EIP-AGRI Focus Group

Soil salinisation

MINIPAPER: Examples of salt tolerant crops as an alternative for farmers

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1 Introduction

Here we want to demonstrate that there are alternatives for commonly grown crops for the cultivation on salt affected soils. Often these alternatives are varieties of well-known crops. However, these different varieties differ in their ability to tolerate saline and/or sodic soils. Farmers who have to do business on these soils often do not know this. This has different reasons. The screening for salt resistant varieties by commercial breeders or research institutions has only just begun. Often the focus of these screening efforts is done for a limited number of commercial important crops and a narrow genetic variation. Therefore, the potential of crops to tolerate salt affected soils is often unknown as well as crops yield performance on a specific soil.

We do not want to compile a complete list of alternatives. We just want to present a few showcases/examples for salt tolerant crops in order to show farmers that they are there. However, farmers always have to consider whether a specific crop or crop variety is suited for their specific field conditions. Additionally there also has to be a (local) marked for the product. In some cases, it might be economically more reasonable for farmers to keep growing their known common crops, even if the yields of these salt sensitive crops decline under saline/sodic soil conditions. The solutions therefore always have to be adapted to specific local field conditions.

2 Potato

Potato is the fourth largest food crop in the world. Since the 1990's potato cultivation has expanded rapidly in Africa, Asia and Latin America. The crop water requirement is relatively low and the tubers provide carbohydrates and are rich in minerals and vitamin C and B. In China, potato cultivation is now promoted since it requires 30% less water for production compared to rice, wheat and maize and it provides more calories and vitamins per hectare. This makes it a healthy crop that requires little water for production. Potato can be cultivated in a wide range of climate zones, but yields are affected by temperature. In general, a night temperature below 15°C is required for tuber initiation and optimal soil temperature is 15-18°C. Tuber growth is sharply inhibited when temperature is below 10°C or above 30°C. Daylength also influences crop growth and different varieties show different responses to both temperature and daylength. Potato does not tolerant waterlogging conditions and cultivation often takes place on ridges. Potato can be cultivated on different soil types and optimal yields can be achieved with (continuous) high soil moisture content with adequate drainage. Average yields in the temperate and subtropical climates are 25-35 ton/ha (in the Netherlands yields are around 40-45 ton/ha), and in the tropical climates yields are 15-25 ton/ha. The total world potato production is estimated at 388 million tonnes in 2017 (FAOSTAT, 2019). Potato can be cultivated for the fresh market, French fries, chips and starch. Therefore, potato is a major crop in the world with a good market value. Potato is often seen as a crop that can be cultivated in areas that are coping with diminishing water supplies and the potato itself is a versatile crop. Most of the cultivated varieties descended from a limited number of wild potato species. There are about 180 different wild potato species that hold the key to further improve the natural resistance to pests, diseases, climatic conditions and abiotic stress as drought and salinity. The potato originates from the Andes where vast areas of saline land are present. Highly salt tolerant crops like quinoa also originate from this area and most likely (highly) salt tolerant potato species exist. At present, potato is considered to be moderately sensitive to salinity where a soil salinity level of 2.5 dS/m (ECe) already results in 10% yield reduction. However, after screening over 300 potato varieties under controlled field conditions in the Netherlands, Saline Farming has identified varieties that show this 10% yield reduction around 7.6 dS/m instead of 2.5 dS/m. So, just be screening existing varieties it is possible to select more tolerant varieties. At present, these more tolerant varieties are, together with a tailor-made cultivation strategy, introduced in salt affected areas in Egypt, Pakistan and Bangladesh with very good results. So, on the short term these potato varieties can already be cultivated under saline conditions. To further improve the salt tolerance level of potato, more varieties can be tested, including the wild types that can be the starting point of selective breeding for salt tolerance. This selective breeding is a long process that can take 10-15 years before the newly developed varieties are market ready and the business model for large scale implementation of a salt tolerant varieties has to be clearer before breeding companies start this long process.

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3 Halophytes

The term halophytes is often used to describe (wild) salt resistant (tolerant) plants, which dominate (natural) habitats with a high concentrations of soluble salts. These plants do not necessarily prefer these environments. However, halophytes outcompete salt sensitive plants (glycophytes), since they have developed various strategies to adapt to saline environments. Most plants commonly used in agriculture belong to the group of glycophytes. These not salt tolerant plants are inhibited in their growth and their life cycle in general in saline environments.

There is a high number of plants species of various orders, which can be categorised as halophytes. Here some examples of known, but rarely used plants/crops, which could be an alternative product grown on salt affected soils are presented. The commercial value of the products is hard to asses, since until now most known halophytes grown by farmers just have an extremely small niche market compared to most other crops.

3.1 Chard

Or Swiss chard (Beta vulgaris subsp. Vulgaris) can be considered as a halophyte, however it is well known by vegetable farmers and consumers. It contains high amounts of vitamins A.
Experiments show that chard grown on a soil with an EC of around 6 dS m-1 showed a yield reduction between 10 – 36% depending on the chard variety compared to a non-saline soil conditions. Therefore, farmers with saline soils can choose chard varieties, which are more salt resistant. One positive side effect of growing chard is, that it takes up considerable amounts of sodium and chlorine from saline soils and by this can - if no "new" salts are added to the soil e.g. by irrigation water - reduce the overall soil salt concentration.

3.2 Buck´s horns plantain

Erba stella or Minutina (Plantago coronopus) is a halophyte which is already known well in some regions (Northern Italy, Canary Islands) and it reportedly can be found on some farmers markets across some other European countries. It is used as salad (compound) or steamed as a vegetable. It has a nutty and salty taste and is more flavourful than most green salads. It is said, that it contains high amounts of vitamins A and C. However, no valid scientific data was found to confirm this fact.

Seeds are available; however there are no different varieties or a breeding program to improve buck´s horns plantain further.

Since it can be used as a green salad and presents a "new" taste to the assortment of green salads, the biggest issue is getting to know the product for a higher number of consumers. Branding could be a way to do this. A big plus towards most other green salads is its firmness and long shelf life (has to be proven - right now it is just an unproven observation). Another big plus is the fact is that it is quite winter hard and keeps growing with temperatures just above zero. Therefore, it could be an addition to the small assortment of green salads, which grow without additional heating in winter.

3.3 Salicornia

Halophyte plants growing near seashores have been collected since ancient times as food, for their medicinal qualities, and for their high salt contents (Davy et al., 2001). The current interrelated crises of dwindling fresh water supplies and increasing soil salinization have awakened new interest in plant species that possess inherent salt tolerance, especially those plants that can achieve high, economically lucrative yields.

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Salicornia with its spongy stems covered by diminutive scale-like leaves together with inconspicuous flowers and fruits is placed in the family of *Amaranthaceae*. It is commonly kwon as pickleweed, glasswort, sea beans, sea asparagus, crow`s foot greens, drift seeds and samphire. This plant as emerged as an important cash crop
halophyte for seawater irrigation, because of its high tolerance. It can grow under hypersaline conditions, and a promising resource to cultivate from arid desert regions in southern europe to the seashores of northern europe. These fleshy plants are distributed alongside the edges of wetlands, salt marshes, seashores and mudflats.

Salicornia europaea, a salt-accumulating halophyte, is a vegetable succulent plant, completely edible for humans and capable of accumulating up to 50% NaCl of dry matter (Kong and Zheng 2014). Saltwater energy farms could be raised in coastal areas. Salicornia has very high economic value, including 30% of oil, which is more than it is possible to obtain from the soybean seeds. The oil also provides raw material for a series of cosmetic and pharmaceutical products. Thus, Salicornia in culture could be better than the soybean with major yields and minor production costs. Besides this its ability to grow in non-fertile soils with saline irrigation. Apparently it has high productivity a and high economic potential and under adverse conditions.

Different species of the Salicornia genus are suitable for vegetable production. These have been accepted by the consumer, who is exclusively interested in the young green plant parts that are sold in the markets as ‘Samphire’ or ‘Sea asparagus.’ The latter name probably reflects the shape of the shoots, which resemble the tops of green asparagus.

The potential of some halophytes to be used as food crops has been recognized. Halophytic plants, including *Salicornia* ssp., and *Sarcocornia* spp. are consumed today in Europe as fresh or cooked gourmet foods. Several studies with these species reported their high nutritional content, which includes proteins, carbohydrates, fibre, calcium, potassium, magnesium, iron, manganese, copper, vitamin C and β-carotene (Ventura and Sagi, 2013). Also, therapeutic applications of *Salicornia* ssp. have been reported based on scientific research (Im et al., 2007). However, the supply of these plants is limited because there few are cultivated on arable land and most are harvested from the wild (Gago et al., 2011). Presently, their market is based mostly on amateur gathering of branches and leaves from wild plants, which limits the market supply.

3.4 Maize

Maize is one of those world’s most important crop plants. It is the second largest agricultural produced commodity in tonnes, stressing its worldwide importance. The world production of the commodity maize increased from roughly 600 million tons in the year 2000 to over 1 billion in 2014 (FAO, 2014).

Maize or corn (Zea mays L.) belongs to the family Poaceae together with its ancestor the wild plant teosinte. Its origin is the region of Mesoamerica where the C4 plant was domesticated by selection of key mutations (Matsuoka et al., 2002). The grains are used for human and livestock consumption; therefore, total grain yield is an important agronomical factor. There are two components of grain yield: Kernel number and kernel weight. Both compounds can be negatively affected by salt stress, however, a lower kernel number is often partly compensated by a higher grain weight, depending on stress intensity and the physiological stage in which the stress occurs (Borrás et al., 2006). However, there is apparently an evolutionary conserved strategy to maintain the full kernel set. Schubert et al. (2009) developed a salt resistant maize hybrid, which was able to maintain full kernel set under salt stress. In contrast, kernel setting of salt sensitive genotypes is affected by salt stress. This example shows that maize has an unexplored genetic potential to implement strategies in future breeding processes, which could prevent the reduction of yield due to salinity. These strategies and their underlying mechanisms have to be identified and understood in order to use this knowledge in plant breeding programs. However, many of these strategies currently identified are based on a complicated interaction of a high (often unknown number) of genes, which does not simplify matters. Nevertheless, there are probably maize genotypes already on the market, which are more salt resistant then other. Therefore, there has to be a screening for salt resistant maize genotypes, like it is done for salt resistant potato varieties by Salt Farm Texel.

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4 Knowledge gaps and potential innovations, sustainability of innovations

Especially for European agriculture research, efforts into salt resistant/tolerant plants have been minimal at best. The focus here has been more on crop diseases resistance, drought and waterlogging resistance as well as nutrient efficiency. In other regions of the world, research efforts into crop salt resistance have been grander. Europe can learn from these foreign efforts and adapt them for their breeding programs of European crops traits. Therefore, there is a tremendous need for research, since the problem of soil salinity is about to get worth before it is getting better in most European countries.

In accordance with the minipaper “Quality aspects of plant varieties in response to soil salinity” the most pressing knowledge gaps, challenges and opportunities regarding soil salinity research needs are listed in table 1:

Table 1. Knowledge gaps, challenges, opportunities

TOPIC	KNOWLEDGE GAPS	POTENTIAL INNOVATIONS	SUSTAINABILITY OF INNOVATIONS	
			PROBLEMS	OPPORTUNITIES
Crop and salinity stress	Limited knowledge on the physiological and molecular basis of salinity tolerance/resistance and agronomic implications	Elucidating the physiological and molecular basis of crop tolerance to salinity and functionalize this knowledge to optimize agronomic management of saline agricultural systems	Needs of a multidisciplinary approach, complex and expensive	Development of salt tolerant/ resistant varieties
Crop quality and salinity	Scarce information on quality improvements of salinized products	1. Profiling the nutritional content of crops grown under saline conditions	Need to define environmental and genetic factors that may interact with salt stress response and affect the nutritional profile of commercial products Need of an accurate inventory of salt-affected areas at regional, national and EU levels	Value areas that are/will be affected by salinization; monitoring and controlling the progression of salinization; anticipating and delaying transitions to irreversible salinization problems
		2. Defining a threshold of commercial return for quality traits improvements vs. yield loss in saline environments	Need to define agronomic determinants that guarantee quality standards	Mapping salt tolerant species/cultivars vs. saline conditions and cultivation protocols

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TOPIC	KNOWLEDGE GAPS	POTENTIAL INNOVATIONS	SUSTAINABILITY OF INNOVATIONS	
			PROBLEMS	OPPORTUNITIES
		3. Profiling the biosynthesis of biofunctional molecules that may have beneficial health implications	Complex interactions between salinity and other environmental factors may limit a stable/constant accumulation of functional molecules	Identification of new active molecules and characterization of their beneficial effects on human health; profiling synergistic effects of different molecules and their multi-functionality as food, feed and nutraceutical uses

However, there are projects in Europe, which want to find/develop salt resistance/tolerant plants:

- The Interreg SalFar project focuses on the degradation of farmland due to salinization. The main driver for increased salinization in the North Sea Region is the continuous rise in sea level. Here in subprojects crop alternatives for saline farming are tested.
- Salt Farm Texel, also known as Zilt Proefbedrijf (Tested on Texel), is a company committed to develop saline agriculture. By identifying salt tolerant crops and varieties, they want to cultivate food in salt affected areas that were assumed to be unproductive.
- EIP.agri Operational Group: Desalination of greenhouse floors by halophytes

These are just examples for some of the coordinate and funded research efforts already existing in Europe. There are many more. Still, the knowledge gaps in the regard of salt resistant crops needs to be addressed in order to secure Europe's self-sustainability in food and feed production.

In accordance with the minipaper "Quality aspects of plant varieties in response to soil salinity" table 2 shows some ideas to coordinate the efforts in operational groups:

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Table 2. Ideas for EIP-AGRI innovative projects/Operational Groups

TITLE	CONTEXT	DESCRIPTION	STAKEHOLDERS	EXPECTED RESULTS/ IMPACTS
1. Agronomic profiling of salt tolerance and product quality traits in European crops exposed to soil salinity	Show cases for the introduction of new tolerant crop varieties and/or varieties with better quality traits	Selection of species/cultivar suited to saline environments Small- and short-time experiments Context-specific analyses of salinization progression vs environmental parameters and quality improvements Training of farmers to farming systems under salinization processes Demonstration on different crop varieties (technical aspects and market opportunities)	Farmers Researchers Advisors Agribusiness Local authorities NGO associations /consumers	New market opportunities Screening for potentially labelling and branding foods Skills and knowledge transfer to farmers Rural cohesion in the territories Increased farmers returns Increased knowledge on ecosystem services Agro-ecological landscape preservation
2. Diversifying and promoting cropping systems	Territories where crop diversification should be increased	Introducing new crops in areas with monoculture/crop rotation Measuring ecosystem services Promoting local/regional distribution of the new crops Develop an environmental label	Farmers Society Participatory approach Advisors Researchers	Creating alternatives for areas where conventional agriculture has to face serious environmental constrains (salinity) and eventually abandonment/desertification Valuing agro-ecosystem services

5 Conclusions

Avoiding increasing soil salinity is a common goal most people can agree on. However, natural soil salinization, competition for water resources, and climate change are among the critical factors that will eventually lead to salinization of most susceptible areas. Ways have to be found to use salt affected agricultural land to produce high quality products for food and feed, increase farmers' income and contain land abandonment. Using and developing salt resistance of crops could and should be used for these purposes. Research on every level is the key to achieve these goals.

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References

Borrás, L. and Westgate, M. E. (2006): Predicting maize kernel sink capacity early in development. Field Crops Research. 95:223-233; doi:10.1016/j.fcr.2005.03.001

Davy, A.J., Bishop, G.F., Costa, C.S.B. (2001): Salicornia L. (*Salicornia pusilla* J. Woods, *S. ramosissima* J. Woods, *S. europaea* L., *S. obscura* P.W. Ball & Tutin, *S. nitens* P.W. Ball & Tutin, *S. fragilis* P.W. Ball & Tutin and *S. dolichostachya* Moss). Journal of Ecology 89(4): 681-707; doi: 10.1046/j.0022-0477.2001.00607

Gago, C., Sousa, A. R., Juliao, M., Miguel, G., Antunes, D. C., and Panagopoulos,T. (2011): Sustainable use of energy in the storage of halophytes used for food. Int. J. Ener. Environ. 5:592–599.

Im, S.-A., Kim, K., Lee, C.-K. (2006): Immunomodulatory activity of polysaccharides isolated from *Salicornia herbacea*. Int. Immunopharmacol. 6:1451–1458; doi:10.1016/j.intimp.2006.04.011

Matsuoka, Y., Vigouroux, Y., Goodman, M. M., Sanchez, J. G., Buckler, E. and Doebley J. (2002): A single domestication for maize shown by multilocus microsatellite genotyping. PNAS 99: 6080-6084; doi:10.1073/pnas.052125199

Kong, Y. and Zheng, Y. (2014): Potential of producing *Salicornia bigelovii* hydroponically as a vegetableat moderate NaCl salinity. HortScience, 49(9):1154-1157.

Schubert, S., A. Neubert, A. Schierholt, A. Sümer und C. Zörb (2009): Development of salt- resistant maize hybrids: The combination of physiological strategies using conventional breeding methods. Plant Sci. 177: 196-202

Ventura, Y. and Sagi, M. (2013): Halophyte crop cultivation: The case for *Salicornia* and *Sarcocornia*. Environmental and Experimental Botany, 92: 144-153; doi:10.1016/j.envexpbot.2012.07.010

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