and soil physical and chemical samples are sampled from each plot after each season. The 2019 is the first out of three experimental years in total, and hence no results are produced yet.

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Research professor in soil science. Have studied the biogeochemistry of trace elements and phosphorus in soils, sediments and water. Special focus on the speciation of trace elements in environmental samples.

## VII Salinity adapted cultivation strategies

27. Reducing Salinity Effect On Alfalfa (*Medicago Sativa*) Production Using Soil Conditioner-Case Of Lahbab Farm In Dubai - Khalil Ur Rahman, Mohammed Khalifa Bin Thaleth and Khalfan Al Suwaidi

**Reducing Salinity Effect On Alfalfa (*Medicago Sativa*) Production Using Soil Conditioner-Case Of Lahbab Farm In Dubai**

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alfalfa, saline water, sandy soil, UAE

Alfalfa forage is the backbone of livestock industry and so is the case of UAE where in addition to significant forage import the local forage production also feeds camels and horses. The soils of the UAE are dominantly sandy (Typic torripsamments, mixed hyperthermic-Entisols) and infertile and hence show poor physical, chemical and fertility properties which require efforts to improve soil health using soil conditioner. Among other forages alfalfa is grown in many farms. Alfalfa is salt sensitive crop (threshold salinity- $EC_e$  2 dS/m) and irrigation with saline water effects its production capacity. A trial has been conducted in Lahbab farm managed by Al Nakhli Management Office Dubai UAE, the farm soil is sandy and irrigated with saline groundwater pumped by 23 pump stations irrigating different parcels of the farm. The trial site is irrigated with water from 8 wells resulting into final water EC of 4.07 dS/m. The water pH ranges between 7.2-7.45 (optimum level from nutrient availability perspective). This water salinity ( $EC$  4.07 dS/m) causes severe hazard and recommended to be used for salt-tolerant crops. Based on the standard relationship of soil salinity- $EC_e$  ( $EC_e = 1.5 \times EC_w$ ), the irrigation (sprinkler) with water ( $EC$  4.07 dS/m) may result to  $EC_e$  (6.06 dS/m). At this soil salinity (6.06 dS/m), according to Maas and Hoffman 1977 equation ( $Y_r = 100 - s(EC_e - t)$ ) alfalfa may lose 30% yield relative to without salinity problem (where  $s = 7.3\%$ ). In an attempt to reduce salinity effect we used soil conditioner at the rate of 20 tons per hectare and mixed with upper 15 cm soil. Cow manure was also applied to improve soil health. The alfalfa seeds (Omani variety) were inoculated, and seeding was done by drill. In this papers all possible options to increase alfalfa production including seed inoculation, soil conditioner application, eradication of weeds, proper soil preparation, irrigation and nutrient management, using mix of different salinity water wells methods have been briefed to enhance alfalfa in existing farms and to introduce in new farms with clear objective. The trial is irrigated with water salinity of 4.07 dS/m classified as highly saline water and suitable for salt tolerant crops. Preliminary results on alfalfa production revealed 33% higher yield compared the control plot where soil conditioner was not used but seeds were inoculated with rhizobium. This improvement is likely due to improved water and nutrient holding capacity due to soil conditioner, better uptake of nutrients that has increased plant growth and better salinity tolerance by plants.

Khalil Ur Rahman, is working with AL NAKHLI Management Office Dubai, United Arab Emirates as Agronomist to Oversea and manage Alfalfa production in different locations to overcome challenges of managing use of saline water without having major impact on fresh biomass yield

28. Crop Intensification option through zero tillage potato cultivation using mulch that improves soil properties in the south-western saline soil of Bangladesh -  
Mustafa Kamal Shahadat, Md. Harunor Rashid, Farzana Jahan Juthi and  
Munmun Ahmed

**Crop Intensification option through zero tillage potato cultivation using mulch that improves soil properties in the south-western saline soil of Bangladesh**

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Zero Tillage, Potato, Mulch, Salinity.

About 0.432 million hectares of land in the south-western part (*viz.* Khulna, Bagerhat and Satkhira) of Bangladesh are salt affected at varying degrees. Where most of the land remains fallow after harvesting *kharif* (July-Oct) rice mainly because of wet soil unfavorable for tillage, late rice harvest (up to end of December), lack of irrigation water and increasing salinity (Nov-April). In order to intensify crop cultivation by utilizing fallow land we investigated zero tillage potato cultivation using different mulch materials and observe soil properties under mulch over the cropping season. For that an experiment was conducted at Khatail village (22°36.479' N latitude and 89°28.715' E longitude) of Khulna, Bangladesh during the period from December 2017 to March 2018. The experiment was designed in RCB with a single factor: Mulching- T1: Rice husk, T2= Rice straw and T3= compost mulch. Data on different yield contributing characters and yield were recorded. An electromagnetic induction (EMI) (DUALEM-1HS) survey was conducted to investigate variability in soil salinity and soil moisture. Significantly highest plant height (48.07 cm), canopy coverage (61.33%) and leaf area index (1.06) were recorded from rice husk followed by rice straw and compost mulch, respectively. Conversely, weed infestation percentage was found highest (43.33%) in compost mulch followed by rice straw (20.00%) and rice husk (13.33%). However, yield and yield attributes did not vary significantly among the treatments except haulm yield. Tuber yield ranges between 19.85 to 21.46 ton per hectare. Rice husk was more efficient in reducing soil salinity (15-30 cm depth) at harvest (0.68 dS/m), which is 17.64% and 29.41% higher than rice straw and compost mulch, respectively. Predicted soil electrical conductivity (EC1:5) from EMI survey (PRP0.5) of each plot showed highly significant negative linear relationship ( $R^2= 0.82$ ,  $\pm SE= 0.56$ ), which indicates with increasing soil salinity tuber yield decreased correspondingly. Though this a preliminary study in this area, however, zero tillage potato cultivation with mulch appears promising for utilizing fallow land in the south-western saline area of Bangladesh.

## 29. Performance Of Intercropping Short Duration Leafy Vegetables With Elephant Foot Yam In The Coastal Area Of Bangladesh - M.H. Rashid, M. K. Shahadat and M. Akkas Ali

### Performance Of Intercropping Short Duration Leafy Vegetables With Elephant Yam In The Coastal Area Of Bangladesh

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Intercropping is a method of crop intensification practiced to provide more yield per unit land per unit of time. It is reported that the use of early maturing varieties, alternating row arrangement, spacing and plant population are some of the important methods that help increase the yield of intercrops. Intercropping offers more stability, less risk, better utilization of limited resources and a wider diversity in the production of crops. The space between two rows of elephant yam at early stage may be utilized by planting any short duration crop as intercrop. On the other hand, elephant yam is a long duration crop. So, short duration vegetable crops could be grown easily with elephant yam in between rows to get quick return. The experiment was carried out at the Multi Location Testing (MLT) site, Satkhira district of Bangladesh with three consecutive years of 2014, 2015 and 2016 to observe the feasibility of intercropping of short duration leafy vegetables with elephant yam. Five intercropping combinations were investigated as T1: Sole elephant yam, T2: Elephant yam+Kangkong, T3: Elephant yam+Red amaranth, T4: Elephant yam+Sabujshak, T5: Elephant yam+Indian spinach with three replications. The variety of elephant yam, sabujshak, red amaranth and kangkong were local, local, BARI Red amaranth-1 and BARI Kangkong-1, respectively. Pooled analysis over three years revealed that highest corm yield (21.63 t ha<sup>-1</sup>) was recorded from sole elephant yam and the highest elephant yam equivalent yield (24.74 t ha<sup>-1</sup>) was obtained from Elephant Yam+Sabujshak intercropping. Intercropping of Sabujshak with Elephant Yam was found more profitable (BCR: 5.86) than rest of intercropping treatments.

### 30. Spaarwater: sustainable and profitable usage of fresh water for agriculture in the Wadden Sea Region - J. Velstra, T. te Winkel, A. Oord, S. Burger, B. de la Loma Gonzalez

#### **Spaarwater: sustainable and profitable usage of fresh water for agriculture in the Wadden Sea Region**

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Spaarwater, salinization, AgriMAR, anti-salinization drainage, agriculture, subsurface drip irrigation, sub-irrigation

In times of climate change delta areas become vulnerable environments where sea level rise, storm surges and salinization threaten the livelihoods of millions of people. The Netherlands is located in a delta region. Salinization is a significant threat for the agricultural sector in the country, which is mostly situated in the low-lying coastal regions. Agricultural fields in these regions suffer from internal upward seepage of saline water, making crop yield highly dependent on the presence and buildup of fresh rainwater lenses. Within the applied research project “Spaarwater” Acacia Water has, as one of the first, done extensive field measurements on the distribution of saline groundwater in and below the root zone, with the goal to develop different measures that strengthen the fresh water management and thereby make traditional agriculture more resilient to salinization. The project came up with three measures: (1) anti-salinization-drainage, (2) AgriMAR – managed aquifer recharge for agriculture and (3) (sub)surface drip irrigation and sub-irrigation. The technological, hydrological and economic feasibility of these measures were studied over a period of 5 years by implementing field pilots in the Wadden Sea Region.

## Introduction

Agricultural fields in the coastal region of the Netherlands are mostly tile drained fields situated below sea level. Due to an upward hydraulic gradient as a result of the position below sea-level, as well as the presence of saline-brackish groundwater, a saline upward seepage flux occurs in a large part of these coastal regions. Therefore, fresh water availability for agriculture in the Dutch coastal delta is scarce. Moreover, due to climate change the chance of dry and hot summers increases; consequently, summer discharges of the Rhine/Meuse decrease and inherently there is less fresh water available to flush polders in the coastal delta. Enhanced brackish saline groundwater seepage further salinizes surface water. Thus, in large parts of the coastal areas salinization is an increasing problem due to soil subsidence, climate change and sea level rise.

## Fresh water lenses

In these regions vulnerable to salinization, crops depend on the fresh groundwater resources available as rainwater lenses between tile drains. These rainwater lenses are floating on saline groundwater due to density differences and imposed flow patterns by tile drainage. They occur mainly in the provinces of Friesland, Groningen, Noord-Holland and Zeeland. The fresh rain water lenses form when there is a year average precipitation surplus (Poot en Schot, 2000). On top of this precipitation surplus the shape and thickness of rainwater lenses (defined by the depth of the fresh- and saltwater interface) depends on soil type and profile, but is mostly dependent on depth and spacing of tile drainage as well as the magnitude of the saline seepage flux. The dependency on the surplus of precipitation and the dynamic shape of these lenses throughout the year make them a fragile system., they can even disappear entirely during the growing season in presence of a precipitation deficit. The resulting up-coning of saline groundwater towards tile drains and capillary rise of saline water through the root zone therefore threaten crop yields in coastal regions, where a large part of the Dutch agriculture and flower industry depends on these freshwater lenses.

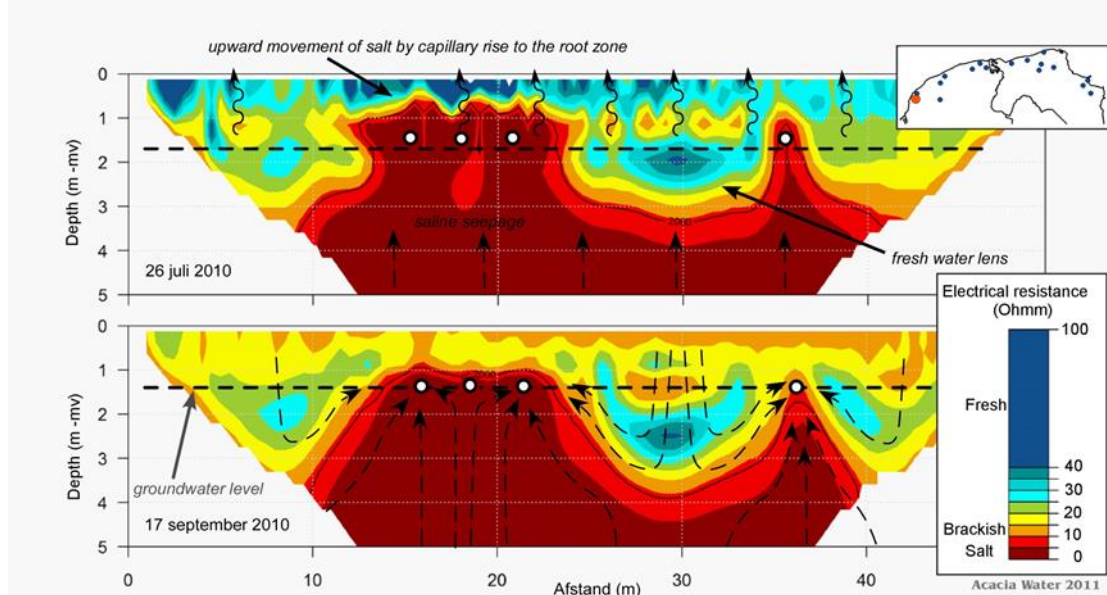


Figure 1. 2-D resistivity ERT profiles on an agricultural plot perpendicular to the tile drains. Showing a fresh rain water lens formed between the tile drains on the right and the absence of a lens due to the tight drain spacing on the left resulting in salinization in the root zone. Arrows indicate direction of flow. A contour line indicates an estimated concentration of 2000 mg Cl l<sup>-1</sup>. The dashed line indicates the observed groundwater level (modified after Velstra et al. 2011)

The aim of the project Spaarwater was therefore to estimate the extent of the salinization risk under future climatic conditions in the coastal regions of the Netherlands and investigate the



implementation of different measures to improve fresh-water availability, such that the agricultural areas dependent on the presence of rainwater lenses become more resilient to climate change.

#### Methods

Anti-salinization-drainage is an adapted version of a controlled drainage system. The principle component is restricting free flow from drains, such that they only discharge when it is necessary, based on pre-determined watermanagement criteria, in this case a water level. Most systems are used for water preservation but in this case the optimize depth and spacing of the tile drainage and raised groundwater level during winter will increase the thickness of the fresh rainwater lens and decrease the risk of salinization. And still maintain the original purpose for dewatering.

To support sustainable agrobusiness the need arises for farmers to become more self-sufficient in fresh water. A self-supporting fresh water storage and recovery system (AgriMAR) was designed and tested at two locations, consisting of a fresh tile-drain effluent collector unit (rainwater harvesting) feeding into a Managed Aquifer Recharge and Recovery system in a brackish aquifer in winter. The stored water in turn is used as irrigation water during the growing season in summer. Whether an AgriMAR is feasible for a farmer differs per situation. Four main factors are decisive: i) the availability and ability to collect sufficient water, ii) the ability to store the water in the deep subsurface, iii) the ability to recover the water from the subsurface and the recovery efficiency iv) the water requirement that depends on the crop.

The use of pump, reel and spraying canon and sprinklers is common in the Dutch agricultural sector. These systems are known for their high water use and low water efficiency. To increase the water use efficiency three systems have been tested over 5 growing seasons: I) subsurface drip irrigation II) surface drip irrigation and III) sub-irrigation.

The Spaarwater measures have been monitored over a course of 5 years to determine their impact on fresh water availability and crop yield at the pilot locations.

A monetary estimate of yield loss due to salinization is missing as salt damage in the field has the same appearance as drought damage, and is therefore often wrongly interpreted. Despite of this difficulty the results at the different pilot locations provided important insights into the effects and dynamics of salinization and the consequences for yield loss. On top of that, salt damage was estimated based on rootzone modelling and expert knowledge.

#### Results

##### Salinization risk

Figure 2 shows the risk of salinization for tile drained plots in 2050 and the increased risk of salinization compared to the current situation. The thickness of the fresh rain water lens and therefor the risk of salinization is determined using a large number of model simulations (SVOoffice). A drain spacing of 10 meters and depth of 1 m was taken as the average configuration. A high risk of salinization is defined when the fresh-salt boundary surface (annual average of the freshwater lens) is at or above the tile drainage level. Which corresponds tot a depth between 0-1 m below surface level. In the case of a moderate and limited risk, this interface lies between 1-2 m and within 5 meters below surface level.

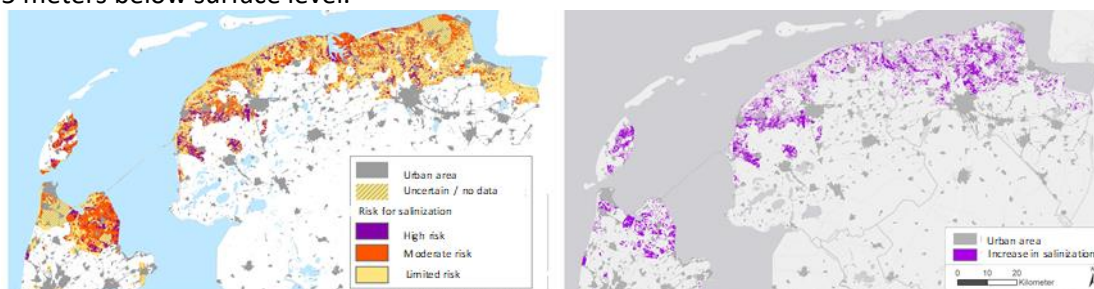


Figure 2. Salinization risk in the Wadden Sea region in the Netherlands based on the thickness of the fresh water lenses in the current situation and the increased risk in 2050.

## Spaarwater measures

### Anti-salinization drainage

Anti-salinization drainage proved its effectiveness within the pilots and can be used in different forms as an effective mitigation measure. Soil profile, permeability, seepage flux, tile drainage spacing and depth dictate what configuration is most effective. Field experiments show that within a couple of years the thickness of the freshwater lens increases with up to 50 cm, both in clay and sand soil profiles (figure 3). Also it was found that the system had no negative effect on dewatering. As a positive side effect the anti-salinization drainage reduced total salt load to the surface water. It was also found that the total load of nutrients (nitrate and phosphate) can be reduced, though the results are not conclusive.

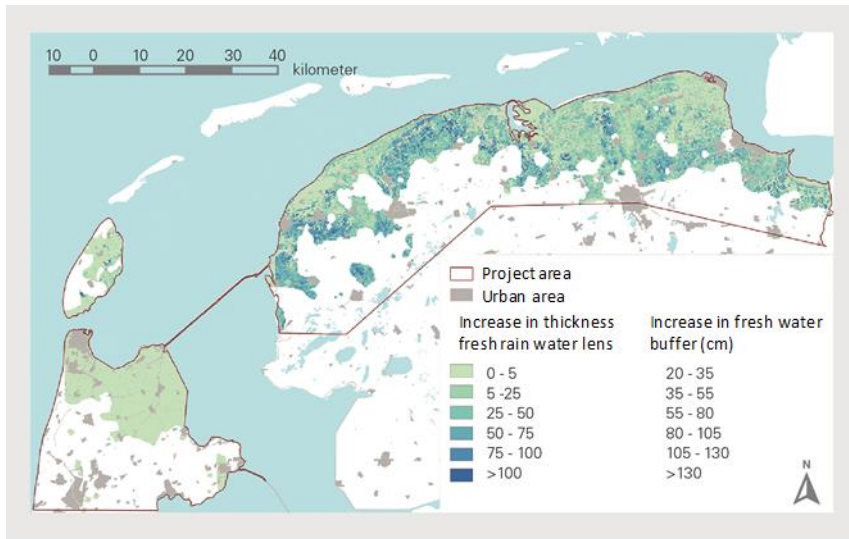


Figure 3. Increase in the thickness of the fresh water lens (cm) and in the fresh water buffer (cm) when anti-salinization drainage is used with a gauge set-up of 30 cm compared to the situation without anti-salinization drainage.

### AgriMAR – Managed Aquifer Recharge for Agriculture

It was found that for a most of the Wadden Sea Region the recovery efficiency is between 25% and 50%. For parts of the Wadden Sea Region, the recovery efficiency is even more than 50%. Which means that for every 100 m<sup>3</sup> of stored water 50m<sup>3</sup> of water can be restored. Except self-sufficiency, another major advantage of AgriMAR relates to fighting crop diseases in the irrigation water. Plant pathogens in surface water used for irrigation are an important crop health hazard. *Ralstonia solanacearum* (RS), endemic in surface water, causes brown rot (bacterial wilt) in potato crops. Other plant pathogens in surface water, such as *Pectobacterium* and *Dickeya* species, cause soft rot in various field crops (flower bulbs, potato, sugar beet).

In this study a system is developed where one water well is used for infiltration whereas three wells are used for abstraction, forcing a soil passage and increased residence time of the water. This is further investigated and developed by TUDelft in an NWO research project.

Preliminary results show that a more advanced system leads to the adsorption and degradation of pesticides and the reduction of pathogens occurs. Except the upscaling potential in the Wadden Sea Region the AgriMAR technology is successfully replicated in Lebanon and Bangladesh.



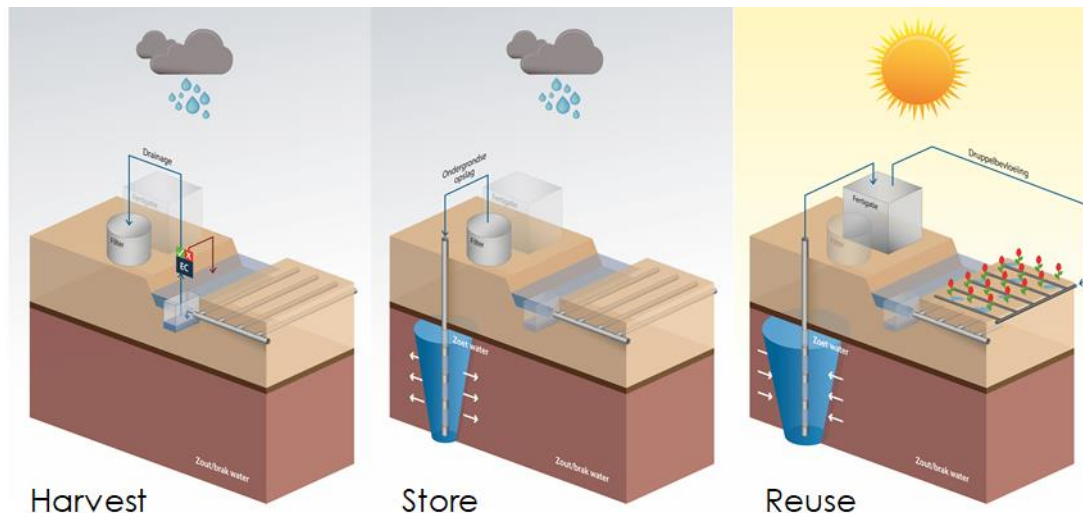


Figure 4. Schematic design of the AgriMAR system. Water is harvested from tile drain effluent, stored in a brackish aquifer at a depth of 10 tot 30m below surface level and recovered for irrigation.

#### Surface-, subsurface drip irrigation and sub-irrigation

These three methodologies have shown to be effective and efficient compared to conventional irrigation methodologies which have an efficiency rate of 50%. There are no losses due to deep percolation, interception, runoff and wind drift. Field tests show that a water efficiency between 78% and 46% has been achieved. The outlook is an efficiency of 85% for sub-irrigation and 90% for subsurface drip-irrigation. Subsurface drip irrigation has additional advantage as it allows for targeted fertilization by fertigation. Fertilizing through the drip lines increases the amount of crop stimulant reaching the roots, and reduces the loss to ground- and surface water. Field tests show that nitrate leaching via soil moisture decreases with 40% and using subsurface drip irrigation allows the use of 50% less nitrogen and 40% less phosphorus while maintaining the same crop yield.

The drip irrigation system has a lot of potential for careful water use, additional yield and crop improvement, certainly during dry periods and contributes to reducing disease pressure and reducing the use of fertilizer. During the dry summer of 2018, a significant increase in yield of 22% was achieved in Borgsweer with subsurface drip irrigation on seed potatoes.

#### Economic and financial feasibility

We will give one example of the costs for AgriMAR and benefits of avoided drought and salinization damage. The total costs for AgriMAR are made up by investment costs, financing costs and yearly recurring operation and maintenance costs. We were able to reduce cost price to € 800,000 and current innovations and cost reductions will result in a system of € 500,000 for a complete system which covers a 100ha farmland. Which translates to an average cost price of €300,-/ha/year. The direct benefits of AgriMAR are presented in terms of crop yield. Avoided drought and salinization damage are monetized and translated into yearly yields/ha. A new methodology for seed potato is presented in this study as no region-specific data on drought damage was available. The model predicts the additional benefits of water availability per year and therefore the direct benefits of AgriMAR. The average lifetime of AgriMAR systems is 15 years. In the analyses arbitrary periods (timeseries 1988-2018) of 15 year benefits based on mm avoided drought are conducted. This results in a total of expected yields per investment period. The benefit-cost comparisons for Groningen are shown in figure 5. The analysis is carried under current and expected climate change conditions, in the latter the benefits will be substantially higher.

#### Conclusions

Within the applied research project "Spaarwater" Acacia Water has, as one of the first, done extensive field measurements on the distribution of saline groundwater in and below the root zone, with the goal to develop different measures that strengthen the fresh water management and

thereby make traditional agriculture more resilient to salinization. The project came up with three measures: (1) anti-salinization-drainage, (2) AgriMAR – managed aquifer recharge for agriculture and (3) subsurface drip irrigation and sub-irrigation. The technological, hydrological and economic feasibility of these measures were studied over a period of 5 years by implementing field pilots in the Wadden Sea Region. Though the results show that salinization will increase it was also shown that all tested measures can be successful in combating salinization, increase the availability and efficient use of fresh water. Ongoing research will focus on the further improvement of these promising measures.

## 31. Desalinization of greenhouse floors - Stephan Jung

### **Desalinization of greenhouse floors**

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soil salinity, greenhouse, organic vegetables, halophytes

#### Introduction

Soil salinization is an increasing problem in the arid environment of greenhouse floors. During plant production salts are applied onto the soil by irrigation water and fertilizers. In organic farming mostly compound fertilizers are used, which not only consist of the desired nutrients, but also (depending on the product) contain sodium (Na) and chlorine (Cl). Since Na is not a nutrient at all for most plants and Cl is just a micronutrient most plants just take them up in low amounts. The rest of Na and Cl remains in the soil where it accumulates over time. Depending on the salt amount applied each year and on the time span the greenhouse soil has been in use, soil salinity problems occur more or less severe. Salads and some vegetables are especially salt sensitive compared to most grain crops. The amount of yield decrease at a specific soil salinity is dependent on soil type, plant species, plant variety and plant management.

In order to avoid growth depression of greenhouse plants excess of (clean) irrigation water has often been used in order to leach out salts below the root zone. However, in order to avoid long periods of soil drying during winter time, leaching of salts was more or less abolished in most commercial run greenhouse farms in Germany. Greenhouse space is expensive; therefore, plant cultivation often takes place all year long. Delaying planting of the next valuable vegetable in order to leach the salts often is unwanted, since it is an economic constrain. The economic constrain of a worsening yield caused by increasing salt levels is too often ignored.

Halophytes are plants that are resistant to soil salinity. Some of these halophytes are able to accumulate salts in their biomass, actively reducing the salt amounts of the soil. However, there is no viable strategy to implement this potential for organic greenhouse farming until now. The EIP agri project „Desalinization of greenhouse floors“ is working on practicable strategies to use the potential of halophytes for greenhouse floor desalinization. One strategy is to cultivate pre-selected halophytes after the final harvest of the main vegetable (e.g. tomatoes). The selected halophyte should at least be able to accumulate the ions (mostly sodium and chloride) that were left behind by fertilizers and irrigation water of the previous crop. Another strategy is to grow pre-selected halophytes in between plant rows of tomatoes or cucumber during their cultivation.

## Material and methods

After conducting a screening of 26 plant species (halophytes) and their general ability to accumulate Na and Cl, the five plant species with the highest salt accumulation were selected. Iceplant (*Mesembryanthemum crystallinum* L.), Buck's-horn plantain (*Plantago coronopus* L.), New Zealand spinach (*Tetragonia tetragonoides* L.), chard (*Beta vulgaris* subsp. *vulgaris*) and spinach (*Spinacia oleracea* L.) were tested for their ability to take up these salts under near practical conditions in a completely randomized block design (n=4).

The plants were tested in a greenhouse soil, which is in use for organic vegetable production since approximately 35 years. The sandy loam soil had a EC of 4,8 dS/m (saturation extract). The irrigation water had an EC of 0,81 dS/m. The soils Na concentration was 153 mg Na kg<sup>-1</sup> (0.01 M CaCl<sub>2</sub>) the Cl concentration 128 mg Cl kg<sup>-1</sup> (hot water extract).

## Results and Discussion

Calculations showed that 55.5 g Na/m<sup>2</sup> and 63.5 g/m<sup>2</sup> are applied to the greenhouse soil by fertilizers and irrigation during the cultivation of tomatoes in one year (Table 1). However, the uptake of these salts into the tomatoes aboveground biomass was minimal. Therefore, most of the applied Na and Cl remained in the soil, accumulated and eventually reached a level, which is not suitable for plant growth and corresponding yields. Especially salt sensitive plants react towards soil salinity with decreased growth or even plant death. Yield decreases were especially observed for lettuce species and radish.

Since experiments were conducted on a grown soil, we had no control to evaluate whether the tested halophytes had a reduced growth. In a pot experiment it was shown for this chard variety that a salt stress of 5 dS/m reduced fresh weight by 20% compared to a control (data not shown). For the other tested plant species, no study with regard to yield reduction under salt stress is known. However, at least no leaf necroses were observed.

At first this plants growth reduction is mainly caused by unspecific osmotic stress effects. Later leaf necroses are caused by specific ion toxicities. Either Na or Cl often cause this ion toxicity depending on the plant species (Munns and Tester, 2008). The effects on growth are highly dependent on plant species and even variety.

The main goal of this study, was to evaluate if the cultivation of a halophyte could take up enough Na and/or Cl in order to avoid an accumulation of these salts over time. Buck's-horn plantain showed the highest Cl uptake, whereas

New Zealand spinach had the highest uptake of Na. However, the Na uptake of Chard and Ice plant were similar. Nevertheless, these salt uptakes are not sufficient enough to take out the applied Na or Cl amounts of one year of tomato cultivation and far too minimal to eliminate the amounts of 35 years from the soil.

It is concluded that cultivation of the tested halophytes is not sufficient to take up enough salts to avoid the built up of salts in the greenhouse soil.

In the future new greenhouse soils should therefore be managed more carefully with regard to soil salinization. Preferably, rainwater should be used for irrigation and the use of fertilizers with high Na and Cl contents should be avoided. This is especially true for fertilizers derived from sugar beet Vinasse. However, the cultivation of halophytes could be helpful to avoid the accumulation of Na and Cl in the soil in the first place. A manual for farmers is developed which presents options with regard to the management of saline greenhouse floors.

Table 1: Input and Output of sodium and chlorine into a greenhouse soil in one vegetation period of tomatoes.

	Sodium (Na)	Chlorine (Cl)	
Fertilisation with sugar beet vinasse	23.2	3.8	g m <sup>-2</sup>
Irrigation (from well)	32.2	59.7	g m <sup>-2</sup>
<b>Sum of input</b>	<b>55.5</b>	<b>63.5</b>	<b>g m<sup>-2</sup></b>
Tomatoes (15,6 kg/m <sup>2</sup> )	0.53	8.54	g m <sup>-2</sup>
Side shoots	0.01	0.90	g m <sup>-2</sup>
Defoliated leaves	0.21	29.14	g m <sup>-2</sup>
Pinching residues	0.01	0.90	g m <sup>-2</sup>
Tomato plant (end of season)	0.85	10.48	g m <sup>-2</sup>
<b>Sum of exports</b>	<b>1.60</b>	<b>49.95</b>	<b>g m<sup>-2</sup></b>
<b>Total amount after one season</b>	<b>53.90</b>	<b>13.55</b>	<b>g m<sup>-2</sup></b>

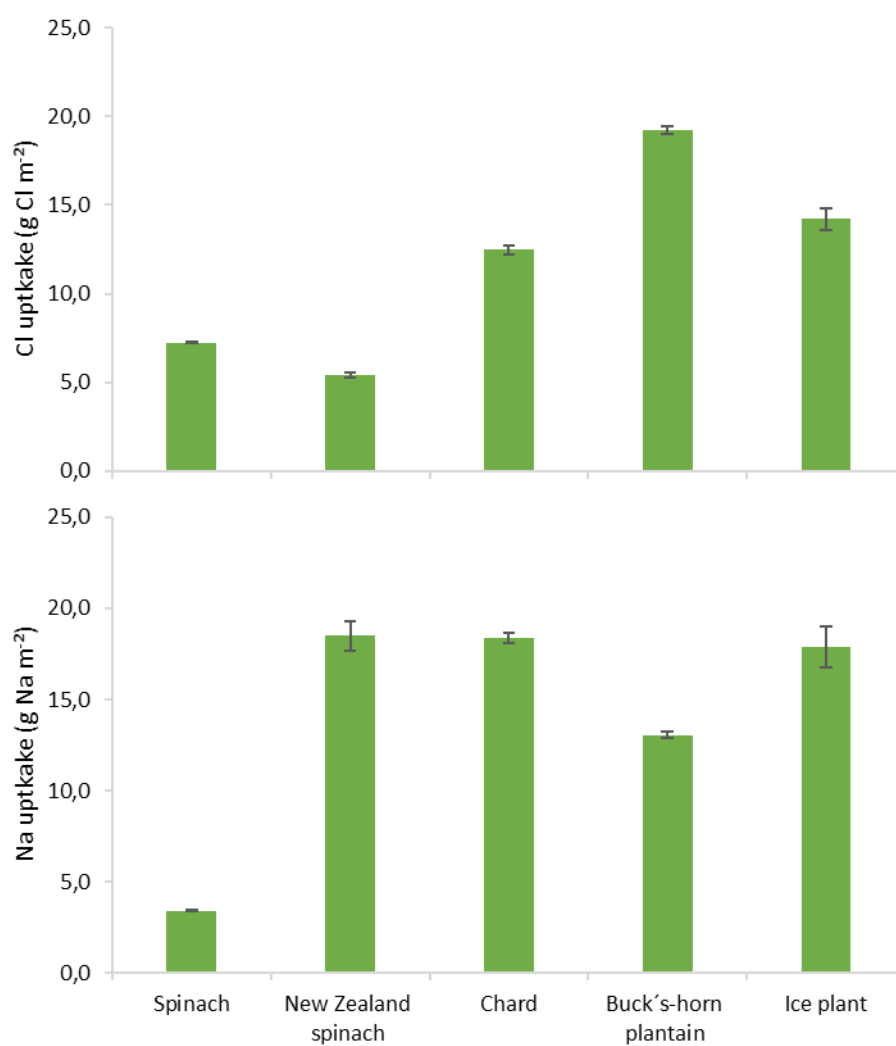


Figure 1: Na und Cl uptake of 'halophytes' after cultivation on a saline greenhouse soil (4.8 dS m<sup>-1</sup>); data show means (n=4) ± SE.

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## VIII Innovation and practical experience at farm level

### 32. Putting Saline Agriculture into Practise - a showcase from Bangladesh - Arjen de Vos

#### **Putting Saline Agriculture into Practice - a showcase from Bangladesh**

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Salt tolerant crops, implementation, farmers, Bangladesh

Coastal Bangladesh is severely affected by salinity. In 2010, over 1 million hectares was salt affected, which is an 20% increase in 10 years (based on the Soil Resource Development Institute (SRDI, Bangladesh) reports from 2000 and 2010). A recent publication shows that soil salinity is one of the main driving forces behind migration in coastal Bangladesh, that can affect 27 million people up to 2050. At present, around 44% of the salt affected area is moderately saline (EC between 4-12 dS/m). The Dutch social enterprise Saline Farming has been working on salt tolerant crops for the past 13 years and has identified salt tolerant crops varieties of common crops like potato, cabbage, cauliflower, carrot and beets (among others) that can be cultivated successfully under these (moderate) saline conditions. Now, these crops are introduced in coastal Bangladesh as part of the Salt Solution project. This project is funded by the Dutch Postcode Lottery and implemented by ICCO, Saline Farming and CODEC and also Acacia Water and Lal Teer Seed are part of the consortium. The Salt Solution project is an innovative climate smart agriculture-based project and throughout the 3-year duration the project will train 5000 farmers directly on saline agriculture in 4 coastal districts, indirectly benefiting 25.000 household members. The project has four outputs including: salt tolerant crop production, increased nutritious food consumption, increased participation and decision-making women in crop production and water management, and involve government personnel with the project intervention to sensitize them towards project intended production technologies of salt tolerant crop varieties. The key interventions of the project are: setting up a field station and development of best practises, demonstration and promotion, scaling up, linking with input suppliers and with markets for sale of produce, research, water management, and influencing government policies.

The objective of the project is to ensure that farmers in the salt affected area in coastal Bangladesh are empowered to improve their yields and livelihoods. At present, the majority of the farmers in the coastal area only grow one crop per year, instead of the 3 crop cycles per year that is standard in the north of the country. By making use of salt tolerant crops and smart soil and water management, it is possible to introduce 3 crop cycles per year in the coastal area as well. By growing different high yielding, nutritious crops with good market value, the smallholder farmers can adapt to the ever-increasing salinity levels and migration can be stopped. However, before this climate smart, resilient form of agriculture can be introduced on a large scale, several limiting factors had to be addressed.

First of all, the project should be embedded on an institutional level. Extension programmes have to be developed as well as the “best practise” for crop cultivation that includes crop/soil/water management, and an agro-service for farmers needs to be developed to assist farmers upon request. Saline Farming has tested the yield potential of several salt-tolerant vegetable crops (potato, cabbage, cauliflower, carrot, red beet, and kohlrabi) at the Saline Farming Research and Training Center in the Netherlands. Given the evidence in these field experiments, Saline Farming has begun to pilot the feasibility of introducing these varieties into the production portfolios of lead farmers in vulnerable areas of Bangladesh. Also, a Saline Farming Research and Training Center has been set up in coastal Bangladesh already together with Lal Teer Seeds from Bangladesh, as part of the ongoing project. Also, the Bangladesh Agricultural Research Institute (BARI) has performed good work in developing and selecting suitable varieties of crops like rice to be cultivated under saline conditions. All these crops and varieties are tested and demonstrated at the Training Center. Also, a cultivation strategy for year-round crop production under saline conditions can be developed here, including rice, potato and vegetable production, both for the winter and summer season (Rabi and Kharif 1 season). Also, smart soil and water management are developed and tested here, like (underground) rainwater harvesting (together with Acacia Water from the Netherlands) and drip irrigation. Soil management focusses on crop rotation, raised bed cultivation, the use of organic inputs to improve soil structure and soil fertility and mulching, for instance. Once the best strategy has been determined, this is implemented by a network of lead farmers that are trained and assisted closely. These farmers will train the farmers in their own community, spreading the awareness of salt tolerant crop cultivation as a way to adapt to increasing salinity levels. All inputs materials are made available locally, like the appropriate seeds as well as improved irrigation systems (drip irrigation). For farmers, “seeing is believing”. By setting up a network of lead farmers that act as farmer field schools for the local community, the farmers can experience saline agriculture from close by. The lead farmers are trained to such an extent that they can act as trainers for their local community as well and become a community extension agent even beyond the project. Also, by crop diversification, the farmers are able to produce different crops to ensure good market value throughout the year. This should be supported by adequate storage facilities and marketing networks to ensure maximum impact. The divers crops are also selected for their nutritional values to improve nutritious food consumption, with around 20% of the yield is used for household consumption. The best way to convince a farmer to change their way of farming is by showing the financial return of investment. For this reason, special attention is given to provide insight in the business model for the farmers, also aiming at shifting the traditional agriculture to a commercial venture. Two years after the start of the project, an independent evaluation took place to determine the effect of the project. In total, 260 farmers were interviewed from a group of 2000 farmers. First results show that 75% of the farmers now use the salt affected land during the dry season. At the start of the project, none of the farmers used this land. Vegetable consumption (150 g/day during 10 month/year) increased from 26% to 74%, food security increased from 15% to 65% and average household income increased by 34%. The project also deals with gender inequality, providing training for women, resulting in an increase in sustainable food production from 9% to 79% and increasing access to land for women from 4% to 87%. Most farmers started with a small piece of land for demonstration of the project but are turning their whole land into the tailor-made adaptive

farming system, that combines smart crop, soil and water management. This is evidence that the chosen approach works and farmers are willing to adopt the new varieties and cultivation strategies. In this stage most attention is given to the winter season when crops like potato, carrot, cabbage and cauliflower are cultivated. The above mentioned results mostly apply to these crops. The yields show no reduction under the moderate salinity levels and the market value of these crops are high, ensuring a good profit for the farmers. The second crop cycle in the dry season is more challenging, with ever increasing salinity levels, in combination with high temperatures and low water availability. So, crops should be both salt and heat tolerant and water availability can be ensured by (rain) water harvesting in times of surplus. The newly build test facility has a special focus on these summer crops (like okra, Indian spinach, bitter melon and eggplant) and underground storage of water. At present, the economic viability of underground water storage is being evaluated. This includes the price of equipment, installation costs and the amount of water that can be stored and the market value of the crops that can be cultivated off season.

Once the input materials are locally available and the farmers are able to acquire these input materials and know how to implement the best practise cultivation strategy, then large-scale implementation of saline agriculture is feasible. As the world seeks to fulfil the Sustainable Development Goals (SDG's) and eradicate poverty, hunger, malnutrition and close the gender gap, we are doing our part to promote marginal communities who are often the most vulnerable to the effects of climate change.

I specialized in saline agriculture 19 years ago during my Masters at the VU University in Amsterdam and since my PhD I have been working on the island of Texel (the Netherlands), focussing on a practical approach to identify salt tolerant crops and implementing this in various countries like Bangladesh, Pakistan and Kenya. Besides the research and implementation, I'm also contributing to scientific papers, I'm part of the EU focus group on soil salinization and an active member of the WASAG-FAO workgroup on saline agriculture. Putting saline agriculture on the international agenda, help farmers to grow food in salt affected areas, and make saline agriculture a mainstream form of agriculture are my greatest ambitions.

### 33. Climate resilient agricultural practices in the saline prone areas of Bangladesh - Muhammad Abdur Rahaman Rana

#### **Climate resilient agricultural practices in the saline prone areas of Bangladesh**

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Bangladesh, climate change, salinity, resilient agriculture

Bangladesh is the most vulnerable countries in the world. Increasing temperatures, erratic and irregular rainfall, drought, cyclones, salinity intrusion and sea level rise are adversely affecting agricultural production. Large-scale climate-resilient agricultural practices are being implemented in different salinity affected areas of coastal belt and islands, which have the potential to reduce the vulnerability and risks associated with salinity and sea level rise and contribute to climate smart food security. The study was conducted to explore the spontaneous and planned resilient practices and their possible contribution to food security in salinity affected areas of the country. The study was conducted in high salinity affected Khulna and Satkhira district of Bangladesh through explanatory and participatory action research including Community Vulnerability Assessment (CVA), Focus



Group Discussion (FGD), Household Survey (HHS), analyzing the determinants of farmer's choices between alternative adaptation measures, Key Expert Interview and Key Informants Interview in the effective study area. Finally through identifying the gaps in the implementation of those practices and the way forward with policy recommendations.

Due to climate change, precipitation patterns changed in Bangladesh, causing more intense rainfall on rainy days and more dry days in the summer season (in a year). As a result, agricultural production, the critical sector in Bangladesh, is suffering. The impacts of climate change have significantly reduced agricultural production in flood-, drought-, and salinity-prone areas.

Shyamnagar Upazila which is in the Satkhira district, is adjacent to the Bay of Bengal and the mangrove forest of the Sundarbans. Being in the nearby Bay of Bengal, the area is highly vulnerable to salinity intrusion into agricultural land, cyclone, storm surge and tidal surge, the impact of sea level rise, drainage congestion and flooding, and storm surges and tidal inundation. Every year, about 500 ha of land are converted to saline land. In 2000, the level of salinity was about 23.93 dS/m, and in 2009 about 28.64 dS/m in the Shyamnagar Upazila.

To cope with climate-induced disasters like salinity intrusion, tidal surges, waterlogging and ensure resilient livelihoods, multi-dimensional resilient options are being practiced in Shyamnagar Upazila. Our research indicates that, at present, 31.3% (Fig. 2) of the farmers of Shyamnagar Upazila have adopted alternative land use practices like shrimp farming instead of crop production. Though the use of land for crop farming is decreasing gradually, there are some alternative options for agriculture emerging, such as embankment cropping, plantation of mangrove trees, cultivation of saline tolerant grass, using flood and saline tolerant rice etc. The major climate resilient agro-based practices of the study area is illustrated in the following Table.

Table : Agro-Based Resilient Practices in Ganges Tidal Floodplain AEZ (Shyamnagar)

Resilient Sector	Options
Salt tolerant T. Aman	BR-22 and BR-23 BR-22 and BR-23, Bina Shail
Salt tolerant BRRRI dhan	33, 56, 57 and 62 BRRRI Dhan 40, 41, 53,54
Salt tolerant Bina dhan	7 & 16 Bina dhan-8 & 10
Salt tolerant Aus	BRRRI dhan 65
Salt tolerant alternate farming	Mele (reed) cultivation, Salt tolerant grass farming
Vegetable farming	Floating dhap cultivation, Dyke farming, Homestead Farming
Resilient livestock rearing	Semi-scavenger housing for goat, Semi-scavenger housing for duck, Semi-scavenger housing for hen, Semi-scavenger housing for sheep
Fish culture	Net fishing, Cage fishing
Salt tolerant wheat	Bijoy, BARI Gom-25, BAU-1059
Salt tolerant potato	BARI Alo-22 CIP Clone -88.163
Salt tolerant sweet potato	BARI Mishti Alo-8,9
Salt tolerant pulses	BARI Mug- 2,3,4,5,6, BM-01, BM-08 BARI Falon- 1, BARI Sola-9
Short duration oilseeds	BARI Sharisha-14,15 BARI Chinabadam -9, BINA China badam-1, BINA China badam-2, BARI Soyabean-6 BARI Til-2,3,4
Salinity Resistant Jute variety	HC-2, HC 95, CVL 1

Saline Sugarcane variety	Tolerant	ISWARDI-40
Others practices	resilient	Land use changing practice, Integrated farming, Crab Patenting, Shifting planation timing

Farmers of the Shyamnagar Upazila have introduced a numbers of climate resilient practices in different agro-based farming, like the introduction of salt-resistant rice varieties such as T. Aman: BR-22 and BR-23; Bina sail Flash Flood; BRRRI dhan 33, 56, 57 and 62; Bina dhan 7 & 16; BRRRI Dhan 47, 61, 67; Bina dhan-8 and 10; T. Aman: BRRRI Dhan 40, 41, 53,54; and Aus: BRRRI dhan 65; T. Aman: BR-22 and BR-23; cage fishing, mele (reed) cultivation, floating cultivation, shifting planting time, short duration rice varieties, integrated farming, crab patenting, semi-scavenger housing for goat duck and hen rearing, net fishing, dyke farming, salt tolerant wheat like Bijoy, BARI Gom-25, BAU-1059 line; salt tolerant potato : BARI Alo-22 CIP Clone -88.163; salt tolerant Sweet Potato : BARI Mishti Alo-8,9, Salt; and heat tolerant pulses : BARI Mug- 2,3,4,5,6, BM-01, BM-08 BARI Falon- 1, BARI Sola-9; short duration and salt tolerant oilseeds: BARI Sharisha-14,15; BARI Chinabadam -9, BINA China badam-1, BINA China badam-2, BARI Soyabean-6 BARI Til-2,3,4; salt resistant jute varieties by Bangladesh Jute Research Institute (BJRI): i) HC-2, ii) HC 95, iii) CVL 1 ; salt tolerant sugarcane varieties by Bangladesh Sugarcane Research Institute (BSRI): i) ISWARDI-40.

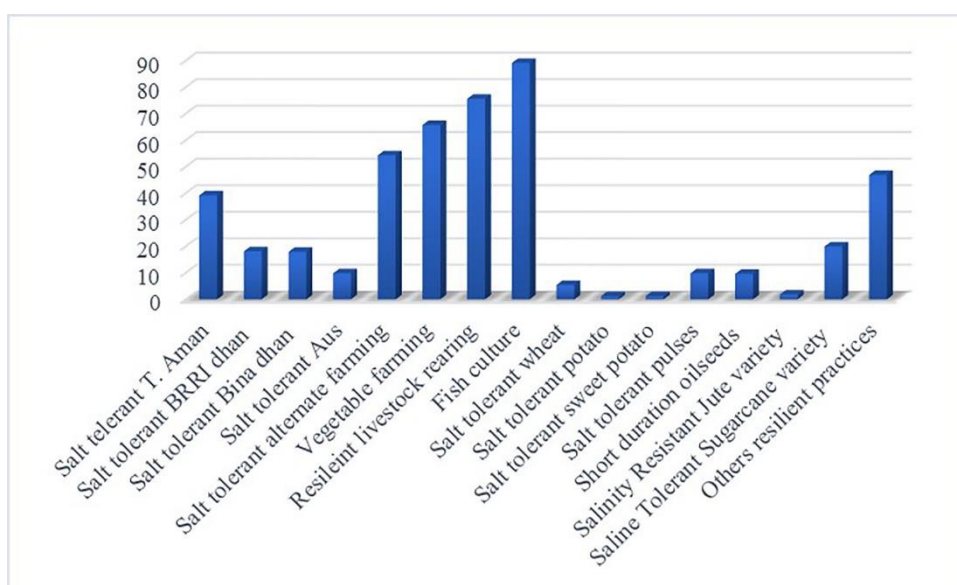


Fig. 1 Climate resilient agro-based practices in Shyamnagar Upazila (Source: Field Consultation)

Figure 1 illustrates that 39.2% farmers use salt tolerant T. Aman varieties BR-22, BR 23, BR 22, Bina Shail; 18.1 % farmers use salt tolerant BRRRI dhan varieties BRRRI 33, BRRRI 56, BRRRI 57, BRRRI 62, BRRRI 40, BRRRI 41, BRRRI 53 and BRRRI 54; 17.9% farmers use salt tolerant BINA dhan varieties BINA 7, BINA 16, BINA 8 and BINA 10; and only 9.8% farmers are practicing salt tolerant Aus varieties BRRRI 65. On the other hand, 54.3% of farmers are practicing alternate cropping including mele (reed) cultivation and salt tolerant grass farming in the study area (Fig. 6). Salt tolerant grass (fodder) farming is increasing day by day found during the community consultation. Resilient livestock farming including

semi-scavenger housing for livestock (hen, duck, sheep, and goat) is practiced by 75.6% of households to protect the livestock from climate-induced salinity and flood-oriented diseases. Fish culture is the common practice of coastal Bangladesh but due to sea level rise, tidal inundation, storm surges and flood this practice is being restricted for the recent time. Most of the farmers stopped fish culture in open pond and now 89.1% farmers are practicing net fish in their *gher* to protect shrimp and other fishes from flood and tidal inundation and some of the homestead level cage fishing, crab farming is observed in the study area which is being practiced by almost 89% farmers (Fig. 1).

Vegetable farming is restricted due to high salinity, waterlogging and flood in the study area. But in the last 20 years, by the initiative of government and non-government organization some climate resilient practices like homestead farming, dyke farming, gher/dhap farming, integrated farming have been introduced in the study area and 65.7% farmers are practicing such farming for their household needs (Fig. 1). Commercial vegetable farming is not possible in the study area which is found from the community opinion. Salt-tolerant wheat, jute, sugarcane, oilseed, pulse etc. are practicing at a small scale.

Land use changing practice, Integrated farming, Crab Patenting, shifting planation timing are introduced as climate resilient practice in the study area. 31.3% crop producers are farming shrimp instead of crop in their paddy field and some of farmers changed crop calendar following seasonal crop suitability in the study area which is shown in the Fig. 2.

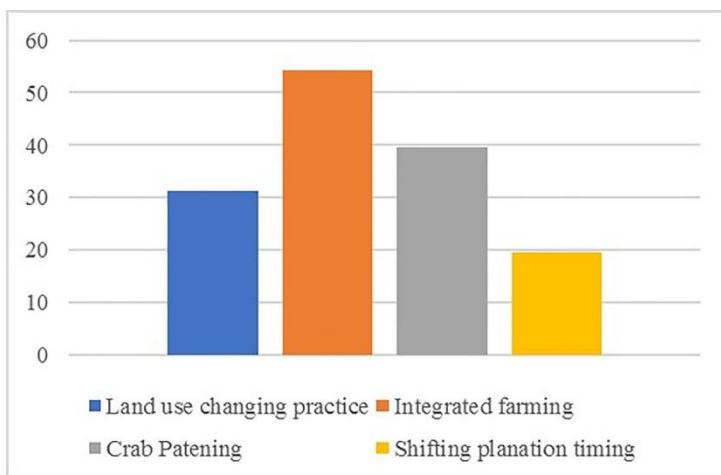


Fig. 2 Alternate climate resilient practices in Shyamnagar Upazila (Source: Field Consultation)

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## 34. Modular farming approach utilizing saline water resources to enhance food and nutrition security in desert environments: two case studies in United Arab Emirates - Dionysia Lyra and Stathis Lampakis

### **Modular farming approach utilizing saline water resources to enhance food and nutrition security in desert environments: two case studies in United Arab Emirates**

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Integrated agri-aquaculture systems; desert environments; salinity  
Producing food in marginal environments is really challenging especially when climate-related constraints and degraded natural resources exist. On global basis, one billion hectares of lands are salt-affected with an estimated annual rate of soil salinization ranging between 0.25 – 0.50 million hectares. In many regions also groundwater salinity is prohibitive for applying conventional agriculture. In particular, over 30% and 70% of the groundwater resources are saline in MENA and GCC region respectively. Desalination units are commonly used to produce fresh water for drinking and irrigation use. Approximately 100 million m<sup>3</sup>/day of reject brine are produced from all types of desalination out of which 70.3 % of global brine production is produced in GCC countries. The reject brine in farming areas is disposed in the soil contaminating the groundwater with more salts. Since 2014 International Center for Biosaline Agriculture (ICBA) has been running a modular farm that integrates agriculture with aquaculture utilizing the reject brine from a small-scale Reverse Osmosis (RO) unit. The modular farm may comprise of various modules such as high-value crops, halophytes, livestock and fish. Modular farms constitute nutrient-dense farm models that can utilize low quality water resources, infertile lands, recycle water and nutrients and can be implemented in marginal lands to foster food and nutrition security of the local communities. The project on modular farms that was funded by EXPO 2020 Dubai® and run by ICBA was completed in 2018 and focused on the optimization of inland and coastal integrated farms targeting increase in production, promoting crops diversity, generating multisource products and income for the local communities improving their health status on parallel. The modular farming approach has captured the attention of the farmers in United Arab Emirates and they have started incorporating halophytic crop species in their farms for various uses utilizing the reject brine from desalination and aquaculture effluents.

Dionysia Angeliki Lyra is a Halophyte Agronomist leading projects on climate-resilient, sustainable modular farming systems customized for desert environments incorporating halophytes and utilizing marginal water and land resources, targeting to enhance the food security of underprivileged rural communities.

## 35. Saline Agriculture, Smart Water Management and Agroforestry - B. Bruning, R. van Opstal, E. van Zandwijk

### **Saline agriculture, Smart water management and Agroforestry on two demo farms in Kenya**

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Saline agriculture, water management, agroforestry

In Kenya, as in most countries, there is an ongoing process of increasing agricultural production to meet the needs of the current and future generation in terms of food, feed and fibre. In Kenya this is even more urgent as undernourishment rates are still an estimated 19% over the 2014-2016 period. All this agricultural land expansion and intensification results in a tremendous increase in pressure on natural resources, and this agricultural development together with unsustainable management practices have led to massive land degradation (erosion, desertification and salinization) and decreasing water quality and availability. Already, 40% of Kenya experiences saline soils and groundwater, and this area is increasing.

This process has led to loss of top-soil, soil nutrients and biodiversity, and subsequent permanent reduction of productivity and in extreme cases to land abandonment. This directly contributes to rural poverty and hunger. All of these processes can be dealt with in a sustainable way, while increasing the income and the production of farmers. This requires that the following is properly addressed:

1. Lack of knowledge on sustainable land and water management.
2. Lack of knowledge on measures and technologies.
3. Lack of financial means for implementation.

There is thus a need for economically feasible ways with which farmers can increase their productivity in salinity-prone areas, without compromising the natural resources they depend on. This needs to be complemented with a financial mechanism.

The goal for this feasibility study was to prove that it is practically and commercially feasible to optimize cultivation under saline conditions by applying salt-tolerant crops (short term), water management (mid-term) and agroforestry (AF, longer term), thus facilitating large scale ecosystem-based, sustainable, commercial saline farming in Kenya. A consortium was formed between Delphy, Nectaerra and Saline Farming. The target group of this study are farmers, of all sizes, who are struggling with draught, land degradation and salinization of soil and water. The most important aim is to break the typical negative trend in agriculture in Sub-Sahara Africa, where production is low (and still decreasing) due to unsustainable practices.

The initial phase of our project focussed on the salinity affected Kajiado county, south of Nairobi. We identified ten farms potentially suitable for trials, shortlisted five which we visited with the consortium. Preliminary interviews with the farmers gave initial information such as cultivated crops, location, soil type, and salinity. During a visit to the five farmers, measurements were done of soil and groundwater salinity, and in-situ samples were collected for laboratory analysis. In addition, general farm management and crop cultivation information was gathered. A Hydrological assessment was made by observations of the hydrogeology, geography, climate, and interviews about runoff, rain events and erosion. In the end, we started practical work on two selected farms. Cultivation of carrots was started September 27<sup>th</sup> 2018. The choice for carrot was made because both farmers already grow carrot and carrots were a commercially sound choice. Two salt tolerant varieties, identified by Saline Farming, were planted and the farmer's normal carrot variety was also

planted for control purposes; all varieties were cultivated with and without mulching. The crops were regularly monitored by a local employee from one of the consortium members.

In addition, a complete design was made for both farms that included water management plans and a design for AF. All these measures were aimed at improving the yields and sustainability of both farms. The carrot planting and harvesting has already been performed, the implementation of the water management and AF is still to be executed. A financial plan was also designed, which we will not go into detail about here.

Two pre-harvests were conducted on December 3<sup>rd</sup> and 13<sup>th</sup> 2018 in order to assess the preliminary results. Salt tolerant variety 2 had a 77% higher yield (amount of carrots and total weight) on Dec. 3<sup>rd</sup>, and this had increased to 94% on Dec. 18<sup>th</sup>. However, salt tolerant variety 2 and the local variety were still 2-3 weeks before maturity (end of Dec-early Jan), while salt tolerant variety 1 should be harvested 2<sup>nd</sup> half of January. When total biomass was considered, both varieties performed better under mulching than under no mulching.

Actual yield improvement will be ever greater when accounting for losses of bad carrots that affected the local variety, because the carrots were not uniform. The salt tolerant varieties were both consistently sized and shaped. Furthermore, with increasing water salinity levels the local variety will continue to show poorer results compared to the saline resistant varieties. Due to the higher yield, quality and uniformity of the salt tolerant carrots, the farmer can start selling to supermarket chains that hold higher standards. This also applies for the processing industry. By providing a more uniform yield in reliable amounts, the farmer accesses larger markets and better prices.

The modelled results of the more detailed future farm designs were also very encouraging. The impact of the combined water management and AF interventions in the improved situation were calculated based on a CN-based rainfall-runoff model. In the improved situation, the land use was adjusted from cropland in poor hydrological condition to cropland in good hydrological condition and the soil texture was slightly adjusted based on the effect of mulching and improved soil management. Our model outcomes show a drastic increase in water availability and a situation where the majority of water does not need to come from already overstressed groundwater resources, but comes from rainfall.

Inversely, the amount of borehole water that is required will drop to 23% (farm 1) resp. 0% (farm 2) compared to the current situation. This will make farm 1 almost self-sustaining and farm 2 fully self-sustaining in an average year. Borehole water can be used as a backup for the dry years. Primarily this is realised by increased infiltration and reduced evapotranspiration. The total gain in water availability from the combined water management and AF interventions averaged over both farms is 524 mm or 98% as compared to the current situation.

Our results, both actual and modelled, clearly show that there is a lot of room for improvement on two average, small scale Kenyan farms. Using the right combination of salt tolerant varieties, a locally adapted farm design, smart water management and the latest insights on long term smart farm design considering soil fertility, nutrient use and soil water balance (i.e. AF), farms can be made much more profitable in the short term, and even more in the long term. Crop yields could be doubled and water use efficiency can also increase dramatically. Farmers are thus provided with a more reliable livelihood, and long term soil and ecological health of the system will improve. These results are more than likely translatable to other farms, in Kenya and beyond. Pressure on natural resources such as ground water resources, will be reduced. Food production will improve in quantity, quality and reliability. These findings provide an optimistic picture, when farmers can be trained in the right farming techniques.

Bas Bruning did his Ph.D on the effect of salinity on symbiotic nitrogen fixation in legumes. Part of this work was done on Texel ,where he continued to work after his Ph.D. Now he implements the knowledge and skills on saline agriculture on a practical scale both in the Netherlands as well as abroad.

## 36. Sustainable Saline Soils Use System for Food Security and Poverty Alleviation in Ghana - Rosemary Nunoo

### **Sustainable Saline Soils Use System for Food Security and Poverty Alleviation in Ghana**

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Land use, Ghana, Food Security, Saline Soils

The continues increase of the world population calls for increase in food, freshwater, and fuel every day. There is an urgent necessity to develop, create, and practice a new type of agriculture, which has to be environmentally sustainable and adequate to saline soils as salinization of Ghanaian soils is on the rise. There is a gap in knowledge on understanding interactions between crops and saline soils. There is therefore the need to evaluate the management technique of farmers in saline soils. The research therefore aims at determining the awareness, perception, adaption and management techniques of farmers. Multi stage sampling technique was employed to selected 300 farmers in the coastal areas on Ghana. Data obtained from the respondents were analyzed using descriptive statistics and inferential analysis. The application of organic matter is the most widely used technique for managing saline soils in study areas. It is widely used for managing Ghanaian saline soils because it is easily accessible and widely known. Saline soils are managed by drainage canals and field drainage systems. The use of halophytes appears be the most feasible, cost effective and beneficial technique which could be adopted for the effective management of Ghanaian salinesoils.

Rosemary Nunoo is a Researcher field of Agricultural Science, Agribusiness Management and Rural Development. I am the Projects Coordinator of Rural Education and Agriculture Development International; a Non-Governmental Organization that promotes, carry out sensitizing programs and extension education on organic agriculture, food security, climate change and environmental sustainability. My aim is to contribute to Economic Empowerment and Poverty Alleviation.



### IX Revitalization of saline degraded soils

37. The monitoring of soil salinity using remote sensing data on agricultural lands of Central Asia - Konyushkova M.V., Pankova Ye.I., Kontonoytseva A.A.

#### **The monitoring of soil salinity using remote sensing data at the agricultural lands of Central Asia**

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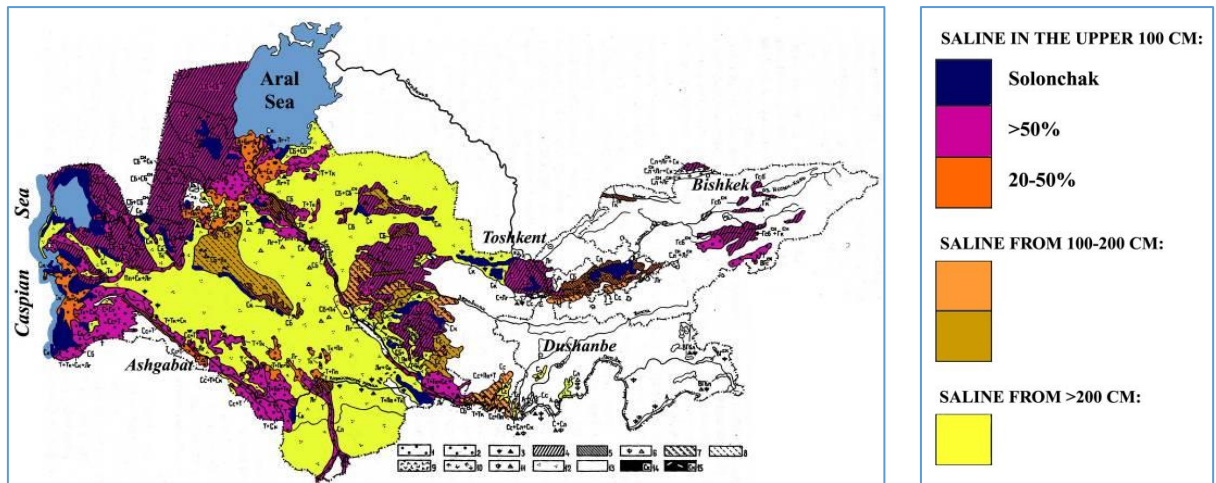
irrigated farming, salinity, monitoring, patchiness, NDVI

Soil salinity is one of main threats to food production in the downstream regions of Central Asia, especially in Uzbekistan and Turkmenistan, where the area of salt-affected soils reach 35% of the countries' area and up to 50% (in Uzbekistan) and 96% (in Turkmenistan) of the irrigated cropland. At present, there is a need to develop a system of soil salinity monitoring with the goal of the sustainable management of irrigated lands which is based on digital technologies such as remote and proximal sensing, hyperspectral soil and plant state detection from drones and digital mapping (scorpan) approach. The goal of this study was to evaluate the applicability of low-resolution MODIS and high-resolution Landsat space-borne imagery for assessing soil salinity and to suggest a procedure for national system of monitoring of soil salinity using remote sensing data. The analysis of remote sensing data performed in this study on the example of Nukus district of Karakalpakstan (Uzbekistan) show the pronounced dynamics in soil salinity on irrigated cropland in this region. It is highly demanded that the national monitoring of soil salinity includes the analysis of remote sensing data for assessment and decision support in the process of soil and water management of irrigated croplands.

#### **Introduction**

Soil salinity is one of the main threats to agriculture in the arid zones of Central Asia, especially in Uzbekistan and Turkmenistan, where salt-affected soils comprise the substantial part of these countries (Fig. 1).

The approaches to monitoring of soil salinity based on remote sensing data are abundant and very well represented in the scientific literature. Still, here, there is a gap between science and application which should be filled in the near future. The goal of this study was to evaluate the trends in soil salinity using low-resolution MODIS and high-resolution Landsat space-borne imagery as well as the scientific approach developed for this region in previous studies and to suggest a procedure for national system of monitoring soil salinity using remote sensing data.



Country	Area of salt-affected soils (% of the country's area)*	Area of salt-affected soils at the irrigated croplands (% of total irrigated)
Uzbekistan	15.6 mln. ha (35%)	2140 ths. ha (50%)
Turkmenistan	17.3 mln. ha (35%)	1673 ths. ha (96%)
Kyrgyzstan	1.2 mln. ha (6%)	124 ths. ha (11%)
Tajikistan	0.6 mln. ha (4%)	115 ths. ha (16%)

\*Source: Vargas et al. (Eds.) 2018. *Handbook for saline soil management*. FAO: Rome.

\*\*Source: Bucknall et al. 2003. *Irrigation in Central Asia: Social, Economic and Environmental Considerations*. World Bank: Washington.

Map source: Pankova et al. 1996. *Natural and Human-Induced Salinization in the Aral Sea Basin*. Dokuchaev Soil Science Institute: Moscow

Fig. 1. The distribution of salt-affected soils in the countries of Central Asia.

## Methods and materials

The test area was Nukus district of Republic of Karakalpakstan (Uzbekistan) which is located in the right bank downstream of the Amu-Darya river (Fig. 2).

The map of croplands has been downloaded from LPDAAC GFSAD collection <https://lpdaac.usgs.gov/products/gfsad30eucearumecev001/> (Phalke et al., 2017).

One of the main challenges for automated interpretation of soil salinity by remote sensing data in Central Asian countries is the continuous use of abundant irrigation during the growing season of cotton (and winter wheat in the last decade). There is a short period between the end of irrigation and cropping the yield of cotton in the end of September when the state of crops can be estimated remotely. This fact confined us to the imagery of this period (second half of September).

Imagery MOD13Q1 (for NDVI) for the second half of September of 2000-2018 was downloaded from USGS server (earthexplorer.usgs.gov). Due to the low resolution of this imagery, there was no analysis of spatial pattern performed. The average NDVI was calculated for Nukus region to see the trends in the state of crops in this span of time.

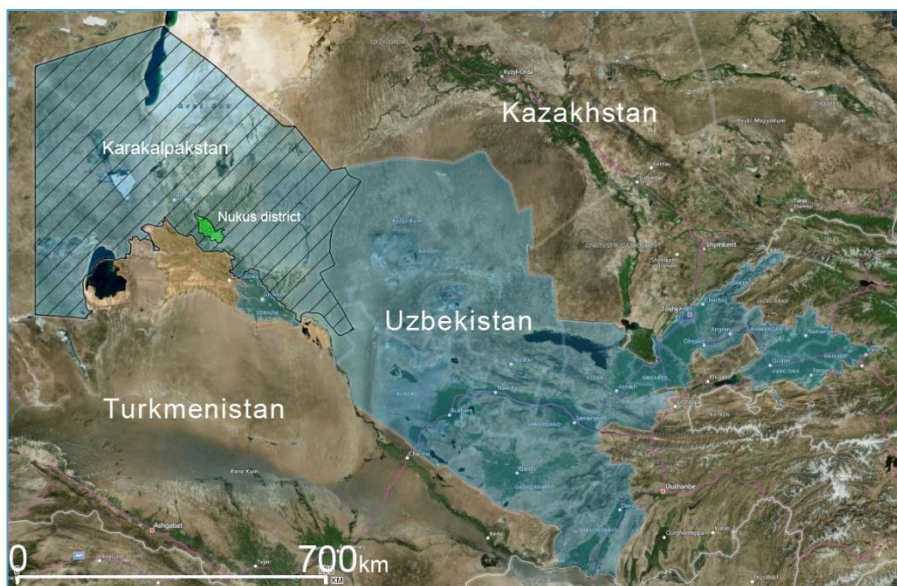


Fig. 2. The location of the study area

The no-cloud Landsat 5 TM imagery for the second half of September of 2000-2010 (16/09/2000, 19/09/2001, 17/09/2006, 20/09/2007, 22/09/2008, 28/09/2010) was downloaded from USGS server (earthexplorer.usgs.gov). We analyzed only this period of time when there was only cotton (without winter wheat) grown in the cropland. The interpretation of imagery was based on the criteria developed for the cotton fields of Central Asia (Pankova et al., 2018). The approach is based on the areas and abundance of patches with low NDVI (cotton failures) which were the evidence of different levels of soil salinity depending on their sizes and percentage of such failures within a field. This procedure deals with high resolution imagery. These criteria are summarized in Fig. 3.

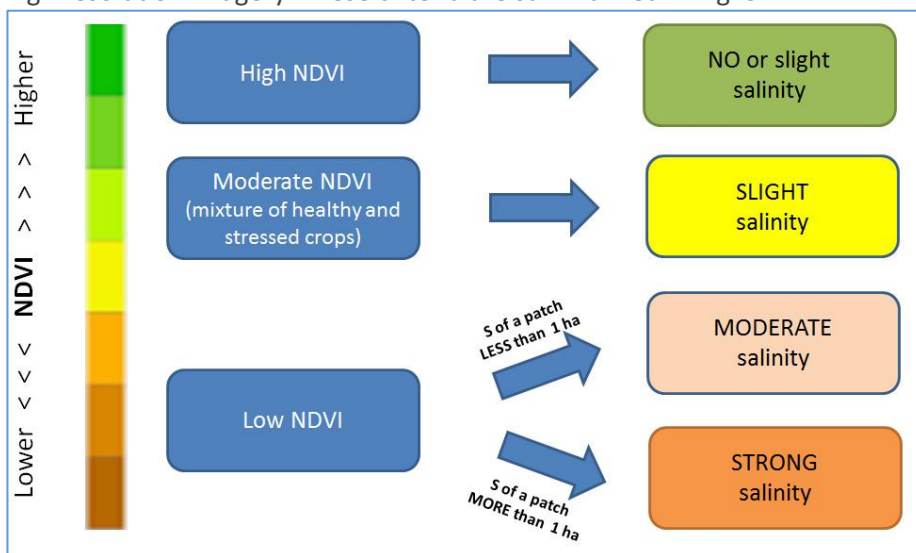


Fig. 3. The criteria for soil salinity assessment based on remote sensing data developed for cotton fields in Central Asia [modified for Landsat imagery from Pankova et al., 2018]

### Results and Discussion

The analysis of MODIS NDVI show the clear trend of increasing the average NDVI values from 2000 to 2018 especially since 2011 which can be correspondent with the introduction of winter wheat crop rotation in this region. During the period of 2000-2010, when the dominant crop was cotton, the minimum values of NDVI are observed in 2000, 2001, 2004, 2005, 2007, 2008 whereas the maximum values are observed in 2002, 2003, 2006, 2009 and 2010.

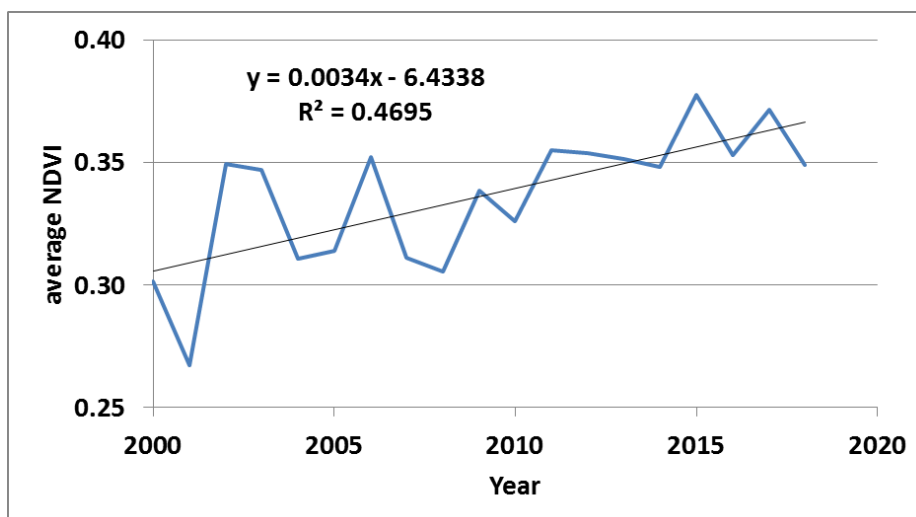


Fig. 4. Dynamics of average MODIS NDVI (MOD13Q1) in Nukus district of Karakalpakstan in September. The analysis of salinity trends according to Landsat data during the period of 2000-2010 show that salinity was very variable in different years. The most optimal years (with enlarged areas of nonsaline and slightly saline soils) in Nukus district were 2006 and 2007; the most negative years (with enlarged areas of strongly and moderately saline soils) were 2000, 2001, 2008 and 2010 (out of six years studied) (Table 1). At the same time, the official statistics on the areas of different categories of salt-affected soils show that the areas are not changing significantly since 2002.

Table 1. Salinity trends in Nukus district of Karakalpakstan according to Landsat data (ths.ha).

Year	Not cropped	Strongly and moderately saline	Slightly saline	Nonsaline
2000	3.1	29.5	16.5	0.7
2001	5.2	29.4	12.2	3.0
2006	3.3	17.9	21.6	7.0
2007	4.4	20.3	19.5	5.5
2008	5.2	28.5	13.2	2.9
2010	4.7	31.6	13.0	0.5

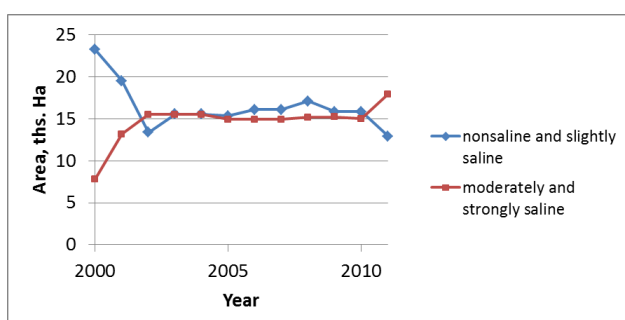


Fig. 5. Salinity trends in Nukus district of Karakalpakstan according to official statistics (ths.ha)

## Conclusion

The analysis of remote sensing data show the pronounced dynamics in soil salinity of irrigated cropland of Nukus region. It is highly demanded that the national monitoring of soil salinity includes the analysis of

remote sensing data for assessment and decision support in the process of soil and water management of irrigated croplands.

#### **Acknowledgement**

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- Maria Konyushkova is a soil expert in the Eurasian Center for Food Security at the Lomonosov Moscow State University. She studies geography and cartography of salt-affected soils in arid regions of Russia and Central Asia using computer-based analysis of space-borne imagery and digital soil mapping. Since 2018, Maria is an expert of the Intergovernmental Technical Panel on Soils (ITPS) of the FAO Global Soil Partnership.

### 38. A Simplified Model for Soil Salinity and Sodicity in Drylands - Isaac Kramer, Yair Mau

#### **A Simplified Model for Soil Salinity and Sodicity in Drylands**

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Sodicity, soil degradation, modeling

#### Introduction

Soil salinity and sodicity present major environmental challenges. Saline soils are characterized by high concentrations of electrolytic mineral solutes, which can have a negative effect on crop yields (Hillel 2000; Läuchli and Grattan 2011; FAO and ITPS 2015). Soil sodicity refers specifically to the relative concentration of sodium ions in soil and soil water and is associated with degradations in soil structure (Hillel 2000). The dangers posed by salinity and sodicity are especially pronounced in arid and semi-arid regions (Chesworth 2008; FAO and ITPS 2015). The limited water resources that define these areas often necessitates the use of low-quality water for irrigation, without which food

production could not be sustained (Hillel 2000). This low-quality water, however, is often high in salt content, and thus can drive the development of salinity and sodicity in dry regions (Hillel 2000).

Modeling can help us understand the challenges presented by salinity and sodicity and devise strategies for minimizing crop loss and soil degradation. Existing models for salinity and sodicity can be divided into two categories, neither of which is suitable to analyzing the effect of changing climatic conditions and irrigation practices on dryland soils. Most existing models are detail-heavy and require the solving of complex equations, limiting their usefulness for long-term analysis (Short, Dawes, and White 1995; Šimůnek and Suarez 1997; Tocci, Kelley, and Miller 1997; Farthing and Ogden 2017). The few simple models that have been presented, however, are not capable of describing the conditions found in drylands (Van Der Zee, Shah, and Vervoort 2014; Mau and Porporato 2015).

#### Model description

To fill this gap, we introduce the SOTE model, a minimalistic model capable of considering salinity, sodicity, and changes in soil water content (manuscript in preparation). We define salinity,  $C$ , as the electrolyte concentration of salts in the soil water (mmol<sub>c</sub>/L). We define sodicity,  $E_x$ , as the relative concentration of sodium ions in the soil's exchange complex. We define relative soil water moisture,  $s$  (dimensionless) as the fraction of the soil's pore volume containing water.

The SOTE model considers water input from irrigation and precipitation and water losses from evapotranspiration, leakage, and runoff. The model focuses on a homogenous unit area of soil with given rooting depth and porosity. Irrigation, precipitation, and evapotranspiration rates can either be drawn from a measured time series, or be artificially created in order to probe the effects of irrigation strategies and climatic conditions. If the latter, irrigation can be considered as either a constant rate (e.g., mm/day), triggered by soil moisture content, or a time-dependent process (e.g., weekly flood irrigation). Likewise, we model precipitation as a stochastic process. Precipitation can be considered as occurring either seasonally or with equal daily probability throughout the simulation period. Unless taken from a measured time series, evapotranspiration and leakage rates are based on soil moisture content.

Changes in salinity and sodicity are driven by the water inputs and outputs and their respective chemical composition. The SOTE model considers irrigation water to be the major source of salt inputs to the system and leaching to be the primary removal mechanism. We are able to calculate the salinity of the system at each time step by tracking the soil water content and total salt mass. As salts pass through the system, they interact with the cations bonded to the soil exchange complex. We model the change in soil sodicity that is driven by this interaction by restricting our focus to only two cations: Na<sup>+</sup> and Ca<sup>2+</sup>. While other cations are common in soils (e.g., K<sup>+</sup>, Mg<sup>2+</sup>), focusing on Na<sup>+</sup> and Ca<sup>2+</sup> allows us to simplify the equations describing the chemical balance of the system and to concentrate on the distinctions between monovalent and divalent cations, as done in (Van Der Zee, Shah, and Vervoort 2014; Mau and Porporato 2015). Divalent cations known to support the formation of soil aggregates, while a high proportion of monovalent cations can lead to soil degradation.

The SOTE model also considers how salinity and sodicity affect the hydraulic conductivity of a soil. Here, we incorporate the empirical models developed by (McNeal 1968; Ezlit et al. 2013), which describe how high concentrations of monovalent cations in a soil's exchange complex (e.g., Na<sup>+</sup>), coupled with relatively low overall salinity, can lead to a breakdown in soil structure and thereby a reduction in soil hydraulic conductivity. The Ezlit model is a modified version of the McNeal model and also considers the boundary between clay flocculation and dispersion and soil-specific parameters. We implement the disaggregation model introduced by Ezlit et al. (2013), which has been shown to accurately predict reductions in hydraulic conductivity as a result of saline and sodic (Dang et al. 2018).

#### Results

We validated the SOTE model against data from Gonçalves et al. (Gonçalves et al. 2006). Conducted in Alvalade do Sado, Alentejo, Portugal, this study measured soil salinity and sodicity in three

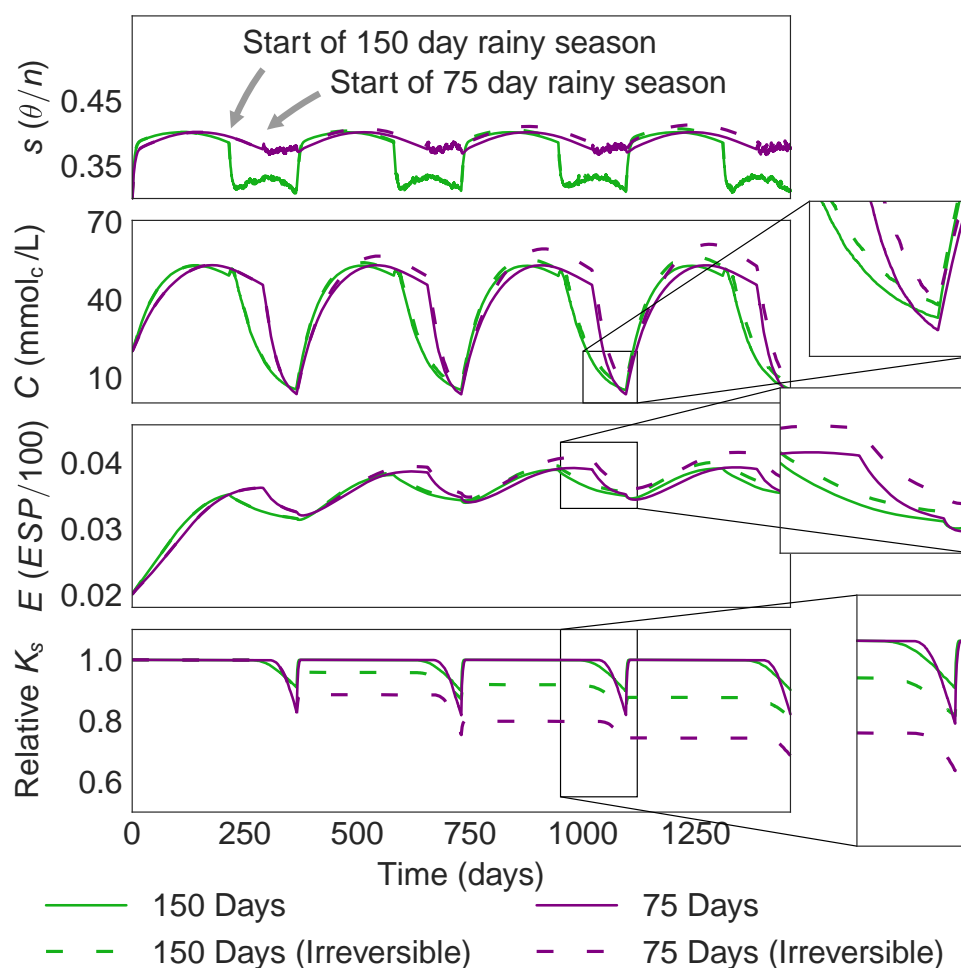


lysimeters over a four-year period. We also compared the SOTE model to simulations produced by the Hydrus software package, which were based on the same experiment and included in Gonçalves (2006). Our validation produces satisfactory results when compared both to the experimental data and Hydrus simulations. Comparison between SOTE and Hydrus shows that the two achieve similar levels of accuracy (as measured by mean absolute error) and precision (as measured by the distribution of errors). We argue that the SOTE model is significantly easier to use as it is specifically designed to investigate salinity and sodicity and requires minimal user modification. The simplified nature of SOTE model results in it being significantly faster than Hydrus and therefore more suitable for long-term analysis or potential integration with global climate models.

We apply the SOTE model to investigate the effect changing rainfall patterns may have on soil degradation. Over the course of the next several decades, climate models suggest that the length of the winter rainy season in Israel, for example, may shorten by nearly half from its current length (approximately five months) (Hochman et al. 2018). The figure below shows the results of SOTE model simulations based on the current 150-day rainy season and the projected 75-day rainy season, holding the expected annual rainfall constant at 450 mm/year. During the portion of the year in which rain was not expected, we applied a moderately saline/sodic irrigation water ( $C_{irr} = 15 \text{ mmol}_c/\text{L}$  and  $E = 0.25$ ) with the irrigation rate set to 1.1 times the potential evapotranspiration rate. The annual evapotranspiration rate was based on a sinusoidal curve ranging between 2 and 7 mm/day. All simulations were run using a sandy loam soil. To account for the possibility that declines in hydraulic conductivity resulting from clay dispersion (in contrast to clay swelling) may be irreversible, we ran the simulations in two ways. In one set of simulations, we allowed hydraulic conductivity to recover regardless of the degree of degradation. In the second, once saturated hydraulic declined below 75% of its starting value, it was not allowed to recover. Each line displayed in the plot below is the mean of 100 simulations.

The simulations show that the shorter rainy season increases the potential risk for soil degradation. Focusing first on the simulations in which declines in hydraulic conductivity are reversible, we observe more complete leaching and slightly higher sodicity levels at the start of the rainy season in the soils with a 75-day rainy season. This combination of lower salinity and higher sodicity can trigger declines in hydraulic conductivity. If the decline in hydraulic conductivity is regarded as irreversible, the cumulative decline in the soil's hydraulic conductivity eventually results in decreased ability to leach salts from the soil. This can be seen in the inset to the salinity plot, where the two soils in which degradation is considered irreversible have higher salinity levels at the end of the rainy season than the soils in which declines in hydraulic conductivity are reversible. The reduced ability to drain these soils results in higher salinity and sodicity during the irrigation season in the simulations with irreversible conditions. Clearly, the presence (or lack thereof) of irreversible conditions exerts considerable influence over the results. Moving forward, it is critical that we increase our understanding of the point at which declines in hydraulic conductivity may become irreversible and if/how we can expect degraded soils to rehabilitate.





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### 39. Droughts impacts on surface salinity levels and implications for irrigation water scarcity in the United States - Edward Jones, Michelle T.H. van Vliet

#### **Drought impacts on surface salinity levels and implications for irrigation water scarcity in the United States**

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River salinity, droughts, water scarcity, irrigation sector

Hydrological droughts have a diverse range of effects on water resources. Whilst the impacts on water quantity are well studied, the impacts on water quality have received far less attention. The agricultural sector, as the largest water user, strongly relies on sufficient water availability, but also suitable water quality. In particular, high salinity levels can constrain irrigation water uses. Here, we statistically analyze the relationship between river salinity (EC) and drought conditions in the United States and develop a new water scarcity indicator to include salinity. Using data from 66 USGS monitoring stations, we find strong increases in river salinity levels during drought conditions

(median increase 21%,  $p \leq 0.05$ ). These increases can adversely impact irrigation activities and other water users when sectoral salinity thresholds are exceeded. Our water scarcity quantifications demonstrate that a combination of drought-induced changes in both water availability and quality (i.e. salinity) can exacerbate water scarcity, and that both water quantity and quality aspects should be considered when quantifying water scarcity for irrigation and other sector uses. Alleviating water scarcity should therefore not only focus on increasing water availability and reducing water demands (quantity aspects), but also on improving water quality (Jones & van Vliet, 2018).

## **Introduction**

Increases in the frequency, magnitude and duration of droughts are expected in most regions worldwide due to climate change (Prudhomme et al., 2014; Trenberth et al., 2014). Hydrological droughts impact both the availability and quality of surface waters (Mosley, 2015; Whitehead et al., 2009). While the impacts on water quantity are well studied, the impacts on water quality have received far less attention. Previous work has demonstrated stream water quality deterioration associated with the low flow conditions induced by drought in various river basins across the world (Caruso, 2001; Mosley, 2015; van Vliet and Zwolsman, 2008). For example, river salinity has been demonstrated to increase during drought induced low-flow conditions due to lowered dilution capacity, increased evapoconcentration, reduced flushing and the increased penetration of salt wedges (Mosley et al., 2012). However, a more comprehensive understanding of the relationship between drought and river salinity is required.

All major water use sectors (domestic, agricultural, manufacturing, power) require an adequate quantity of water of acceptable quality for their intended use. Yet, quantifications of (sectoral) water scarcity have typically neglected considerations of water quality (van Vliet et al., 2017). As the largest water user globally, accounting for approximately 70% of withdrawals, the agricultural sector is strongly dependent on sufficient water availability for irrigation. However, the agricultural sector is also constrained by water quality requirements, especially salinity (Flörke et al., 2019), but no previous studies have analyzed agricultural water scarcity accounting for salinity.

Here, we aim to address these two knowledge gaps by analyzing the relationship between drought and river salinity and accounting for salinity in water scarcity quantifications for rivers in the United States. We also aim to combine these two elements, focusing on impacts of droughts on river salinity levels and including a salinity dimension in quantifications of water scarcity during non-drought and drought conditions. As salinity is a critical water quality parameter for food production, we especially focus on the implications of salinity-induced water scarcity for the agricultural sector. Hence, the objectives of this study are as follows: (1) to investigate the influence of hydro-meteorological drought on salinity levels; and (2) to assess the impact of drought-induced changes in river salinity levels on (agricultural) water scarcity, including both water quantity and salinity impacts.

## **Methods**

We studied observed daily river salinity (electrical conductivity; EC) data obtained from the United States Geological Survey (USGS) for 66 monitoring stations located across the Southern USA. Each site had a minimum of 3,650 (10 years) observations within the study period 2000–2017. Where available, discharge data at these sites was also downloaded. The Drought Severity and Coverage index (DSCI) from the United States Drought Monitor (USDM) was used to identify drought periods. Drought periods were identified as periods when the sum of the mean and standard deviation of DSCI for the study area was exceeded for a period of >6 months. The relationship between EC and the drought indicator (DSCI and discharge) was examined using correlation analysis. Significant changes in river EC levels during drought periods compared to both non-drought periods in the same

time series (Mann-Whitney) and to the long-term monthly average (Wilcoxon Signed Rank) were analyzed statistically.

For the assessment of water scarcity including salinity, we considered the 15 major river basins in the state of Texas. An average EC value was derived per river basin from the aforementioned monitoring stations. For investigating the effect of drought-induced salinity changes on water scarcity, we applied the average percentage increases in EC previously observed. Monthly river discharge measurements at the most downstream monitoring station within each catchment, cross-checked with the Texas Water Development Board’s (TWDB) surface water availability quantifications ( $R^2 = 0.98$ ), was used to approximate surface water availability. Sectoral surface water use was obtained per catchment from the TWDB. Salinity-driven water scarcity was quantified using the method developed by van Vliet et al. (2017) . This indicator presents the ratio of sectoral water use of acceptable water quality (salinity) to the overall water availability and considers, in addition to the required sectoral water withdrawals, also the extra water withdrawal to obtain water of acceptable quality by dilution.

## Results

Both DSCI and discharge were found to strongly correlate with river salinity (EC). A statistically significant ( $p \leq 0.05$ ) positive relationship between DSCI and EC was found at 55 of the 66 monitoring sites with a median correlation coefficient of 0.55. This relationship was linear; the more severe the drought conditions (i.e. higher DSCI), the greater the EC. A negative relationship was found between discharge and EC, indicating that low discharges are associated with high salinity (EC values) and vice versa. Statistically significant ( $p \leq 0.05$ ) negative correlations were found at 39 of the 40 monitoring stations, with a median correlation coefficient of -0.76. The inverse (and non-linear) relationship is best described statistically by power relations ( $EC = aQ^b$ ; average  $R^2 = 0.5$ ) and by the dilution model ( $EC = a/Q + b$ ; average  $R^2 = 0.4$ ) proposed by van der Weijden and Middelburg (1989). At most sites, river EC levels during drought periods were found to be statistically significantly ( $p \leq 0.05$ ) higher than during non-drought conditions (59/66 monitoring stations) and when compared to the long-term average (54/66 monitoring stations) (Figure 1). The median percentage increase in river EC values was 21% compared to non-drought conditions, and 14% higher compared to the long-term average.

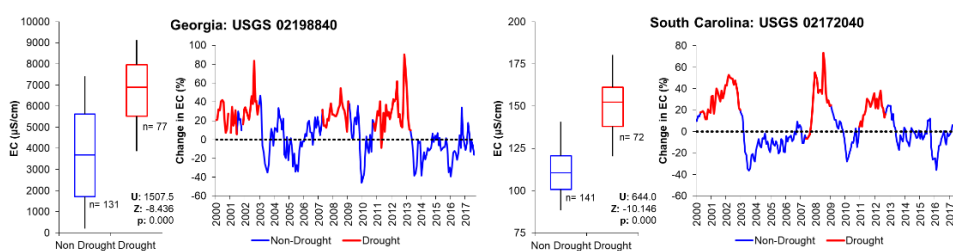


Fig 1: Boxplots showing summary statistics and percentage change in electrical conductivity (EC) observed during drought (red) and non-drought (blue) conditions for selected stations in Georgia and South Carolina

The impact of including a salinity dimension in quantifications of water scarcity for the 15 major river basins in Texas was found to be substantial, in particular during severe droughts like the 2011 drought (Figure 2). Increases in water scarcity as a result of drought-induced decreases in water availability was compounded by water quality degradation (increases in river salinity). For example, the median water scarcity value including salinity was 0.7 in non-drought conditions, three times greater than the associated water scarcity quantifications derived from the traditional criticality ratio (water demand/ availability). Drought-induced changes in river salinity also lead to substantial

increases in water scarcity quantifications. For example, a 10% increase in river salinity led to an average increase in water scarcity by factor 2. These temporal increases in surface water salinity levels, induced by drought, can adversely impact irrigation and other sector water uses in particular when salinity threshold values for these sector water uses are temporarily exceeded. Our results demonstrate that agricultural water scarcity intensification during drought conditions can occur due to reduced water availability, increased river salinity, or (most typically) a combination of these factors.

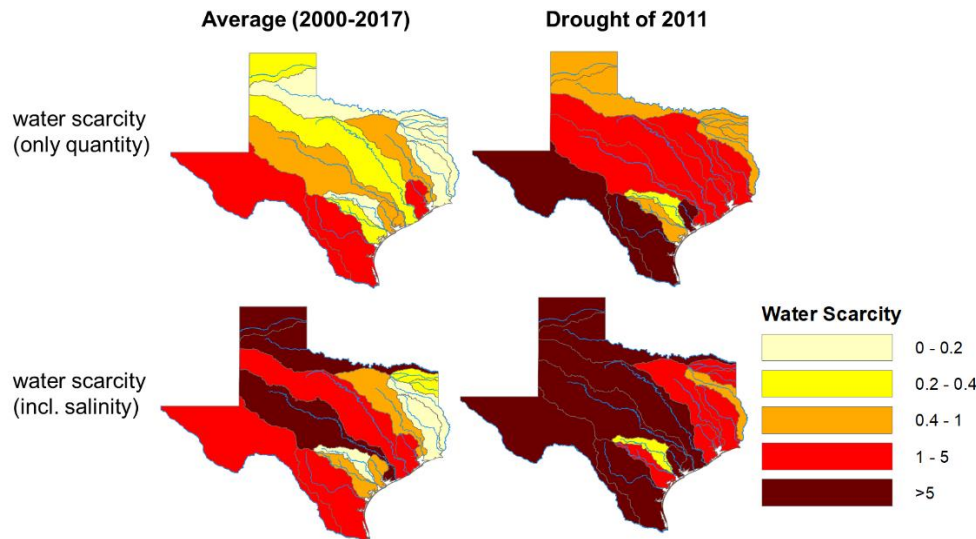


Figure 2: Water scarcity solely based on water quantity (upper panels) and including a salinity dimension (lower panels) for the entire period (left panels) and for the 2011 severe drought (right panels).

## Conclusions

Our results demonstrate that droughts are associated with substantial increases in river salinity, in addition to reduced water availability, and that both of these aspects should be considered when quantifying water scarcity for irrigation purposes and other sectoral uses. Alleviating water scarcity should not only focus on increasing water availability and reducing water demands (quantity aspects), but also on improving water quality (Jones and van Vliet, 2018; van Vliet et al., 2017). Our conclusions will continue to become increasingly important as rising water demands associated with population growth, increased water consumption per capita and economic growth, coupled with diminishing water availabilities and qualities, continue to exacerbate water-related issues in most world regions.

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## 40. Soil salinity in Denmark - Laurids Siig Christensen

### Soil salinity in Denmark

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Soil salinity, dynamics.

#### Introduction

Denmark is a nation of islands, generally with a low altitude (<200 m) above sea level. The landscape is rich in marshland and meadows and no spot is more than 50 km from the sea. Denmark is a relatively small country of 42.900 km<sup>2</sup> with an exceptionally long coastline of 7.300 km. Denmark is also a nation with intensive farming and food production, arable land constituting 62% of the country. Altogether, this means that Denmark is expected to be among the 15 countries in the world that will have to pay the highest costs of accommodating to climate changes.

On the other hand, Denmark has a unique location between a freshwater sea, the Baltic Sea, and the North Sea, representing a perfect gradient (0,6 – 3,2% wgt/vol) of salinity. This means that Denmark has optimal conditions of experimenting with halo-tolerant and halo-philic plant production.

The present study is the first attempt to study the salinity in soil and dynamics of soil salinity in Denmark. It is done, not only to understand the situation but also to identify locations where attempts to cultivate salt tolerant plants can be made in order to develop a contingency in food production against climate changes.

### Methodology

Estimation of salt concentration in soil was done by measuring conductivity in an aqueous phase after solubilizing salt of a soil sample. However, the linkage between conductivity and concentration of NaCl – as the only relevant parameter in a context of climate changes in the North Sea region - is not simple as pH and other ions such as nitrate and phosphate from fertilization can contribute significantly to conductivity. For this reason, the present study is only a preliminary screening and its correlation to NaCl-concentration is not validated.

An addition of one weight equivalent of deionized water to dried soil samples was used routinely to extract salt from soil. However, sample preparation is not simple given the high diversity in nature of soil samples, and a modified procedure is to be developed – especially when soil of very low particle size or high humus content is sampled.

Based on a series of dilutions of NaCl in deionized water, a standard curve of correlation of NaCl concentration and conductivity was made revealing the relationship in the concentration range of no conductivity interactions between ions – to be used as a rule of thumb:

Concentration of NaCl (% wgt/Vol) = 0,05 x conductivity (mSiemens/cm)

In sampling of soil there was a focus on smaller islands since agriculture on these islands often is allowed close to the coastline.

### Results and discussion

Sources of salinization of arable land experienced in Denmark are:

- flooding by the sea,
- spray from breaking waves on the coast,
- reflux in drainpipes during storm and high tide,
- mist (aerosols) from the sea
- seepage from the sea
- accumulation as a result of flood followed by evaporation

Conductivity in Denmark in farmland distant from the sea and prior to the growth season was found in the range of 0,2 – 0,6 mS/cm suggested to be the baseline salinity in Danish soil when not notably being affected by the sea.

A few areas exist in Denmark that are regularly flooded by the sea. One example is the river valley of *Varde Å* at the North Sea coast. A gradient of salt concentration was demonstrated with increase in salinity towards the North Sea coast but modification of the sample preparation in this clay soil did not allow any quantification.

Minor flooded areas are also seen surrounding western parts of the *Limfjorden* in North Jutland. A conductivity of 43-44 mS/cm was found in the water of *Limfjorden*. Conductivities in the range of 1,3-2,3 mS/cm were found in soil of areas surrounding *Limfjorden*.

The River Valley of *Varde Å* is Nature 2000 area and is no longer used for any other purpose than pasture. However, the coastal areas of the western parts of *Limfjorden* should be mapped in more detail in search for candidate areas for saline farming.



Incidental flooding is experienced in other parts of Denmark including the island of Rømø in the Danish Wadden Sea. Conductivities of 0,9-1 mS/cm found on Rømø indicates an affection that is declining over time since the last flood.

Soil in river valleys near the North Sea coast in general revealed a low to moderate affection by salt while samples collected from the rivers were fresh water with conductivities of 0,28-0,29 mS/cm. Fjords along the North Sea coast were found to contain brackish water, one example being *Ringkøbing Fjord* with a conductivity of 5,9-6,0 mS/cm.

Spray from waves breaking on the coast incidentally is seen affecting the crops on islands at distances up to 100 m from the coast. One example was a rape field on the island of Sejerø where growth was inhibited in a zone of 100 m off the coast. Conductivities of 0,8 to 1,0 were found. Samples were first collected 6 months after the incidence, but compared to the baseline salinity found on of the island, affection by salt being washed away from the root zone was evident. Salinity in the sea surrounding the island was found at different time points varying from 27-33 mS/cm.

On the island of Sejerø, incidental reflux in drainpipes are observed. One such spot was sampled, revealing a salinity of 0,97-0,98 mS/cm. According to farmers and own observations, affection of the crop yields disappears 5-10 years after an incidence.

The impact of mist from the sea could not be measured with any statistical significance due to the high variation in soil salinity but can be observed on windows etc. The fungicide effect of airborne salt has been exploited for hundreds of years in berry and fruit production, the plantations often being placed in the coastal landscape on slopes oriented towards the sea.

Seepage of sea water into coastal areas was previously insignificant due to precipitation and seepage of rain in the direction of the sea. However, seepage of sea water has been noted for the past decades to become more prominent as a result of drainage of arable land and the increase in use of water for drinking, irrigation, etc. Salinity as a result of seepage is normally not affecting the root zone of farm crops. However, it can be observed on islands, affecting the roots of trees and in deeper layers of soil, in ponds and in wells where conductivities of 1,7 - 2,3 mS/cm were measured while baseline conductivity was measured in topsoil.

Flood by sea water and subsequent evaporation is a rare phenomenon in Denmark, seen most significantly on the island of Læsø where an ancient production of salt flakes has been re-established. This island does not at any point reach an altitude of 5 m above sea level. On the flooded areas the downward flow of sea water is stopped by layers of clay 2-4 meter below terrain. Salinities of >10% (wgt/vol) can be measured in ponds in these areas while on other locations of the island, salinity in the root zones of the sandy soil can be found as low as 0,21 mS/cm (range found: 0,21-0,6 mS/cm).

Affection of crop yields as a result of saline soil has not yet been acknowledged as a problem of any significance in Denmark. The country - from this perspective – is favored by high precipitation of 750 mm in annual average and sandy soil where the effect of salt, incidentally introduced, is most often eliminated in few years by the drainage of salt to deeper layers in the soil. Locations where attempts to develop salt tolerant plant production can be initiated and commercialized might be found but it will require detailed mapping of salinity in candidate areas and understanding of its dynamics. Such studies will continue.

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Involved as a part time farmer and food producer in research and development in food production and chairman of a small branch organisation for innovative food SME's, Taste of Denmark, (Smagen af Danmark).

Among other activities, the first test site for halo-tolerant and halo-philic crops has been established in Denmark.

#### 41. Recovery opportunities and prospects for the use of degraded land in the context of structural economic and technological changes - Mikhail Kislitskii

##### **Recovery opportunities and prospects for the use of degraded land in the context of structural economic and technological changes**

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Digital technologies, agriculture, economics, structural and technological shifts, management, agricultural land fertility

Soil degradation is a serious agricultural issue. Salinization and salinization of agricultural lands is distinguished by specialists as a complex technological task.

In the context of global economic and climatic transformations, the restoration of saline soil fertility can be seen as a response to the threat of hunger in parts of the world and a measure to ensure food security.

According to the land cadastre, the area of saline (non-alkaline) soils in Russia is 16.3 million hectares, or about 9% of agricultural land, and more than 23 million hectares (12.5%) are represented by saline soils of solonetzic complexes. Thus, about 21% of the agricultural land in Russia is saline (Shishova L.L. and Pankova E.I. (2006). Saline soils in Russia. *Moscow*. 854 pp.). In the south of the European part of the country, soils of solonetzic complexes dominate with chloride and sulfate salinity chemistry, often with increased alkalinity in the solonetzic and subsolonetz horizons. In the south of Western Siberia, soda salinization soils predominate predominantly; in the southeastern part of Siberia, saline soils are distributed locally, mainly in closed basins and river valleys. This is especially true of irrigated lands, which are confined to the southern territories, where saline soils are usually widely developed or there is a threat of secondary salinization. Of the greatest practical importance in Russia are saline soils of agricultural land in the south of European Russia and Western Siberia. Saline soils are especially widespread in the south of Russia within the semi-desert, dry-steppe, steppe and forest-steppe zones. In some regions, for example, in the Astrakhan region, the Republic of Kalmykia, the Republic of Dagestan, the Novosibirsk region, etc., saline and solonetzic soils occupy up to 30% or more of the area of arable land. In this regard, the problem of the use and reclamation of saline soils for the southern regions of Russia is very acute. (Vargas R., Pankova E.I., Balyuk S.A., Krasilnikov P.V. and Khasankhanova G.M. (2017). Guidelines for the management of saline soils. *Rome, Food and Agriculture Organization of the United Nations*. 154 pp. )

The restoration and prevention of soil degradation prone to salinization and salinization requires the improvement of economic mechanisms both in terms of state participation and cooperation between business and the state.

The problem of reclamation of degraded lands requires the participation of society, business and the state.

The restoration of saline (non-solonetz and solonetzic) soils is possible through structural and technological shifts in the agricultural sector of the economy.

Structural and technological shifts can be classified on the following grounds:

- by sources of origin: economic (market and non-market), social, managerial, political, mixed;
- Reach: global, trans-regional, national;
- on time manifestations: short-term, medium-term, long-term;
- by objects of influence: production, management, infrastructure, mixed;
- by the nature of the effect: aggressive, latent, mixed;
- by the result of the impact: destructive, positive, mixed;
- according to adaptation mechanisms: production, managerial, social, cultural, mixed;
- in relation to security: global, trans-regional, national, intersectoral, sectoral, mixed;
- in relation to production: modernization, innovation, management, infrastructure, mixed;
- by structure: technical, telecommunication, digital, communicative, spiritual and philosophical, socio-psychological, mixed;
- by beneficiaries: personal-social, production, managerial, mixed;
- in relation to development: ensuring crisis-free development, ensuring development through a crisis, not ensuring development (destructive);
- on threats: military, economic, biological, food, information, technical and technological, social and spiritual, and others, mixed;
- by the nature of regulation: managed, spontaneous, mixed;
- according to the depth of transformation: radical, infrastructural, attributive-semantic, mixed;
- by subjects of management: non-subjective (global, national), state (external and internal), commercial (transnational, trans-regional, national).

The answer to the challenges and threats determined by structural and technological shifts is digital solutions used in the production of agricultural products and the management of an agricultural organization. Digital technologies, actively penetrating into all spheres of human life, open up new possibilities for solving long-standing problems, including in the area of returning degraded agricultural lands to circulation.

The work of returning degraded agricultural land into circulation is economically costly and requires the scientific development of solutions. It should be borne in mind that, according to scientists, about 80% of degraded agricultural lands are formed due to natural processes. It is advisable to direct the efforts of agricultural producers to restore degraded due to the anthropogenic impact of agricultural land.

Models of cooperation between society, business and the state in solving the problem of restoring the fertility of saline and saline lands for agricultural purposes are based on options for their participation.

The state has the ability to solve problems of an institutional nature. Establishment of a legal regime and conditions for working with saline soils, development of an economic mechanism to attract investment in restoring the fertility of polluted and degraded lands, and the formation of organizational and economic incentives (tax, financial and others).

As a subject of the economy and a regulator of economic relations, the state is able to attract the necessary financial resources for the preparatory work for the involvement of saline soils in the circulation: to conduct fundamental comprehensive scientific research; to develop and adopt a state program; economic policy instruments to stimulate business participation in solving the problems of salinization of agricultural soils.

The business community, as a rule these are large agricultural organizations, has the opportunity to pay for the actual restoration work if the state prepares and pays for the project documentation based on scientific research. It is necessary to consider the commercial factor in cooperation with business. Major players in the agricultural industry will participate in the project, subject to their profit. In Russia today, the entrepreneurial culture of big business includes refusing to finance long-

term projects. If the project does not pay off within a year or two years, then the chances of its support from large commercial companies are small.

It should be noted that the vast majority of the saline soils in Russia are located in areas of intensive agricultural production. In the regions of the country that specialize in the production of agricultural products and food, a very small number of agricultural holding companies have a significant impact on the regional economy. Therefore, monopoly conditions for their functioning and the maximum level of favor from the regional authorities are taking shape. The consequence of this state of affairs is the implementation of aggressive crop rotation and an increase in the share of depleted, degraded and saline agricultural soils.

Small and medium-sized agribusinesses are ready to participate in projects to involve saline soils in the agricultural turnover as part of the functioning of local communities. Here, an important role is played by the support of local authorities, which consists in the exemption of such lands from local taxes and the timely processing of permits.

The local community, which includes formal and informal groups of residents of rural settlements, living directly or nearby with saline soils, has an organizational resource that is realized through the inclusion in the work, strategic planning of the development of the territory, volunteer activities. The population is most interested in solving the problems of preserving and restoring the fertility of agricultural lands. Agricultural production is the basis for the preservation of their lifestyle and place of residence.

There are traditional economic models of cooperation between society, business and the state in solving problems. These include: government programs; public-private partnership projects; socially significant projects of socially oriented non-profit organizations and others.

A new form of cooperation, ensuring maximum satisfaction of the interests of the local population, is the digital local economic model. Its foundation is blockchain technology, white marketing and confidence building. In Russia, such a mechanism was used by the farmer Mikhail Shlyapnikov. He attracted bitcoins through closed and open forms of ICO, created his own cryptocurrency "Colion", issued crypto futures and crypto-bills. The farmer directed the collected funds to create an autonomous local model of the agrarian economy, which allowed him to solve the problem of attracting new families for permanent residence in the countryside and introduce degraded lands into circulation. His experience is applicable in regions with a high proportion of saline soils in the structure of agricultural land.

The activity of the local population in the context of implementing a digital local economic model for restoring the fertility of saline soils is an important tool - a tool for building confidence in attracting investment.

In addition to blockchain technology, a number of digital technologies can be used to solve the issue of restoring the fertility of saline soils.

At the level of forming an information base, collecting big data, forming complex models of a geographical and climatic nature, the most leading technology is space monitoring.

The study of soil conditions, the formation of accurate maps of saline areas is most effective when using solutions based on the use of digital technologies: the Internet of things and unmanned aerial vehicles (mainly drones).

Strategically important is the implementation of the principles of precision farming, which are aimed at the use of digital technologies in the production of crop production. The use of automated robotic systems and units in the process of sowing, agricultural and harvesting not only reduces costs, increasing productivity and profits, but also provides a preventive package of measures to preserve soil fertility. Point fertilizer application, continuous monitoring of soil conditions, the formation of a medium-term and long-term crop rotation plan allow the prevention of various types of soil degradation.

Artificial intelligence, like digital technology, integrates the use of a range of digital technologies and robotic systems. It is the basis for the qualitative implementation of the Digital Agriculture concept, which involves the use of digital technologies in restoring the fertility of saline soils.

In conclusion, it should be noted that the raw material nature of the Russian economy supports the functioning of a low-efficient model of economic relations. The reclamation of saline soils, the return to circulation of degraded agricultural land is only fixed by the state on paper. The state does not apply real actions that significantly change the situation. Despite the stable growth of the agricultural sector in Russia in recent years, the structure of manufactured products is of a raw material nature. The export of agricultural products to global markets is due to low labor costs, the desire to minimize costs. Profitability of agriculture in Russia does not reach the indicator of simple reproduction. Therefore, agricultural producers in Russia do not have a source of funding for saline soil remediation.

The opportunities for restoration and prospects for the use of degraded lands in the context of structural economic and technological changes are not limited to the use of digital technologies. A key element in restoring soil fertility is the strength of local and business communities.

PhD, Master of Social Psychology, Corresponding Member of the International Academy of Agricultural Education. Researcher of strategic planning of rural development, digitalization of the agricultural economy and the socio-psychological climate of rural settlements.

## 42. Revitalisation of degraded lands – Ties van der Hoeven

### **The Theoretical Foundation for a Botanical Approach to the Remediation of Sediments, Soils and Saline Waters**

Ties van der Hoeven, The Weather Makers B.V.

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Typically, when sediments and soils degrade through weathering, land abuse and the presence of pollutants and toxins, they are treated with chemicals or through flushing, which uses up precious fresh waters. These processes are expensive, energy intensive and resource consuming. Our proposed approach to the problem is different. In essence we recommend turning to the biodiversity of plants for solutions to remediating sediments and soils. The rationale goes like this; there are many species of plants, of which 2 %, or approximately 7,800, are considered salt tolerant or halophytic species. From this pool of plants there are species that are preadapted to tolerate different salinities, climates and various pollutants and toxins. The challenge will be to find the species adapted to the specific conditions in the eastern Mediterranean.

A broadly-based screening of halophytes is highly recommended. A number of years ago we searched for species of plants that we hoped would grow on exposed bedrock on coal mined land in Appalachia in the southern USA. Out of our search we found two species of warm season perennial grasses that survived and established themselves in the inhospitable landscape. They were switchgrass, *Panicum virgatum*, and Atlantic coastal panic grass, *Panicum amarum*. The key to the treatment of sediments and saline soils is the selection and screening of a wide variety of halophytes.

For many years we have been aware of the decline of landscapes through contemporary agriculture. The causes include irrigation, overgrazing by livestock, and the spread of urbanization across former farming and ranching areas. Salinity levels in soils are rising and expanding. This crisis is compounded by the scale of salination now spreading over vast stretches of the Earth. For 'The Weather Makers' project to re-green the Sinai desert, we were forced to confront the fundamental issue of salts in the ecology of soils in arid lands. We discovered that salinity threatens to destabilize the world's

food supplies. Salt damaged soils occur in over 75 countries. More than forty percent of land used for crop cultivation are affected by excess salts. Yields on such soils have been reduced by over fifty percent. These soils are characterized by very low organic matter and much reduced biodiversity. Saline and sodic soils (soils which have excess sodium ions) are crippling farmers' ability to produce their crops. Climate change is amplifying the problem. Higher temperatures, stronger winds and fewer and less reliable rains result in an increase in salinity and the collapse of soils. As a consequence, deserts continue to expand and displace farming communities. What is needed is a broadly-based ecological effort to reverse the salting of soils, including sediments, and irrigation water as well. Fortunately for our collective future, Nature has a broad host of strategies to accomplish this most important challenge. We are exploring these strategies.

#### Phytoremediation of Sediments and Saline Soils

Phytoremediation of saline soils and waters is a complex process. The basic physiological strategy of the plants involves the roots of halophytes. They are active in helping dissolve the calcium carbonate, essential for supplying calcium ions. Such plants have the ability to dissolve calcite (calcium carbonate) into the soils through their roots.

Tolerance to salts and heavy metals share a common physiological mechanism. Because of this, halophytes are the best and most potent plants for desalination and soil remediation. They accumulate salt in their tissues and are able to dissolve soil calcite in their root zones to provide essential calcium ions. These ions are then exchanged with harmful sodium ions at cation exchange sites. This is one of the key steps in the phytoremediation process. The roots of alfalfa, *Medicago sativa* are good at dissolving calcite and forming calcium ions. Alfalfa is becoming an important tool in reducing the salinity of agricultural soils. It may also be proven important for remediating sediments deposited in lakes or catchment basins.

It should be noted here that there is credible evidence that the addition of compost, especially compost made from halophytes, can greatly speed up the process. What is not yet known, is whether increasing carbon through the addition of biochar can enhance the rate of soil recovery. We hope this issue will be studied in the near future to determine the role and significance of biochar in the management of saline conditions.

There is evidence, cited below, that a diversity of plant species and microbial communities leads to improvements in saline and sodic soils. This evidence would suggest that compost and compost teas may prove important in soil and sediment remediation. As mentioned, plant diversity is a major factor. In soil restoration experiments, about half of the improvement was due to increased plant diversity.

Phytoremediation of saline soils results in an increase of organic carbon, total nitrogen, available phosphorus, and available potassium ions in the soil. Levels of exchangeable calcium and magnesium increase. This in turn leads to an improvement in the bulk density of the soils. Plant based treatment also leads to an increase in soil porosity, water holding capacity, soil permeability and increase of infiltration rates.

It should be noted that other soil and sediment problems can be treated in a similar manner. Cadmium contaminated soils have been remediated with the halophytes.

## X Traits affecting salinity tolerance

43. Development and characterization of an EMS mutated wheat population and identification of salt tolerant wheat lines - Lethin Johanna, Shakil Shahriar S.M., Hassan Sameer, Sirijovski Nick, Töpel Mats, Olsson Olof, Aronsson Henrik

**Development and characterization of an EMS mutated wheat population and identification of salt tolerant wheat lines**

Johanna Lethin, phd student at university of Gothenburg

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Salt tolerant wheat

*Triticum aestivum* (wheat) is one of the world's oldest crops and has been used for more than 8000 years as a food crop in North Africa, West Asia and Europe. As the human population grows larger and the soil salinity becomes more prevalent, there is an increased pressure on wheat breeders to develop salt tolerant varieties to meet increased demands on both yield and grain quality. Here we developed a wheat mutant population using the moderately salt tolerant Bangladeshi variety denoted BARI Gom-25, with the primary goal of further increasing salt tolerance.

After titrating the optimal ethyl methanesulfonate (EMS) concentration, ca 30.000 seeds were treated with EMS at a final concentration of 1%. Under the conditions used, 1676 lines survived through the first four generations *i.e.* a stable population was established. By developing an assay for salt tolerance, and by screening the entire mutant population, 70 lines exhibiting increased salt tolerance were identified. These selected lines typically showed a 70% germination rate on filter paper soaked in 200 mM NaCl compared to the control line that showed 0-30% germination under the same conditions. From two of the salt tolerant lines, genomic DNA was prepared and the mutation frequency determined to be one per ca 20 000 bp depending on the mutant used. The most salt tolerant lines were also tested for root growth in the laboratory, and under saline conditions in Bangladesh, from which the salt tolerant lines showed clearly stronger salt tolerance phenotype than the wild-type.

I'm a Phd-student in my third year at the University of Gothenburg where I work with a mutant population with the goal to find a salt tolerant wheat line. I did my bachelor degree in USA, my master in south Sweden, but are now back in Gothenburg which also is my hometown.

44. OsHAK9, a potassium transporter, is essential for seed germination in rice under salt stress - Peng Zeng, Luofeng Qian, Ting Xie, Xumei Qian, Yuqian Jiang, Zhoufei Wang, Henrik Aronsson, Jinping Cheng, Hongsheng Zhang

**OsHAK9, a potassium transporter, is essential for seed germination in rice under salt stress**

Peng Zeng<sup>1</sup>, Luofeng Qian<sup>1</sup>, Enshun Xu<sup>1</sup>, Ting Xie<sup>1</sup>, Xumei Qian<sup>1</sup>, Yanhao Cheng<sup>1</sup>, Yuqian Jiang<sup>1</sup>, Zhoufei Wang<sup>1</sup>, Henrik Aronsson<sup>2</sup>, Jinping Cheng<sup>1</sup>, Hongsheng Zhang<sup>1</sup>

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Salt stress, Seed germination, MutMap sequencing, Potassium transporter *OsHAK9*

Salt stress is one of the prevalent abiotic stresses to world agriculture. It is estimated that over 6 % of the world total land area are affected either by salinity (397 million hectares) or associated forms of sodicity (434 million hectares). Due to disturbances in global climate, salinity and other abiotic stress pose a serious challenge to ensure food supply for the growing human population.

Rice is one of the most important staple cereal crops in the world, feeding more than 50% of human beings, especially in Asia countries. It is the agricultural commodity with the third-highest worldwide production after sugarcane and maize. Rice provides 20% of the world's dietary energy supply, while wheat supplies 19% and maize 5%.

However, approximately 30 % of rice-growing area in the world is affected by salinity, particularly along low-lying coastal areas during the dry season. High salinity severely affects rice plants' normal physiology, especially during early stages of growth. During seed germination, salinity alters the imbibition of water, damages ultrastructure of cells, disturbs ions balance and hormonal metabolism. To alleviate the negative impact of salinity on rice production, enhancing salinity tolerance in the field has been advocated. Hence, it is of great importance to identify salt tolerant genes and employing to facilitate genetic engineering.

To achieve this goal, a genetic screening of the mutant population treated by Ethyl methanesulfonate (EMS) of Nipponbare was conducted. Luckily, a dominant and stable mutant *GSS1* was isolated, which showed salt sensitive at the seed germination stage. In order to explore the gene contributed to this phenotype, an  $F_2$  progeny was developed by crossing *GSS1* to Nipponbare, and followed by MutMap sequencing. Based on the results, a significant SNP was obtained on chromosome 7 with a high SNP-index, predicting to encode a potassium transporter protein *OsHAK9*. It is suggested that the mutation identified in *OsHAK9* is responsible for the phenotype of *GSS1*. Combined with transcriptional, physiological and genetic analysis, we demonstrate that *OsHAK9* is responsible for salt stress at the seed germination stage.

Peng Zeng is a PhD student from Nanjing Agricultural University (NAU), China, who studies Plant Genetics and Breeding. Her research is mainly about salt tolerance during rice seed germination stage and exploring salt tolerant genes and mechanism. Now she has participated in a salt tolerant wheat project in University of Gothenburg as an exchange student.

#### 45. Genome Wide Analysis Of WRKY Transcription Factors In The Wheat Genome With Emphasis On Regulating Salt Tolerance - Hassan Sameer, Lethin Johanna, Blomberg Rasmus, Mousavi Hesam, Aronsson Henrik

##### **In silico based screening of WRKY genes for identifying functional genes regulated by WRKY under salt stress**

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*WRKY, transcription factors, salt stress, wheat, gene*

Soil salinization is an increasing global threat to economically important agricultural crops such as bread wheat (*Triticum aestivum* L.). A main regulator of plants' responses to salt stress is WRKY transcription factors, a protein family that binds to DNA and alters the rate of transcription for specific genes. In this study, we identified 297 WRKY genes in the Chinese spring wheat genome (Ensembl Plants International Wheat Genome Sequencing Consortium (IWGSC)), of which 126 were identified as putative. We classified 297 WRKY genes into three Groups: I, II (a, b, c, d and e) and III based on phylogenetic analysis. Principal component analysis (PCA) of WRKY proteins using physicochemical properties resulted in a very similar clustering as that observed through phylogenetic analysis. The 5` upstream regions (-2 000 bp) of 107 891 sequences from the wheat genome were used to predict WRKY transcription factor binding sites, and from this we identified 31 296 genes with putative WRKY binding motifs using the Find Individual Motif Occurrences (FIMO) tool. Among these predicted genes, 47 genes were expressed during salt stress according to a literature survey. Thus, we provide insight into the structure and diversity of WRKY domains in wheat and a foundation for future studies of DNA-binding specificity and for analysis of the transcriptional regulation of plants' response to different stressors, such as salt stress, as addressed in this study.

He pursued his PhD in Plant Physiology at the University of Gothenburg in 2001. Most of his research has involved chloroplasts i.e. chlorophyll biosynthesis, protein targeting, and vesicle transport. However, his main project today is to produce salt tolerant non-GM wheat aimed for Bangladesh to increase the crop yield and thereby the daily food intake for the people of that country.

#### 46. Molecular breeding of *Triticum aestivum* in abiotic stress - Esteri Viitanen, Sameer Hassan, Henrik Aronsson

##### **CYTOCHROME P450. In silico analysis reveals the three-dimensional structure-function relationship in Chinese spring wheat**

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Sameer Hassan, University of Gothenburg  
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Cytochrome P450, molecular dynamics (MD) simulations, homology modeling, heme binding

Cytochrome P450 (CYPs) are heme-containing enzymes that perform oxidation-reduction reactions. They are involved in plant defense and secondary metabolite biosynthesis by catalyzing many biosynthetic reactions in plants leading to various compounds such as fatty acid conjugates, plant hormones, secondary metabolites and lignins. Based on a previous study made with Chinese spring wheat, a specific cytochrome P450 was strongly upregulated when exposed to salt stress. The biochemical characterization of this CYP enzyme and its three-dimensional structure have not been reported so far. Therefore, the binding properties and the three-dimensional structure of this enzyme were identified through homology modeling, molecular docking and molecular dynamics simulations. By combining different bioinformatics tools, a better understanding in the upregulation of the enzyme during increased salt stress could be achieved. The homology model that was built

revealed the three-dimensional structure of the protein backbone of our target protein, and the intermolecular binding properties between the heme cofactor and the protein backbone were further identified through molecular docking. Additionally, the conformational changes in the CYP enzyme that were measured through the molecular dynamics simulations revealed structural flexibility of our target enzyme. These simulations provided a deeper understanding in the functional consequences of plasticity found in our CYP enzyme. A better understanding of CYP enzymes and their structure-function relationship can be thus acquired from MD simulations than what is currently available from experimental techniques such as X-ray crystallography. This study combined different bioinformatics tools for achieving a better understanding of the enzyme and its correlation to enhanced salt stress in wheat.

Esteri Viitanen is currently working in Karolinska Institutet, Sweden, in the department of Cell and Molecular Biology. However, she did her Master's thesis research project at the University of Gothenburg. During her master's thesis project, she characterized the three-dimensional properties of a Cytochrome P450, thus achieving a better understanding of the structure-function relationship of this enzyme and its correlation to increased salt tolerance.

#### 47. Effects of elevated salinity on agronomic and physiological parameters of different mutated wheat lines - Hesam Mousavi, Johanna Lethin, Nupur Naik, Olof Olsson, Henrik Aronsson

##### **Effects of elevated salinity on agronomic and physiological parameters of different mutated wheat lines**

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Saline farming, wheat, salt stress, plant breeding

Background: Abiotic stresses e.g. salinity and drought are destructive parameters negatively influencing the yield and productivity of crop plants worldwide. Ionic imbalance takes place due to excessive accumulation of Na<sup>+</sup> and Cl<sup>-</sup>, which in addition reduces the uptake of other mineral nutrients, e.g. K<sup>+</sup>, Ca<sup>2+</sup>, and Mg<sup>2+</sup>. This leads to disruption of many metabolic processes in the plant. Salt stress can negatively affect wheat growth e.g. reduced yield, 1000 grains weight, spike length, and number of grains. Moreover, it can interrupt proper filling of the grains, which altogether are leading to a vast reduction in yield, efficiency and profit of the farming and insufficiency of food sources worldwide.

Material & Methods: From a mutant wheat population developed by OlsAro Crop Biotech AB 23 lines together with a control line were cultivated in the field at Salt Farm Texel. The different lines were irrigated using different salt concentrations: 0.6, 4, 8, 12, 16 and 20 dS/m<sup>-1</sup>, with four replications for each of the concentrations. Following the completion of the plants' life cycle, the

height and number of tillers were assessed. Afterwards, wheat spikes were harvested and transferred to the lab where spike length, total grain weight and grain weight of eight spikes were measured. Further calculations and statistical analyzes of the results were performed using Excel and Minitab 18 Statistical Software.

Results and conclusion: Elevated salinity triggered more or less reductions in different evaluated parameters of the assessed wheat lines as well as the control. Once plants faced low, medium and severe salt concentrations, 9 out of 23 mutant wheat lines stood out and were defined as promising lines compared to the other lines and the control. Although the promising lines were not responding as efficient as the control in all parameters, they were ahead of the control regarding total grain weight (yield). Total grain weight (yield) and grain quality are considered very significant parameters determining a good final outcome. Thus, these wheat lines with enhanced salt tolerance are vital and can help decrease hunger and poverty in regions confronting salinity as a challenge for food production. Therefore, in different breeding programs, specific effort is crucial to develop efficient lines, which can mitigate the adverse effects of elevated salinity and prevent massive reduction in yield and yield components.

Hesam Mousavi. A research and teaching assistant who is working at the University of Gothenburg, Sweden.

## XI Interactions among salinity, roots and microbial communities

48. Rhizobiome of resurrection plants-potential source of plant growth promoting bacteria - Zivko Jovanovic, Svetlana Radovic, Tamara Rakic, Jelena Lozo, Djordje Fira

### **Rhizobiome of resurrection plants-potential source of plant growth promoting bacteria**

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rhizobiome, resurrection plants, plant growth promoting bacteria, salinity

A major consequence of climate change is that fresh water is becoming increasingly scarce, and global sea level rise threatens food production in fertile coastal lowlands. In addition, millions of hectares of degraded soils are available world-wide.

Rhizosphere bacterial communities play a vital role in maintaining health of the plant host, with special importance to plant productivity. *Ramonda serbica* Panč. and its sibling species *R. nathaliae* Panč. et Petrov. are paleoendemic species, remnants of the Tertiary tropical and subtropical flora in Europe. They are the rare resurrection plants of Northern Hemisphere temperate zone able to survive completely dehydration state. These plants are shade-adapted growing in the shallow soil in the rock crevices of the exclusively north-exposed slopes in canyons, gorges and high mountain peaks, the most often sheltered by the surrounding forest canopy.

To characterize rhizobiome of resurrection plants soil samples from rhizosphere of *R. serbica* and *R.nathaliae* were collected during April 2018 from their natural habitats in south-eastern region of Serbia. Using selective medium, *Pseudomonas* and *Bacillus* strains have been isolated from soil samples, and confirmed by sequencing 16S rDNA gene fragment.

To test plant growth potential of selected bacteria seed priming method has been used. The effect of five isolated strains on plant growth under saline condition have been tested on wheat and pepper. Inoculated seeds have been germinated on sodium chloride solution (175 mM). Our results showed that, among investigated strains, *Pseudomonas putida* can increase plant survival under salt stress, but the effect is plant-dependent. It has effect on germination of wheat under salt stress condition, inoculated seeds germinated faster than control (non inoculated seeds). However, that effect has not been observed on pepper seeds.

Further investigation will be performed in order to test other bacterial species from rhizosphere and their effect on plant survival under salinity stress.

Research Associate at University of Belgrade-Faculty of Biology. Investigate the effect of bacteria on plant growth under stress conditions.

49. Endophytic fungi-mediated salinity stress tolerance in *Solanum dulcamara* (Bittersweet) - Sasirekha Munikumar, J. Theo M. Elzenga, J. Dick van Elsas, N. Nataraja Karaba

**Novel fungi from a wild relative of potato for preventing salinity stress**

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Salinity stress, Endophytic fungi, *Solanum dulcamara*

Changes in global climate that are predicted in the IPCC scenarios can strongly affect natural ecosystems and food security (IPCC, 2014). As a result of climate change, the abiotic stress factors such as drought, salinity, and flooding are predicted to increase in the coming decades. Amongst abiotic stresses salinity is the most serious threat to agriculture by affecting the crop productivity. Continuing salinization of arable land is expected to have overwhelming global impact, resulting in a 30 per cent loss of agricultural land over the next 25 years and up to 50 per cent loss by 2050 (Carillo *et al.*, 2011). High salinity induces rapid osmotic stress and delayed ionic (toxicity) stress; especially due to high Na<sup>+</sup> concentrations (Munns and Tester, 2008; Sekmen *et al.*, 2013 & Gupta and Huang, 2014).

In order to understand plant adaptation to environmental stresses our efforts are, exclusively, focused on the plant's genome. Most of plant studies on stress responses do not consider the fact that the plants in natural ecosystems have symbiotic associations with fungi. There are two major groups of fungal symbionts known to be associated with plants, mycorrhizal fungi, which reside not only in the root but also extend their mycelia out into the rhizosphere, and

endophytic fungi (EF), which reside entirely within plant tissues and are associated with leaves, stems and roots (Rodriguez *et al.*, 2004). Symbiotic association with mycorrhizal or endophytic fungi can provide fitness benefits to several crops (Redman *et al.*, 2002; Waqas *et al.*, 2012 & Hamayun *et al.*, 2017). Endophytes isolated from grasses are known to confer stress tolerance to genetically distant plants, such as tomato and rice (Rodriguez and Redman, 2008; Redman *et al.*, 2011). These observations have led to the hypothesis of habitat adapted symbiosis (HAS) where endophytes inhabited in plants, that increase resistance to the prevailing biotic and abiotic stresses of their habitats.

A well-known example is plant root colonizing basidiomycete fungus, *Piriformospora indica*, discovered in the Indian Thar desert, provides significant growth promoting activity in symbiotic association with a wide spectrum of plants (Verma *et al.*, 1998 & Waller *et al.*, 2005). *P. indica*, protect the legume *Medicago truncatula* from salinity stress. Root colonizing endophytic fungi confers the salinity tolerance in *M. truncatula* via stimulating antioxidant enzymes, accumulation of osmoprotectant like proline and expression of defense related genes and transcription factors (Li *et al.*, 2017). These studies have provided a *proof of concept* that EF could be harnessed to ameliorate plant growth under abiotic stresses and provide an additional and alternate approach towards management of these stresses in crop plants. Nevertheless, the information available on the mechanisms of the acclimation response conferred by endophytic fungi is still inadequate. Why do plants depend on the presence of EF for their full stress resistance response, still remains a question that begs an answer.

Bittersweet nightshade (*Solanum dulcamara* L.), a wild relative of potato, is a semi-woody vine, native to Eurasia. It has widespread occurrence in ecologically contrasting habitats, ranging from wetlands to coastal dunes (Dawood *et al.*, 2014; Zhang *et al.*, 2016). Despite of its extremely wide ecological amplitude, *S. dulcamara*, its associated microbiomes and their interaction with each other, are hardly studied. *S. dulcamara* and its endophyte community were therefore chosen as a model for adaptive strategies that plants evolved to utilize endophytic services to survive under various abiotic stress conditions. The purpose of this study is to investigate how this plant grows in environmental gradients and whether *S. dulcamara* plants indeed depend on their associated endophytic fungal community to maintain plant fitness. Comparing the endophytic community found in plants from different habitats will provide a method to test the 'habitat adapted symbiosis' hypothesis.

To test our hypothesis, the composition of endophytic fungal communities in *S. dulcamara* were examined from contrasting habitats, i.e. dry and wet regions, on the island of Schiermonnikoog, the Netherlands. The endophytic fungal communities were isolated from whole plants (leaves, stems, and roots). The results show that almost all plant parts were colonized by endophytic fungi. In total, 242 isolates were recovered, out of which 153 were identified by molecular characterization. Colonization frequency was higher in leaves and roots, followed by stems. The identified fungi were divided into 21 genera from dry and 17 genera from wet habitats. The endophytic fungal community differed between both habitat and plant parts. The isolates, with respect to their plant parts and habitats, were classified as common or specific to explore their potential role in habitat adaptation. Based on their occurrence in common and specific habitats, salt stress tolerance ability of twenty-one isolates were tested. Almost all the isolates tested were grown up to 300 mM NaCl concentration and few grown on 600 and 1200 mM. The morphology of the EF isolates changes between the salt treatment. The change in morphology is probably due to different metabolic reactions activated by different salt concentrations. Further studies will be conducted to

test the abilities of isolates to confer stress tolerance to their plant hosts. The novel endophyte identified from this study can be used to improve the crop productivity under suboptimal conditions such as salinity.

It is evident that symbioses with endophytes play a vital importance in the distribution of plant communities worldwide. These symbioses are responsible in many of the cases for adaptation to the biological and environmental stresses. Exploitation of such plant symbiotic organisms is a potential approach which will lead to sustainable development of the agricultural production and ecosystem management.

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The main focus of her doctoral research is to identify the endophytic fungi (EF) which can impart abiotic stress tolerance such as drought and salinity to plants and to understand their mechanism of interaction with plants.

#### [50. Elucidation of root traits that contribute to yield stabilisation in potato under climate change - Jan Henk Venema and J. Theo M. Elzenga](#)

#### **Elucidation of root traits that contribute to yield stabilisation in potato under climate change**

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abiotic stress resilience, root architecture, robust potato cultivars

The global production of potatoes is currently estimated at almost 400 million tons, ranking the first highest produced non-cereal crop and the fourth highest produced crop worldwide after wheat, corn and rice. In comparison to other major crops, potato produces the highest amounts of calories per unit water input. In addition to carbohydrates, potatoes are a rich source of other essential nutrients such as fibres, vitamins, proteins and antioxidants. It is anticipated that in the next 20 to 50 years the world potato production will decline by 18-32% as a consequence of abiotic and biotic stresses associated with climate change. Hence, stabilising and enhancing potato crop productivity can contribute significantly to fulfil the nutritional requirements of the rising world population. In order to improve potato yields, we need to identify sustainable production practices and develop new robust potato cultivars that best fit in the predicted climate change scenario. Potato tuber yield is, particularly in coastal production areas, increasingly limited by salinization as well as by prolonged periods of water shortage or excess. Modern potato cultivars have relatively small and shallow root

systems, accounting at least partially for its sensitivity to drought and high nutrient demand. There is a tremendous potential in increasing yield and particular abiotic stress resilience of the potato by exploring its below-ground responses to abiotic stresses and identifying genetic loci that affect root vigour, architecture and plasticity. However, due to its complex root system, root development and adaptation to edaphic-stresses are unexplored in potato. As a result, breeding of potato cultivars with improved root systems is still a matter of trial and error and the development of generic selection tools on functional root traits is an unexplored approach to effective breeding. Therefore, a Dutch consortium of plant physiologists and three private breeding companies launched a research project in October 2017 focusing on improvement of the root system of future potato cultivars. This project, subsidized by the European Agricultural Foundation for Rural Development (ELFPO) and Province of Groningen, started with an exploration of the variation in root phenotypic plasticity among a large panel of cultivars under abiotic-stress conditions (salinity, drought, flooding and low nitrogen). Nine cultivars that strongly contrasted in abiotic-stress tolerance and root plasticity were selected and are currently used to identify related root anatomical, morphological and architectural traits. At the same time, field trials will be performed in 2019 and 2020 to examine which of these root traits are functional to improve the yield under a particular abiotic stress. From September 2019 onwards, we will also be involved in a potato project financed by NWO-TTW and the Holland Innovative Potato consortium, which aims to identify genetic loci and hormonal control underlying root vigour and plasticity under salinity stress and low nitrogen availability. Both projects (i) contribute to our understanding of plasticity of the potato root system and its contribution to yield under variable growth conditions and (ii) are aimed to identify (simple) generic selection tools and molecular markers, which assist the breeding of more stress-tolerant (robust) potato varieties. We expect that the development of potato cultivars with improved rooting will contribute to a more climate-proof and sustainable cultivation of potatoes with stabilized yields and decreased inputs of nutrients and water.

After finishing his Master in Biology, Jan Henk Venema did a PhD at the Laboratory of Plant Physiology of the University of Groningen. The title of the Thesis was: “Low-temperature tolerance of tomato and related wild *Lycopersicon* species. A comparative study on chloroplast functioning”. After his graduation in 2001 he was appointed as post-doc at the Plant Ecophysiology research group led by Prof. Theo Elzenga working on several research projects in which he cooperates with breeding companies to find selection tools that support the breeding of robust crops.

## 51. Root system architecture and grass productivity under salt stress - L. Wang, J. Theo M. Elzenga

### **Root system architecture and grass productivity under salt stress**

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Salinization, root system architecture, salinity tolerance, productivity

Salinization of arable land and growing population demand more salt-tolerant plants in coming future. Salt-marsh grasses are potential resource for salt-tolerant screening. Under salt stress, grasses **root system architecture(RSA)** reshaped in many ways. The healthy status of root under stress condition help benefit grass adaptation and productivity. Salt tolerance plant can also grow by the seaside and improve the transition zone of the land and ocean. More salt tolerance plant grow near seaside as fodder to the birds and small animals. Three plant species form different

habitat adapt to salt stress differently. *L.perenne* is widely used in the pasture as a grass for cattle and sheep. *F.rubra* is common in both land and seaside however mostly in higher salt-mash. *P.maritima* is popular distribute in the low salt mash frequently flooded by seawater.

To screening high-quality salinity tolerant grass from nature field, we investigated the above mentioned three species from different habitats. Using winRHIZO, we scanned the plant root to quantify RSA data and Stress-induced morphogenic responses. Moreover, we determined the growth rate and yield of the plants to assess their salinity tolerance. The results show that: 1) In salt, three species developed similar number of seminal root. But *Festuca rubra* and *Lolium perenne* showed more lateral root and root hair than *puccinellia maritima*. 2). Shoot yield in *P.maritima* and *L.perenne* increased in 50mM NaCl compared with control. *p.maritima* showed less decrease with salt level rise. *F.rubra* showed liner decreased in both root and shoot yield as the salt gradient increases. 3). Water content was much higher in *P.maritima* under salt than the other two grass. This indicate that *P.maritima* had high ability to retain water in plant tissue. 4). Root-shoot ratio(RSR) positively grow correlated with salt gradient increase. However, *P.maritima* showed less increase in RSR with salt than *F.rubra* and *L.perenne*. These together may indicate that *F.rubra* shoot depressed much more in salt and even more in root. *P.maritima* as predicted to be less stressed and the yield increased in lower salt. In high salinity, such as 150 and 200mM, *P.maritima* is merely first among equals.

Selection of grasses with natural high nutritional value under mild stress conditions to improve fodder quality for dairy cattle

1. Plant salinity tolerance selection under salt stress: physiology and ion flux.
2. Root distribute in root architecture research: primary, seminal and root hair.
3. Productivity of the plant under salt stress

## XII Alternative use of salt-tolerant plants

52. Evaluating crop salt tolerance from field trials at Salt Farm Texel – a new venue  
- G. van Straten, A. de Vos, J. Rozema, B. Bruning, P.M. van Bodegom

### **A new venue to assess crop salt tolerance from field trials and its application to potato at Saline-Farming**

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Field testing, crop salinity tolerance, parameter estimation, parameter uncertainty, salinization

#### Abstract

A novel method to determine salt tolerance parameters and their uncertainty range from yield-soil salinity data in well-designed field trials is applied to search for relatively salt tolerant potato

varieties. While potato at large is moderately salt tolerant, with an  $ECe_{90}$  (i.e. the soil salinity  $ECe$  where the yield on average drops by 10%), of around 4-6  $dS\ m^{-1}$ , the experiments indicate that potato varieties exist that are significantly more salt tolerant, with an  $ECe_{90}$  of up to 8  $dS\ m^{-1}$ . This underlines the value of controlled field trials in the quest for salt tolerant varieties to feed the growing world population facing global salinization.

## Introduction

To alleviate salinization problems, it would be beneficial to offer farmers crop varieties that are relatively salt tolerant. While the quest for such varieties may benefit from insights in the genetic mechanisms and quick phenotyping methods, it will always be necessary to test their ultimate performance in the field. Proper field tests require that other limitations such as water and nutrients are controlled for as much as possible. This is one of the unique assets of the test facility at Saline Farming (SF).

In an earlier paper (van Straten *et al.*, 2019) we showed that data uncertainty alone can be responsible for substantial differences from year to year. Our improved method enabled us to estimate from yield – soil-salinity curves both the salt tolerance parameters as well as their uncertainties. This is important if we wish to discriminate between varieties. In this contribution we apply the method to multiple potato varieties tested over a number of years, with the aim to find productive potato varieties that are significantly more salt tolerant than others.

## Materials and methods

The test field of SF is divided into 56 plots, where the crops are irrigated with fresh water until emergence. After emergence the field is randomly separated in 7 irrigation treatment groups, of 4 or 8 replications each, irrigated with fresh-water – seawater mixtures with electrical conductivity of 1.5, 4, 8, 12, 16, 20, 32  $dS\ m^{-1}$ . The amount of irrigation is such that the equilibrium soil salinity in the root zone is reached within about 2-3 weeks. The seasonal mean soil salinity was determined from about 8 to 10 data samples taken throughout the season, with a variety of methods (saturated paste, 1:2 dilution, suction cup extracts), details of which are described in van Straten *et al.* (2019) and elsewhere in this conference. All soil salinities were expressed in  $ECe$  (equivalent saturated paste extract  $EC$ ).

Ignoring the negligible tuber production at 32  $dSm^{-1}$ , each variety in each year provides 24 or 48 data points of yield versus seasonal mean soil salinity. Overall, from all data together, the response has the commonly observed S-shape, which is best described by the van Genuchten-Hoffman equation (vGH, Eqn 1) (Van Genuchten and Hoffman, 1984):

$$Y = Y_0 \frac{1}{1 + \left(\frac{ECe}{ECe_{50}}\right)^p} \quad (1)$$

where  $Y$  is the yield observed at soil salinity  $ECe$ ,  $Y_0$  is the zero-observed-effect yield,  $ECe_{50}$  is the soil  $ECe$  at which the yield is reduced to 50%, and  $p$  is a slope parameter. Visual inspection shows that sometimes a linear curve, or a threshold shape, as described by the Maas-Hoffman equation (MH) (Maas and Hoffman, 1977) are equally possible. In this paper we only report the results of the vGH equation, because it is mathematically better behaved and agronomically more plausible than the MH model. Standard salt tolerance parameters are the  $ECe_{50}$  and the slope parameter  $p$ . Rather, because of its agronomical relevance, we prefer to report the results in terms of  $ECe_{90}$  and its evaluated uncertainty instead, but we stress that this is just another way of presenting the same results.

## Results

An example of the results obtained with our method is presented in Figure 12-left, showing the data points (tuber yield as a function of seasonal mean  $ECe$  of the soil), the least squares fit (solid red line), and the fitted (dotted green lines) and prediction (dashed magenta lines) errors. The latter shows the possible yield variation if a trial is made at a single soil  $ECe$ . Figure 12-right shows the 2-D cross sections of the approximate-95% uncertainty ellipsoids of the three parameters: the two salt tolerance parameters,  $ECe_{90}$  and slope parameter  $p$ , and the estimate of the zero-observed-effect yield, which is about 60 tons/ha for these data. The parameter estimates are partly correlated. The most relevant in the context of salt tolerance is the relationship between  $ECe_{90}$  and  $p$ .

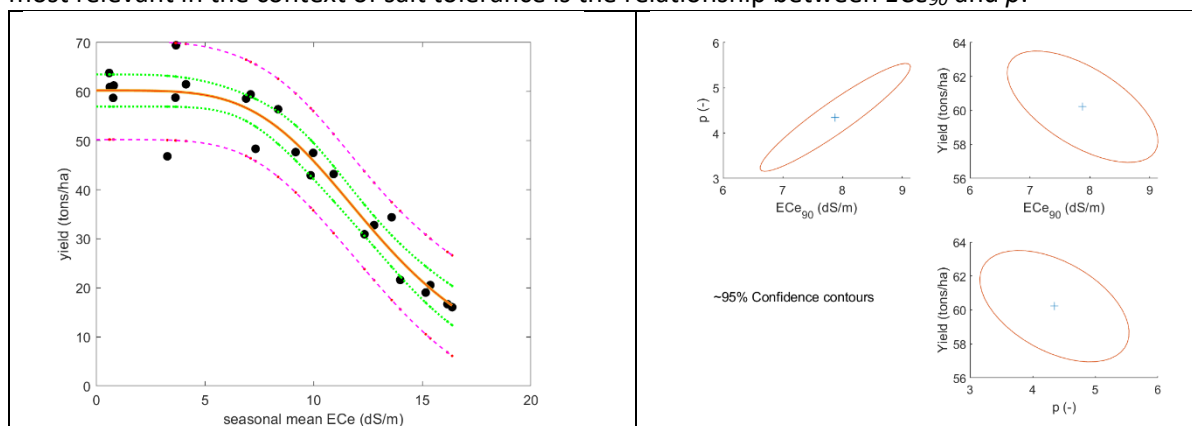
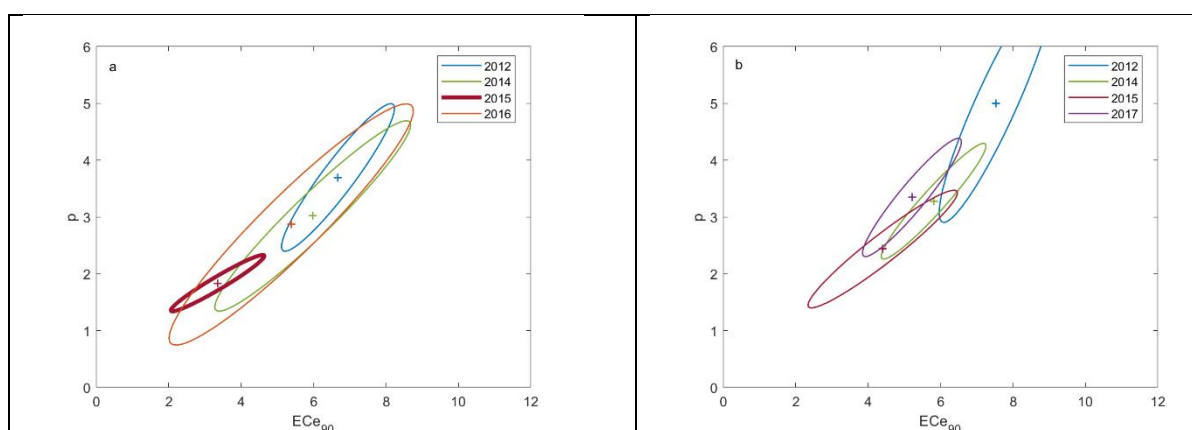


Figure 12. Left: Example of a single year fit to the data (variety “Riv”, 2017). Right: Approximate 95% confidence region of the estimation parameters. Further explanation see text.

A higher  $ECe_{90}$  means a more salt tolerant crop, but a higher  $p$  indicates a steeper descend of the yield as soil salinity increase, i.e. a higher sensitivity to increased salinity.

Figure 13 shows the relationship between  $ECe_{90}$  and  $p$  for varieties with several years of experimentation. A higher  $ECe_{90}$  is associated with a higher  $p$ , both across years and varieties. This suggests that the soil EC at which the yield is negligible is roughly a constant for all potato varieties, being just above  $20 \text{ dSm}^{-1}$ .

Part of the year-to-year variation in the annually estimated salt tolerance parameters may be due to variation in the zero-observed-effect yield  $Y_0$ , which is quite low in some years (Table 1).



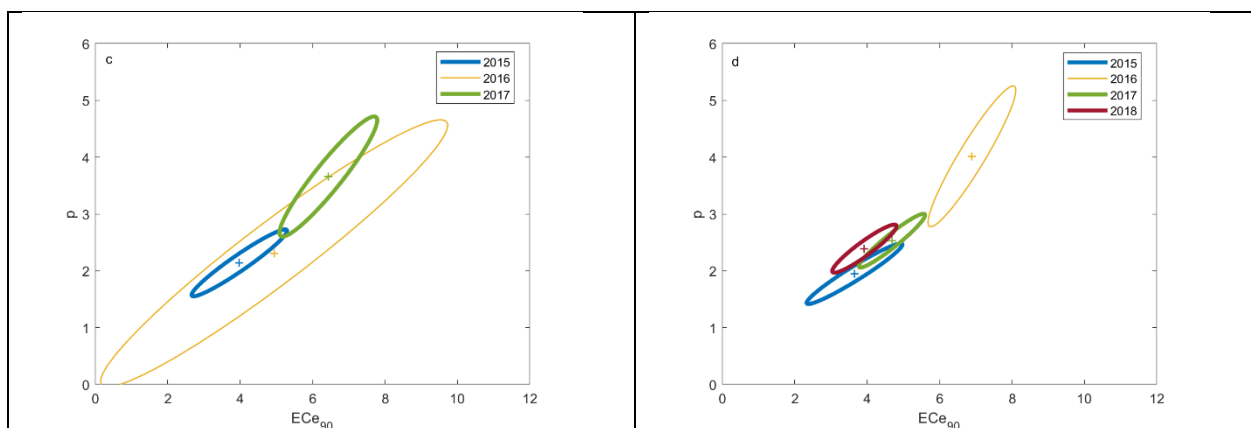


Figure 13. Approximate 95% confidence contours for salt tolerance parameters for some selected potato varieties tested over multiple years; (a) Achilles; (b) Miss Mignonne; (c) Focus; (d) Metro. Ellipses for years where the estimated zero-observed effect yield is higher than 50 tons/ha (see Table 1), are indicated with a thicker line.

A further analysis of this issue, and the simultaneous estimation of the crop tolerance parameters over a number of years is the topic of an upcoming journal publication. Here we simply marked with bold lines in Figure 13 the results for all years that have an estimated zero-observed-effect yield of more than 50 tons/ha, which is comparable to yields that are commercially realized in The Netherlands (CBS).

Table 1. Estimated zero-observed-effect yields in tons/ha. Values above 50 tons/ha are indicated in bold.

	2012	2013	2014	2015	2016	2017	2018
<i>Achilles</i>	26		28	<b>51</b>	33		
<i>Miss Mignonne</i>	18		43	28		34	
<i>Focus</i>				<b>51</b>	23	<b>50</b>	
<i>Metro</i>				<b>61</b>	43	<b>55</b>	<b>63</b>
<i>Nicola</i>						<b>61</b>	50
<i>“Riv”</i>						<b>60</b>	<b>50</b>

With this in mind, the uncertainty regions for Metro (Figure 13d) overlap in years with good yields, so that a consistent picture of the approximate salt tolerance parameters is obtained ( $ECe_{90}$  of around  $4 \text{ dS m}^{-1}$  and a  $p$  just over 2), while on the other hand the result for Focus is indecisive, and conclusions have to wait for the upcoming simultaneous multiple-year estimation. In contrast to the varieties in Figure 13, several varieties were tested over two years only. In Figure 14 two examples are given of varieties with good yield in both years of testing.

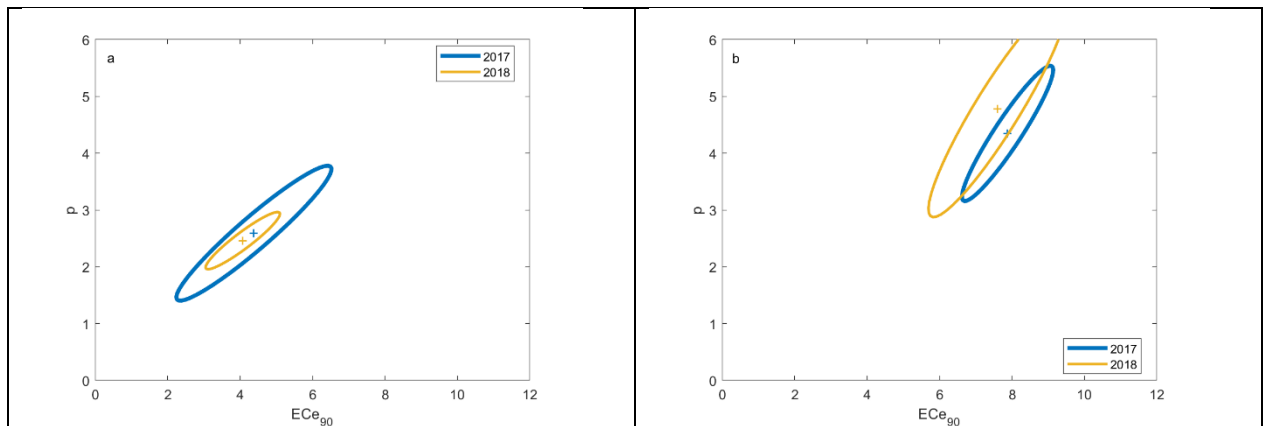


Figure 14 Clearly distinct salt tolerances for the potato varieties Nicola (a, left) and “Riv” (b, right).

Care is needed in view of the effect of yield variations over the years. However the clear overlap of the uncertainty regions gives confidence in the approximate values of the estimated parameters. It can be seen that variety “Riv” (Figure 14 Right) has an  $ECe_{90}$  of about  $8 \text{ dS m}^{-1}$ , which is considerably higher than the  $4 \text{ dS m}^{-1}$  for Nicola (Figure 14 Left), and as shown by the clearly distinct uncertainty regions, the difference in salt tolerance parameters is significant. Given the considerably higher  $p$ , the fall off of variety “Riv” (cf. Figure 12) is more rapid than with variety Nicola.

## Conclusions

The combination of a well-designed test facility and the robust determination of salt tolerance characteristics over a number of years of field testing, as presented here, are pre-requisites for a reliable assessment of the cultivation potential of varieties and crops on salt-affected soils. More work is needed when tested varieties show large differences in estimated zero-observed-effect yield, but for varieties where the yield between years is similar, clearly distinct salt tolerances between potato varieties are found, one of them with  $ECe_{90}$  as high as  $8 \text{ dSm}^{-1}$ , compared to the mean over all varieties of about  $4 - 6 \text{ dSm}^{-1}$ . Although some care is needed since tests for this variety were only performed over two years, the result offers promising perspectives for production of potato on moderately salt affected soils.

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53. Saline plant molecular factory for production of pharmaceuticals, functional feed, and biofuels using biorefinery technologies - Mette Hedegaard Thomsen, Tanmay Chaturvedi, Iwona Cybulska

**Saline plant molecular factory for production of pharmaceuticals, functional feed, and biofuels using biorefinery technologies**

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Halophytes, aquaculture, biorefinery

Halophytes are some of the most productive molecular factories found in nature and their use has been described since medieval times. Halophytes were used for medicinal purposes e.g., species like *Salicornia europaea*, *Crithmum maritimum* etc. Recently, halophytes have gained renewed interest as crops of the future. Soil salinity has been reported as a major factor to farm land degradation and halophytes have been suggested as a viable commercial alternative to conventional high input crops.

At the same time, processing of lignocellulosic biomass into fermentable sugars requires high input in the form of heat and clean/process water. The technology for 2<sup>nd</sup> generation production has been developed over the last 20 years and it is ready for industrial implementation. However, progress on implementation is slow. Now, research focus has shifted to co-production of value added products (e.g. from lignin, by using GMO, and microbial catalysts) to add to the feasibility of the processes using biorefinery concepts, or to new types of more complex biomasses including aquatic biomasses such as seaweed and terrestrial halophytes from coastlines. These biomasses produces a wide range of secondary metabolites, which represent a value-added fraction and hold the potential to increase biorefinery feasibility.

Adapting to the changing environment, an aquaponic system was developed where halophyte biomass would be grown along side fish for the co-production of nutraceuticals and bioenergy. Phytochemicals such as strong antioxidants, flavonoids, antimicrobials, anti-inflammatory, and even anti-cancer compounds were extracted from the biomass as the first step in the process. This fraction represents a value-added fraction which can be sold to e.g: cosmetic industry, pharmaceutical industry, oil/gas and chemical industry (as antimicrobials), or as functional food for humans or animals. The extractives-free (fiber) part of the biomass was found to have a favorable composition of carbohydrates, very suitable for animal feed (dietary fibers) or production of biofuels or platform chemicals by fermentation. Compared to other lignocellulose biomasses (such as wheat straw and corn stover) it was found that the halophyte lignocellulose (fiber fraction) contained low amounts of lignin and residual salt and hence was very easy to fractionate (needed much lower processing heat and no catalysts). Halophytes were found to be very interesting crops with great potential as biorefinery feedstock, and due to their bio-remediation and bio-reclamation capabilities, they could have great relevance in combination with European industries such as aquaculture (fish production) and industrial wastewater treatment.

Tanmay Chaturvedi is an Assistant Professor at the Department of Energy Technology, at the Aalborg University. He has been working with biomass characterization and halophyte fractionation for the past 8 years. His primary focus is on researching the production of value added biomass derived products within the framework of a biorefinery.

#### 54. Bio-fractionation of *Salicornia bigelovii* to increase the value of the green biomass - Aslak Christiansen, Henning Jørgensen, Dionysia Lyra

##### **Bio-fractionation of *Salicornia bigelovii* to increase the value of the green biomass**

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Bio-fractionation, Halophytes, protein-concentrate and bio-ethanol.

Increasing pressure on global food production and dwindling freshwater and land resources pose serious worldwide constraints on crop productivity. Soil salinity is one of the major factors contributing to land degradation and loss of crop productivity affecting over 1 billion ha worldwide according to most recent estimates (Wicke et al., 2011). In order to bring salt-affected areas back into production and stop the degradation of the soils, alternative crop species should be considered for saline Agriculture, utilizing saline lands and brackish/saline water resources. Halophytic species, or salt-loving plants, can be productive when grown in saline environments and can be used for food, feed, and biofuel. Such halophytic species are exemplified by *Salicornia bigelovii* Torr. (figure 1), that is a highly salt-tolerant plant that has gained interest as a potential crop for saline agriculture (Bresdin et al., 2016). It can be consumed as a fresh vegetable or grown to maturity and harvested for the seeds that are rich in protein and oil. However, seed harvesting and collection of the seeds has shown to be difficult due to the undomesticated nature of the plant, resulting in shattering of seeds and uneven ripening of seed spikes. Furthermore, the use of the remaining biomass as animal feed after seed harvest is limited due to the high ash content of halophytic biomass of 30 – 50 % dry matter. The high ash content limits the range of animals it can be fed to, and the ones that can tolerate it can only ingest limited daily amounts.

Because of these complications, new ways of utilizing the salty green biomass of halophytes was tested in an effort to increase the value of the halophytic biomass and consequently make saline cultivation more viable.

In this study, bio-fractionation as a concept, was applied to fractionate the fresh green biomass of *S. bigelovii*. In this concept the biomass was first fractionated with a double screw press into a fiber-rich pulp and a salt and protein-rich juice fraction. Since *S. bigelovii* uses vacuolar compartmentalization of salt as a primary salt tolerance mechanism it should be easily removed with the sap/juice. The fiber fraction was rewetted with saline water and pressed again to increase the removal of salt and nitrogen into the juice fraction. A large part of the nitrogen/protein in the biomass will be extracted into the juice, and from the juice protein can be precipitated by heat coagulation, yielding a protein concentrate. The fiber-rich pulp can be utilized for biofuels production, e.g. ethanol, by a combination of hydrothermal pretreatment, enzymatic saccharification, and fermentation. The aim of this project was to investigate the potential of *S.*

*bigelovii* as a crop for the production of protein and biofuel based on this concept. The cultivation of *S. bigelovii* was combined with aquaculture by irrigating the plants with the nutrient-rich effluent water from fish tanks, thereby using the biomass crop as a biofilter and increasing biomass growth and consequently the yield of the different fractions. The mass balance of dry matter, ash and nitrogen were determined for all the fractions, and the potential yield of bio-ethanol from the fiber was evaluated.



The *S. bigelovii* biomass used in the experiment was grown in experimental plots at the International Center for Biosaline Agriculture (ICBA) in Dubai, as part of an ongoing improvement program. The plants were sowed in late November 2017 and harvested in mid-May. The biomass was fractionated directly after harvest to minimize breakdown of protein. The experimental setup consisted of 4 genotypes of *S. bigelovii* grown under 2 different irrigation treatments, being either reject brine from reverse osmosis desalination of saline groundwater (RO) or reject brine that had circled through the

aquaculture tanks (AQ).

The calculated yields/ha ranged from 103 – 151 t/ha of fresh green biomass with an average dry matter content of 15 %, an ash content of 39 %, and a nitrogen content of 1.2 %, resulting in dry matter yield/ha of 15 – 21.5 ton, which is similar to earlier reports of 14-24 t/ha DM for *S. bigelovii* (Glenn et al., 1991). Generally, the yields were higher in the RO treatment, but no significant differences were found between treatments or genotypes due to a high standard deviation within the different genotypes. Due to this, it was not possible to document any positive growth response under the AQ treatment compared with the RO treatment.

Upon fractionation, the succulent nature of *S. bigelovii* resulted in the majority of the fresh weight ending up in the juice fraction (82-85 %) with no significant difference between genotypes. There were only negligible differences in the recovery of DM, ash, and nitrogen in the different fractions for all genotypes and treatments. Bio-fractionation proved to be an effective way of extracting ash and nitrogen into the juice during fractionation, with roughly 90 % of the ash and 80 % of the nitrogen ending up in the juice fraction.

After heat precipitation of the protein roughly 40 % of the whole plant nitrogen was recovered in the protein concentrate, with crude protein contents of 15 % and ash contents above 30 %. The crude protein content was considerably lower compared to values found for other protein concentrates, which can partly be attributed to the high ash content of the protein concentrate. The high ash content of the protein concentrate reduces its value as a protein feed for livestock, but it might prove useful as feed for fish in aquaculture systems. The quality of the protein precipitated from the juice, with regards to the concentrations of the essential amino acids, was superior compared to other protein fodder sources such as soybean meal protein.

The effective removal of ash into the juice fraction reduced the ash content in the fiber fraction down to 10-13 % on a dry matter basis, a reduction in total ash of 66-72 % compared with whole unfractionated plants. Despite the significant removal of ash, the fiber fraction was still of a low feeding quality due to the remaining salt content still being high and the crude protein content being only 4 %. The compositional analysis of the fiber material with respect to the concentration of cellulose and hemicellulose showed that carbohydrates constituted 45 % of the fiber material, which is similar to other lignocellulosic biomass such as wheat or rice straw (Anwar et al., 2019). The monomeric sugars were primarily constituted by glucose (59), xylose (30%) and arabinose (15%),

with no significant differences between the two genotypes. Therefore, conversion of the carbohydrates in the fiber into sugars for potential bio-ethanol production was examined as an alternative use of the fiber fraction.

Fiber samples from two genotypes under the RO treatment went through hydrothermal pretreatment and enzymatic hydrolysis with enzyme loadings of 5 or 10 mg enzyme protein/g dry matter. The highest conversion of carbohydrate into sugars was with the 10 mg enzyme protein/g fiber treatment of 88 %. Other studies with *S. Bigelovii* have found degrees of conversion of 91 % and 92 % of the carbohydrates in the fiber and shown that the sugar from the fiber fraction is highly fermentable (Bañuelos et al., 2018, Cybulska et al., 2014).

When calculating the yield/ha of sugars from the fiber fraction produced based on the biomass yields, sugar yields of above 4 t/ha was obtained, which was similar or higher than the sugar yields from wheat straw (Dahl-Lassen et al., 2018). This indicates a potential for the fiber fraction produced to be used as a feedstock for bioethanol production. Bio-ethanol from halophyte biomass has been proposed as a sustainable way of producing bioenergy and biofuels, by not competing with freshwater resources, arable land or edible crops. In addition, it will contribute to binding carbon in the soil of otherwise uncultivated lands. The calculated yields of protein concentrate ranged from 3 - 4.3 t/ha, representing roughly 500 – 700 kg crude protein/ha.

It is important to note that the yields of bio-ethanol and protein concentrate estimated on the basis of this study was only based on 6 months growth, hence year-round cultivation would provide even higher yields.

In the hot and dry environments in regions like Dubai, irrigation with saline water makes cultivation of halophytes possible all-year-round. By having a crop rotation of different halophytes, it would be possible to provide year-round bio-filtering for aquaculture production and reducing the operational costs of a biorefinery plant by operation year-round. Other interesting halophyte species with a high biomass yield to be tested for the applicability of bio-fractionation are *Batis maritima*, *Sesuvium portulacastrum* and *Atriplex nummularia*.

In conclusion, these results provide support for the use of bio-fractionation as a useful method for improving the value of halophytic green biomass by producing valuable fractions.

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Danish master student studying Agricultural development at the University of Copenhagen. I am very interested in the cultivation of halophytes and the utilization of the biomass.

## Additional extended abstracts

### 55. Genetic characterization of salinity tolerance traits to increase salinity tolerance in crops - Mark Tester

#### **Genetic characterization of salinity tolerance traits to increase salinity tolerance in crops**

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Association genetics; saltwater agriculture; high-throughput phenotyping

One-third of the world's food is produced under irrigation. This is challenged by over-exploitation of water resources and global environmental change. This talk will focus on the use of forward genetics to discover genes affecting salinity tolerance in barley, rice, and tomatoes, along with some recent genomics in quinoa, a partially domesticated crop with high salinity tolerance. Rather than studying salinity tolerance as a trait in itself, we dissect salinity tolerance into a series of components that are hypothesised to contribute to overall salinity tolerance.

For tomatoes, the focus is on association genetics of tolerance in wild tomatoes. Tomatoes have been phenotyped in The Plant Accelerator® and in the field for three years, and analyses are currently in progress.

For quinoa, the genome has been sequenced to high quality, and now about 1,000 lines have been re-sequenced. Up to 1,300 lines are being phenotyped in The Plant Accelerator and 10 field trial sites to identify natural variation in a range of domestication and tolerance traits.

The application of this approach provides opportunities to significantly increase abiotic stress tolerance in crops and thus contribute to increasing agricultural production in many regions.

To deliver our research, we have now established a company, Red Sea Farms LLC, where we combine engineering and plant science to develop and use saltwater-based agricultural systems, to reduce the water and carbon footprint of modern agriculture, and to do this environmentally sustainably and economically viably.

Mark Tester is professor of plant science at King Abdullah University of Science and Technology, Executive Director of the Food Sector at NEOM and co-Founder of Red Sea Farms LLC. Prior to joining KAUST in February 2013, he was an ARC Federation Fellow and professor of plant physiology at the University of Adelaide, when he established The Plant Accelerator. Previously, he was a Senior Lecturer at the University of Cambridge, where he also received his PhD in 1988.

### 56. Identifying crop-varieties suitable to grow under saline conditions - Andrés Parra González, Bas Bruening, Arjen de Vos

#### **Identifying crop-varieties suitable to grow under saline conditions**



Andrés Parra González. Saline Farming  
Bas Bruning. Saline Farming  
Arjen de Vos. Saline Farming

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Saline agriculture, crop selection, carrots, salinity threshold

Salinization is one of the major difficulties that agriculture will face in the next decades, threatening global food security. Several factors such as climate change and inappropriate agricultural practices contribute to the steady increase of soil salinity over time. In addition, the increasing human population is challenging the optimization of our food systems to become more efficient regarding land and water resources. It is not easy to quantify the extent of salinization around the world, although recent publications report that about 1 billion hectares are salt affected. In addition, agriculture uses about 70% of the available water resources, which increase to about 80% in arid and semi-arid regions. Therefore, most irrigated lands are high water-stress areas. These facts highlight the urgency to create and adapt to new forms of agroecosystems with higher resilience which will help us to cope with the current agricultural challenges. One of the strategies which is taking place to counteract the effects of salinization is *saline agriculture*, an innovative strategy to enhance soil and water availability through the cultivation of salt tolerant crops in salt affected soils using salt (brackish) water. Salt tolerant crops could be understood as the pillars of saline agriculture. In this sense, not only halophytes but also conventional crop-varieties with potential to grow under saline conditions, will play an important role in the development of saline agriculture.

Based on controlled field trials performed in the open-air lab at Saline Farming, we have identified varieties which show a higher tolerance than commonly believed and some of them have been already implemented in areas affected by salinization. Part of the scientific community, policy makers, farmers and other stakeholders, commonly use the FAO crop salt tolerance list to check about the feasibility for a crop to grow under saline conditions. This fact might result in the underestimation of certain crops to deal with salinity, as crop salt tolerance varies significantly among crop varieties. In the last years, more than 800 varieties of more than 50 crops of different families have been tested in our facilities. This way, the yield performance of potatoes, lettuces, cabbages, legumes or grasses among others, has been examined in order to select those with more potential to grow under saline conditions. To determine the exact level of salt tolerance, crops are exposed to 7 different salt concentrations ( 1, 4, 8, 12, 16, 20 and 35 dS/m), and each treatment is replicated eight times, resulting 56 randomized blocks of 160 m<sup>2</sup> each. The field is accurately irrigated with a determined frequency by means of drip irrigation, ensuring that variation in soil salinity levels is minimal within the different plots. Before the season starts, irrigation events using only fresh water usually take place in order to reach the moisture level of the soil and promote a uniform germination. Salt treatments start when most of the crops have germinated and the seedlings are established. The salinity levels corresponding to each treatment increase gradually, avoiding an osmotic shock to the young plants. To validate the results, soil salinity is monitored on a regular basis by mean of different methods, which are related to the electrical conductivity of a saturated soil extract (ECe), the standard method to measure soil salinity. Crop data (yield data) is plotted against ECe to obtain a growth response curve for each one of the varieties which has been harvested. In addition to the classical parameters to address crop salt tolerance, threshold (maximum soil salinity level where yield is not reduced) and slope (yield reduction per unit increase



in salinity), we present our results using new parameters which offer a more practical approach to address crop salt tolerance, such as the ECe90, ECe75 or ECe50 (soil salinity where crops can reach 90, 75 or 50% of their potential yield respectively).

In relation to the classical approach, several crops have showed a salinity threshold much higher than is commonly believed. For instance, some potato, carrot or cabbage varieties which are usually listed as moderate sensitive crops, show more potential than expected when growing under saline conditions. This way, they might be considered as moderately tolerant varieties, according to the “division for classifying crop tolerance to salinity” of the FAO. Furthermore, it is interesting to mention the potential that some sensitive or moderately sensitive varieties present for the future of saline agriculture, especially the high yielding varieties. Crop salt tolerance is usually expressed in relative terms, but when yield is expressed in absolute values (kg/ha) some sensitive crops can show a better performance than other more tolerant varieties when they are exposed to certain salinity levels. As an example of this condition, we show the performance of two carrot varieties, normally considered as a salt sensitive crop. One of them is a high yielding (Nantes type) variety, which appears to be sensitive to salinity (threshold = 0.3 dS/m, slope = 4.8%, ECe90 = 1.6 dS/m), the other variety, which is moderately tolerant (threshold = 4.1 dS/m, slope = 6.6%, ECe90 = 5.6 dS/m) is a Chantenay type with a lower yield potential. This difference related to the yield potential makes that the salt sensitive variety has higher yield under saline conditions (up to 13 dS/m ECe) than the moderately tolerant variety. This fact demonstrates how a sensitive variety can still perform better under saline conditions than another variety rather tolerant. Thus, the further identification and description of varieties with a high potential to grow under saline conditions will help farmers to take better decisions about which crops or varieties to grow. The selected varieties together with appropriate soil and water management would tackle the negative effects that salinity causes, ensuring better yields.

Finishing my Master in Agroecology I had the opportunity to start working at Salt Farm Texel, where I have been developing my career as part of the Research & Development department during the last five years

57. Constraint-level excess water in coastal soil can be a resource for cropping during winter in the southwestern region of Bangladesh - Md. Enamul Kabir, Bidhan Chandro Sarker

### **Constraint-level excess water in coastal soil can be a resource for cropping during winter in the southwestern region of Bangladesh**

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## Waterlogging, crop establishment, coastal wet soil, cropping intensity

In Bangladesh, crops are grown in almost three growing seasons. In the southwestern coastal region, the prevalence of single monsoon rice in a year is attributed by: (i) soil remains saturated until after the ideal sowing window for winter crops and (ii) lack of fresh irrigation water in the dry period of winter and after winter season (November to early April) despite abundant availability of saline water in the canals and rivers. As excess soil water prevents sowing of winter crops timely, it is considered as the first constraint of crop establishment (salinity becomes second constraint after the crop establishment, during subsequent growth). To establish winter crops (sunflower, maize and wheat, new crops in this region) in excess water during optimum sowing window, a series of field experiments were conducted through a number of crop establishment methods (e.g., dibbling or transplanting or by zero tillage) after rice harvest. Some field interventions led to establish crops timely. Among them, cultivation of short duration high yielding rice variety (HYV) (to vacate the land early) and light drainage of standing water after rice harvest facilitated timely sowing. In addition, during mid-December, the canal was disconnected from the tidal river to keep the canal water less-/non-saline (at this time the canal water remains fresh). Wheat was cultivated (optimum sowing window between November to mid-December) in 2016-17, 2017-18 following light land preparation and in 2018-19 following zero tillage. In all three years wheat had several sowing dates. Sunflower was cultivated by dibbling the seed in wet soil in 2017-18 and in 2018-19 the seedling of sunflower was transplanted. Earlier in 2013, 2014 and 2015, maize was cultivated following conventional sowing (moisture at field capacity) and dibbling in the wet soil. In case of dibbling in all crops in all years the soil moisture was ~40% (v/v). Late summer rainfall (just before the start of winter season) is considered as a tough year for cropping and the no rainfall before winter is a smooth year. The general response of crops to sowing time and method showed that early sown crops in wet soil (without land tillage) produced the maximum grain yield compared to those of late sowing in conventionally tillage.

**Wheat:** In 2016-17 season (a smooth year), among eight sowing dates (24 November '16 to 9 January '17, seven days interval), first and second sowings produced grain yield over 4.1 t/ha. The grain yield was reduced in the subsequent sowing dates: 2.5 t/ha in the last sowing while the country average yield of wheat is ~3.5 t/ha. In 2017-18 (a tough year), the rice harvest was completed in early November but due to late summer rain (before winter season) the sowing was delayed (between 19 December to 4 January) and the number of sowing dates was also reduced (four sowing dates, five days interval). The grain yield was 2.7 t/ha in first sowing (19 December) and 1.3 t/ha in the last sowing (4 January). Comparing between 2016-17 and 2017-18, it was concluded that the yield reduction was mainly due to late sowing. In 2018-19 (a smooth year), the grain yield was more or less similar to that of 2016-17 particularly when the yield comparison was made at the same sowing date e.g., 19 December in all three growing season (~3.7 t/ha in 2016-17 and 2018-19, 2.7 t/ha in 2017-18). It indicates that yield reduction in delayed sowing is associated with other factors, particularly the higher solute potential (SP, more negative value) of soil reduced grain yield. SP in the soils of early sown plots was low, i.e., more fresh water was present in the profile. Moreover, in-season rainfall (late February to early March) in 2016-17 and 2018-19 presumably lowered the SP. There was no rainfall during the growing season 2017-18. The electrical conductivity (EC) of the confined canal water (source of irrigation) was <3 dS/m even at the end of growing season.

**Sunflower:** Early (end of November) dibbling of sunflower (hybrid, Hysun 33) produced ~3.5 t/ha seed yield in 2016-17 and 2017-18 when the previous rice had short duration. Farmers in this region are usually less interested to cultivate early and short duration rice. Giving emphasis the farmers choice (late and long duration rice as previous crop), sunflower seedling was grown in seedbed when the monsoon rice at maturity stage. Just after harvesting the rice sunflower seedling (two- or three-weeks-old) was transplanted in three different dates. The result showed that early transplanted sunflower produced higher seed yield irrespective of seedling age than that of late ones. Measured SP of soil profile supports the yield reduction likewise wheat: early transplanted seedlings did

encounter low SP and produced higher seed yield. Also early seed dibbling at the same date of sowing seed in the seedbed produced similar seed yield as in first transplanting and vice-versa in case of late dibbling and transplanting.

Maize: A three year (2013, 2014, 2015) study in this region with maize during winter was investigated to find out the suitable sowing method and time for fitting the crop to realize higher grain yield. Also the maize crop was irrigated by pond (non-saline), canal (less saline) and river (high saline) water. This preliminary study revealed that traditional cultivation of maize (waiting for drying the land after rice harvest to field capacity then land preparation by full tillage) faces terminal stresses (fresh water scarcity, soil and water salinity) that reduce grain yield severely particularly when the previous rice is long duration one the land topography is low. On the other hand when the crop was dibbled (without waiting for reducing the moisture level to field capacity) in the same type of land, the grain yield was higher. In addition conjunctive use of fresh (pond water) and saline (canal, river) water realized higher grain yield.

It was found that all early sown crops utilized the fresh water in the soil profile efficiently, less irrigation water (from canal) was required and the salinity of the irrigation water and soil was not at the constraint level for yield reduction. Conversely, the later sown crops did face fresh water scarcity, increased salinity of water (canal and river) and soil that reduced yield of all tested crops. As excess water during sowing time of winter crops is the main constraint for crop establishment, following the management and crop planning options in the above mentioned crops, sowing of seed was possible in the wet soil. The established plants utilized relatively fresh profile water than the late established one. The early established crop required less irrigation water and that water was relatively fresh. The late sown seed suffered from: poor emergence, vigour, growth and yield. Also late established crop did face soil drying; more amount of water with frequent irrigation was needed. The  $EC_{1:5}$  (1 part of soil and 5 parts of water) of soil was increased. The amount of soil water (weight basis) is directly related to the SP that ultimately determines the plant's ability to uptake water. Higher the soil water lower the SP and the lower the soil water, the higher the SP that exerted the more negative effects of plants. The late sown plants miss out the opportunity to utilize the fresh profile water, exposed to higher SP thus produced low yield in all tested crops. Thus the profile water can be utilized for winter crop production if the crop seed are sown early of the winter season in the wet soil. It can be concluded that the excess water during winter crop sowing (considered as a constraint of cropping) can be a resource for cropping in winter through proper field management in the southwestern coastal region of Bangladesh. Through this way of cropping, farmers are getting a second crop after rice, cropping intensity has been increasing and the livelihood is improving of the resource-poor farmers.

Dr Md Enamul Kabir is a professor in Khulna University, Bangladesh and has been working on crop establishment, nutrient management in saline and waterlogged soil. He did his PhD from Murdoch University, Australia on nutrient management of crop in dry topsoil condition.

58. Cropping System Based Irrigation for Improving Crop and Water Productivity in the Coastal Zone of Bangladesh - Khokan Kumer Sarker, S.S.A. Kamar, M.A. Hossain, M. Mainuddin, R. Bell, E.G. Barrett-Lennard, D. Gaydon, M. Glover, R.R. Saha, M.S.I. Khan and M. Maniruzaman

### **Cropping System Based Irrigation for Improving Crop and Water Productivity in the Coastal Zone of Bangladesh**

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cropping pattern, rice equivalent yield, salinity, system productivity

## Background

The coastal areas of Bangladesh comprise more than 30% of the cultivable lands of the country but 30% of the lands are affected by salinity. Agricultural land is underutilized and cropping intensity in coastal zone of Bangladesh (173%) is significantly below the country's average cropping intensity of 199% (BBS, 2011, Battacharya et al., 2015). In the saline areas, transplanted monsoon season (T. Aman) rice is grown as a sole crop during June-September using traditional long-duration low-yielding varieties. The land remains fallow for the rest of the year for most land. Cropping intensity can be increased in slightly saline areas by adopting proper soil and water management practices and by the introduction of salt-tolerant crop varieties (Haque, 2006). Crop diversification is an option to achieve paradigm change from the traditional one crop cultivation to two or more crops per year. The feasibility of different cropping patterns based on more efficient water management to produce two or three crops in a year has not been demonstrated in the salt-affected areas of the coastal region in Bangladesh. Therefore, a field experiment was undertaken on diversified cropping patterns with different crops and water management practices, aiming to increase the production, water productivity, and economic returns for farmers.

## Materials and method

The field experiments were conducted on farmers' fields of the village of Sikandorkhali, Amtali, Barguna, Bangladesh (latitude and longitude of 22°07'45.842''N and 90°13'44.04''E) during Kharif-I, Kharif-II and *Rabi* (winter) season of 2016-2017 and 2017-2018. The experimental site belongs to the agro-ecological zone, Ganges Tidal Floodplain (AEZ-13). The land situation is medium-low land and the soil texture is clay loam. The field experiments were established in a randomized complete block design with five cropping patterns and three replications. The treatments were: (i) CP1: Mustard -transplanted pre-wet season rice (T. Aus) -T. Aman, (ii) CP2: Sunflower-T. Aus-T. Aman, (iii) CP3: Maize -T. Aus -T. Aman, (iv) CP4: Wheat-Mungbean-T. Aman, (v) CP5: Fallow-Fallow-T. Aman (Farmers' practice, control). Standard crop management practices and irrigation scheduling of different crops were followed. Mustard (BARI Sarisha-14), a low salt tolerant variety was sown at the seed rate of 7 kg/ha. Sunflower (cv. Hisun-33) was sown with a row-spacing of 60 cm and plant to plant distance along the row was 40 cm. Maize (Hybrid Maize cv. NK40) was sown with a row-spacing of 60 cm and plant to plant distance along the row of 20 cm. Wheat (cv. BARI Gom-25), a moderately salt-tolerant variety was sown at 140 kg seed/ha with a row spacing of 60 cm and continuous seed sowing within rows. During Kharif-I season, T. Aus (BRRI Dhan 48) were planted in the experimental plots in rows 20 cm apart with 20 cm plant to plant spacing and three or four seedlings per hill. During the Kharif-II season, the short-duration (105-115 days) high-yielding T. Aman variety (BRRI Dhan 73) was transplanted in the experimental plots in straight rows 20 cm apart and at 15 cm plant to plant spacing and two or three seedlings were transplanted per hill. The traditional rice variety (BR 23, CP5) was planted August-September and harvested mid-December to mid-January. The total crop duration of local Aman variety (BR 23) varied from 140 to 150 days.

Different intercultural operations were performed as recommended for high yield. Crop yields were determined at harvest. The mean yield of each crop was taken from each plot within one square meter. The rice equivalent yield (REY) and production efficiency (PE) were considered to compare the performance of cropping patterns. Total system productivity (TSP) was calculated as the summation of REY. Gravimetric soil water content, soil salinity and osmotic potential were determined on soils sampled from 0-15, 15-30, 30-45 and 45-60 cm soil depths. The electrical conductivity in a 1:5 extract ( $EC_{1:5}$ ) was determined and converted to salinity in the saturated extract ( $EC_e$ ) of field soil water and osmotic potential (kPa) of field soil solution using the formula derived from [Rengasamy \(2010\)](#). Irrigation schedules followed BARI recommendations and irrigation water was applied based on the gravimetric soil moisture determination at different crop growth stages. The amount of irrigation water to replenish the soil water deficit was estimated using the standard formula suggested by [Micheal \(1978\)](#). Water productivity (WP) was estimated as a ratio of total crops grain yield to total water use to the system, and expressed as  $kg/m^3$ . The profitability analysis was performed based on variable cost (VC). Variable cost was estimated based on the operating cost of land preparation using machinery, chemicals, human labour, fertilizers, and irrigation.

### Results and discussion

The REY, PE and TSP were better in CP2 and CP3 followed by traditional cropping pattern of CP5. The grain yield of short duration T. Aman rice was similar (2.39 t/ha in 2017 and 3.89 t/ha in 2018) in all treatments, and lower than traditional yield of T. Aman (Local variety: 3.5-4.6 t/ha) due to damage to the early-maturing T. Aman by rats and birds. The alternative early maturing modern rice cultivar achieve comparable grain yield to farmers' varieties ([Maniruzzaman et al., 2019](#)), but are still harvested 15-30 days earlier, which is sufficient for early establishment of Rabi crops like mustard, sunflower, maize and wheat. The timely sowing of mustard, sunflower or maize (but not wheat) after T.Aman harvest could be option for intensifying cropping system. The cropping system productivity can be increased in the coastal zone of Bangladesh by using improved varieties, available suitable water resources and standard irrigation schedules and crop management practices. The system water productivity of the improved cropping patterns of CP1 (Mustard-T.Aus-T.Aman), CP2 (Sunflower-T.Aus-T.Aman) and CP3 (Maize-T.Aus-T.Aman) were better than the cropping pattern of CP4 (Wheat-Mungbean-T.Aman) and the traditional cropping pattern of CP5 (Fallow-Fallow-T. Aman) in the salt-affected areas of coastal zone. The soil water contents among the treatments in soil profiles decreased from sowing to harvest but the soil water content was lower in treatment of CP5 (Fallow-Fallow-T.Aman) followed by other cropping patterns. Salt accumulated in soil during the growing season rising from 4 dS/m (November) to 17 dS/m (March) in 0-60 cm soil profiles. The soil salinity in field soil was greater in treatment CP5 (Fallow-Fallow-T.Aman) followed by other cropping patterns with two or three crops in a year. The osmotic potential varied from -300 kPa to -845 kPa during the growing season from January to March. The greatest osmotic potential was measured in the traditional cropping pattern, CP5 (Fallow-Fallow-T.Aman). The highest soil salinity and osmotic solute potential were recorded in CP5 during February/March. The benefit-cost ratio was similar among the treatments, but the gross margin was quite different among the improved cropping patterns. The diversified cropping patterns incorporating Rabi crops like mustard, sunflower and maize under CP1, CP2 and CP3 enhanced the productivity and profitability of the system and represent alternative options instead of one rice crop per year in the salt-affected areas of Bangladesh. Based on two years result, the improved cropping patterns of Mustard-T.Aus-T.Aman; Sunflower-T.Aus-T.Aman; Maize-T.Aus-T.Aman were more profitable than traditional cropping pattern of Fallow-Fallow-T.Aman. Short duration and high yielding T.Aman rice is necessary for timely sowing/planting of Rabi (winter) crops for improving the cropping system productivity as well as intensifying cropping system in the salt-affected coastal zone of Bangladesh.

### Acknowledgements

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- Dr. Khokan Kumer Sarker is working as a “Scientific Officer” at Irrigation and Water Management Division under Bangladesh Agricultural Research Institute. He is directly involved as a co-researcher of ACIAR-KGF Project which is implementing in coastal regions of Bangladesh and West Bengal, India. He has developed water saving technologies like alternate furrow irrigation, emitter for drip irrigation and conjunctive use of fresh and saline water irrigation for different crops, etc.

59. Effects of Fresh and Saline Water for Irrigation of Sunflower in the Salt-Affected Coastal Zone of Bangladesh - Khokan Kumer Sarker, S.S.A. Kamar, M. Mainuddin, R. Bell, E.G. Barrett-Lennard, D. Gaydon, M. Glover, M.A. Hossain, K.F.I. Murad, M.H. Rashid, M.S.I. Khan, M.M.K. Shadat and M. Maniruzzaman

#### Effects of Fresh and Saline Water for Irrigation of Sunflower in the Salt-Affected Coastal Zone of Bangladesh

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conjunctive use, soil salinity, water productivity

## Background

The scarcity of fresh water and drought combine with varying degrees of soil and water salinity to limit the expansion of irrigated agriculture in the coastal zones of Bangladesh. The crops depend on soil type, water availability and changing climate to achieve the desired crops yield through efficient use of available resources. The major cropping pattern is a sole crop of transplanted monsoon season rice (called T.Aman) in the salt-affected areas of Bangladesh. Planting sunflower (medium saline tolerant) after harvest of T.Aman has potential as an irrigated dry season crop around surface and groundwater sources with low salinity water (Akanda et al., 2015). In addition to the limited volumes of fresh water, there are some sources of saline water stored in canals in saline-prone areas of Bangladesh which can be used for irrigation. In most cases, saline water reduces crop yield, but with the careful and appropriate soil-water and plant management practices could be used for crop production in saline areas of Bangladesh (Mojid and Hossain, 2013). The scarcity of suitable fresh surface and groundwater has led the farmers to implement the conjunctive use of saline and fresh water to irrigate crops (Ma et al., 2008). Judicial use of fresh (low saline) and saline (medium saline) water for irrigation could increase crop production, but the sustainability and profitability of use of fresh and saline water for crop production may vary with soil type and crop tolerance to salinity. At early growth stages, crops are very sensitive to irrigation water as well as soil salinity. At later growth stages, saline water can be used to irrigate the plants which have greater salinity tolerance. Appropriate irrigation scheduling and method are very important for saline water irrigation. The technique of fresh and saline water irrigation is needed to minimize yield reductions and achieve better utilization of existing surface water sources in coastal regions of Bangladesh. Therefore, the objectives of this study were to assess the effect of fresh and saline water irrigation on sunflower yield, soil salinity, and determine the scope of fresh and saline water irrigation for sunflower cultivation at the salt-affected areas of Bangladesh.

## Materials and method

The experiments were conducted during 2016-2017 and 2017-2018 on farmers' fields at Pankhali, Dacope and Amtali, Barguna in the coastal regions of Bangladesh. The type of the soil was clay loam with average field capacity (weight basis) of 31.8% at Amtali and 37.3% at Dacope and average bulk density was 1.45 g/cm<sup>3</sup> at Amtali and 1.39 g/cm<sup>3</sup> at Dacope. The experiments were carried out with six irrigation (IR) treatments and replicated thrice. The treatments were: T<sub>1</sub>: 2 IR at vegetative and flowering stage with fresh water (FW), T<sub>2</sub>: 2 IR given at vegetative with FW and flowering stage with saline water (SW), T<sub>3</sub>: 2 IR given at vegetative with FW and grain filling stage with SW, T<sub>4</sub>: 3 IR at vegetative, flowering and grain filling stage with FW, T<sub>5</sub>: 3 IR at vegetative with FW and flowering and grain filling stage with SW, T<sub>6</sub>: 3 IR at vegetative and flowering with FW and grain filling stage with SW. Standard crop management practices were followed. The unit plot size was 30 m<sup>2</sup> at Dacope and 100 m<sup>2</sup> at Amtali. Recommended fertilizer dose (N<sub>129</sub> P<sub>32</sub> K<sub>60</sub> S<sub>21</sub> Mg<sub>6</sub> Zn<sub>2</sub>B<sub>1.6</sub> kg/ha) was applied in the form of urea, triple super phosphate, muriate of potash, gypsum, zinc sulfate and borax. Sunflower (cv. Hisun-33) was sown with row to row and plant to plant spacings of 60 and 40 cm, respectively. In this study, the seed was sown into untilled (no-tillage) wet soil by dibbling method in U-shaped slot with sub-surface placement of banded fertilizer. Mixed fertilizers were placed



manually into subsoil and soil packed on top of the fertilizers. Irrigation scheduling followed BARI recommendations. Irrigation was applied at the following growth stages: initial growth stage, vegetative growth stage, flowering and grain development stage. The salinity of pond, canal and river water at both locations was monitored at 10 days interval during the crop growing season. The water salinity of the pond, canal and river ranged from 0.5 dS/m to 1.9 dS/m, 0.7 to 5.0 dS/m and 2.0 dS/m to 24.7 dS/m from November to April, respectively. Soil samples were collected from each treatment to monitor soil water, soil salinity and osmotic potential at different growth stages within the soil profiles at 15 cm increments to 60 cm. The electrical conductivity ( $EC_{1:5}$ ) was determined and converted to saturated extract salinity ( $EC_e$ ) using the formula derived from [Rengasamy \(2010\)](#). Adequate plant protection measures were taken at vegetative stages. Total seasonal crop water use was calculated as the sum of total irrigation water applied (I), effective rainfall ( $P_e$ ) and soil water contribution between planting and final harvest and the water productivity ( $kg/m^3$ ) was calculated as the ratio of seed yield and total seasonal water use ([Michael, 1978](#)). When the treatment effects were significant, means were compared for any significant differences using R-statistical models at  $P \leq 0.05$ .

### **Results and discussion**

The sunflower yield increased with increased number of irrigations with fresh or saline water irrigation at both locations. The seed yield of sunflower had no significant difference among the treatments. In this study, the treatment T6 (FW at vegetative and flowering stages and SW at grain filling stage) produced seed yield at around 2.23 t/ha at Dacope and 1.93 t/ha at Amtali during 2017. During 2018, the treatment T5 (FW at vegetative stage and SW at flowering and grain filling stage) produced seed yield around 1.71 t/ha at Dacope and 1.55 t/ha at Amtali. Water productivity was significantly affected by irrigation levels, decreasing greatly with increasing amount. Water productivity was greater at Dacope than Amtali in both seasons of due to less rainfall, higher seed yield as well as yield response to better utilization of soil moisture by no-tilled system at Dacope. The soil water content was observed greater at initial crop growth stage and then levels decreased gradually at later stages. The soil water contents of the treatments to 60 cm depth decreased from sowing to harvest. On average, the changes in soil salinity varied from 2 dS/m (December) to 10 dS/m (March) in 60 cm soil profiles. The highest changes in soil salinity occurred during the latter half of February in all treatments. Irrigation with medium saline water (canal water) after fresh water (pond water) may cause slightly increase in soil salinity. On average, the osmotic potential of soil water was -200 to - 659 kPa in 0-60 cm soil profiles from sowing to harvest and highest in February. The higher osmotic pressure was found in later growth stages of crop in both years due to more soil water uptake and soil moisture evaporation from the soil surface in both locations. However, the technique of the conjunctive use of fresh water (low salinity of  $EC \leq 1.9$  dS/m) at early growth stages and saline water ( $1.9 \geq EC \leq 5$  dS/m) at later growth stages of sunflower could be an alternative irrigation schedule to intensify the cropping system in the coastal saline areas of Bangladesh where fresh water availability is limited in supply.

### **Acknowledgements**

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## 60. Mycologically Synthesized Nanoparticles for Prevention of Soil Salinity - K. Harish Kumar, Dr. V. P. Savalgi,

### **Mycologically Synthesized Nanoparticles for Prevention of Soil Salinity**

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Zinc nanoparticles, Salinity, Maize and Foliar spray.

Fertilizer pour into the soil is one of the major reasons for the development of salinity in the soil of agricultural lands. Nanoparticles in the form of foliar nutrition would be a better solution for enhanced mineral application to the plant without wastage losses in the soil. This would prevent harmful exo-osmotic effect on soil microorganisms that are caused because of fertilizer application in the soil. Plant grows better and yields will be higher than the farmer's practice of normal recommended dosage of fertilizer application. Foliar sprays should be planned in such a way that split application of nanoparticle formulations are distributed over crop growth period instead of single and twice application. Even severe doses of foliar sprays at a time would cause lesions on foliage surface and may attract the disease pests. Nanoparticles synthesized through the living

systems approach are safer to the nature, preventing the harmful by-products release into the nature and also utilize the nature's machinery and energy.

By keeping these points in view, as part of my master's research experiments were planned and conducted to compare and find out the best dosage concentration and type of nanoparticles for application on maize crop growth, yield and influence on soil enzymatic activity and different functional groups of microorganisms. Zinc was the nutrient used for these experiments on maize, mycological nanoparticles (Zn MNP's) were synthesized using fungi isolated from rhizosphere and chemically synthesized nanoparticles (Zn CNP's) were procured from commercial seller.

Zinc nanoparticles were synthesized from the fungi that were isolated from the rhizosphere soil of different crops. Prior to the nanoparticle synthesis, fungi were tested for metal tolerance assay and zinc solubilization assay to arrive at potential isolates. It was the first time that fungal isolates were correlated for Zinc solubilization assay and nanoparticle synthesis to arrive at potential isolates for the synthesis of nanoparticles (Kumar and Savalgi, 2017). The synthesis method used was incubation of precursor in the fungal extracellular enzyme extract. The mycologically synthesized nanoparticles confirmed using the UV-Visible Spectroscopy, X-ray diffraction analysis (XRD), Atomic Force Microscopy (AFM).

Soil samples from the fields of Main Agricultural Research Station, Dharwad, India were collected with the aim of isolating zinc solubilizing microorganisms. Available zinc content of soil was taken as base for sample collection. Out of 30 samples collected 15 samples from 0.1 to 0.38 ppm, 6 from 1.3 to 2.0 ppm and 9 from 2.1 to 2.5 ppm of available Zinc. Higher population of zinc solubilizers were found in lower zinc containing soil samples. Fungal isolates showing higher zone of zinc solubilization in Zinc solubilization assay and higher zinc metal tolerance in Zinc metal tolerance were selected and analyzed for the synthesis of Zinc Nanoparticles (Zn NPs) by the incubation method.

Characterization of microbial synthesized Zn MNPs was done by UV-Visible spectrometer, which exhibited a peak at 260 nm. Confirmation of this Zn MNPs was further done by Atomic Force Microscope which shown spherical shape. X-ray Diffraction (XRD) analysis revealed the presence of Zn MNPs with the 2 $\theta$  values of 31.74 $^\circ$  and 36.23 $^\circ$ . The sharp peaks exhibited in XRD graph indicated the presence of capping agent from the mother protein of the fungus, this mother protein present around the mycologically synthesized nanoparticles help the synthesized nanoparticles better dispersivity and prevent aggregation. Out of 30 isolates, two fungal isolates viz., 3F and 9F were potent of producing zinc nanoparticles in size range of 20 to 60 nm, confirmed using AFM imaging. The principle agent responsible for the formation of the nanoparticles is confirmed as the amino acids chains present in the extracellular enzyme extract and not the enzymatic action by Jain *et al.*, 2012.

A pot culture experiment with maize hybrid was performed, during *rabi*, 2015-16 to analyze the effects of microbial synthesized (Zn MNPs) and chemical synthesized nanoparticles (Zn CNPs) on the maize crop growth and yield. Five different concentrations of both CNP's and MNPs were used as comparison treatments, farmer practice of soil ZnSO<sub>4</sub> application with 25 kg ha<sup>-1</sup> was used as reference and a treatment with recommended package of practices excluding zinc was used as control. Treatments were applied as foliar spray at 30 and 60 days after sowing at different concentrations ranging from 250 to 1250 ppm. Microbial synthesized Zn NPs spray of 750 ppm exhibited higher response of increased chlorophyll content and yield parameters over all other treatments.

Five different treatments were used for each type of foliar nanoparticle application along with a control without any zinc application and another treatment check for comparison that is farmers practice of recommended dosage of zinc sulfate application, totally twelve treatments were applied. Nanoparticle foliar spray ranged from concentration range of 250 ppm to 1500 ppm at two intervals of crop growth 30 and 60 days after sowing.

Pertaining to the results MNPs application put-forth higher yields compared to the C NP's, owing to the fact that MNPs were well dispersed and covered by thin layer of mother protein which

prevented the particles from aggregation, which favoured the easy entry of M NP's through the cuticular layer of the plant. Out of dosage concentration range 750 ppm was proven good for yield and were no negative impacts were observed till the dosage of 1500 ppm of both type nanoparticles. But for the environmental perspective MNPs proven to be beneficial. The improved chlorophyll content due to more availability of Zinc, which acts as a co-factor for chlorophyll synthesis, improved the amount of photosynthates thereby improving the yield of maize. Nanoparticles foliar application proven to be superior over farmer practice of recommended dosage of fertilizer application.

Soil enzyme activity of dehydrogenase and phosphatase were high in treatment receiving 750 ppm of microbial synthesized Zn NPs, when compared to the farmer's practice of application of recommended dosage of fertilizer application. The microbial population of different functional groups was analyzed in the rhizosphere, which included nitrogen fixers, phosphate solubilizers and potassium solubilizers, shown that treatments receiving foliar applications of zinc nanoparticles developed higher population. Thus improving the beneficial microbial population content in the rhizosphere of the crop, that would be attributed by the root exudates of plants receiving Zn NPs. Increased rate of root exudates due to high photosynthates may be the probable reason for the development of high population densities in the soil. The results presented in indicated that the bacterial population was significantly higher in nanoparticle-treated samples as compared to the control. These results were in confirmation with Sindhura *et al.* (2014).

Application of zinc nanoparticles increased photosynthetic efficiency, as zinc available in higher quantities to the plant improved chlorophyll, and chlorophyll content in leaves is in positive correlation with the plant.

From the present study it is inferred that microbial synthesized ZnNPs were more beneficial than chemical synthesized ZnNPs at their corresponding concentrations as better growth and yield parameters of maize were observed. Similar results were observed by Fathi *et al.* (2017), applied foliar spray of Zinc oxide and Iron oxide nanoparticles on maize crop under salinity conditions put forward better chlorophyll content, shoot, root dry weight and increase gas exchange range through the stomata. No negative impacts were observed even at the higher concentrations of foliar sprays of 1500 ppm in both Zn MNPs and Zn CNPs but foliar spray of 750 ppm was found to be optimum concentration for better growth and yield parameters of maize. Hence usage of higher concentrations would be non-economical. ZNPs besides acting as nutrition to the plants also help in increasing the salinity stress regulators such as super oxide dismutase (SOD), catalase (CAT), peroxidase (POD), ascorbate peroxidase (APX) when applied under salinity stress conditions (Latef *et al.*, 2017). Absorbed Zn MNPs inside the tissues of plants would have improved the transportation of solutes at a higher, this may be the reason for the MNPs performing better over CNPs in the maize growth and yield parameters. Further, following method of foliar spray application of zinc nanoparticles will prevent the development of salinity in the cultivated soil that would occur due to excess application of fertilizers.

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K. Harish Kumar, Doctoral degree: In Agricultural Microbiology (Persuing), Research Problem: Development of Cobalamin rich product, *Propionibacterium* spp., Master's research: Evaluation of microbially synthesized zinc nanoparticles, on Growth and yield of Maize (*Zea mays* L.)  
Bachelors: Bachelor of Science in Agriculture

## 61. Building small farmers' capacities on climate-resilience farming in saline affected regions of Haryana, India - Pawan Kumar

### **Building small farmers' capacities on climate-resilience farming in saline affected regions of Haryana, India**

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India, Saline crops, Wheat, Mustard, Broccoli, Beetroot, Small farmers

#### **Introduction**

Soil and water salinity is one of the major constraints in sustainable food production in many parts of the world's , affecting 20% of cultivated land, and 33% of irrigated land<sup>6</sup>. In India alone, the area under salt-affected soils is about 6.73 million ha. The five states together accounting for almost 75% of saline and sodic soils in the country. The area under salt-affected soils in country would almost triple to 20 million ha by 2050

S M Sehgal Foundation (SMSF), a NGO's works with small farmers in Nuh district, Haryana. Agriculture is the mainstay of livelihoods and 75% of the district area has saline ground water. Tube wells is used mostly for flood irrigation. The skewed application of fertilizers, flood irrigation and high evapotranspiration rate further increases soil salinity resulting low farm productivity.

#### **Study Conducted**

With the objective to analyze the effect of saline water irrigation on yields of salt-tolerant crops, the study was conducted in three blocks<sup>7</sup> of Nuh district,<sup>8</sup> engaging 78 farmers from 13 salt-affected villages.

The field demonstrations of salt tolerant varieties KRL 10 for Wheat (cereal), Saki F1 for broccoli, Indum Ruby Queen for beetroot (vegetables) and CS 58 for mustard (oil crop) done at farmers' fields. The one-acre plot area is considered for this study.

Soil samples were collected from each farmer's field before planting. Two water samples were collected during the crop season. Direct seed sowing was done for wheat, mustard and beetroot, whereas broccoli grown with transplanted seedlings. The minimum and maximum salinity of irrigation water varied from 0.97 to 4.158dS/m for broccoli, 2.178 to 6.922dS/m for beetroot, 0.97 to 7.946dS/m for mustard and 2.882 to 7.946dS/m for wheat. Soil EC varied from 0.15 to 4.29 dS/m with pH between 6.5 to 8.8.

For economic viability analysis gross benefit calculated for each crop. Comparative benefit analysis of broccoli and beetroot done with salt tolerant wheat (STW) and salt tolerant mustard (STM). Similarly, the gross benefit received from STW and STM compared with salt intolerant wheat (SITW) and mustard (SITM).

<sup>6</sup> Pooja Srivastava, Rajesh Kumar: [Soil salinity: A serious environmental issue and plant growth promoting bacteria as one of the tools for its alleviation](#). Saudi J Biol Sci. 2015 Mar; 22(2): 123–131. Published online 2014 Dec 9. doi: 10.1016/j.sjbs.2014.12.001

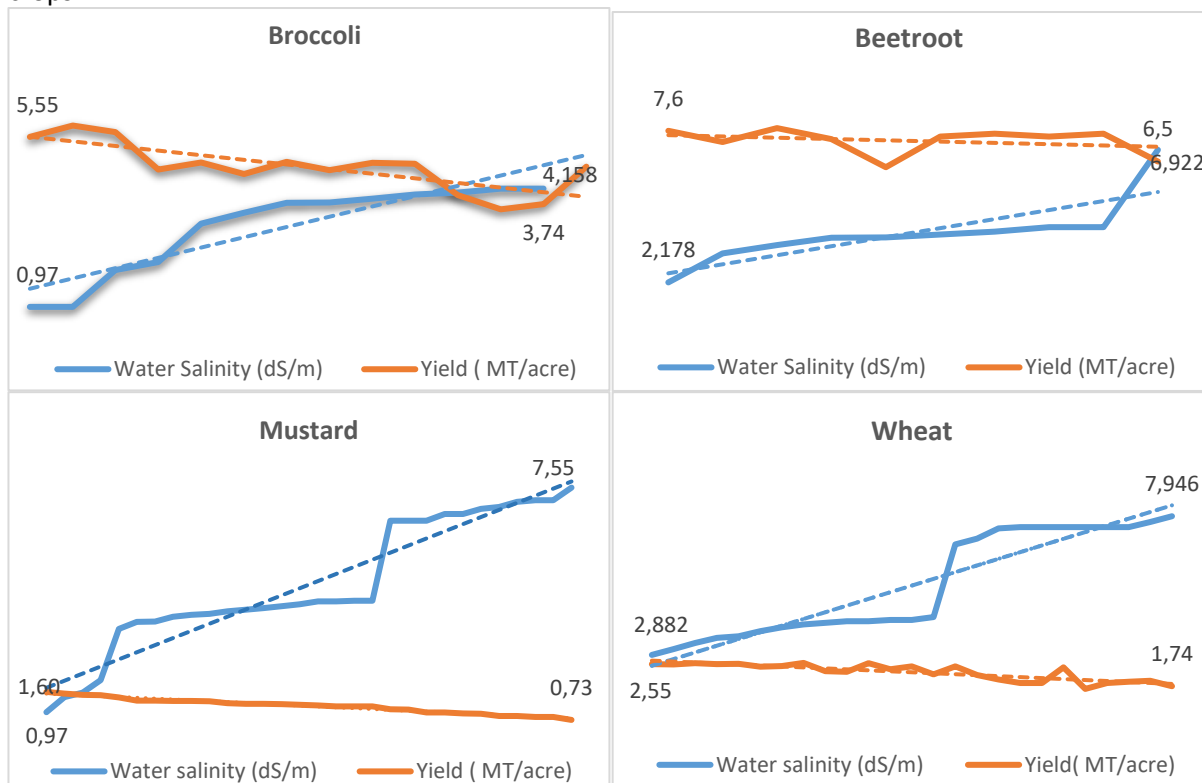
<sup>7</sup> Block is a district subdivision for the purpose of Rural Development Department and panchayati raj institutes.

<sup>8</sup> A district (zilā) is an administrative division of an Indian state or territory.

All four crops are grown in winter season, therefore, the comparative study helps farmers to make decision on the selection of crop and area under each crop.

### Results and Discussions

The results showed that yield reduced with increase in water salinity, though no set trend was observed between salinity and yield. Figures below show impacts of saline water irrigation on yield of different crops.



Crop	Increase in Salinity (dS/m)	Yield Reduction
		MT /acre
Broccoli	3.19	-1.81
Beetroot	4.74	-1.10
Mustard	6.98	-0.87
Wheat	5.06	-0.81

Among all, broccoli is most sensitive to salinity and yield reduces up to 1.81 MT/ acre with increase of 3.19 dS/m water salinity, whereas wheat is least affected with salinity and yield is decreased only 0.81 MT/ acre with increase in salinity from 2.88 to 7.94. Wheat crop is more salt tolerant than mustard because it requires 5-6 irrigations. Mustard needs one irrigation only.

The economic benefit analysis shows broccoli more profitable than all other crops, which provides highest income of INR 107,292 per acre compared with INR 72,400, INR 41,634 and INR 40,646 received respectively from beetroot, mustard and wheat. Moreover, broccoli also resulted higher returns of 61.83% (INR 66,342) and 62.16% (INR 66,692) over STW and STM respectively, whereas beetroot resulted 43.44% (INR 31,450) and 43.92% (INR 31,800) higher returns per acre over STW and STM. Although, STW and STM gave 6.20% (INR 2431) and 7.53% (INR 2847) higher return per acre against local salt-intolerant varieties.

### Conclusions

Broccoli and beetroot are more profitable crops can be grown between 2.178 to 6.92 dS/m irrigation water salinity, whereas wheat and mustard well adopted to high salinity and can withstand up to salinity of 7.946

dS/m. The germination of STW and STM are found 12% higher than SITW and SITM. Greater income and reduction in cultivation cost create huge potential for small farmers particularly who do not have access to freshwater, and will help them come out of vicious cycle of extreme poverty.

Pawan Kumar, Director-Agricultural Development, currently working with S M Sehgal Foundation India . He has more than 25 years' development sector experience and working with small farmers in India. He is post graduate from The Queens College ,Oxford

## 62. Effect of irrigation water alkalinity on performance of some wheat cultivars in a semi-arid region of northwest India - Pawitar Singh, O P Choudhary and Pritpal Singh

Effect of irrigation water alkalinity on performance of some wheat cultivars in a semi-arid region of northwest India

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RSC, Cultivar, Grain yield, Yield parameters

### Introduction

It is estimated that about 10 m ha of irrigated land in the world suffer from secondary salinization and sodification. In Northwestern parts of India, this problem is more acute in groundwater's which contain high concentrations of bicarbonates and variable soluble salts. These poor quality ground waters are also concentrated in drier Southwestern regions of Punjab which constitutes about 25 percent saline, 69 percent alkali and 6 percent saline-alkali water, where wheat is the most common winter crop. Therefore, the present research study was conducted with objective to observe the performance of six wheat cultivars (KRL 210, PBW 621, HD2967, PBW 590, PBW 550 and Berbet) to four levels of residual sodium carbonate (RSC) in irrigation water (0, 3, 6.5 and 10 me L<sup>-1</sup>).

### Methodology:

The experiment was conducted at research farm of Punjab Agricultural University, Ludhiana, India in a split plot design with three replications on *sandy loam* soil. The soil in 0-30 cm layer had pH = 7.9; electrical conductivity (EC) (1:2 soil : water suspension) = 0.20 dSm<sup>-1</sup>; organic carbon = 0.28%; calcium carbonate <1 %; clay content = 7.2% and exchangeable sodium percentage (ESP) = 4.2. Good quality water (GW) used as control (RSC 0) had EC = 0.40 dS m<sup>-1</sup> and sodium adsorption ratio (SAR) = 1.2. Three levels of RSC water (3 me L<sup>-1</sup> [EC 0.60 dS m<sup>-1</sup> and SAR 3.8], 6.5 me L<sup>-1</sup>[EC 0.90 dSm<sup>-1</sup> and SAR 7.3] and 10 me L<sup>-1</sup>[EC 1.40 dSm<sup>-1</sup> and SAR11.0] were created by dissolving 0.25, 0.55 and 0.84 g of NaHCO<sub>3</sub> per liter in GW. The experimental field plots had been receiving respective alkali irrigation water for 18 years before start of this experiment.

### Results and Discussion

Soil pH and ESP significantly increased with increasing levels of RSC of irrigation water (Table 1). The soil pH progressively increased to 7.80, 8.59, and 9.46 at RSC 3, 6.5, and 10 levels compared to GW at 0-15 cm soil depth. The value of ESP at RSC 10 was highest (58.62) over RSC 0 (4.20) at respective soil depth. The data presented in Table 1 revealed that grain yield of different wheat cultivars differed considerably at different RSC levels.



**Table 1 Effect of Increasing RSC levels of irrigation water on soil properties and grain yields of different wheat cultivars**

Treatment	Soil depth (0-15 cm)		Grain yields (t/ha)						Mean
	pH	ESP	KRL210	PBW621	HD2967	PBW590	PBW658	Berbet	
<b>RSC 0</b>	7.35	4.20	5.30	5.94	5.81	4.80	5.83	5.30	<b>5.49</b>
<b>RSC 3</b>	7.80	13.71	5.22	5.86	5.64	4.36	5.23	5.20	<b>5.26</b>
<b>RSC 6.5</b>	8.59	28.41	5.14	5.37	5.47	3.91	4.90	4.43	<b>4.87</b>
<b>RSC 10</b>	9.47	58.62	4.58	5.19	4.82	3.79	4.29	3.79	<b>4.41</b>
<b>Mean</b>	<b>8.30</b>	<b>26.20</b>	<b>5.06</b>	<b>5.59</b>	<b>5.43</b>	<b>4.21</b>	<b>5.06</b>	<b>4.68</b>	
<b>LSD (5%)</b>	<b>0.38</b>	<b>0.79</b>	<b>RSC = 0.13 Cultivar = 0.14 RSC x Cultivar = 0.28</b>						

The wheat cultivars KRL 210, PBW 621 and HD 2967 performed better at RSC 6.5 me L<sup>-1</sup>, but at higher RSC (10 me L<sup>-1</sup>), PBW 621, showed higher tolerance compared with other cultivars. Although relative decrease in grain yield of PBW 621 and KRL 210 was almost same at RSC 10 me L<sup>-1</sup> but PBW 621 produced higher grain yield in absolute terms than KRL 210. Absolute grain yield of PBW 590 was less compared to Berbet when irrigated with CW and waters having RSC of 3 and 6.5 me L<sup>-1</sup>. At the highest RSC water (10 me L<sup>-1</sup>), performance of both cultivars was on par. However, relative decrease was more in Berbet than PBW 590 at respective RSC level. Compared with CW irrigation, the maximum relative decrease in grain yield at each RSC level was observed in cultivar PBW 658, whereas minimum reduction was observed in KRL 210 (salt tolerant). Nevertheless, in absolute terms, high yielding cultivars PBW 621 and HD 2967 produced higher grain yield than established salt tolerant cultivar KRL 210 at all levels of RSC. The decreased grain yield of wheat cultivars irrigated with high RSC waters may be ascribed to the Ca-deficit in the soil solution (Minhas and Bajwa 2001) caused due to high RSC in irrigation water and hence, lower Ca in plants relative to Na (Choudhary et al. 1996). The adverse effect of high pH on other soil properties (Choudhary et al. 2001) and poor aeration because of high ESP levels (Josani et al. 1998) also could account for grain yield reduction. The above results clearly suggests that, at medium RSC level (up to 6.5 me L<sup>-1</sup>), performance of PBW 621 and HD 2967 in absolute grain yield terms was similar and higher than other cultivars but salt tolerant cultivar KRL 210 produced more than 97 % relative yield ( yield relative to GW ) compared with 95% for cultivar HD2967 and 90% for PBW 621. At RSC 10 me L<sup>-1</sup>, cultivar PBW 621 produced significantly higher grain yield (5.19 t ha<sup>-1</sup>) than cultivar HD 2967 (4.82 t ha<sup>-1</sup>) and KRL 210 (5.06 t ha<sup>-1</sup>). On the basis of relative yield, these cultivars were similar (84-87%) in their performance at this RSC level. Differential response of wheat cultivars (PBW 343, PBW550 and PBW 502) was also observed by Choudhary et al., (2012) at different RSC levels. They found that PBW 343 wheat cultivar performed better than other two cultivars at RSC greater than 5 me L<sup>-1</sup>.

**Table 2 Relationship of grain yields of wheat cultivars with their yield parameters**

Cultivars	R <sup>2</sup>
<b>KRL 210</b>	
(1) GY = 3.471 + 1.02 GWS	<b>71.1**</b>
(2) GY = 2.923 + 0.63 GWS+ 0.004 SPIKES	<b>78.8**</b>
<b>PBW 621</b>	
(1) GY = -0.8524 + 0.71 SL	<b>74.2**</b>
(2) GY = 0.5653 + 0.39 SL + 0.005 SPIKES	<b>78.3**</b>
<b>HD 2967</b>	

(1) $GY = 1.713 + 0.011 \text{ SPIKES}$ (2) $GY = 1.297 + 0.009 \text{ SPIKES} + 0.12 \text{ SL}$	94.0** 94.3**
<b>PBW 590</b> (1) $GY = -2.463 + 0.76 \text{ SL}$ (2) $GY = -1.842 + 0.51 \text{ SL} + 0.005 \text{ SPIKES}$	72.8** 74.7**
<b>PBW 658</b> (1) $GY = 2.920 + 1.32 \text{ GWS}$ (2) $GY = 1.027 + 0.83 \text{ GWS} + 0.008 \text{ SPIKES}$	89.8** 93.5**
<b>Berbet</b> (1) $GY = -1.074 + 0.018 \text{ SPIKES}$ (2) $GY = -0.661 + 0.016 \text{ SPIKES} + 0.27 \text{ GWS}$	87.3** 87.5**

**Abbreviations:** GY= grain yield, GWS= grain weight spike<sup>-1</sup>, TGW = thousand grain weight, SPIKES= number of spikes m<sup>-2</sup>, SL = spike length)

The regression equations based on correlation of grain yield with their yield parameters (SL, TGW, GWS and SPIKES) of different wheat cultivars were computed to identify the most important yield parameter influencing the grain yield of each cultivar (Table 2). Grain weight spike<sup>-1</sup> was most important contribution factor for KRL210 (R<sup>2</sup>= 71.1) and PBW 658 (R<sup>2</sup>= 89.8) towards grain yield. The predictability (R<sup>2</sup>) further improved to 78.8 % in cultivar KRL 210 and 93.5 % in case of cultivar PBW 658 when number of spikes m<sup>-2</sup> were included in the regression. For PBW 621 and PBW 590 cultivars, spike length was the important yield parameter and grain yield prediction further improved on adding number of spikes m<sup>-2</sup> as another parameter for both cultivars. For cultivars Berbet and HD 2967, number of spikes m<sup>-2</sup> were most important contributing factor for grain yield and predictability improved further upon addition of spike length for HD 2967 and grain weight spike<sup>-1</sup> for Berbet (Table 2). These results suggest that contribution of different yield parameters to grain yield was different in each cultivar. Such information can be helpful for plant breeders and biotechnologists for finalizing their breeding programmes to bring improvement in tolerance of different wheat germplasm, so that such developed cultivars are able to perform better in a sodic / alkali environment.

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63. Kale forage (*Brassica napus*) solution for use, phytoremediation and preservation of salty soil - Benbessis Yamina, Halilat Med Taher & Salhinasrine

**Kale forage (*Brassica napus*) solution for use, phytoremediation and preservation of salty soil**

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Salinization, phytoremediation, *Brassica napus*, NaCl, EC, SAR, TDS.

This study aims to evaluate the potential of the use of Kale forage (*Brassica napus*) for the mitigation of an experimentally saline soil. The plants were subjected to different concentrations of sodium chloride (tap water, tap water+50mm.l<sup>-1</sup>NaCl and tap water+100mm.l<sup>-1</sup>NaCl), and they were planted in an extremely saline soil ([EC1:5(soil: water)= 4dS.m<sup>-1</sup>, SAR= 2.14 (mmol.l<sup>-1</sup>)<sup>0.5</sup>].

Salinity and total salts concentration in soil decreased despite increasing NaCl concentration, also, chloride, calcium and potassium decreased at each sodium chloride concentration, while magnesium and sodium increased in the soil. Similar for the SAR. The cultivation of the kale forage (*Brassica napus*) lead to export in its biomass up to 9g/pot (about1.59 t.ha<sup>-1</sup>) of minerals and this quantity increased by increasing NaCl concentration, chloride is the most element absorbed and accumulated in kale forage biomasse up to 8078mg/pot and the total of sodium exported was up 110mg/pot. It is therefore clear that *Brassica napus* culture is an effective and strategic crop for salty soils phytoremediation.

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## 64. Halophytes: Alternative applications for saline plants - Yanik Nyberg

### Halophytes: Alternative applications for saline plants

Yanik Nyberg

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Aquaculture – Remediation – Environmental Engineering – Wetland restoration

Halophytes are increasingly used in agriculture, and we are seeing practitioners of saline agriculture spring up around the world, producing crops such as *Salicornia Europea* for vegetable markets in Europe. However, there are many more applications for halophytes than just vegetables.

From remediating wastewater on shrimp farms, to protecting river banks from erosion, halophytes have the potential to revolutionise sectors from agriculture to environmental engineering.

The proposed presentation explores a variety of applications for the use of halophytes, and suggests ways in which international and academic collaboration could foster transnational projects for the improvement of the natural environment.

Example projects to be explored are:

- Regional halophyte nurseries that can supply halophyte seedlings for agriculture and ecosystem restoration alike
- Identifying non-native halophytes to restore ecosystems in anticipation for climate change and the changing environment.

- Halophytes in remediation: targeted application of halophytes in industrial and agricultural contamination zones