Saving fresh water by crop cultivation on salinizing soils, a survey

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Abstract

Global soil salinization covers large coastal and inland areas as a result of climate warming and poor irrigation practices. Water supply for the cultivation of vegetable and fodder crops covers a major part of fresh water sources at the expense of drinking water and water for industrial purposes.

Salinity adapted crops are being cultivated in saline agriculture. Some high salt tolerant crops produce well under seawater (EC 40-50 dS/m) irrigation, other crops can be cultivated under brackish conditions. First we consider soil salinization viewed by soil scientists and crop physiologists. Second, we discuss the definition of salt tolerance of crops and measurement of salt tolerance in the field and other controlled indoor conditions. Growth response curves obtained under field or indoor conditions indicate how crop yield varies with increased salinity. Above a threshold salinity value in the curve, plant yield decreases with increased salinity (slope). Threshold salinity and slope values are generally applied to classify crops as salt tolerant, salt sensitive or intermediate. In saline agriculture crops are being cultivated as vegetable crops, fodder crops, ornamentals and as bio-energy crops. Use of large amounts of brackish water (salt concentrations ranging from 1 to 50% of that of seawater, EC values 0.1-25 dS/m), often regarded unsuitable for crop cultivation, can be successfully applied in saline agriculture, saving significant volumes or fresh water. There is an increasing need of salt tolerant crops for large scale saline agriculture at a global scale. Traditionally salt tolerance crops have been obtained by selection and breeding. Alternatively improved salt tolerance of crops can be obtained by genetic engineering. Genes involved in salt tolerance may be transferred and activated in salt sensitive crops.

Keywords: Salinization, saline agriculture, salt tolerance, crops, green manure, sugar beet, biofuel

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1 Global warming, rising seawater level, salinizing soil, the need to save fresh water

Currently agriculture has to compete with domestic and industrial uses for fresh water. Good quality fresh water is rapidly becoming a limited and expensive resource in particular since sea level rise through global warming is causing salinity of ground and surface water to increase. Attempts to reduce of the use of fresh water for drinking water purposes and industrial purposes appear to fail since the world population of humans is steadily increasing. In addition irrigation in semi-arid and arid areas with high evapotranspiration rates gradually leads to soil salinization, which may be irreversible. For a world-wide survey of risks and opportunities of saline groundwater we refer to van Weert et al. 2009 and http://www.un-igrac.org/publications/342. Fresh water is a limited resource and may get depleted at least locally and temporarily. In contrast the availability of brackish and more saline water is unlimited. While only about 1% of the water on earth is fresh, there is an equivalent supply of brackish water (1%) and a vast quantity of seawater (98%). If brackish water and seawater could be used for crop cultivation on salinizing soils vast amounts of fresh water will be saved (Rozema and Flowers 2008).

2 Agricultural exploitation of brackish and saline water

In this paper we briefly consider global soil salinization and –as an adaptive strategy- the realistic option of practicing saline agriculture. Salt tolerant crops are needed with good yield under irrigation with brackish water with salt concentrations ranging from 1 to 50% of that of seawater or even 100% seawater. As a result fresh water will be saved. To obtain crops with improved salt tolerance a more detailed understanding of the molecular mechanisms and genes involved in salt tolerance is needed.

Our paper presents an overview of recent national and international progress of saline agriculture with some examples. The purpose of our paper is to consider salt tolerant agriculture as an adaptation option to depleting fresh water sources, to show its potential and review research problems solved and others to be answered. We explain the notion of saline agriculture and the salt tolerant crops needed. We briefly discuss the criteria of salt tolerance from an agricultural point of view and the molecular mechanisms of salt tolerance of plants. We describe a few examples of practicing saline agriculture and finally we evaluate the research approaches to obtain improved salt tolerance of crops by genetic engineering and conventional breeding and the perspective of saline agriculture.

3 Saline agriculture and salt tolerance of crops, hydroponic and field studies

Saline agriculture is crop cultivation by irrigation with brackish and more saline water as well as crop cultivation on salinized soil. Saline agriculture may not only deliver food products for human consumption such as vegetables and fruits, cattle fodder, raw materials for industrial use, but also biofuel and biodiesel (Yuan et al 2008; Asif and Muneer 2007; Balat and Balat 2009; Liu et al 2012) .

In saline agriculture saline or brackish water is used to irrigate crops which are adapted to increased salinity. A few vegetable crops, such as *Salicornia* can be irrigated with seawater, with a NaCl concentration of about 500 mM (or about EC 50 dS/m)(Katschnig et al. 2013). *Salicornia* belongs to a specialized family in the plant kingdom where almost uniquely such seawater salinity tolerance has evolved. The majority of crops in saline agriculture do not grow well under seawater irrigation, but produce valuable yields when cultivated with brackish (salt concentrations ranging from 1 to 50% of that of seawater) irrigation water. The salt tolerance of crops can be characterized by a threshold salinity (EC dS/m) above which the crop yield is significantly decreased and the slope quantifying the yield reduction with further increased salinity of the root zone of the crop (Fig.1).

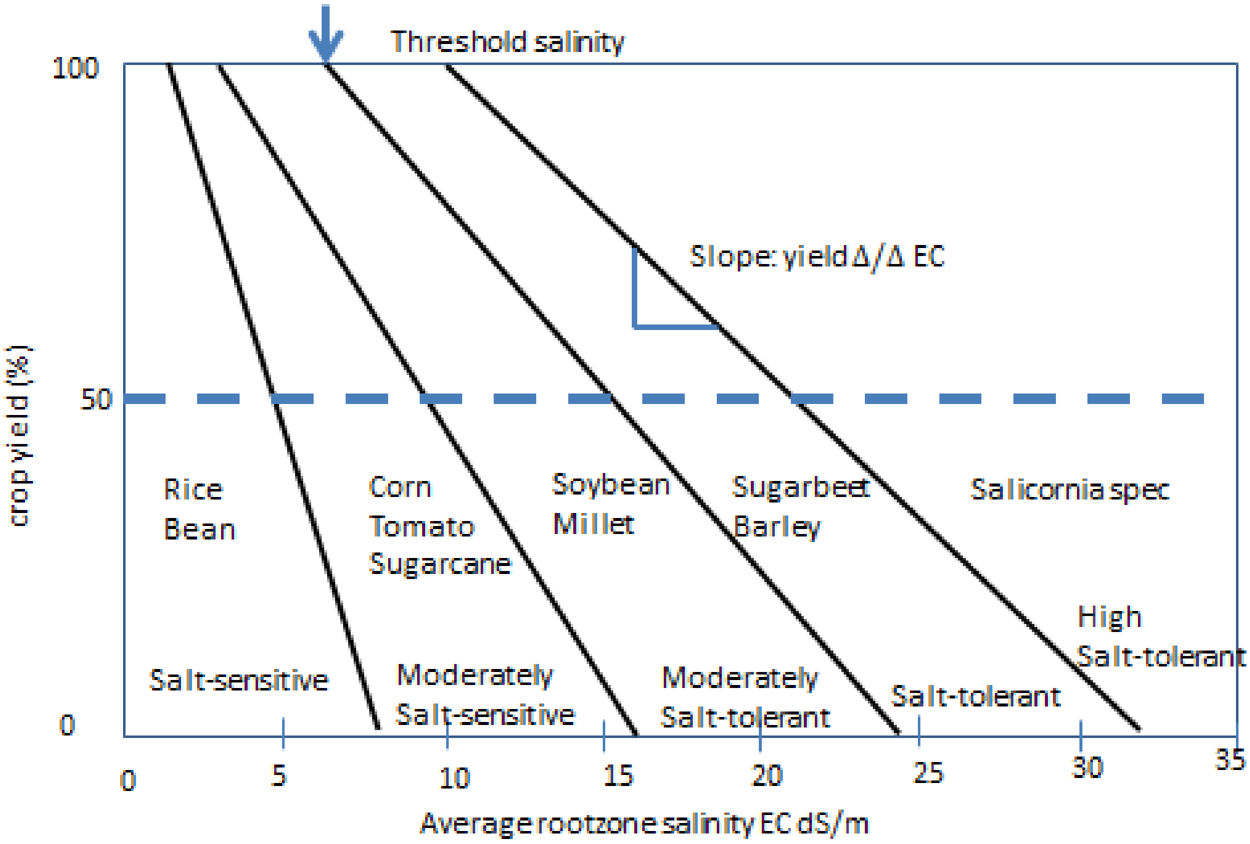
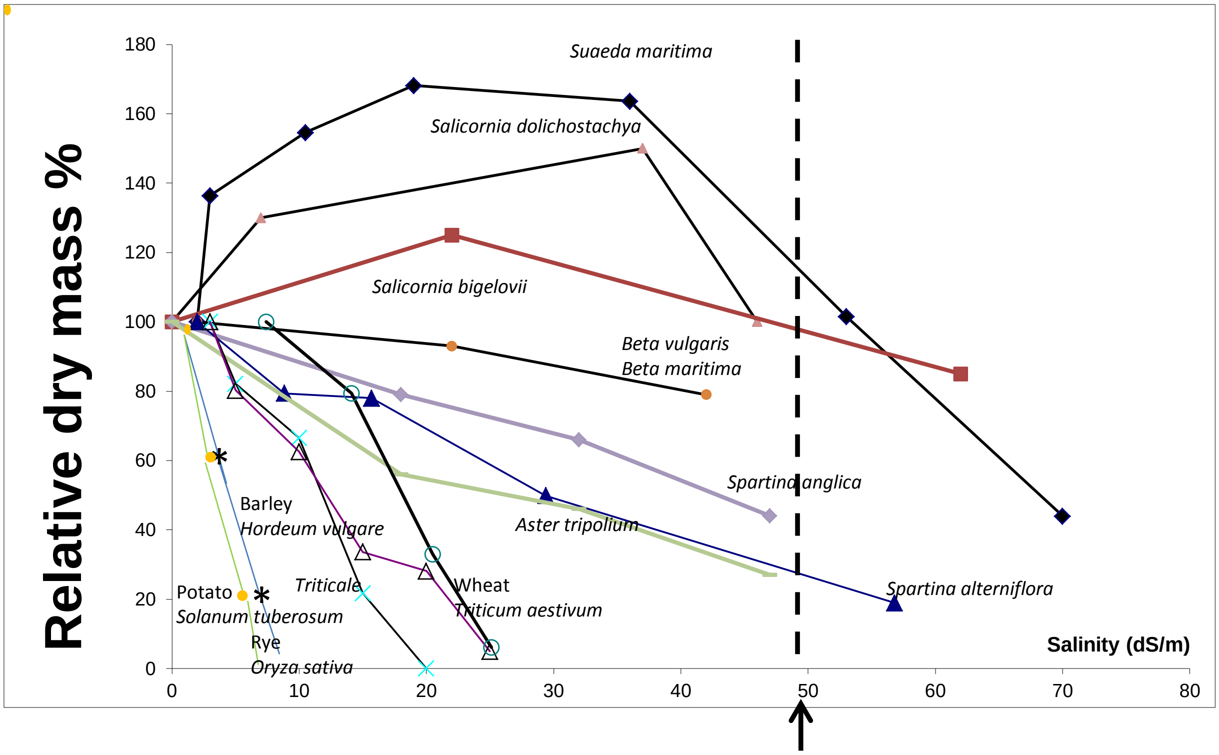


Fig.1. Threshold salinity and slope criteria for the salt tolerance of crops. Salinity of the root zone expressed as ds/m Electrical Conductivity. Above EC 30 dS/m no cultivation of conventional crops is possible, although green tips of the salt march halophyte species grow well under seawater drip irrigation (Katschnig et al. 2012; Katschnig et al. 2013) (Fig. 1). With 50 % of the maximum yield crop as target, crop cultivation could be feasible up to about EC soil salinity 15 dS/m.

The threshold salinity-slope criteria for salt tolerance have been developed by the United States Department of Agriculture (USDA) salinity lab in Riverside, California, and is based on correlative data of crop yield in relation to EC values of the irrigation water or salinity of the crop root zone (Maas and Hoffman 1977). The latter root zone salinity may be assessed as Electrical Conductivity (EC) of a saturated paste of the soil. The Electrical Conductivity of a solution extracted from a soil wetted to a saturation paste is measured. In practice, the soil: solution ratio ranges from 1:2 to 1:5 and is intended to approximate the water content of the soil under field conditions. However depending on weather, climate and soil type, the water content of the soil under field conditions is variable. Therefore, we prefer in many cases to assess the EC values of the soil moisture by measuring fresh and dry weight of the sampled soil, measure the EC of a soil extract and calculate the EC value of the soil moisture, in which the crops are rooting. Such EC soil moisture values are more close to the EC values of the salinity measured in hydroponic studies (Fig.2). Hydroponic salinity studies are generally performed indoor under controlled light, humidity and temperature conditions (Katschnig et al 2013; Rozema and Schat 2013; de Vos et al. 2013). EC values of the culture solution in hydroponic studies do not vary and plant roots of crops experience the same salinity throughout the root environment. In the field soil moisture salinity varies with depth and surface salinity may increase with increased evapotranspiration, while soil salinity is reduced with rainfall. So, in the field there may be considerable spatial and temporal variation of soil moisture salinity. Qualitatively the ranking of crops from salt-sensitive, moderately salt-sensitive, moderately salt-tolerant to salt-tolerant derived from the threshold-slope criteria (Fig. 1) agrees well with those obtained from the salinity-growth response curves of the plant dry mass (Fig. 2). Quantitatively values of the salt-tolerance criteria derived from the two systems may vary considerable. In addition, soil salinity is variable in time and space and plant roots show halotropism, which means a response of plant roots to avoid a saline environment (Calavan-Ampudia et al. 2013). In a soil with variable soil salinity, plant roots tend to grow away from saline to less saline sites. This is not possible in hydroculture, since plant roots experience the same salinity throughout the root solution. As a result, salt tolerance inferred from field studies may differ from hydroponic studies.



Seawater 50 dS/m ≈ 500 mM NaCl ≈ 30 g NaCl/L

Fig. 2 Salinity-growth response curves of the dry mass of native plant species and crops. EC (dS/m) values of culture solutions in indoor hydroponic studies under controlled light, temperature and humidity conditions. The Modified after Rozema and Schat (2013). The vertical interrupted line indicates the EC salinity of seawater.

The curves in Fig. 1 indicate that salt tolerance of crops such as wheat, barley, potato and rice is substantially lower than that of wild plant species. In contrast, dry mass increase of some succulent native plant species (*Salicornia* spec. and *Suaeda* spec.) from salt marshes is enhanced under increased salinity (EC 10-40 dS/m) compared to the control salinity (EC 0 dS/m). *Salicornia* species (a.o. *Salicornia dolichostachya* and *Salicornia bigelovii*) are cultivated using seawater (Fig. 2) and brackish water and their green tips are now widely consumed as vegetable crops (www.zeekraalwijzer.nl/).

Among crops sugar beet and seabeet are relatively salt tolerant (Fig. 1; Table 1) . Rice, tomato and potato are relatively salt sensitive crops. Breeding and selection among cultivars attempts to obtain improved salt tolerance. Field trials on the Island of Texel are underway to identify potato varieties with enhanced salt tolerance. Alternatively improved salt tolerance of crops can be obtained by genetic engineering.

Fig 3. Seawater drip irrigation of *Salicornia dolichostachya* on the Island of Texel (Katschnig et al. 2012). At the background the Waddensea. Green tips of various *Salicornia* species are cut from native plants from coastal salt marshes or from cultivated *Salicornia* plants irrigated with brackish water or seawater. Photograph Diana Katschnig

Table 1 Salt tolerance of crops based on threshold EC salinity value (dS m^{-1}) and slope assessing the percentage yield decrease per unit increase of salinity (EC dS m^{-1}) above the threshold value. Salinity represents the salinity of the irrigation water or the salinity of a saturated soil paste extract. Modified After Maas and Hoffman (1977); Maas (1985); Rozema (1991); Rozema and Verhoef (1997).

Crop species	Threshold value (dS m^{-1})	Slope (% yield decrease per unit dS m^{-1})
Salt tolerant crops		
Barley, *Hordeum vulgare*	8.0	5.0
Cotton, *Gossypium hirsutum*	7.7	5.2
Sugarbeet, *Beta vulgaris*	7.0	5.9
Wheat, *Triticum aestivum*	8.6	3.0
Moderately salt tolerant crops		
Soybean, *Glycine max*	5.0	20.0
Cowbean, *Vigna unguiculata*	4.9	12.0
Millet, *Sorghum bicolor*	6.8	16.0
Moderately salt sensitive crops		
Sugarcane, *Saccharum officinarum*	1.7	5.9
Corn, *Zea mays*	1.7	12.0
Broad bean, *Vicia faba*	1.6	9.6
Egyptian clover, *Trifolium alexandrium*	1.5	5.7
Cucumber, *Cucumis sativus*	2.5	13.0
Lettuce, *Lactuca sativa*	1.3	13.0
Tomato*, Lycopersicon esculentum*	2.5	9.9
Salt sensitive crops		
Rice, *Oryza sativa*	3.0	12.0
Potato, *Solanum tuberosum*	1.7	12
Bean, *Phaseolus vulgaris*	1.0	19.0
Carrot, *Daucus carota*	1.0	14.0
Grapefruit, *Citrus paradisi*	1.8	16.0
Orange, *Citrus sinensis*	1.7	16.0
Plum, *Prunus domestica*	1.5	18.0

4 Mechanisms of salt tolerance at the molecular level

Growth of most plant species is reduced under saline conditions. This growth reduction is caused by the adverse osmotic effects of salinity and followed by salt specific detrimental effects (Munns and Tester 2008). Salt tolerance in a low saline environment is often found to correlate with the capacity to maintain low shoot Na^+ levels (Munns and James 2003). However, plants in a high saline environment or exposed to long term salinity are better off by controlled absorbance and accumulation of Na^+, because under saline conditions water absorption is hampered in plants, which is caused by the low water potential of the external environment. Some salt adapted plants can use Na^+ as a cheap osmolyte and adjust their water potential to continue water absorption (Flowers and Colmer 2008).

To be able to use Na^+ as a cheap osmolyte, the plant has to store the Na^+ inside the vacuole. Inside the cytoplasm Na^+ would interfere with enzyme functioning, which is detrimental for cell functioning. Absorption and storage of Na^+ in the vacuole can lead to a water potential disequilibrium inside the cell. The synthesis of osmolytes in the cytoplasm is therefore important to maintain a water potential equilibrium within the cell. Compatible osmolytes protecting enzyme functioning include a.o. glycerol, mannitol, glutamate and proline and betaines. Many monocots do not use Na^+ as an osmolyte, but instead produce and accumulate osmolytes to lower the water potential of the plant. The production of osmolytes is energetically expensive, which often results in a growth reduction of these plants.

Another factor important for plants to be able to use Na^+ as a cheap osmolyte is the ability to tightly control Na^+ translocation and accumulation in the plant in order to avoid Na^+ of being toxic to the plant. Mechanisms to regulate the internal Na^+ translocation and accumulation include Na^+ influx into the roots, Na^+ efflux from the roots back to the soil, Na^+ loading and retrieval from the xylem, Na^+ efflux from cells and compartmentation of Na^+ into the vacuole (Munns and Tester, 2008, Flowers and Colmer 2008). Main groups of ion channels and Na^+ transporters involved in these processes are: the plasma membrane Na^+/H^+-antiporter SOS1, the Na^+-transporters of the HKT family and the tonoplast membrane Na^+/H^+-antiporter NHX1. (Fig. 4).

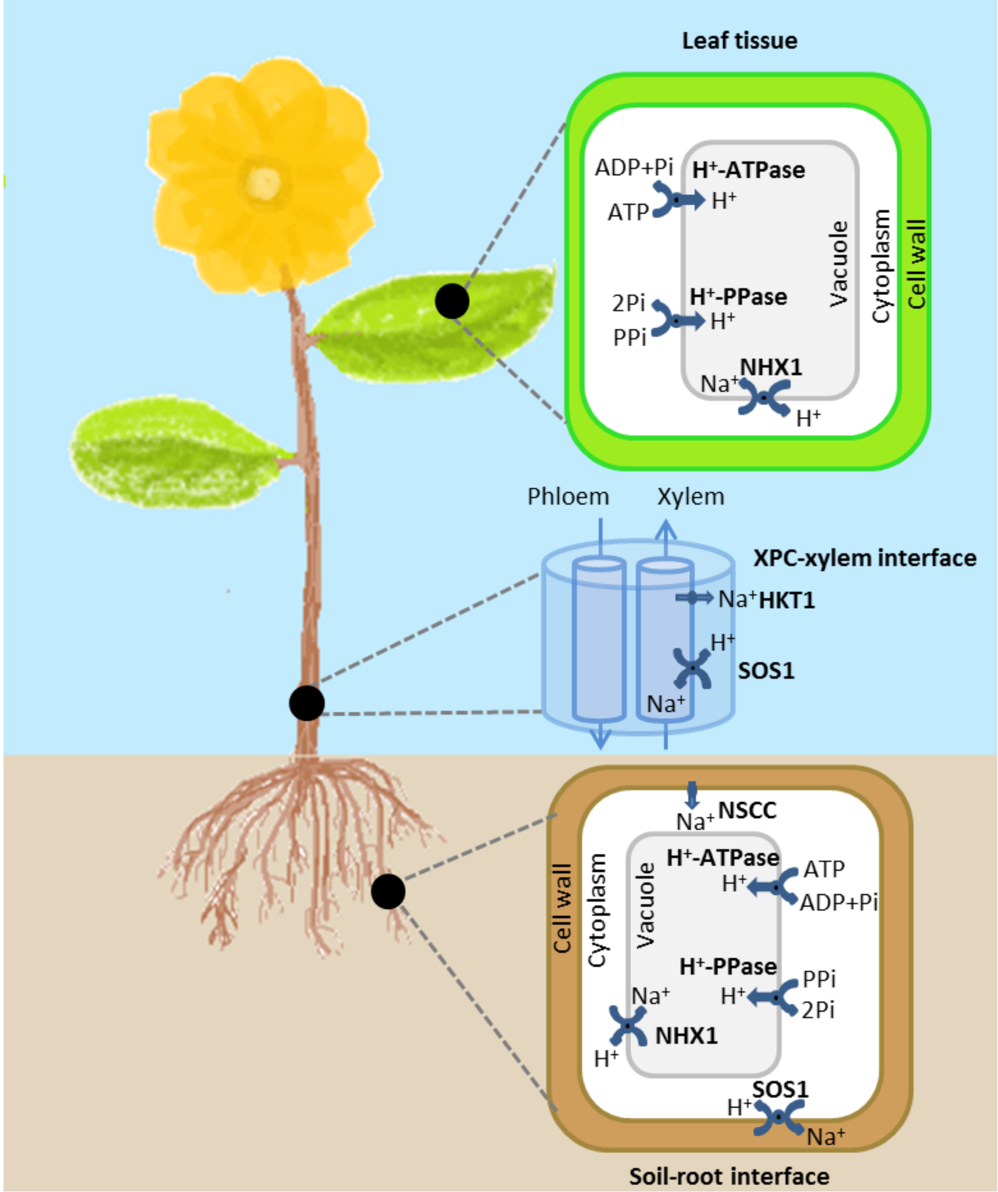


Fig. 4. Mechanisms of Na^+ transport at the soil-root and at the xylem parenchyma cell (XPC)-xylem interfaces and at the leaf tissue. Na^+ transport is mediated by ion channels, uniporters and H^+-coupled antiporters. Abbreviations: NSCC: non-selective cation channel, NHX1: Na^+/H^+-exchanger 1, SOS1: salt-overly sensitive 1, HKT: high-affinity K^+ transporter 1, ATP: adenosine triphosphate, ADP: adenosine diphosphate, P_i: inorganic phosphate. For references and more details on the functioning of transporters, antiporters and genes involved we refer to the PhD Thesis of Katschnig 2014.

5. Genes involved in salt tolerance

Salt overly sensitive 1 (SOS1). (SOS1) has been identified as a necessity to salt tolerance in *Thellungiella salsuginea*. However, how SOS1 exactly affects plant salt tolerance is not clear. At the cellular level the plasma membrane located antiporter SOS1 primary functions in secondary active Na^+ efflux across the plasma membrane, although other cellular functions have also been proposed. The *in planta* role of SOS1 is still a subject of debate. In *Arabidopsis*, SOS1 has been localized to the epidermal cells of the root tips and to parenchyma cells surrounding the vasculature of roots and shoots. Within the root, SOS1 has opposite effects on Na^+ concentrations in the inner and outer part of the root. Expressions of *SOS1* in epidermal cells of the roots lead to lower Na^+ concentrations in the plant by extruding Na^+ from the root (Shabala *et al.* 2005). On the contrary, expression of *SOS1* in the xylem parenchyma cells, where it functions in the loading of Na^+ into the xylem, leads to accumulation of Na^+ in the shoot (Munns and Tester 2008).

High-affinity K^+ transporter (HKT)

The high-affinity K^+ transporter (HKT) gene family has been a recent focus of studies investigating plant salt tolerance (Almeida *et al.* 2013). Members of the HKT gene family can be divided into two classes, class 1 and class 2. members of the HKT1 gene family code for proteins functioning as low affinity Na^+ influx transporters, the HKT2 members are Na^+-K^+-co-transporters (Munns and Tester 2008). *Arabidopsis* only possesses one member of the HKT family: *AtHKT1;1*. The *in planta* role of AtHKT1;1 has been a subject of discussion. After the first suggested role for AtHKT1;1 in root sodium influx was discarded showing that root sodium influx was not lower in *athkt1;1* than in wild type plants. Based on reduced Na^+ in phloem in the *athkt1;1* mutants a so-called recirculation model, was formulated in which it was proposed that ATHKT1;1 might work by reloading excessive shoot Na^+ into the phloem (Berthomieu *et al.* 2003). Evidence against this model was provided with Na^+ tracer flux studies (Tester and Davenport 2003, Davenport *et al.* 2007). Later the exclusion model was proposed by Sunarpi *et al.* 2005. They showed that *athkt1;1* mutants accumulate more Na^+ in shoots and xylem sap than wild type plants, and that AtHKT1;1 was located at the plasma membrane of xylem parenchyma cells. In this exclusion model HKT1;1 functioned by retrieving Na^+ from the xylem sap into the parenchyma cells, preventing excessive Na^+ from reaching the photosynthetic tissue in the shoots. Support for the exclusion model was later provided using cell specific overexpressing of *AtHKT1;1* in xylem parenchyma cells. Increased influx in these cells resulted in more salt tolerant plants (Moller *et al.* 2009, Plett *et al.* 2010).

Na^+, K^+/ H^+ antiporter (NHX)

Improved plant salt tolerance is often claimed by constitutive over-expression of the vacuolar Na^+, K^+/ H^+ antiporter *NHX1*. In contrast, also the opposite, no effect of over expression of *NHX1* on plant salt tolerance was found. NHX1 functions in Na^+ and K^+ compartmentalization into the vacuole. This compartmentalization of Na^+ in the vacuole is thought to be a strategy to avoid build-up of Na^+ in the cytoplasm, where it is toxic to enzyme functioning (Glenn *et al.* 1999). NHX1 gene expression was shown to be increased in shoots of various plant species upon salinity, in glycophytes (*Arabidopsis*), as well as in halophytes (*Suaeda salsa* ; *Atriplex gmelinii*). As NHX1 is a Na^+/K^+-H^+ antiporter which transports Na^+ against its concentration gradient, it needs the electrochemical gradient created by the proton pumps to provide the energy for this transport. Therefore, it is of importance to consider the H^+ pumps in this regard, the V-type H^+-ATPase and the H^+-PPase . Because H^+-ATPase has different task, it is most likely that the V-H^+-PPase provides the energy necessary for increased transport of Na^+ by NHX (Shabala 2013).

6 Breeding for increased salt tolerance in crop plants

Salt tolerance in plants is determined by a number of different genes (Flowers and Flowers 2005). This genetic complexity makes it difficult to engineer salt tolerant crops. Moreover, the lack of understanding of all genes involved in salt tolerance (Fig. 4) hampers the efforts to improve crop salt tolerance. The pros and cons of different strategies to enhance crop salt tolerance have been discussed in several publications: Flowers and Colmer (2008); Flowers and Flowers (2005); Rozema and Schat (2013); Shabala (2013).

7 Durum wheat, an example of improved salt tolerance by genetic engineering and conventional breeding

Conventional breeding, accelerated by molecular work has proved to be a successful strategy. As shown by increased salt tolerant of wheat by breeding with the use of molecular markers in the near proximity of the tolerance trait (Munns et al. 2012) who managed to increase the seed grain yield of durum wheat by using the ancestral gene pool. Wheat is worldwide one of the most important cereal crops. Therefore, increasing salt tolerance in wheat is of major importance. Improved growth of wheat under saline conditions is correlated with its ability to exclude Na^+ from its shoots, and maintenance of a low Na^+ concentration in the photosynthetic tissue. An ancestor of durum wheat, bread wheat, was found to be better capable of excluding Na^+ from its shoot than the commercial durum wheat. Munns and co-workers crossed the gene in the gene locus *Nax2*, *TmHKT1;5*, which is only present in bread wheat, into durum wheat. *TmHKT1;5* is expressed in the xylem parenchyma cells and functions in the retrieval of Na^+ from the xylem, which prevents Na^+ from reaching the shoots. As a consequence of the lower Na^+ concentration in the shoot, due to the presence of *TmHKT1;5*, the salinity tolerance of durum was substantially increased. They further showed that the observed increase in salinity tolerance was also stable under field conditions. Growing the wheat under saline field conditions resulted in an increase of seed yield of 25% in comparison with the wheat without the *TmHKT1;5* gene (Munns et al. 2012). Thus, the seed yield of durum wheat was substantially improved under saline field conditions by the introduction of an ancestral gene originating from bread wheat through selective breeding. While wheat and durum wheat are relatively salt tolerant crops (threshold value 8.6 dS/m; slope 3.0) it remains to be seen if similar improved salt tolerance can be obtained in a salt sensitive cereal crops such as rice with a threshold 3.0 dS/m; slope 12.0 (Table 1).

8 Legumes for green manuring under brackish drip irrigation, an example field study

The research into salt tolerance mechanisms and underlying genetics ultimately should lead to putting saline agriculture into practice. Below we describe an experimental field in The Netherlands with results of field trials with green manures .

1. On a one-hectare experimental field on the Wadden island of Texel numerous plant species are being tested for their salt tolerance every year. This experimental field (*www.**ziltproefbedrijf**.nl/*) uses an automatic drip irrigation system to supply 8 x 20 meter plots with water of the following conductivity values: 1, 4, 8, 12, 16, 20 and 32 dS/m. Every salt level is replicated eight times. The goal of this field site is to enable the salt tolerance measurements under field conditions of various species and to analyze aspects of salt tolerance of crops (Bruning and Rozema 2013; Bruning et al. 2014). For example, a potato (*Solanum tuberosum*) variety has been identified producing well under irrigation with a salinity (De Vos et al., in prep).


Melilotus officinalis


Medicago sativa

Fig. 5. The response of two legume species *Melilotus officinalis* and *Medicago* sativa to increased salinity (EC values in dS/m; 20 dS/m ~ 200 mM NaCl) of drip irrigation water on the experimental field on the Island of Texel. Note the pencil of which the length (14 cm) indicates the scale. Photograph Bas Bruning.

Other research focusses on the identification of a legume species (Fabaceae) to be used as a green manure in a saline agricultural system. Adding nitrogen to a saline agricultural cropping system using legumes as green manure would greatly improve the sustainability of the system (Bruning and Rozema 2013). Such sustainable green manuring is needed since the production of synthetic fertilizer is currently responsible for about 2% of the global energy production. Additionally, application of synthetic fertilizer leads to eutrophication of natural ecosystems. Fig. 5 shows the growth of two legume species, *Melilotus officinalis* and *Medicago sativa*, at varying salt concentrations. *Medicago sativa* is a commercially important legume species and often reported to be moderately salt sensitive (i.e. Noble et al. 1984) and the genus *Melilotus* contains many species that are tolerant to salinity considering they are glycophytes (Rogers et al. 2008). The plants in the picture are 11 weeks old and the salinity treatment started four weeks after sowing.

Both species persist at 20 dS/m after seven weeks of salinity treatment, all though we know from experience from previous years that *Medicago sativa* at 20 dS/m will not survive in the long term. The plants in the picture demonstrate a classic Maas and Hoffmann (1977) graph at which the threshold value for both species appears to be at 8 dS/m. It is clear from the pictures that *Melilotus officinalis* grows larger than *Medicago sativa* (see marker for size reference).

Additionally, this species obtains almost all of its nitrogen via symbiotic fixation (Bruning et al., submitted), even at high salinity levels. Large nodules are visible in the picture up until the highest salt concentration (Fig. 5). This is important since the process of nitrogen fixation is often reported to be more sensitive to salinity than general plant growth is (Delgado et al. 1994). Thus, *Melilotus officinalis* appears to be a suitable candidate to be used as green manure because it produces a significant percentage of its maximum biomass at salinity levels between 8 and 16 dS/m and shows abundant nodulation at those salt levels.

9 Sugarbeet cultivation on salinized land in China for bio-ethanol production

In a Chinese-Dutch cooperative project, we aim to grow sugarbeet on salinized arable land (Zhang et al. 2011) in the province of Shandong with the goal to convert sugars contained in the beet to bio-ethanol for bio-fuel purposes. Saline agriculture may thereby deliver not only vegetable and fodder crops, but also biomass and carbohydrates for bioenergy purposes (Asif and Muneer 2007; *cf* Rozema and Flowers 2008; Yuan et al. 2008; Liu et al. 2012; Rozema and Schat 2013).The conversion of sugarbeet sugar into ethanol is more efficient than that of carbohydrates in cereal crops. As compared to other crops grown for bio-ethanol such as sugar cane and corn which are both salt sensitive, salt tolerance of sugarbeet enables cultivation in saline soils. Also in comparison with the production of bio-diesel extracted from the seeds of soy (*Glycine max*), canola (*Brassica napus)*, other oilseeds and palm fruits, the current production of ethanol from sugarbeet requires less land per unit of biofuel than does biodiesel (Yuan et al 2008; Asif and Muneer 2007; Balat and Balat 2009; Liu et al 2012).

During the growing seasons of 2013 and 2014 preliminary field trials of sugarbeet sowing, germination and growth on an experimental field at the salinized arable land in Shandong were performed. There was limited and variable germination and seedling emergence both after manual and mechanical sowing, probably as a result of high and variable soil salinity. Sensitivity to salinity of germination of sugarbeet and salt tolerance during later growing stages of sugarbeet has been reported (Bernstein and Hayward 1958; Durrant et al. 1974; Rozema 1975; Zare et al. 2012). Locally, with sufficiently lowered soil salinity after irrigation with fresh Yellow River water and natural precipitation, substantial sugarbeet growth occurred. However, sugarbeet appeared to be susceptible to anoxic conditions (Rozema et al. 1985; Drew 1997; Colmer and Flowers 2008) occurring in the flooded soil after monsoon rains in July and August (Fig.6).

Fig. 6 Paper pot precultivated sugarbeet plants (left) to be transplanted to the tip of furrows ploughed on the land. Photograph right represents experimental flooding of sugar beet plants, simulating summer monsoon rains. Sugar beet plants are susceptible to anoxic soil conditions in such waterlogged soils. Photograph Barry Ammeraal.

In 2014 we used paper pot pre-cultivation (Fig. 6, left) of sugar beet plants which were transplanted at the beginning of the growing seasons to the tip of furrows on the field. Sugar beet plants on the tips of the furrows survive flooding conditions as a result of monsoon rainfall.

As part of the project, here we compare possible differences of salt tolerance among commercially available sugarbeet cultivars (*Beta vulgaris*) and compare that with salt tolerance of its ancestor seabeet (*Beta maritima),* by exposing seedlings to increased salinity in hydroponic culture and measure growth rate and its components.

10 Perspective of saline agriculture

The practice of saline irrigation water for crop cultivation started only some decades ago. Experimental trials using seawater and mixed saline and fresh water have been conducted world-wide. We refer therefore to papers in the special Issue Sustainable cultivation and exploitation of halophyte crops in a salinizing world (Rozema et al. 2013). A benefit of using saline water in agriculture is that seawater contains most macro- and micronutrients which are essential for crop growth and quality. Seawater is effectively an unlimited resource that is supplemented by massive volumes of brackish groundwater and waste water, all available for saline agriculture. Another benefit of saline agriculture is that growing halophytes may be combined with aquaculture of sea fish and shrimp. In such sustainable marine agrosystems, inorganic nutrients in the saline effluent from fish or shrimp ponds can be used to promote the growth of halophytes (Buhmann and Papenbrock 2013). Also saline drainage water (Ventura and Sagi 2013) can be used for the cultivation of saline crops.

Despite current progress i.e. the increased salt tolerance of Durum wheat (6), saline agriculture is still in great need of crops with improved salt tolerance. While wheat and durum wheat are relatively salt tolerant crops (threshold value EC 8.6 dS/m; slope 3.0 % yield decrease per unit dS m^{-1}) it remains to be seen if similar improved salt tolerance can be obtained in a salt sensitive cereal crop such as rice (*Oryza sativa,* threshold EC 3.0 dS/m; slope 12.0 % yield decrease per unit EC dS m^{-1}) (Table 1).

We consider it a real breakthrough if in the future by selection, breeding and genetic engineering the salt tolerance of the staple food crop rice (*Oryza sativa*) and potato (*Solanum tuberosum*, threshold 1.7 dS/m; slope 12) could be substantially improved. To achieve this a better understanding of the molecular functioning of the different transporters in crops under saline conditions is of first importance. Realistically, to obtain such high salt tolerance of crops, growing well under brackish conditions with salt concentrations up to 50% of that of seawater will take (a) decade(s) rather than years.

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