Salinity tolerance traits in three grass species
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CHAPTER 6

The future of saline dairy farming: making the best of a growing challenge

Liping Wang, Theo Elzenga
INTRODUCTION

The coming century is marked with various challenges in resources and environment (Panta et al., 2014; Duarte and Caçador, 2021). The conventional culture systems have caused a strain on freshwater availability and rising levels of saline groundwater, reaching the rooting zone of crops and adding to the concerns on salinization damage to agriculture (Sentis, 1996; Metternicht and Zinck, 2003). Salinity has become a problem of agriculture, constraining crop growth and animal husbandry systems (Amores et al., 2013; Islam et al., 2020; Uddin et al., 2019). Feeding the world’s growing populations in a sustainable way becomes one of our most pressing challenges in the future (Ritchie and Roser, 2017). Dairy and meat products play a pivotal role. In some areas dairy products and meat products provide more than 62% income (Arulmohi et al., 2017). However, the production of forage is becoming difficult by salinization of pasture land, threatening future sustainable development goals (SDGs) in the lives and livelihoods of dairy farmers. For future SDGs, sustainable animal husbandry and dairy farming systems are indispensable parts (Stoorvogel et al., 2017; Hülsmann and Ardakanian, 2018; Liu et al., 2018; van Noordwijk et al., 2018; Katarzyna et al., 2019).

Although the development of salt tolerant forage for animal husbandry has not specifically been targeted, initiatives to remedy the problems caused by salinity in the soil to agriculture in general, like salinity tolerance crop varieties, application plant growth promoting bacteria and fungi and different approaches to ameliorate salinization itself, have seen a steady increase. Some cases have been successfully launched worldwide; for example, saline farming is gaining popularity as a management practice for salt affected soils (Dagar et al., 2016, 2019; De Waegeamaeker, 2019; Negacz et al., 2021). However, the production of food and forage under saline conditions still deserves much more attention. One option, currently still not well studied, is the development of high nutritional and easily palatable halophytes for using as fodder. Halophytic plant species or varieties of species, are naturally well-adapted to salt affected soil, even requiring salinity for optimal growth, and in some cases obtain a better nutritional quality under saline conditions as these enhance the production of the secondary metabolites to adjust osmolality (Fokkema et al., 2016).

Halophyte agriculture and development—From halophyte agriculture to saline dairy farming

The exploration of growing crops under saline conditions, or halophyte agriculture, has been a topic of study for several decades. In 1947 one of the earliest initiatives, the US Salinity Laboratory at Riverside was launched. In the beginning of 21 century, the International Center for Biosaline Agriculture (ICBA) was founded in the United Arab Emirates. And recently, more countries, including Australia, the Netherlands, Russia, China, Morocco and Egypt, have initiated similar bio-saline agriculture centers at different scales (Negacz et al., 2021). From the very start the identification and dissemination of suitable salt-tolerant forage species to enable profitable farming on salt affected soil was a main goal (Rogers and Bailey, 1963; Semple et al., 1998, 2003; Masters et al., 2001; Masters, 2015). Also, in the Netherlands with a decades long, strong research tradition in identifying salt-tolerant varieties of common crops such as potato, cabbage, carrot, cauliflower and beets (De Vos et al., 2016; Van Straten et al., 2016). These successful crops have already been introduced to other coastal areas such as Bangladesh. Australian farmers
have been using halophytic shrubs and herbaceous species to incorporate into their farming systems for almost a century. The species tested at saline sites across southern Australia have also been tested in Iran as part of an international project (Khorsandi and Siadati, 2017).

Halophytes were considered as the best potential sources for saline farming due to their inherent resistance to salinity and ability of completing their life cycle at >200 mM NaCl conditions (Glenn et al., 1999; Flowers and Colmer, 2008; Mishra et al., 2017). Using naturally halophytic plants is low cost and immediately feasible. Halophytic species are abundant in most coastal areas like the Wadden sea region or the Mediterranean. Moreover, halophytes are highly diverse and often have a perennial life cycle. Halophytes that are used in bio-saline based agroecosystems often have multiple uses: they are grown for food or forage, have nutraceutical properties, and are planted as part of remediation efforts (Duarte and Caçador, 2021). Halophytes, such as Salicornia species and Portulaca oleracea have medicinal value (Pereira et al., 2017, Hwess et al., 2018). Some species have a high nutritional value as they are rich in Omega-3 fatty acid and vitamin A, vitamin C, Mg, K, Ca and Fe mineral elements (Simopoulos, 2004). More recently, the essential oils in halophytes that were used as additives to animal feed proved to be beneficial to health and productivity of ruminants (Oliveira et al., 2020; Oliveira et al., 2021).

Systematic analyses of salt tolerant varieties of crop species on different soil types have been underway the last decades, for example at Saline Farming on the Wadden Sea island of Texel in the Netherlands, where a test facility of sandy soil had been established. The Salt Solution project in coastal Bangladesh, closely associated with the Texel initiative successfully introduced salt-tolerant crops in combination with innovations in soil and water management (De Vos et al., 2021). Ben Hamed et al., (2021) highlight some effective activities that achieved sustainable farming systems in the Mediterranean area. Using salt-tolerant halophytes varieties can be a successful approach in combination with non-traditional farming practices, such as intercropping, crop rotation and aquaponics (Ben Hamed et al., 2021). Using freshwater (from surface water source) together with saline water (groundwater with ECw varying from 6 to 10 dS/m) and applying this through different systems of irrigation (furrow and drip) on several different crops (alfalfa, date palms and okra) proved feasible in in the Moroccan Tafilalt oasis. About 40% water was saved compared to furrow irrigation, while allowing farmers to produce reasonable yield (Choukr-Allah, 2021).

At a global level, saline agriculture is expected to expand to about 93.2 × 10^9 kg by 2030 and thereby cover at least 50% of food needs (Hazbavi and Silabi, 2021). However, with climate change the expected growth of traditional crops and pastures will become even more uncertain in the driest areas. Based on model studies on the predicted need for food it has been suggested to focus on increasing the use of saline land for pastures (O’Connell et al., 2006). The most effective strategies are diversifying farms separating crop and livestock areas: using elite perennial halophytic shrubs, augmented by perennial grasses and short-season annual legumes, the saline or dry areas could be made productive as pasture, for breeding sheep and cattle (Fereidoun et al., 2019). One of the remaining challenges is the nutritive value, i.e. the nutrients quality and palatability, of halophytes forages for grazing animals. Researchers and farmers need more skills and expertise in the building of saltland pastures to explore future saline farming (Norman et al., 2004, 2008, 2016; Lymbery et al., 2013, Choukr-Allah, 2021).
Saline dairy farming - Growing fodder on saline soils a way to improve fodder quality

The Poaceae family, or grasses, are used in pasture land and as fodder, sometimes mixed with Leguminous forage, worldwide in both dry land and wet environments (floodplains and drained peatlands). This use of grasses in dairy farming, cattle and sheep breeding is projected to remain at a very high level. By growing halophytic grasses in salt affected soil or originally natural saline areas (like the coastal floodplains), farmers can set up future sustainable saline farming. The salt tolerant grasses that would be most suitable, do show specific acclimation strategy to environmental conditions with a low water potential by adjusting osmotically by increasing their organic solute content rather than accumulating salt. These species and varieties can potentially become precious resources for future sustainable husbandry as the nutritional quality even increases under saline conditions that are limiting to growth and yield for most traditional crop species.

On Schiermonnikoog, a barrier island in the Wadden Sea of the northern coast of the Netherlands, *Puccinellia maritima*, Seaside alkali grass, growing lower elevation sites and thus frequently flooded and exposed to seawater, were highly preferred by geese grazing in the salt marsh meadows during the summer season, while other species were avoided (Fokkema et al., 2016). The specific environmental conditions on the coastal meadow influence the nutritional value of grassland species that were being grazed by small herbivores and yearling cows. The nutritional value of *Puccinellia maritima* actually improves under salt stress as the osmotic adjustment is predominantly by the synthesis of easily digestible, small organic compounds. This energy consuming strategy to deal with high soil salinity levels, is for *Puccinellia*, a species that does not have salt glands to expel NaCl, the mechanism to survive saline conditions. Being highly palatable could even be a very big competitive advantage, as less grazing-tolerant herbs and forbs will be eliminated by the grazing itself, and grazing-tolerant grasses become more prone to salinity stress when frequently grazed.

Not all the salt tolerant species acclimate to high salinity by increasing the osmotic value through synthesis of secondary metabolites, such as carbohydrate and amino acid; only non-true halophytic grasses do. True halophytic species increase the leaf osmotic potential by increasing the salt content which causes unpalatability for animals. The Improvement of nutritive value of plants growing on marginal land, characterized by drought or salinity, was already proposed as a plant selection goal (Monjardino et al., 2010; Monjardino et al., 2015).

**BOUNDARY CONDITIONS TO APPLY SALINE DAIRY FARM SYSTEM**

As discussed above, the development of halophyte agriculture is seen worldwide as a challenge and desired goals seem currently reachable. The marginal areas that are currently not suitable for crop growth, like coastal areas suffering from salt intrusion or dry inland areas affected by salt, could be made productive by saline dairy farming systems. What are the conditions that have to be met for a sustainable saline dairy (or agriculture) system? Saline agriculture can only be implemented when seeds/plants, soil and water/irrigation form a system of matching components. To evaluate the feasibility and evaluations of (1) yield, nutritious and marketing
value of the crop; (2) the impact of the project (what are for instance the longer term effects of irrigation with brackish water?); (3) marketing of novel crops; (4) contribution to the Sustainable Development Goals (SDG) (for instance an assessment to improving livelihoods and welfare) (De Vos et al., 2021; Wijbenga and De Zilte Smaak, 2021).

**CHOOSE OF SPECIES AND/OR VARIETIES**

The species must be profitable for development of local livelihood. The species used in saline farming need to have high yield and a high market value. The halophytic crop plant can be either staple crops, vegetables, or fodder plants for husbandry animals. The main plant families containing halophytic species are Chenopodiaceae, Poaceae, Avicenniaceae, Caryophyllaceae and Compositae (Badri and Ludidi, 2021). The certain institutional level test for the yield potential of several salt-tolerant crops is needed before using in the field (Bruning et al., 2015; De Vos et al., 2016). Salinity tolerant species have been identified that potentially could be developed in a profitable cultured plant, either as a crop for human food, for fodder, or for energy (biofuel), but also as a source for pharmaceutical or cosmetic compounds (Wijbenga and De Zilte Smaak, 2021; Pereira et al., 2017; Hwess et al., 2018).

**Figure 6.1 The Value of the plant that accumulates different osmolarity during salinity stress and the potential use value score (0-10, including use for food, fodder, drinks, seasoning, fuel, medicinal and culinary etc.) Accumulating of NaCl in firstly give a certain amount of salt to animal as needed, in some case even used as facial and body care product for its salt element, thus the value will firstly increase however, this profit will end when plants accumulating too much salt as they became too salty and produce more by-product that are harmful. Accumulation of Toxic during salinity stress is no profit at all. Accumulation of carbohydrate and amino acids and protein will be the most ideal plant with high value that might bio-synthesis organic matters in the cell thus increasing the osmotic potential to confront with the in vitro salty environment. accumulation of medical content during salinity stress will give profit for the medical component. Due to oxidative stress and photosynthesis limitation we suppose not all the way up line for value score. the value will, however, decrease when osmolarity becomes too high.**
### Table 6.1 Accumulation of content during osmotic adjustment under salinity

<table>
<thead>
<tr>
<th>Osmolarity</th>
<th>NaCl</th>
<th>toxic compounds:</th>
<th>Carbohydrate</th>
<th>Proline, Amino acids,</th>
<th>phenols, phenolic acid etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant</td>
<td></td>
<td>Lipids of Organic acids, Alkaloids, etc.</td>
<td>Protein, Glycinebetaine</td>
<td>Puccinellia maritima (Fokkema et al., 2016; Faustino et al., 2019); Matricaria chamomilla (Cik et al., 2009); Hordeum marinum (Huang et al., 2018); Sweet marjoram and sweet fennel (Abd EL-Azim and Ahmed, 2009); Hordeum vulgare (Jones and Storey, 1978)</td>
<td>Aerva javanica (Ul-Hassan and Bano, 2015); Mentha pulegium (Queslati et al., 2010); Matricaria chamomilla (Cik et al., 2009); Cat~haranthus roseus (Osman et al., 2007); Nigella sativa (Bourgou et al., 2010); Matricaria chamomilla (Cik et al., 2009); Mentha spicata (Al-Amier and Craker, 2007)</td>
</tr>
<tr>
<td>Salicornia (ssp, Katschnig, 2015; Lv et al., 2012); Aster tripolium, Atriplex halimus (Valderrabano et al., 1996); Sporobolus ssp (Naidoo and Naidoo, 1998); Salicornia spp.</td>
<td>Puccinellia maritima (Fokkema et al., 2016; Faustino et al., 2019); Matricaria chamomilla (Cik et al., 2009); Hordeum marinum (Huang et al., 2018); Sweet marjoram and sweet fennel (Abd EL-Azim and Ahmed, 2009); Hordeum vulgare (Jones and Storey, 1978)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Achillea fragrantissima (Abd EL-Azim and Ahmed, 2009); Catharanthus roseus (Jaleel et al., 2008); Solanum nigrum (Bhat et al., 2008)</td>
<td></td>
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</table>
The future of saline dairy farming: making the best of a growing challenge

SETTING UP OF SALT FARMS

The salt farms that are located in coastal regions or salt affected dry land areas, usually have to deal with fresh water scarcity. Frequent monitoring of salinity levels in the soil is essential. Knowing the salt level before and after seasonal farming activities, and even before and after rainfall, is essential to keep the system sustainable. The fresh water used for irrigation can be generated from salty water or from collected and stored rainwater. The cultivation practice for seasonal, year-round rotation, and intercropping should be also pre-tested. The successful and unsuccessful use of halophytes in intercropping and crop rotation systems conducted at either greenhouse or open fields are summarized in Ben Hamed et al., (2021). For dairy farming the set of requirements should also include the availability of fresh water intake for feeding animals after salty feed.

QUALITY OF THE FARMING ACTIVITIES

Sustainable saline dairy farming is strongly dependent on the species selection of true halophytes (accumulate NaCl as osmotic adjustment) or non-true halophytes (in vivo biosynthesis of osmotically active organic compounds). The true halophytes, such as found in the Amaranthaceae family, are able to grow in saline environments however by using salt, stored in the vacuole, for the osmotic adjustment (Flowers and Colmer, 2015). In addition, they produce secondary metabolites that can potentially be toxic. In Saltbush (Atriplex nummularia), accumulation of oxalate was shown to be associated with the uptake of nitrate, as opposed to ammonium, by the plants (Al Daini et al., 2013). Utilizing these plants as forage for ruminants is problematic as the accumulated salt must be excreted and the harmful content must be degraded, leaving almost no nutritional value (Masters et al., 2005a; Norman et al., 2013, 2016). When sheep graze on this kind of halophytes they need to have access to fresh water to excrete the harmful compounds. Sheep can drink up to 12 liters of water per day, and their feed intake decreases as the concentration of the salt in the diet increases (Warren et al., 1990; Masters et al., 2005b). Therefore, care has to be taken to avoid the potential disadvantages of using halophytes: (a) low digestibility, (b) unpalatability, and (c) high concentrations of potentially toxic compounds like oxalate in leaves (Norman et al., 2004; Masters, 2015).

PROSPECT TO DEVELOP SALINE DAIRY FARMING

The extent of salinization is difficult to estimate, however extremely high, threatening the primary production system, coastal biodiversity, and human health. Shahid et al., (2018) counted the total area of saline and sodic lands occupying about 10% of worldwide arable land. however, many countries with salinity threat are surfing major water scarcity problems thus recall of efficient use of freshwater and irrigation systems are not applicable, although it can play a major role in restoring freshwater agriculture in degraded soils (Negacz et al., 2019; Negacz et al., 2021). If salinity cannot be cheaply managed for sustainable agriculture, one of the best options to obtain production from saline land and maintain the salt marsh ecosystem is to
develop salt-tolerant plants (halophytes) that have value as fodder for ruminant livestock (such as sheep and cattle). Animal-source foods are nutritionally dense sources matching particularly well with the nutrients needed by people. Richness in energy, protein, and various essential micronutrients simultaneously support normal development, physiological functioning, and overall good health (Smith et al., 2013). Saline pasture with non-true halophyte potentially containing small organic compounds support grazing animals with more carbohydrate amino acids thus making the development of saline dairy farming feasible.

The idea of using salinity tolerance crops in saline conditions is not new. However, there are still high demands to increase opportunities and capacities to produce available food under saline soil and low water conditions. Researchers and farmers need collaboratively making efforts to incorporate salt-tolerant forages into domestic farming systems. Although much more successful stories have been made. However, in the remaining space development, identification and dissemination of more suitable valuable herbaceous species and halophytic forages, such as *P. maritima*, still under high demands, particularly regarding nutritive value for grazing animals. As well as research of economically and social viable modeling for the sustainability of the farming system. The more non-true halophyte needs to be explored for a high quality sustainable saline dairy farm system.

The further study at physiological and molecular level is highly needed. The candidate genes involved in the osmotic acclimation could become targets in the breeding programs aimed at increasing the nutritional value without higher fertilizer requirements. The cost for saline farming is always higher than “normal” agriculture, especially during the start-up phase. After a series of strictly controlled tests, the harvested halophytes crop has to prove itself on the food market.

In this thesis, we tested three grass species that are rarely used/common used, from normal land and from saline land, even some with wide distribution. We mimicked the grazing of plant, and tested different growth media to understand the factors of salinity tolerance of grass. In the other chapter we tested the ion transport of plants and the influence of endophyte in growth and ion transport. *Puccinellia maritima* is supposed to be a model for forage grasses under saline conditions in comparison with two of the other cultivated grass species *Festuca rubra* and *Lolium perenne*. Thus, we believe salt marsh grasses such as *P. maritima* can be used as a potential fodder for scale up production for future saline dairy farms, also cattle and sheep. We highlight the importance of exploring the halophytes and should consider the endophytic fungi that benefit plants in harsh conditions. For the building up of a future salt farm, not only the halophyte plant itself is important. In breeding programs, these different traits could be exploited, within subspecies as they are examples associated with (temporary) reduced above ground productivity.