1 Saline Agriculture

A Call to Action

Pier Vellinga, Atiq Rahman, Barbara Wolthuis, Edward G. Barrett-Lennard, Redouane Choukr-Allah, Theo Elzenga, Angelica Kaus, and Katarzyna Negacz

CONTENTS

1.1	Introduction: Saline Agriculture from the Cradle of Civilization to the Present and Future	3
1.2	Initiatives to Grow Crops under Saline Conditions	5
1.3	Four Reasons to Invest in Producing Food under Saline Conditions	6
1.4	Two Lines of Action	7
1.5	In Support of the UN Sustainable Development Goals	8
1.6	Toward an Innovative Agenda	8
1.7	Conclusion	9
	References	10

1.1 INTRODUCTION: SALINE AGRICULTURE FROM THE CRADLE OF CIVILIZATION TO THE PRESENT AND FUTURE

The association between human civilizations and salinity has existed for thousands of years. The primary causes of the decline of the ancient Mesopotamian civilizations (located in modern Iraq) were three major salinization events: the first and most severe was from 2400 BC to 1700 BC, the second was between 1300 and 900 BC and the third occurred after 1200 AD (Jacobsen and Adams 1958). The reasons for these failures are familiar to irrigated agriculturalists today: the over-irrigation of land led to a rising water-table and consequent salinity and waterlogging, and there was major silting of water-courses and canals (Gelburd 1985; Shahid et al. 2018). In a similar manner to these ancient civilizations, most agricultural production today is still largely based on the use of freshwater resources and salinity remains a major threat (Figure 1.1).

The extent of salinization is difficult to estimate. The total area of saline and sodic lands is likely to be ~10% of arable land worldwide (Shahid et al. 2018). Ghassemi et al. (1995) estimated that ~20% of irrigated land is salt-affected; however, remote sensing studies show that in some countries up to 50% of irrigated land is salt-affected (Metternicht and Zinck 2003). The desertification of irrigated lands amounts to ~1.5 Mha around the world (Sentis 1996). The total surface area which

FIGURE 1.1 World map representing countries with salinity problems based on Negacz et al. (2019)

can be used for saline agriculture depends on several conditions such as water availability and soil fertility (Negacz et al. 2019).

More efficient use of freshwater and irrigation systems can play a major role in restoring freshwater agriculture in degraded soils. However, many countries with salinity problems are experiencing major water scarcity problems. Hoekstra and Mekkonen (2016) have developed a global map indicating the number of months in which water demand exceeds supply (Figure 1.2).

Many of the factors leading to soil salinization are being exacerbated by climate change; projections indicate more persistent droughts, an acceleration of sea-level rise and more extreme weather events projected by the Intergovernmental Panel on Climate Change (Pörtner et al. 2019). Salinization problems will become increasingly manifest in many coastal areas and wetlands, deltas of major rivers and small

FIGURE 1.2 The number of months per year in which blue water scarcity exceeds 1.0 at 30 × 30 arc min resolution for period: 1996–2005. (From Mekonnen and Hoekstra, 2016.)

islands, not only through sea-level rise and more severe floods associated with storms, but also through groundwater intrusion by saline waters (Tiggeloven et al. 2020). In regions with semi-arid to arid climates, the availability of good quality water will continue to decrease so irrigation will continue using lower quality groundwater (FAO 2019b).

1.2 INITIATIVES TO GROW CROPS UNDER SALINE CONDITIONS

In the last few decades, there have been several initiatives in exploring the feasibility of growing food under saline conditions. The U.S. Salinity Laboratory was one of the earliest initiatives launched in 1954. More recently, the International Centre for Biosaline Agriculture (ICBA), initiated in 2000 in the United Arab Emirates, has led the way in conducting research on problems and solutions for agricultural productivity under saline conditions (ICBA 2019, 20). Similar initiatives, usually at a smaller scale, have been undertaken in other countries like Australia, the Netherlands, Russia, China, Morocco and Egypt. Indigenous food production practices illustrate the wide variety of saline tolerant crops and agricultural practices that used to occur. Several international initiatives have been taken to explore and re-introduce indigenous knowledge and practices for food production in saline soils; examples are the International Partnership for the Satoyama Initiative.

Food production with saline soil and water is currently a marginal business and there is continuing momentum in maintaining the status quo. Often public money is used to ensure the continuity of freshwater availability (Chapter 13 of this book). Furthermore, there is an important element of cultural heritage and tradition in freshwater agriculture that keeps farmers and agricultural policymakers on the traditional track of continuity in freshwater provision to farmers at whatever the economic and environmental cost. For example, in Pakistan, farmers have the right to continue receiving freshwater through the canal command system even though there is increasing evidence that this distribution is becoming unsustainable now and the deficits will be even greater in the future (Zawahri 2011).

The explanation for this may be that under the present market conditions, with agricultural subsidies and the exclusion of environmental costs and externalities, saline agriculture cannot compete with freshwater agriculture. This market distortion makes it generally more financially attractive to overdraw on freshwater and land resources than to invest in food production with saline soils and water. Furthermore, under present international market conditions, it is seen to be “cheaper” to deforest virgin areas or drain freshwater lakes and wetlands, than to revitalize saline lands. However, markets do not reflect the real costs of the use of land. Compared to trees, grasses absorb only a fraction of CO₂. Deforestation to create more land for cattle grazing therefore means a massive loss of compensation of CO₂ and is a high driver of climate change. So far, the FAO life cycle assessment does not take that into account, whereas research has clearly shown the relation between deforestation, meat production, water scarcity and CO₂ implications on land use (Schmidinger and Stehfest 2012). Therefore, revitalization and regeneration of soils is a viable option in many situations. It does require specific skills in water and soil management, and it takes several years of investment before production levels are at their potential.

The pressure to repair the market failure is increasing from three directions: (1) growing food demand and subsequent calls for more land (FAO 2009), (2) the urgency to reduce greenhouse gas emissions and subsequent calls to stop deforestation and drainage of wetlands, and (3) the growing opportunities to produce food on salinized lands ([Chapter 7](#) of this book).

Recently the FAO (2019a) has initiated a thematic working group with the aim “to explore the opportunities offered by saline environments (water and soil) for agriculture”. The European Commission in its EIP-AGRI program (EIP-AGRI 2019) has initiated a focus group on saline agriculture around the question: “How to maintain agricultural productivity by preventing, reducing or adapting to soil salinity”.

Recent initiatives cover not only crops, soil and water but also circular saline farming (farming that includes the use of all residual biological products in the production chain). Multi-functional solutions are being explored such as combinations of food production and flood protection through activities like mangrove-based agroforestry. In addition, a number of traditional/indigenous crops with salt-tolerant varieties are being identified. Nature-based solutions are being explored such as wetland farming and marine farming next to hydroponics (floating agriculture) and integral farming (ICBA 2015b).

However, as saline farming is about new food products and new markets, it is difficult to develop specific food chains of significant volumes. It is recognized among experts for example that quinoa (ICBA 2015a) and potatoes (van Straten et al. 2019) have salt-tolerant varieties with some 80% yield and excellent quality when produced under moderately saline soil and water conditions. Still, this potential is not used even though there are millions of hectares of underutilized moderately saline land areas. An additional challenge is the production of dedicated seeds as seed rights can have a positive as well as a negative effect on the use of salt-tolerant varieties/species. In conclusion, there are a number of groups and regions experimenting in saline agriculture. However, the field is fragmented and the development of saline farming appears to be an uphill battle.

1.3 FOUR REASONS TO INVEST IN PRODUCING FOOD UNDER SALINE CONDITIONS

During the 2019 International Saline Futures Conference at Leeuwarden in the Netherlands, researchers and practitioners presented a range of reasons for boosting investments in the exploration and further development of food production under saline conditions. The arguments can be summarized in four lines:

1. *There is a need to address growing freshwater scarcity.* Freshwater scarcity is growing. The area of salinized land is growing rapidly. Public funding of freshwater for agriculture is likely to reach its limits. [Chapter 4](#) of this book describes the situation regarding salinization for the North African countries. [Chapter 3](#) of this book provides an overview for the situation in Australia. Increasing the efficiency of freshwater use is one line of action; a parallel one is the introduction of salt tolerant species in combination with specific water and soil management practices. These two lines have synergistic benefits.

2. *There is a need to stop the loss of biodiversity while meeting growing food demand.* Population growth inducing the global food demand exerts pressure on land-use change. The smart use of saline lands can prevent the progressing destruction of unique ecosystems and biodiversity hotspots, such as the remaining forests and coastal wetlands.
3. *There is a need to adapt to climate change.* Climate change is bringing more severe weather events such as droughts, erratic rainfall patterns, more severe cyclones and accelerated sea-level rise. More frequent and severe coastal storm surges will cause salinity intrusions into river-deltas and low-lying coastal areas and small islands, resulting in increasing salt stress and yield losses. The inundation of fertile low lands is likely to become an existential threat to agricultural livelihoods in many places around the world, leading to the internal displacement or migration of local inhabitants as described by Rahman and Uddin (2021). Food production under saline conditions and innovation in this field could help to create an economic and social perspective for the regions and populations affected.
4. *There is a need to increase opportunities and capacities to produce food under saline soil and water conditions.* A wide range of experiments around the world is showing a large economic potential for innovative saline agriculture systems. [Chapter 29](#) of this book reports a series of successes in growing quinoa in regions of North Africa. [Chapter 11](#) of this book report on innovations in the field of integral saline farming where aquaculture and crop production are being combined. [Chapter 21](#) of this book report on successful pilots on potato yields under saline conditions in Bangladesh. [Chapter 30](#) of this book explores the potential of edible halophytes as new crops in saline agriculture using the example of the ice plant.

1.4 TWO LINES OF ACTION

Based on the reasoning presented above, we propose to focus on two lines of action:

1. *Building the international community of saline agricultural science and practice* by organizing meetings for sharing knowledge; by setting up specialized journals, social media platforms, conferences and webinars; by developing a network of cutting-edge science, innovations and policy solutions in agriculture and water management.
2. *Enhancing investment* in research, experimental centers and pilots for food production under saline conditions. Agendas of climate change adaptation and food production under saline conditions provide opportunities for new initiatives by national and international organizations such as the FAO, World Food Program (WFP) and multilateral financing organizations like the Green Climate Fund, the World Bank, the Development Finance Institutions (DFI's) and private impact investors. A major bottleneck is the availability of "bankable" projects. To meet this challenge, it is important to invest in capacity building, set-up local pilot projects and establish regional centers of excellence for saline agricultural research and development, and engage with investors at an early stage to allow for economic upswing.

1.5 IN SUPPORT OF THE UN SUSTAINABLE DEVELOPMENT GOALS

Increasing investments in saline agriculture are fully in line with the majority of the UN Sustainable Development Goals. [Chapter 2](#) of this book shows that in particular “Zero hunger” (SDG 2), “Decent work and economic growth” (SDG 8) and “Addressing freshwater scarcity” (SDG 6) are supported. In addition, “Partnerships for the goals” (SDG 17) in the context of saline agriculture is most relevant. Saline agriculture and the underlying hydro-geological conditions vary greatly by geographic area. It is clear that the situation and the relevant processes differ enormously by region and within regions, they differ by location. However, experts and practitioners can unite in the quest to grow ecologically and economically viable crops in under conditions of freshwater scarcity and moderately to highly saline soils.

Enhancing investment in saline agriculture requires the development of new partnerships. Partnerships between research and practitioners in the fields of agriculture, water, economics and food are all equally important: partnerships should also include experts in rural sociology, economics and finance. In fact, a transdisciplinary community is required to move forward. New investments are necessary because the international and national communities are relatively small and fragmented at present.

Relatively new is the concern of farmers in delta regions with abundant rainfall, such as in South East Asia as described by [Chapter 8](#) of this book and the situation around the North Sea as described by [Chapter 5](#) of this book. Sea level rise, more frequent flooding, saline groundwater seepage and more persistent droughts are increasingly threatening the yields in these fertile lands. The prospect of sea-level rise by 1–2 meters over the next one hundred years is creating a sense of urgency.

1.6 TOWARD AN INNOVATIVE AGENDA

We argue that any agenda on food production under saline conditions should be transdisciplinary and multinational covering field experiments as well as socio-economic research and policy evaluation. A local focus with stakeholder participation is crucial, as is (inter)national knowledge sharing and dissemination. Financial support and new investments are also necessary as the international and national communities are at present relatively small and fragmented. [Figure 1.3](#) illustrates how different stakeholders and different scientific disciplines could work together.

The 2019 International Saline Futures Conference presented the following fields for investment in capacity building, and research and development:

1. identifying and improving salt tolerant crop varieties
2. innovation in farming practices: exploring regenerative techniques and practices enhancing the carbon content of soils, integral farming including aquaculture and crop farming, hydroponics
3. evaluation and innovation considering the full value chain including product and market development and promotion
4. field testing and large-scale pilot projects

FIGURE 1.3 Illustration of a transdisciplinary approach toward food production under saline conditions. (Inspired by R.W. Scholz, G. Steiner, Sustainability Science, August 2015, doi: [10.1007/s11625-015-0326-4](https://doi.org/10.1007/s11625-015-0326-4).)

5. training and capacity building, including the establishment of an international scientific journal and on-line networks
6. development of regional centers for research and large-scale pilots
7. development of supportive land and water use policies
8. creation and implementation of investment opportunities

We argue that existing national salinity centers such as in the USA, Australia, Morocco, Egypt, Jordan and India together with international centers such as ICBA should be reinforced in terms of scope and budget. But new centers also need to be established. The fertile soils of the world's deltas threatened by climate change and related salt water flooding and seepage require urgent attention. Innovations in coastal agriculture, land use and water and soil management are of crucial importance to ensure the longer-term food production in deltas. Innovation in land use in these areas is equally required to avoid loss of economic welfare and subsequent migration away from these climate-vulnerable areas (Hassani et al. 2020).

1.7 CONCLUSION

As participants of the 2019 International Saline Futures Conference, we conclude that the opportunities to produce food, fuel, forage and fiber under saline soil and water conditions deserve much more attention at an international and national level for four reasons: (1) *The need to address the growing freshwater scarcity*, (2) *the*

need to stop the loss of biodiversity while meeting growing food demand, (3) the need to adapt to climate change, and (4) the increasing capacities to produce food under saline soil and water conditions. We propose a transdisciplinary approach in developing and implementing a “Research to Development Continuum” to ensure a continuous interaction between farmers, researchers, marketers and investors. Two lines of investment are recommended to address this challenge: (A) *capacity building and strengthening the international community including its national and local stakeholders*, and (B) *strengthening existing and setting up new expertise centers in particular through a combination of two agenda’s: climate change adaptation and saline agriculture.*

These conclusions and recommendations will be introduced in the discussions with national and international business and agencies including agriculture, food and seed companies, waterboards and agricultural ministries, the FAO, World Food Program (WFP), World Bank, UNEP, IsDB, Development Finance Institutions (DFI’s), the Green Climate Fund and Private Impact Investors.

REFERENCES

- Atzori, Giulia. 2021. “The Potential of Edible Halophytes as New Crops in Saline Agriculture: The Ice Plant (*Mesembryanthemum crystallinum* L.) Case Study.” In *Future of Sustainable Agriculture in Saline Environments*. Routledge, Taylor & Francis Group, London.
- Barrett-Lennard, Edward G., and Hayley Norman. 2021. “Agriculture in Salinizing Landscapes in Southern Australia: Selected Research ‘Snapshots.’” In *Future of Sustainable Agriculture in Saline Environments*. Routledge, Taylor & Francis Group, London.
- Beauchamp, Isa Camara. 2021. “Stakeholder Perspectives on the Issue of Salinization in Agriculture in The Netherlands.” In *Future of Sustainable Agriculture in Saline Environments*. Routledge, Taylor & Francis Group, London.
- Choukr-Allah, Redouane. 2021. “Use and Management of Saline Water for Irrigation in the Near East and North Africa (NENA) Region.” In *Future of Sustainable Agriculture in Saline Environments*. Routledge, Taylor & Francis Group, London.
- EIP-AGRI. 2019. “European Innovation Partnership ‘Agricultural Productivity and Sustainability’ – EIP-AGRI – European Commission.” *EIP-AGRI*. eip/agriculture/en/european-innovation-partnership-agricultural.
- FAO. 2009. “High Level Expert Forum - How to Feed the World in 2050.” FAO. http://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf.
- . 2019a. “Saline Agriculture | Land & Water | Food and Agriculture Organization of the United Nations | Land & Water | Food and Agriculture Organization of the United Nations.” <http://www.fao.org/index.php?id=99230>.
- . 2019b. “The Multi-Faced Role of Soil in the Near East and North Africa.” Policy brief. Global Soil Partnership. FAO. <http://www.fao.org/3/ca7123en/CA7123EN.pdf>.
- Gelburd, Diane E. 1985. “Managing Salinity Lessons from the Past.” *Journal of Soil and Water Conservation* 40 (4). Soil and Water Conservation Society: 329–31.
- Ghassemi, Fereidoun, Anthony J. Jakeman, and Henry A. Nix. 1995. *Salinisation of Land and Water Resources: Human Causes, Extent, Management and Case Studies*. CAB International.
- Gould, Iain, Jeroen De Waegemaeker, Domna Tzemi, Isobel Wright, Simon Pearson, Eric Ruto, Leena Karrasch, et al. 2021. “Salinization Threats to Agriculture across the North

- Sea Region.” In *Future of Sustainable Agriculture in Saline Environments*. Routledge, Taylor & Francis Group, London.
- Hassani, A., Azapagic, A., & Shokri, N. (2020). Predicting long-term dynamics of soil salinity and sodicity on a global scale. *Proceedings of the National Academy of Sciences*, 117(52), 33017–33027.
- ICBA. 2015a. “Quinoa for Marginal Environments, Project brief International Centre for Biosaline Agriculture.” Project Brief. ICBA. https://www.biosaline.org/sites/default/files/Projectbrieffiles/Quinoa-Project_Brief-Final-2.pdf.
- . 2015b. “Integrated Aqua-Agriculture for Enhanced Food and Water Security.” International Center for Biosaline Agriculture. April 28. <https://www.biosaline.org/projects/integrated-aqua-agriculture-enhanced-food-and-water-security>.
- . 2019. “ICBA at 20: A Look at History.” International Center for Biosaline Agriculture. December 19. <https://www.biosaline.org/corporate-publications/icba-20-look-history>.
- Jacobsen, Thorkild, and Robert M. Adams. 1958. “Salt and Silt in Ancient Mesopotamian Agriculture.” *Science* 128 (3334). JSTOR: 1251–58.
- Lyra, Dionysia Angeliki, Efstathios Lampakis, Mohamed Al Muhairi, Fatima Mohammed Bin Tarsh, Mohamed Abdel Hamyd Dawoud, Basem Al Khawaldeh, Meis Moukayed, et al. 2021. “From Desert Farm to Fork: Value Chain Development for Innovative Salicornia-Based Food Products.” In *Future of Sustainable Agriculture in Saline Environments*. Routledge, Taylor & Francis Group, London.
- Mekonnen, Mesfin M., and Arjen Y. Hoekstra. 2016. “Four Billion People Facing Severe Water Scarcity.” *Science Advances* 2 (2). American Association for the Advancement of Science: e1500323. doi:10.1126/sciadv.1500323.
- Metternicht G.I. and Zinck J.A. 2003. Sensing of Soil Salinity: Potentials and Constraints.” *Remote Sensing of Environment* 85 (1). Elsevier: 1–20.
- Negacz, Katarzyna, Bas Bruning, and Pier Vellinga. 2021. “Achieving Multiple Sustainable Development Goals through Saline Agriculture.” In *Future of Sustainable Agriculture in Saline Environments*. Routledge, Taylor & Francis Group, London.
- Negacz, Katarzyna, and Pier Vellinga. 2021. “Cost or Benefit? Estimating the Global Economic Potential of Saline Agriculture.” In *Future of Sustainable Agriculture in Saline Environments*. Routledge, Taylor & Francis Group, London.
- Negacz, Katarzyna, Pier Vellinga, and Arjen de Vos. 2019. “Saline Degraded Lands Worldwide: Identifying Most Promising Areas for Saline Agriculture.” *Paper Presented at the Saline Futures Conference*.
- Pörtner, H. O., D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, M. Nicolai, A. Okem, and J. Petzold. 2019. “IPCC, 2019: Summary for Policymakers.” *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*.
- Rahman, Atiq, and Md. Nasir Uddin. 2021. “Challenges and Opportunities for Saline Agriculture in Coastal Bangladesh.” In *Future of Sustainable Agriculture in Saline Environments*. Routledge, Taylor & Francis Group, London.
- Schmidinger, Kurt, and Elke Stehfest. 2012. “Including CO₂ Implications of Land Occupation in LCAs—Method and Example for Livestock Products.” *The International Journal of Life Cycle Assessment* 17 (8): 962–72. doi:10.1007/s11367-012-0434-7.
- Sentis, I. 1996. “Soil Salinization and Land Desertification.” *Soil Degradation and Desertification in Mediterranean Environments*. Logroño, Spain, Geoforma Ediciones, 105–29.
- Shahid, Mohammad. 2021. “Response of Quinoa to High Salinity under Arid Conditions.” In *Future of Sustainable Agriculture in Saline Environments*. Routledge, Taylor & Francis Group, London.
- Shahid, Shabbir A., Mohammad Zaman, and Lee Heng. 2018. “Soil Salinity: Historical Perspectives and a World Overview of the Problem.” In *Guideline for Salinity*

- Assessment, Mitigation and Adaptation Using Nuclear and Related Techniques*, edited by Mohammad Zaman, Shabbir A. Shahid, and Lee Heng, 43–53. Cham: Springer International Publishing. doi:[10.1007/978-3-319-96190-3_2](https://doi.org/10.1007/978-3-319-96190-3_2).
- Tiggeloven, Timothy, Hans de Moel, Hessel C. Winsemius, Dirk Eilander, Gilles Erkens, Eskedar Gebremedhin, Andres Diaz Loaiza, et al. 2020. “Global-Scale Benefit–Cost Analysis of Coastal Flood Adaptation to Different Flood Risk Drivers Using Structural Measures.” *Natural Hazards and Earth System Sciences* 20 (4). Copernicus GmbH: 1025–44. <https://doi.org/10.5194/nhess-20-1025-2020>.
- van Straten, G., A. C. de Vos, J. Rozema, B. Bruning, and P. M. van Bodegom. 2019. “An Improved Methodology to Evaluate Crop Salt Tolerance from Field Trials.” *Agricultural Water Management* 213. Elsevier: 375–87.
- Vos, Arjen de, Andres Parra González, and Bas Bruning. 2021. “Case Study: Putting Saline Agriculture into Practice – A Case Study from Bangladesh.” In *Future of Sustainable Agriculture in Saline Environments*. Routledge, Taylor & Francis Group, London.
- World Data Lab. 2020. “Water Scarcity Clock.” https://worldwater.io/?utm_source=google&utm_medium=search&utm_campaign=WaterscarcityData&campaignid=6444167483&adgroupid=77198318295&adid=376808482557&gclid=Cj0KCQjw2or8BR CNARIsAC_ppyYcIxtPIjWJt26sStlBVQPWWhiuZ6cODYw0JAQ4BD0DrwLaS2zQf8aAnl3EALw_wcB.
- Zawahri, Neda A. 2011. “Using Freshwater Resources to Rehabilitate Refugees and Build Transboundary Cooperation.” *Water International* 36 (2): 167–77. doi:[10.1080/02508060.2011.557994](https://doi.org/10.1080/02508060.2011.557994).