PLANT RESEARCH INTERNATIONAL

WAGENINGEN UR

Perspectives for the growth of salt tolerant cash crops

A case study with potato

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Report 572

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Plant Research International, part of Wageningen UR
Business Unit Agrosystems
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Executive summary

Irrigated agriculture is the biggest consumer of freshwater as worldwide more than 40% of the food production is from irrigated land. More than 30% of the world's irrigated areas suffer from salinity problems. During the past century, salinity has even been accelerated, resulting in a gradual loss of high quality farm land and grazing land. Thus, salinity remains one of the most serious threats to agriculture as it may have negative effects on crop yield. This emphasises the urgency to develop new ways to deal with salinity in agricultural practice. In this report we review the effects of salt on plants and their natural tolerance mechanisms to cope with salinity.

We focus on the question how to anticipate on or even benefit from plants' tolerance mechanisms in the cultivation of cash crops. We mention different farm management systems that may result in a more resilient agricultural practice under brackish or saline circumstances. To get more insight in the approach and in how to find hands-on solutions for the local situation we elaborate a Case Study on potato. The choice for potato is obvious as this staple crop is fast becoming the most important cash crop in the world, its market perspectives in developing countries are increasing according to FAO trend analyses and last but not least, potato has the lowest Water Footprint compared to other staple crops.

In literature, potato has been classified as moderately sensitive to salinity. Although, salinity will generally decrease shoot growth and the proportion of extra-large tubers, it will not affect tuber number, and sometimes even result in a higher dry matter tuber yield. We show that for potato different strategies are effective to optimize crop growth under saline conditions with respect to: 1) irrigation practices, 2) soil coverage by mulching, 3) intercropping or mixed cropping and 4) possible integration with aquaculture. We will discuss the requirements for a sustainable irrigation management and the confrontation with dilemma's.

Finally, we shortly highlight the way forward. We consider cooperation between the "Golden Triangle" Government, Business and Research to be highly useful in further advancing the "more crop per drop" opportunities as every partner can contribute from its own mandate: Government from its responsibility for institutional arrangements; Business from its access to venture capital and Research from its possibilities to expand knowledge. Therefore, we recommend to formulate future proposals with respect to PPP issues together with the public and private sector and plea for an integrated approach. For a research agenda we identified following urgent theme's: development of smart rotations, integration of agricultural systems, valorization of valuable secondary metabolites, attention to effects of irrigation frequency, attention to long run (thousands of years) interest and smart technologies to prevent pollution of water resources.

May 2014

1. Plant growth under saline environmental conditions

More than 6% of world's land and 30% of the world's irrigated areas suffer from salinity problems (Jensen *et al.*, 2000). Meanwhile, the increased population and a severe imbalance of human nutrition challenge the world's agricultural production. Salinity remains one of the most serious environmental problems and over the past century, it has even been accelerated, resulting in a gradual loss of high quality farm land and grazing land (Shannon and Grieve, 1998; Jensen *et al.*, 2000). So, new ways to deal with salinity in agricultural practice have to be developed. This review will shortly address the backgrounds of salt tolerance and then focus on the question: How to anticipate on or even benefit from plants' tolerance mechanisms in the cultivation of cash crops?

1.1 Effects of salinity on plant species

Soil salinity may have two effects on plant growth. Firstly, it impedes water uptake by roots because a lower soil potential (i.e. soil matric potential + osmotic potential) reduces the gradient for water movement into a plant. This is referred to as the osmotic effect of salinity and is similar to the effect of drought. Secondly, salt entering the plant in the transpiration stream will injure the cells in the leaves, as both sodium and chloride (probably mainly sodium) inhibit enzyme activities in the cytoplasm reducing growth (Greenway and Osmond, 1972; Flowers and Dalmond, 1992). This is called the salt-specific or ion-excess effect of salinity (Greenway and Munns, 1980). Figure 1 summarizes the deleterious effects of salinity on plant growth.

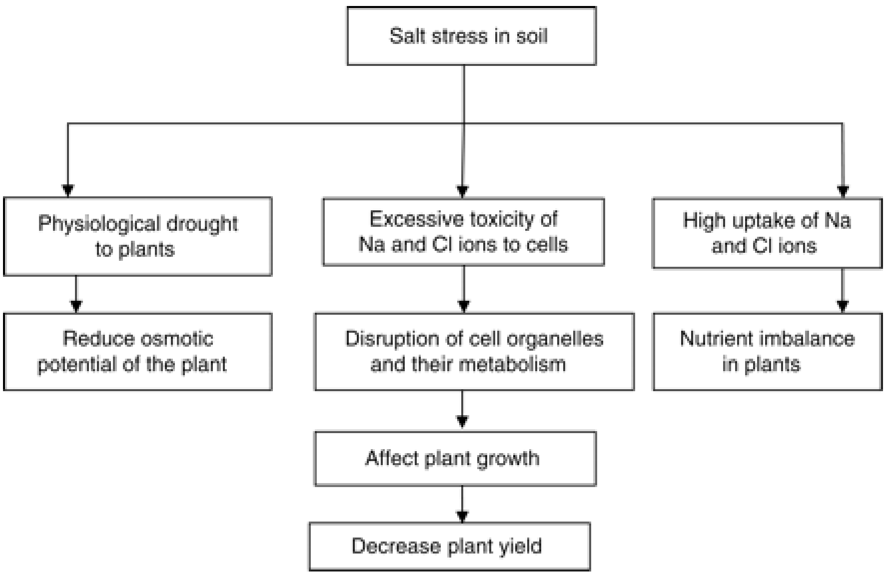

Figure 1. Effects of salt stress on plant growth (Evelin et al., 2009).

As shown in the figure, plants respond to the different forms of stress in different ways.

- Osmotic stress triggers the production of the hormone absciscic acid (ABA) in the root tips which causes (partially) stomatal closure and thus restricts photosynthesis. This affects plant growth immediately by a decrease of shoot growth, decrease of nutrient uptake, inhibition of the translocation of mineral nutrients, especially K, and changes in root/shoot ratio (Wang *et al.*, 2013). It introduces a rapid response for adaptation.
- Ionic stress however, develops over time due to a steady accumulation in the shoot and an inability to tolerate the ions that have accumulated. Ionic stress manifests its toxic effect after some days or weeks, depending on

the species, and is revealed in leaf and meristem damage or as symptoms typical of nutritional disorders and results in an increased senescence of the older leaves.

Depending upon the composition of the saline solution, the uptake of required nutrients may be disturbed due to competition effects among cations or anions (Bernstein *et al.*, 1974). Moreover, an increase of exchangeable sodium ions in the soil solution may lead to formation of sodium carbonate, which raises the pH (Bernstein *et al.*, 1974; Levy and Veilleux, 2007). These alkaline conditions reduce availability of nutrients, such as phosphate, iron, zinc and manganese, to the plants. Indeed, calcium deficiency symptoms are common when Na/Ca ratio is high in soil water (Kleemann, 2000; Olle and Bender, 2009).

1.2 Natural mechanisms of tolerance

Many plants have developed sophisticated devices to cope with salinity. Salt tolerance is a complex, quantitative, genetic character, controlled by many genes (Shannon and Grieve, 1998) and mechanisms of salinity tolerance fall into three categories (Munns and Tester, 2008):

1. Na exclusion to prevent Na from accumulating to toxic concentrations within leaves. Na^+ can be excluded either directly by the roots or - as often happens in halophytes - at leaf level by salt glands or salt bladders, excreting ions, mainly Na and Cl, from mesophyll tissues to leaf surfaces. Here solutes crystallize (Figure 2) and are eventually blown or washed away.
2. Accumulation of Na and Cl at the cellular and intracellular level to avoid toxic concentrations within the cytoplasm, especially in mesophyll cells in the leaf.
3. Osmotic adjustment. Plants may adjust to the osmotic stress by starting an active process of uptake of soil solutes (inorganic ions like K) and / or *de novo* synthesis of organic compounds. The ions will be sequestered in cell vacuoles, and organic solutes may accumulate both in the cytoplasm and in organelles to balance their osmotic effects. Generating organic solutes in a hypersaline soil can consume a large fraction of a plant's available energy at the expense of growth rate (Yeo, 1983).

Figure 2. Salt crystals on salt grass (from Flikr).

Figure 3 summarizes the adaptive responses of plants to ionic and osmotic stress.

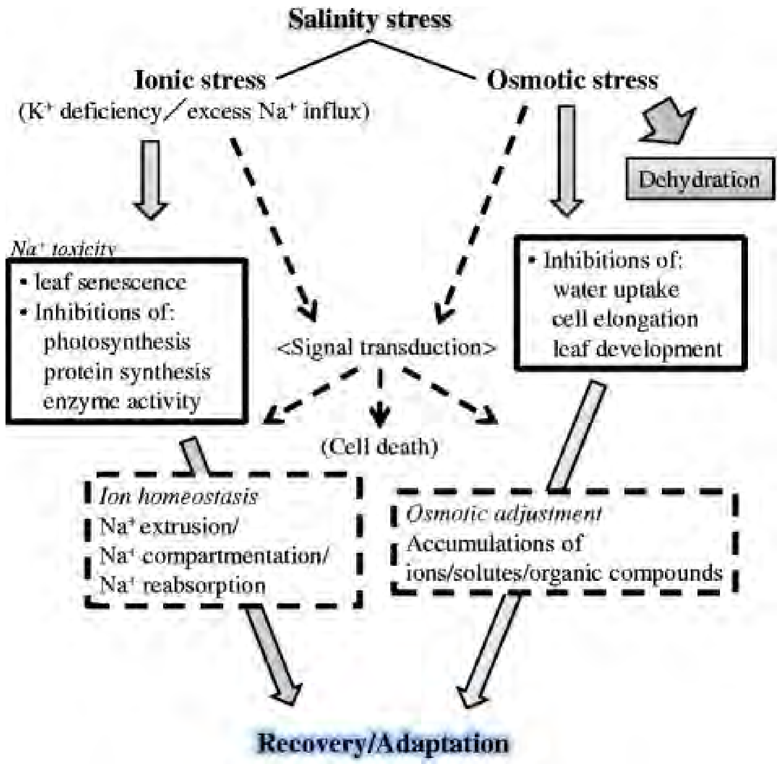

Figure 3. Adaptive responses of plants to different forms of salt stress (Oliveira et al., 2013).

The relative importance of the three adaptation processes clearly varies with plant species, but may also vary with the length of exposure to salinity, the concentration of the salt, and local environmental conditions, i.e. soil water supply in relation to transpiration demand. Water use efficiency (WUE) bears on this outcome and can range from 2 to 9 g dry mass produced per kilogram water transpired depending upon evaporative conditions. In winter months, WUE is highest and salts will not concentrate in leaves to the same extent as they would during summer when WUE is lowest.

1.3 Growing cash crops under brackish or saline conditions

In agricultural practice, salt tolerance parameters under salt stress are: yield, tolerance during germination, conservation of root- and shoot dry weight, shoot number, leaf size, canopy volume, resistance to leaf damage, maintenance of flowering, seed and fruit set, leaf and fruit quality. As depicted in Figure 4, plants differ greatly in their tolerance to salinity and the degree to which growth is reduced (Munns and Tester, 2008).

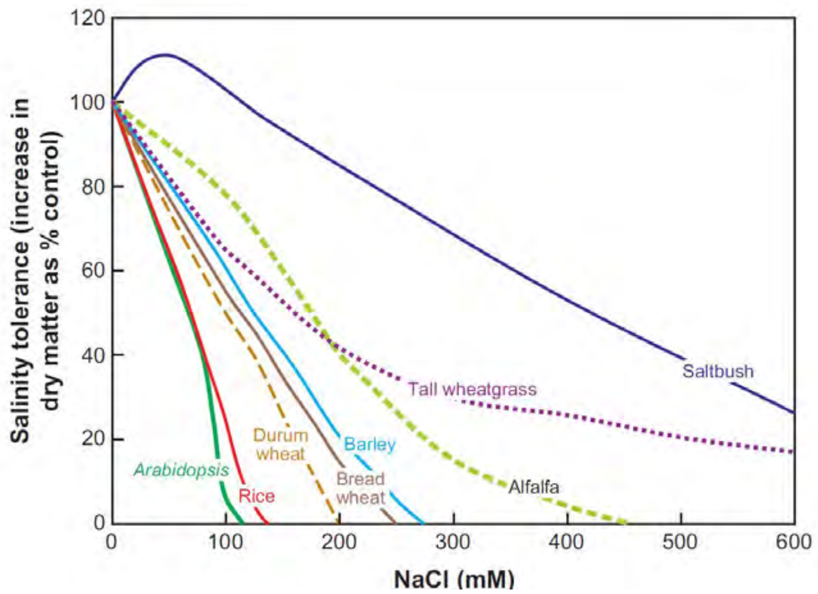

Figure 4. Diversity in salt tolerance of various plant species (Munns and Tester, 2008).

For practical use, salt tolerance can be adequately measured on the basis of two parameters (Shannon and Grieve, 1998): 1) the threshold (EC_t), the electrical conductivity as measured in the saturated extract and that is expected to cause the initial significant reduction in the maximum expected yield and 2) the slope (see Figure 5).

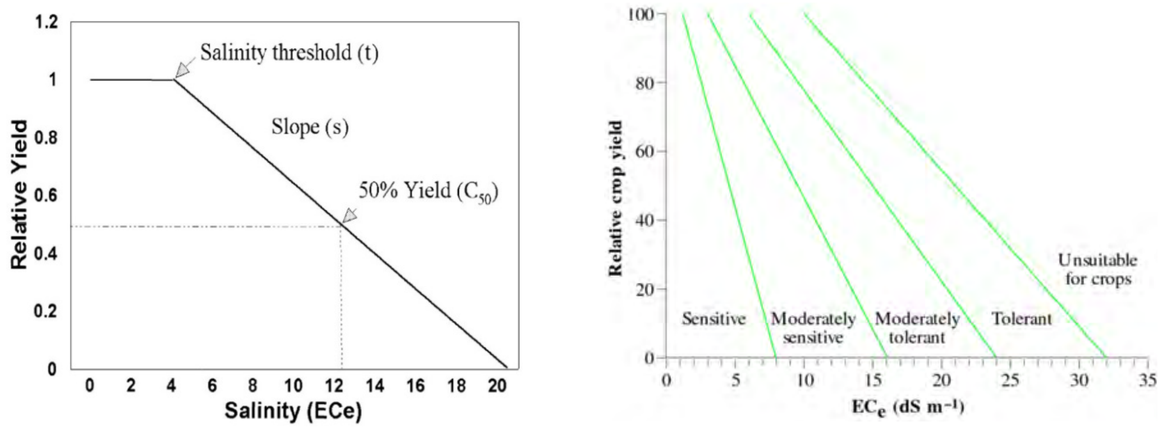

Figure 5. Salt tolerant parameters relating relative yield to increasing salinity in the root zone (left) and different categories for crops (right) (Shannon and Grieve, 1998).

How can salinity be expressed?

Salinity is the concentration of dissolved mineral salts present in waters and soils on a unit volume or weight basis. Increased saline conditions in the soil can have two major effects on plant growth: a) it causes osmotic hindrance for water uptake thereby reducing transpiration and crop growth, and/or b) specific solutes cause toxicity in the plant causing growth reduction.

While for a) total salt content is important, for b) the concentration of specific solutes matters. In literature different measures of salinity are considered, depending on the aim of the research. The total salt content is generally summarized by the electrical conductivity *(EC)* which increases as the total salt content increases. The *EC* is expressed as dS m^{-1} (= mS cm^{-1} or mmho cm^{-1}). Concentrations of specific solutes are expressed in g L^{-1}, mmol L^{-1} (mM), or meq L^{-1}. These two measures cannot be mutually compared: *EC* is determined by the sum of all solute concentrations (better: activities; however, not linearly), where a concentration refers to a single solute. In some cases, authors refer to salinity caused by NaCl and express it as a concentration measure.

Both the *EC* and the concentration in a soil solution may vary with varying water contents. This occurs, for example, when water and nutrient uptake by the roots occurs in a different ratio than the ratio in the soil solution. It also occurs at the soil surface where water evaporates and solutes remain in the soil. Although the true *EC* and true concentration around the roots will determine the actual osmotic hindrance or toxicity, crop salinity tolerance is sometimes related to the *EC* of a soil saturation extract: EC_e (dS m^{-1}). In this way the measure is standardized, and the *EC* value is not influenced by the local water content, as stated by Richards (1954) in the famous USDA handbook 60 on saline and sodic soils: "*The soluble-salt concentration in the saturation extract … tends to be about one-half of the concentration of the soil solution at the upper end of the field-moisture range and about one-fourth the concentration … at the lower, dry end of the field-moisture range. The salt-dilution effect that occurs in fine-textured soils, because of their higher moisture retention, is thus automatically taken into account. For this reason, the conductivity of the saturation extract (EC_e) can be used directly for appraising the effect of soil salinity on plant growth.*"

As an approximation (based on a log-log diagram) the total salt concentration expressed in meq L^{-1} equals a little more than 10 times the *EC* expressed in dS m^{-1} (Richards, 1954; his Figure 4).

Other standards for expressing soil salinity that have been used in literature are *EC* values of different soil:water by-volume extracts, such as 1:1.5, 1:2, and 1:5.

Table 1. Relative salt tolerance of selected group of cash crops from a broad survey by the USDA Salinity Laboratory Riverside (Shannon and Grieve, 1998).

Salt-tolerance category			
Sensitive	Moderately sensitive	Moderately tolerant	Tolerant
Almond	Broad bean	Beet	Barley
Apple	Cabbage	Broccoli	Bermuda grass
Apricot	Capsicum	Brome grass	Cotton
Avocado	Clover	Fescue, tall	Date
Bean	Cucumber	Olive	Sugar beet
Carrot	Grape	Ryegrass, perennial	
Citrus	Lettuce	Safflower	
Onion	Lucerne	Sorghum	
Peach	Maize	Wheat	
Plum	Peanut		
Strawberry	Potato		
	Spinach		
	Sugar Cane		
	Tomato		

Based on a broad survey by the USDA Salinity Laboratory at Riverside (Shannon and Grieve, 1998) a selected group of current cash crops has been categorized in the four levels of salinity tolerance (Table 1). Plant species do not only differ in their salt tolerance but often also in their bandwidth to withstand saline conditions (Figure 6). This allows farmers to select the most adequate crops for the actual salinity level and environmental conditions of their fields.

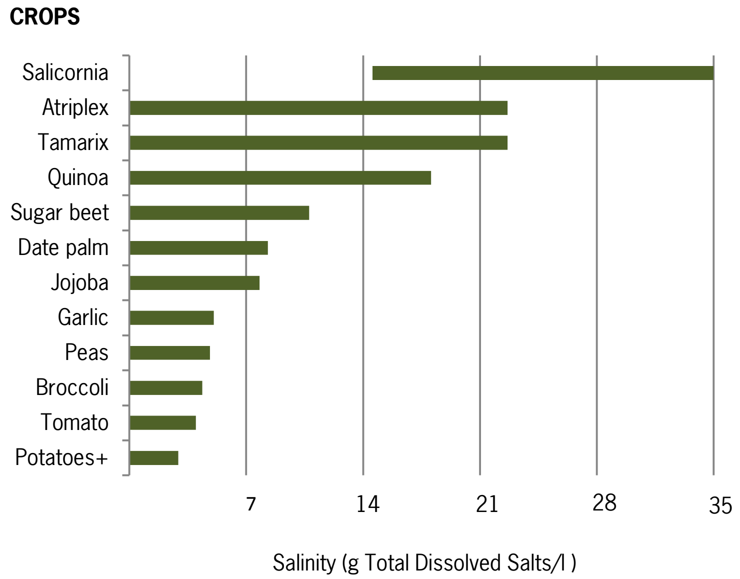

Figure 6. *Salinity tolerance of different cash crops and their bandwidth.*

Introduction of salt tolerant crop species like quinoa or sugar beet may result in more resilient crop rotations and high value cash crop products. Improvement of the production potential may arise from breeding for deep roots and increased transpiration efficiency.

2. Anticipating salinity in our agricultural approach

At the moment, irrigated agriculture is the biggest consumer of freshwater as worldwide more than 40% of the food production is from irrigated land (Jacobsen *et al.*, 2012). This emphasises the need to focus on water saving strategies and optimization of the possibilities to irrigate with brackish water. The potential for water saving by improving irrigation strategies has been estimated to be about 52% of the actual water use in agricultural production for Europe (Table 2).

Table 2. Initiatives to be carried out in agricultural practice and their water saving effects (Jacobsen et al., 2012).

Initiative	Water saving
Improvement of the conveyance of water to the field	22%
Use of waste water for irrigation	10%
Better irrigation scheduling	10%
Use of drip irrigation in row crops	10%

Apart from choosing salt tolerant crops or cultivars as described in the former chapter, salinity can also be anticipated through farm management, through precision agriculture techniques such as early warning of salt damage and on the long term through breeding programmes.

2.1 Farm management strategies

Many water saving irrigation strategies have already been described in literature (Jacobsen *et al.*, 2012). Irrigation with brackish water can be effective in flushing salt ions away from the root zone (sprinkler) or in causing a transport of salt ions towards the periphery of the root zone (drip irrigation). Moreover, with an alternating partial root zone drying irrigation regime, often termed Alternate Partial Root Drying (ARD or PRD), ABA production will be increased inducing partial stomatal closure and plants are triggered to increase Water Use Efficiency (WUE) and to modify their growth.

Sprinkler irrigation with brackish or saline water may cause injury to the leaves, while drip irrigation appears to be a better method for irrigation with saline water with a leaching requirement of 15-20% (Jacobsen, Jensen *et al.*, 2012). Drip irrigation has certain advantages (Hansen and May, 2011), as:

1. It will not cause foliar accumulation,
2. Soil in the wetted area around emitters where root density is the highest, salt accumulation is lowest,
3. High frequency drip irrigation applications can maintain a relatively constant soil water content and soil salinity level over time near the drip lines.

With drip irrigation, water is applied at local points at or just below the soil surface, while root water uptake occurs throughout the rooted zone and evaporation occurs at the complete soil surface. This results in unequal salt distribution in the top soil (e.g., Hanson and May, 2011).

Both drip and sprinkler irrigation can also have disadvantages as well. Especially in (semi-) arid regions with less that 400-450 mm annual rainfall, care should be taken to prevent a build-up of salinity (Smedema *et al.*, 1992).

When considering salinity in (drip) irrigation several aspects should be taken into account. Among them are (Abrol *et al.*, 1988):

- The effect on root water uptake (RWU). Since RWU is strongly correlated to yield this means that reduction in RWU will lead to reduction in yield.
- The effect of site conditions, mainly differences in soil types and climate.
- The effect of timing of irrigation, e.g., frequent versus less frequent irrigations.
- The effect of use of extra water for leaching, which may control the salinity in the root zone but may be harmful as the leachate may reach deeper groundwater which quality may then degraded.
- The effect of conjunctive use of fresh and saline water.

Depending on these aspects irrigation strategies may vary from situation to situation. There is a need to study what strategy is best for a given situation.

Apart from irrigation strategies also fertilization strategies can be effective to mitigate the effect of salinity. Different strategies are mentioned in the literature, like:

1. Increased fertilization with K (Elkhatib *et al.*, 2004; Romheld and Kirkby, 2010; Wang *et al.*, 2013). Due the similarities in physicochemical properties between Na and K, Na can compete with K during uptake and key metabolic processes. K deficiency can usually be observed under salinity stress. It has been found that an increasing K supply in a saline culture solution increased K concentrations in plant tissue corresponding with a decrease in Na content and an increase in plant growth and salt tolerance.
2. Foliar application with supplementary P and K (Malakondaiah and Rajeswararao, 1979a; Malakondaiah and Rajeswararao, 1979b; Kaya *et al.*, 2001; Hussein *et al.*, 2010). It has been shown for cereals, peanuts and different tomato cultivars that foliar spraying with a P/K-application can mitigate some of the negative effects of salinity on plant growth, and increased the concentrations of these nutrients in the leaves.

2.2 Early warning

An accurate irrigation regime in which water supply is optimally matched with plants' demand is an important aspect of precision agriculture. Detection and diagnosis of salinity is difficult in the early stages of its occurrence. Visual inspection of crops provides obvious clues to salt stress only after the condition is well advanced. Crop yields can significantly be reduced even when the plant shows no visible symptoms yet. Therefore, it is important to monitor levels of salinity with root depth at an early stage. Hillel (2000) provides useful examples of early warning models:

- Visual inspection of the soil surface to detect tell-tale signs of rising salt contents,
- Visual inspection of the crops to detect clues to the onset of salt stress (stunted growth, scorching of leaf tips, etc.),
- Planting salt-sensitive plants within the crop at regular intervals (and especially at locations known to be prone to salinity) as indicators of increasing salt concentrations,
- Monitoring the quality of the irrigation water, which may vary over the season,
- Monitoring the soil profile to detect changes in salinity by soil sampling or EC sensors (e.g., the new Dacom equipment as used in the STOP-project),
- Monitoring the salinity of the groundwater by sampling the water via observation wells or by using in situ EC-sensors,
- Measuring temperature of the crop canopy in comparison with the ambient air temperature to detect the occurrence of salinity induced stress,
- Assessing fractional areas infected with salinity by non-destructive methods, like IR photography of other remote sensing techniques,
- Applying modelling methods to assess and predict the interactive processes of water and salt dynamics. Predictions should be calibrated and validated by data from field measurements.

2.3 Breeding

Breeding for salinity tolerance has proven to be difficult due to its complex character of different mutual interacting or non-interacting mechanisms underlying salt tolerance (Witcombe *et al.*, 2008). Until the mid-1990s there was only limited success and there has only been little progress since then (Flowers and Flowers, 2005). A variety of approaches has been advocated, including conventional breeding, wide crossing, the use of physiological traits and, more recently, marker-assisted selection and the use of transgenic plants. None of these approaches offers a universal solution. Conventional breeding programmes have rarely delivered enhanced salt tolerance, while wide crossing generally reduces yield to unacceptably low levels (Witcombe *et al.*, 2008). There has been success using physiological criteria as the basis of selection of rice (Dedolph, 1997) and a similar approach has recently been advocated for wheat (Munns *et al.*, 2002).

Under field conditions a large number of distinct stress factor combinations can exist and multiple cycles of stress and recovery typically occur during the growth period of the plant. So, acclimation or adaptation to a combination of these abiotic stresses and relief cycles could be very different from the adaptation to a single stress event such as that studied in the laboratory (Mittler and Blumwald, 2010). Therefore, Witcombe *et al.* (2008) argued that the simplest approach to breeding for stress tolerance is also the most effective, namely to select for yield which is the integrating trait and to carry out the selection in a representative stress environment. This can be enhanced by the use of screens for stresses such as salinity where the stresses are carefully managed and by carefully choosing parents of crosses so that various physiological traits can be pyramided. Future breeding programmes that follow a 'systems biology' approach to integrate ‘omics’ databases with experimental results from both controlled and field studies will probably be the most informative. In the meantime, wide hybridization (with backcrossing to the most well-adapted parent) with selection in the target environment offers the best opportunity for widening the genetic base of stress resistance for sustainable agriculture.

3. Urgency to act now!

3.1 Global assessments

The concept of 'water security' has become a prominent feature in the global water agenda and in the international development discourse more generally (ADB, 2013). The concept acknowledges the synergies between water-dependent sectors and the need to consider these links when planning for effective water resources management and policy. The term has evolved from an early focus on national security and geopolitical concerns, to more recent definitions that incorporate interconnected socio-economic, environmental and risk-management dimensions. For example, Grey and Sadoff (2007) define water security as:
"the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies."

3.1.1 Is there enough water for "water security"?

The Comprehensive Assessment of Water Management in Agriculture, a five-year multi-disciplinary research program involving 700 scientists, concludes that there are sufficient water resources to produce food for a growing population, but that trends in consumption, production and environmental patterns, if continued, will lead to future water crises in many parts of the world (IWMI, 2007). Recent spikes in food prices, partially caused by the increasing demand for agricultural products in non-food uses, underline the urgent need to invest in agricultural production, of which water management is a crucial part.

3.1.2 The need for "more crop per drop"!

The Comprehensive Assessment also states that if we continue with business as usual, without further improvements in water productivity, by 2050, the amount of water evaporated in the required crop production will almost double from today's amount. So much water is not available. Therefore we require a fresh look at integrated approaches that combine different elements, including e.g. adapting irrigation to new needs, enhancing water productivity, using non-conventional water resources, and promoting the use of low-quality water in agriculture.

The need for targeted investments, while realising water is part of a larger system. Turral *et al.* (2010) provide a brief review of the development and current situation in global irrigation, and look at the drivers affecting irrigation performance, development and modernization. The conclusion is that the options for new developments are limited, and that future investment will need to be more precisely targeted to specific niches in different agro-ecological and economic contexts. The World Bank (2007) concludes that technical solutions on water management are no longer enough: "*water management must be seen holistically as part of a larger overall system, in recognition that the water sector is not an isolated "sector" but an integral part of a wider economic system*".

3.1.3 Extent of salt-affected soils

Salt-affected soils are located all over the world but they mainly occur in semi-arid and arid regions and also along the coastal belt of also humid regions (Wicke *et al.*, 2013). The global extent of salt-affected land, including wastelands and deserts, as calculated from the FAO Harmonized World Soil Database (Figure 7), amounts to 1.1 Gha. For comparison, the total agricultural land area worldwide (excluding pastures) extends to 1.5 Gha. It is important to note in this context again the continuous salinization of land (especially irrigated agricultural land in semi-arid and arid regions). Although the actual rate of salinization is not well studied, global irrigation-induced salinization is estimated at a rate of 0.25 to 0.5 Mha per year.

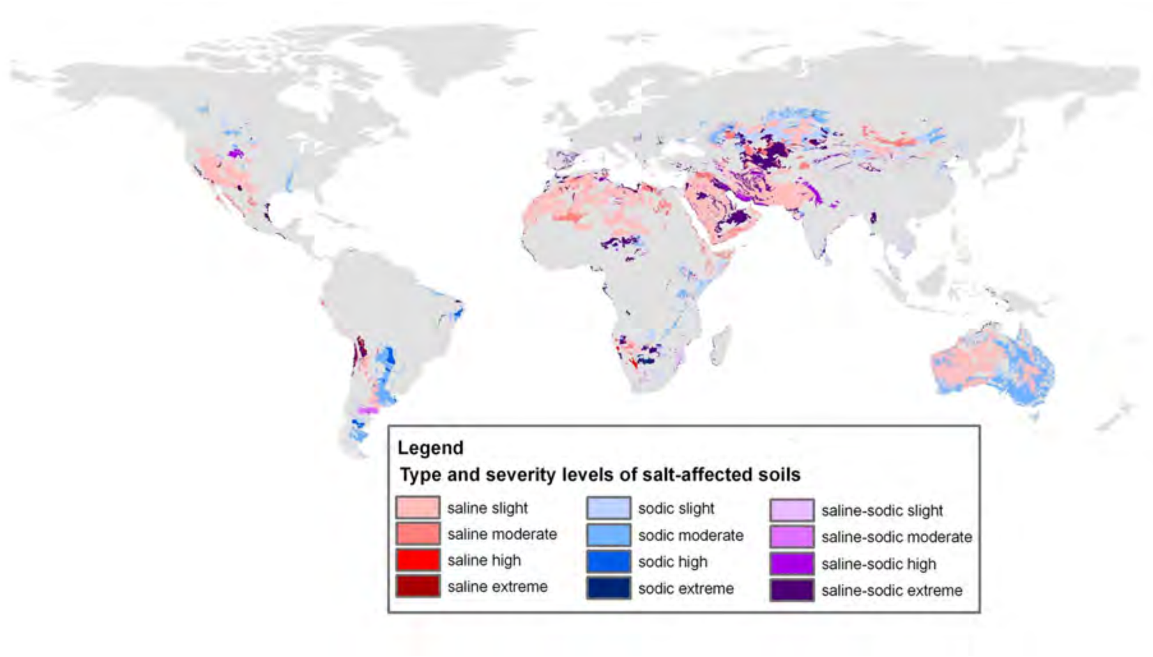

Figure 7. Worldwide salt-affected soils (From FAOSTAT).

3.2 Scale problems: global vs local!

There is a scale-problem with the 'global studies'. They certainly show the serious "water gap" in the overall water requirement (Figure 8) and the urgency to act. Moreover, they also point in the direction of potential solutions, including the already mentioned "more crop per drop". But, while the global studies are an excellent tool for 'agenda setting', the urgent actions that are required can only be taken at local level! This has far-reaching implications.

The extent of salt-affected soils all over the world, as well as the need to further develop non-conventional water resources, have created new opportunities as well. In many areas where until recently salinity was fought, including the Netherlands, it is now realised that in many instances it is much better to 'live with salinity' than to fight it! Accepting this paradigm shift learns us to look for opportunities instead of fighting the threats.

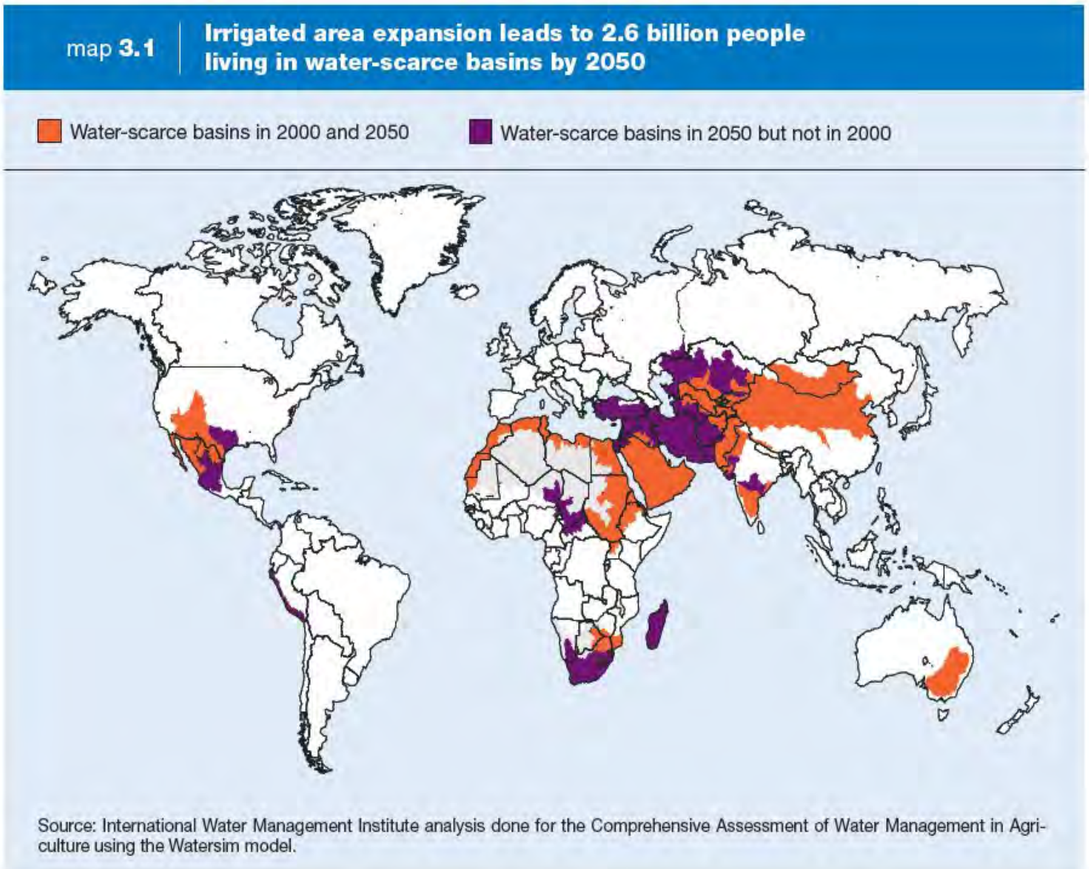

Figure 8. Global Water scarce basins in 2000 and 2050.

3.2.1 Local solutions

Salinity is often a local phenomenon and therefore local solutions to 'live with salinity' are site-specific. Moreover, because it is now widely accepted that the water sector is not an isolated "sector" but cross-cutting as an integral part of a wider economic system, there are more elements than just water to be taken into account when trying to enhance water productivity. Such elements are nation or region specific implying that there is not one single set of 'one-size-fits-all' solutions. The Netherlands, for instance, have a reputable knowledge in the realm of "more crop per drop" and it is well-known that "spectacular" water savings are possible when investment in technology and practices are targeted towards this goal (Figure 9). However, such improvements are only possible in specific situations and at local level. Extrapolation to the global level is difficult.

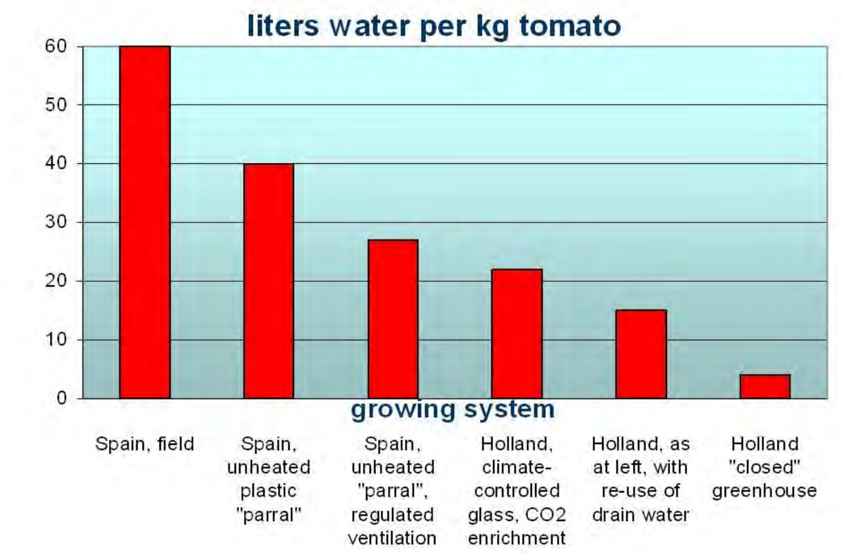

Figure 9. Water use efficiency of tomato (Van Kooten et al., 2008).

3.2.2 National food sufficiency

Although it may be theoretically better for a water scarce country to import its staple food from elsewhere and use its own water resources for crops that yield a better income to the rural population, a large dependence on food from beyond its own frontiers is strategically not wise. It increases the vulnerability of such countries. This emphasizes again the need for local solutions. To get more insight in the approach and in how to find hands-on solutions for the local situation we will elaborate a case study in which we focus on potato as important global cash crop referring to some preliminary results from experiments in developing countries like Egypt and come up with a research agenda.

4. Case study: Potato and how to act for this particular crop

4.1 Focus on potato

The question may arise why this study focusses on potato, while salt tolerance of potato has been studied for decades already. Moreover, experiments related to 'living with salinity' with salt tolerant potato cultivars are already ongoing in the Netherlands and Egypt for some years. Yet, the focus on potato in this study is obvious as this staple crop:

1. Is becoming the most important staple cash crop in the world, and
2. It has the lowest Water Footprint compared to other staple crops.

4.1.1 Worldwide importance as staple cash crop

On global scale, potato production is of growing importance. FAO data from 2012 show that potato belongs to the top six in the ranking of cash crop production based on production area, although it is only number twelve in the ranking of global cash crop production based on economic value (Figure 10 A and B, respectively).

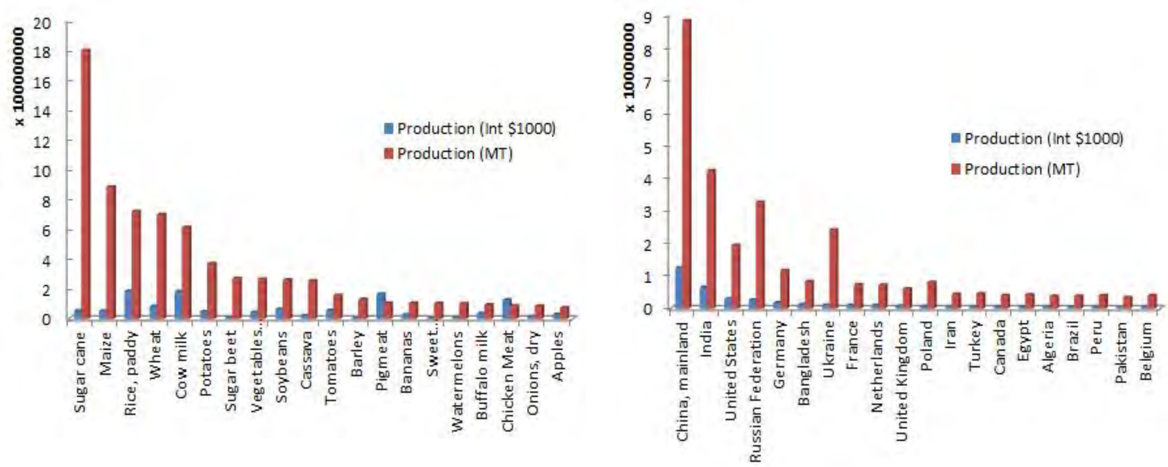

Figure 10. A) Ranking potato on global cash production based on production area and B) Ranking countries on income from potato cultivation (FAO, 2012).

However, the good news is that the FAOSTAT trend analysis show that production of potato in developing countries has been growing the last decades (Figure 11). This situation has evolved rapidly indicating that a sustained trend may result in most of the worlds' production of tubers coming from Asia, Africa and Latin America. The demand for potato and products likely are foreseen to grow in developing countries as the world population is predicted to grow from 7 billion to 9 billion by 2050 mainly in developing countries (Table in Figure 12). Europe, on the contrary, is expected to be the only region where the population may decline and European companies will need to target growing markets in Asia, South America and even Africa (World Potato Markets, 2011).

Most potato production is at its subsistence level as most potato is cultivated under suboptimal circumstances with suboptimal agricultural practices in China and India (Figure 10B) and with salinity and drought becoming more and more severe threats. In the next chapter, we will focus on the potato cultivation and possibilities to improve its production potential under saline conditions.

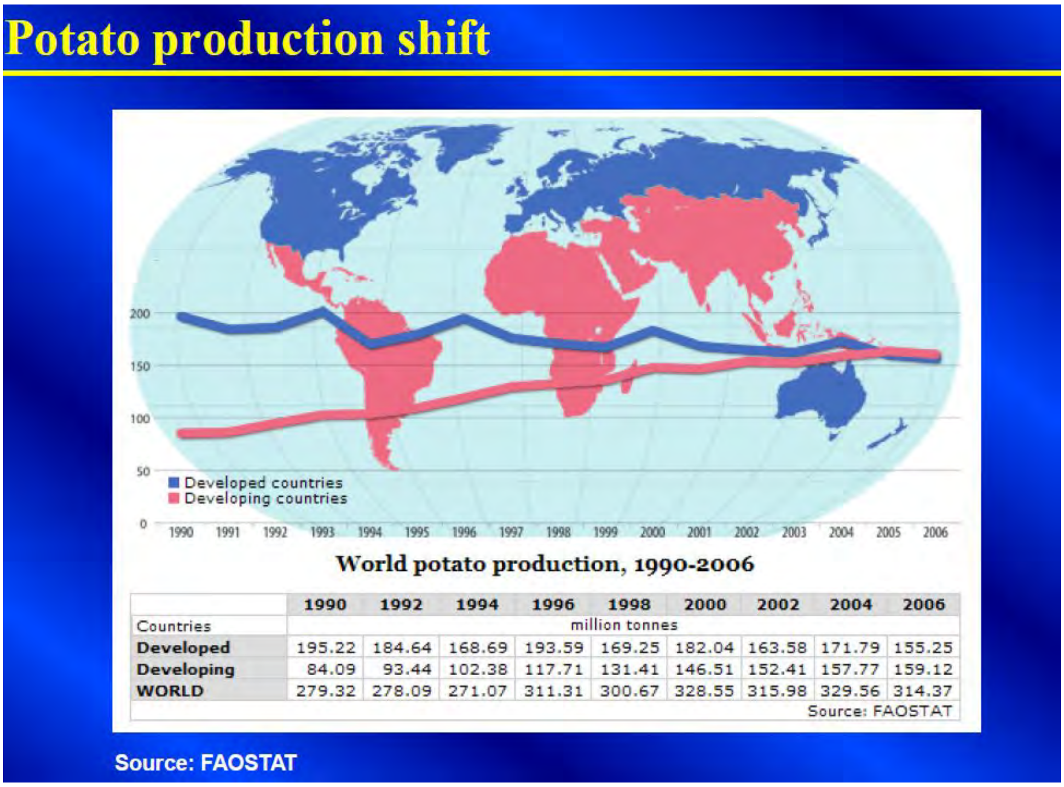

Figure 11. Potato production shift from 1900 untill 2006 (FAO, 2012).

Population growth 2010- 2050

Year	World	Asia	Africa	Europe	Latin America	North America	Oceania
2010	6 909	4 167	1 033	733	589	352	36
2020	7 675	4 596	1 276	733	646	383	40
2030	8 309	4 917	1 524	723	690	410	45
2040	8 801	5 125	1 770	708	718	431	48
2050	9 150	5 231	1 998	691	729	448	51

Source: UN

Figure 12. Expected growth of the world until 2050 in the different continents (World potato Markets, 2011).

4.1.2 Water use

A rather new approach is the idea of considering water use along supply chains which has gained interest after the introduction of the so called 'Water Footprint' concept by Hoekstra in 2002 (Hoekstra, 2007). The water footprint is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect or embedded water use. The water footprint is a comprehensive indicator of freshwater resources appropriation in addition to the traditional and restricted measures of water withdrawal. The water footprint of a product is the volume of freshwater used measured over the full supply chain. It is a multidimensional indicator, showing water consumption volumes by source and polluted volumes by type of pollution. All components of a total water footprint are specified geographically and temporally. Potato has the lowest water footprint compared to other common staple crops. Figure 13 shows the water footprints of different staple crops calculated on basis of fresh product (A) and dry matter (B), respectively. It can be seen that potato performs as best in this series. But having the lowest water footprint of all staple crops, potato still has a huge potential of improving its water footprint in different regions. In north-western European countries the water footprint is slightly above 100 litre/kg, far below the world average of 287 litre/kg (Figure 14).

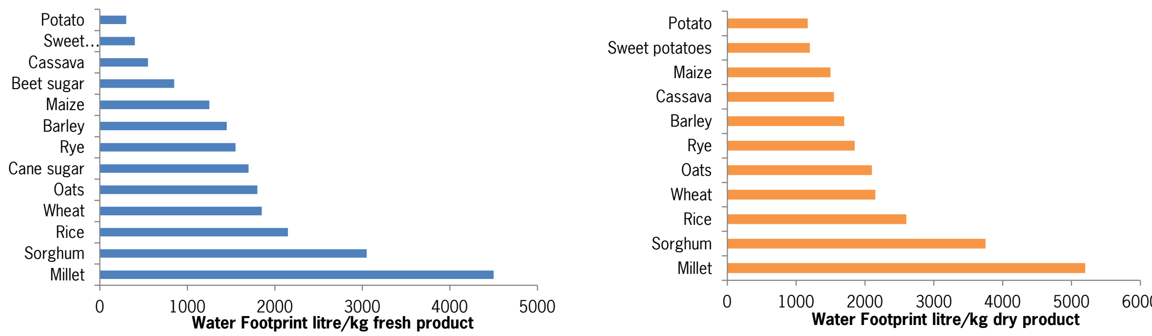

Figure 13. Water Footprint of different staple crops: A) based on fresh weight production and B) based on dry weight production.

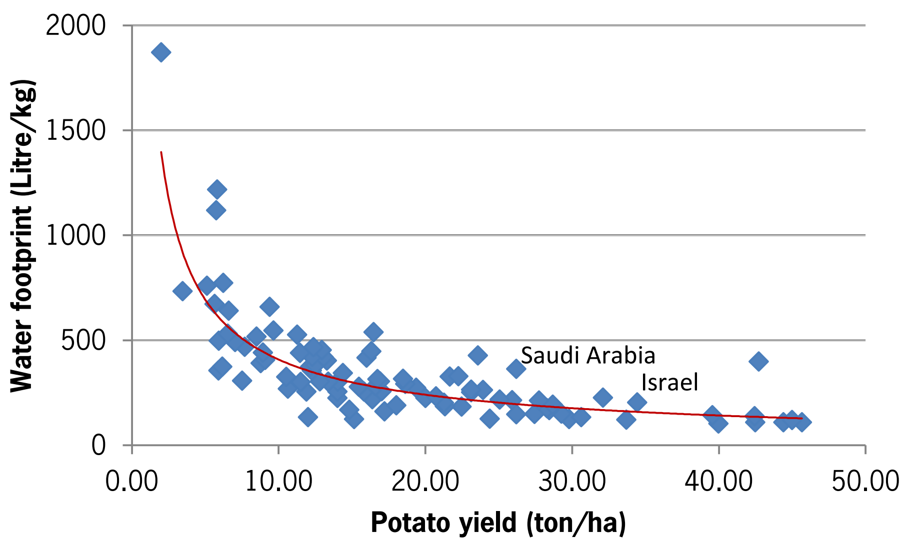

Figure 14. Potato water footprint of individual countries.

4.2 Market and its perspectives

Until the millennium change, the major potato production areas were Europe, Eastern Europe and the Russian Federation (Meyhuay, 2001). During the last decade, developing countries have increased their participation and their harvests nowadays surpasses the production of Europe (Figure 15). As mentioned earlier, most production capacity (tonnes/ha) is at a subsistence level. Although China is world's largest grower, only 0.4% of its crop is exported, while most processing and exports are still from Europe, North America and Oceania (World Potato Markets, 2011). In fact, the high productivity level in developed countries in Europe, North America, Australia and others have left few possibilities to augment potato production by conventional methods.

World potato area, yield and production, 2009

	Harvest (million tonnes)	Yield (tonnes/hectare)	Area (million hectares)
Europe: Central EU-5	35.744	**43.94**	0.813
Europe: Other	88.012	16.11	5.462
Asia	146.015	16.18	9.027
Africa	17.626	9.98	1.766
North America	24.151	**42.43**	0.569
Other America	16.362	16.85	0.971
Oceania	1.672	**37.66**	0.044
World	**329.581**	**17.67**	**18.652**

Source: FAO.

Figure 15. Subsistence versus surplus potato production at different continents (Wold potato markets, 2011).

Both the worldwide high production level and the increasing market perspectives for potato in developing countries makes potato interesting to study further in the context of an increase of salinity in developing countries and the urgency to save water.

Potato having the lowest water footprint of all staple crops, is an attractive crop for water scarce countries that want to improve their food self-sufficiency situation. By exchanging 1 m^3 of water from growing wheat towards growing potato, they can produce almost double the amount of dry matter. Wheat is then better imported from outside the country. This trend of replacing grain crops by potato emphasises the growing importance of this crop in the Middle East, North Africa and China. This is also the region with brackish water resources and thus the reason for developing salt tolerant potatoes and cultivation methods for using marginal waters.

4.3 Cultivation of potato

Potato *(Solanum tuberosum)* decends from different native cultivars (Figure 16) originating from tropical areas of high altitude in the Andes. The potato was introduced to Europe by the Spanish at the end of the sixteenth century, where the long photoperiod inhibited tuber formation. However, selection against the obligatory demand of short photoperiod for tuber initiation and growth allowed higher tuber yields in Europe. The long days and moderate temperatures of the temperate regions of Europe allowed longer periods of photosynthesis, efficient translocation of assimilates from haulm to tubers and low transpiration rates during the cool nights. Nowadays, the crop is grown throughout the world but is of particular importance in the temperate climates. In Table 3 some characteristics of potato are summarized.

Figure 16. Different native potato cultivars originating from Peru (Anderson, 2010).

Table 3. Characteristics of potato cultivation, yield and use (FAO, 2012; FAO, 2013; World potato Markets, 2011).

Mean worldwide production	Production (2011/2012)	~ 330 Mtonnes
	Yield	~ 18 tonnes/ha
	Area	~ 19 Mha
Use	Human consumption (direct, frites, chips)	50 - 60%
	Animal feed	25%
	Seed production	10%
	Industrial products	5 - 15%
Cultivation	Optimum main daily Temp	18 - 20 °C
	Night temp	< 15°C
	Optimum soil temp for tuber growth	15 - 18 °C
	Inhibition tuber growth	< 10 °C, > 30 °C
	Growth period early varieties	90 - 120
	medium varieties	120 - 150
	late varieties	150 - 180
	Daylength requirement early cult.	15 - 17
	late	shortday
	Optimal soil pH	5 - 6
	Fertilizer requirements	80 to 120 kg/ha N, 50 to 80 kg/ha P and 125 to 160 kg/ha K
	Sowing depth	5 - 10 cm
	Plant spacing under irrigation	0.75 x 0.3 m
	Water requirement 120 - 150 days	500 - 700 mm

Optimal Yield and reduction at soil salinity	Temperate and subtropical climate	25 - 35 ton/ha
	Tropical climates	15 - 25 ton/ha
	EC_e = 1.7 mmhos/cm	0%
	EC_e = 2.5 mmhos/cm	10%
	EC_e = 3.8 mmhos/cm	25%
	EC_e = 5.9 mmhos/cm	50%
	EC_e = 10.0 mmhos/cm	100%

Figure 17 shows the different stages of the potato growth. Potato is mostly reproduced vegetatively from tubers, which are formed in the soil on underground stems (stolons).

Morphologically the tuber is a swollen stem with an apical bud and a few axillary buds that are usually dormant at harvest. Short day length and low temperatures (especially at night) enhance tuber initiation and increase the number of tubers formed. High nitrogen concentration in the plant and low solar radiation restrict tuber formation. Shortly after initiation, both the weight and volume of the tubers increase almost linearly, so called tuber bulking. Although many tubers may be initiated during the first four to six weeks of growth, only a fraction of these tubers actually achieve commercial size (greater than 30 mm diameter). The duration and rate of tuber bulking vary among cultivars and depend on environmental conditions. Bulking rate is greater under short days and moderate temperatures (Levy and Veilleux, 2007). Crop rotations with maize, beans and alfalfa, are common in the potato cultivation to maintain soil productivity, to check weeds and to reduce crop loss from insect damage and diseases, particularly soil-borne disease.

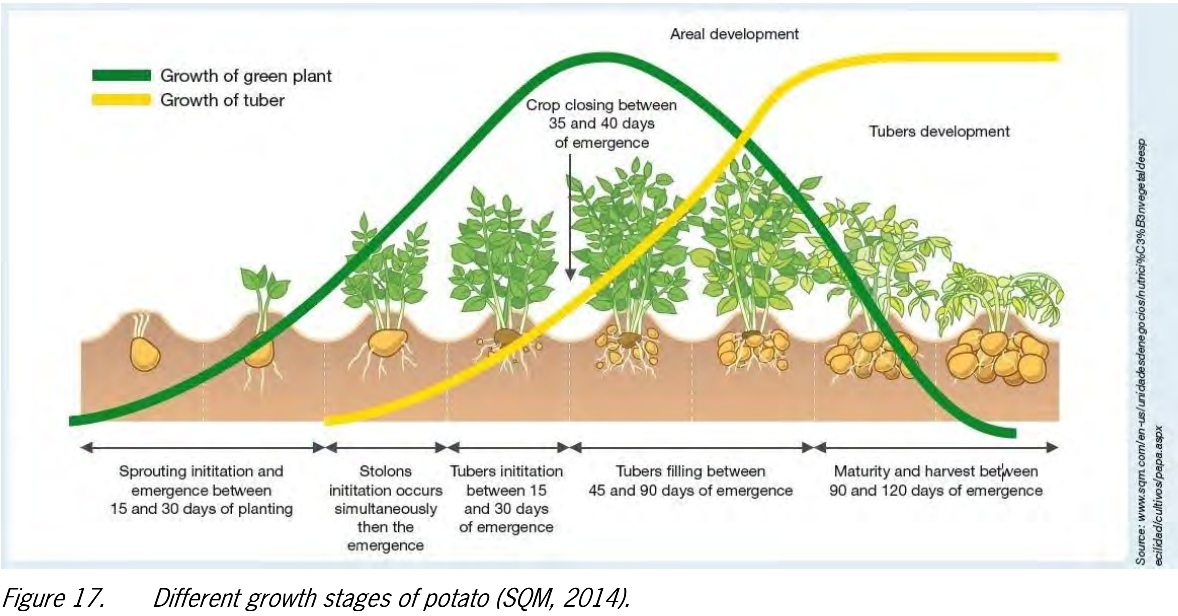

Figure 17. Different growth stages of potato (SQM, 2014).

4.4 Salt tolerance of potato

Salt tolerance of potatoes has been studied for a long time already, especially in desert areas like Israel (Bernstein *et al.*, 1951; Bouaziz, 1980; Bruns and Caesar, 1990; Levy, 1992; Shannon and Grieve, 1998; Bustan *et al.*, 2004; Shaterian *et al.*, 2005; Levy and Veilleux, 2007). Potato has been classified as moderately sensitive to salinity up to EC-values in order of magnitude of 7 dS/m when no extreme weather conditions, like heat waves occur (Bustan *et al.*, 2004). Salinity retards plant emergence, reduces growth of both haulms (shoots) and tubers, and hastens maturity (Levy, 1992; Nadler and Heuer, 1995).

Potato leaves are very sensitive to saline water and are severely damaged by overhead irrigation with saline water (Levy and Veilleux, 2007), especially at the beginning of tuber formation (Bruns and Caesar, 1990).

During the period of bud initiation the crop is even more sensitive to salinity. In this growth stage, salinity reduces the proportion of extra-large tubers in favor of smaller, more commercially acceptable tubers. Such a crop response is also found as a result of drought (Haverkort *et al.*, 1990). Although, salinity will generally not affect total tuber number, it will decrease the proportion of extra-large tubers. However, dry matter yield of large tubers will increase resulting from a preferential supply of assimilates (Bernstein *et al.*, 1951; Paliwal and Yadav, 1980; Nadler and Heuer, 1995). As a result, total yield of the tubers is hardly affected until EC 6, as depicted in Figure 18.

The physiological age[1] of seed tubers may affect their response to salinity. Plants developing from physiologically 'young' or physiologically 'old' seed tubers are more susceptible to salinity than those developing from seed tubers at the proper physiological age (Levy, 1992).

#	Treatment	Water applied (mm)
1	Non-saline, 1·5 dS m^{-1}	480
2	Saline, 3·0 dS m^{-1}	480
3	Saline, 6·0 dS m^{-1}	480
4	Non-saline, 60% of water applied	288
5	Non-saline, irrigation withheld between days 57 and 74 after planting	442

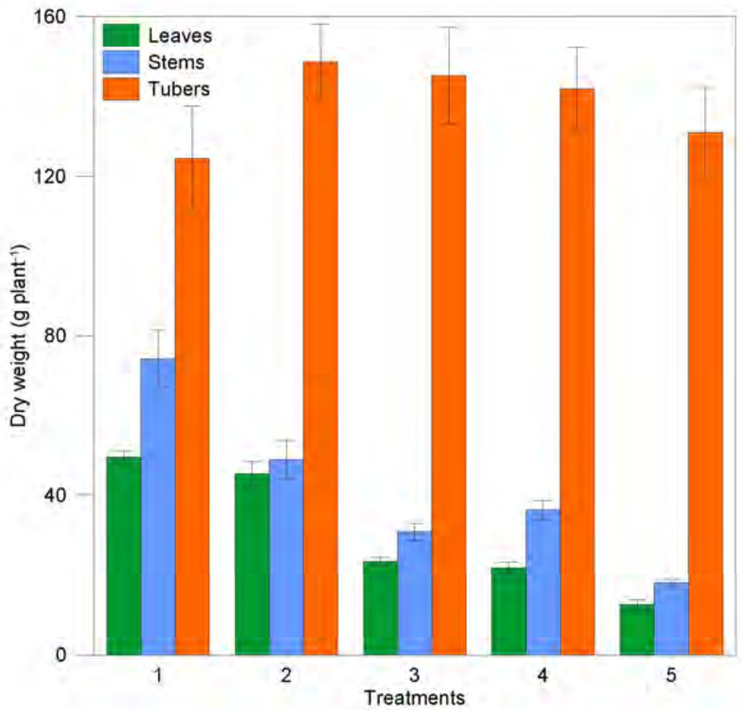

Figure 18. The effect of salt stress or water stress on the accumulation of dry weight in potato plants (reproduced after Heuer & Nadler, 1995).

Cultivar differences in salt tolerance of potato have also been well documented (Levy, 1992), but the relationship between tolerance and physiological or morphological characters has not been made and a consistent relationship between maturation time and salt tolerance has not be shown either. Levy (1992) suggests that salt tolerance may

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[1] i.e. Stage of maturation with a physiological functionality which is affected by environmental (stress) factors.

be partly attributed to earlier maturity (salinity escape) as long as earliness is not associated with yield decline. This speculation is also consistent with general observations that higher growth rates allow a plant to dilute the effects of ions that accumulate in the tissues as a result of high salinity. At the moment, experiments in which different cultivars (produced by Meijer BV, Rilland, the Netherlands) are tested for their salt tolerance both in the Netherlands and in Egypt.

4.5 Possibilities to cope with salinity in potato cultivation

For potato different strategies are possible to optimize crop growth under saline conditions with respect to:
1) irrigation practices, 2) soil coverage by mulching, 3) intercropping or mixed cropping and 4) possible integration with aquaculture.

4.5.1 Irrigation practices

Under saline conditions, the irrigation regime in a row crop is important. Common methods for potato are furrow and sprinkler irrigation. Yield response to frequent irrigation is considerable because the crop has a shallow root system and requires a low soil water depletion. However, irrigation with brackish or saline water will cause accumulation of salt near the root zone with a profile depending on the forms of the ridges and the irrigation practice. Figure 19 shows different salt accumulation patterns under furrow irrigation with different bed forms and different irrigation regimes. It can be seen, that a symmetric (and most common) furrow irrigation pattern may result in an unfavourable salt accumulation within the root zone.

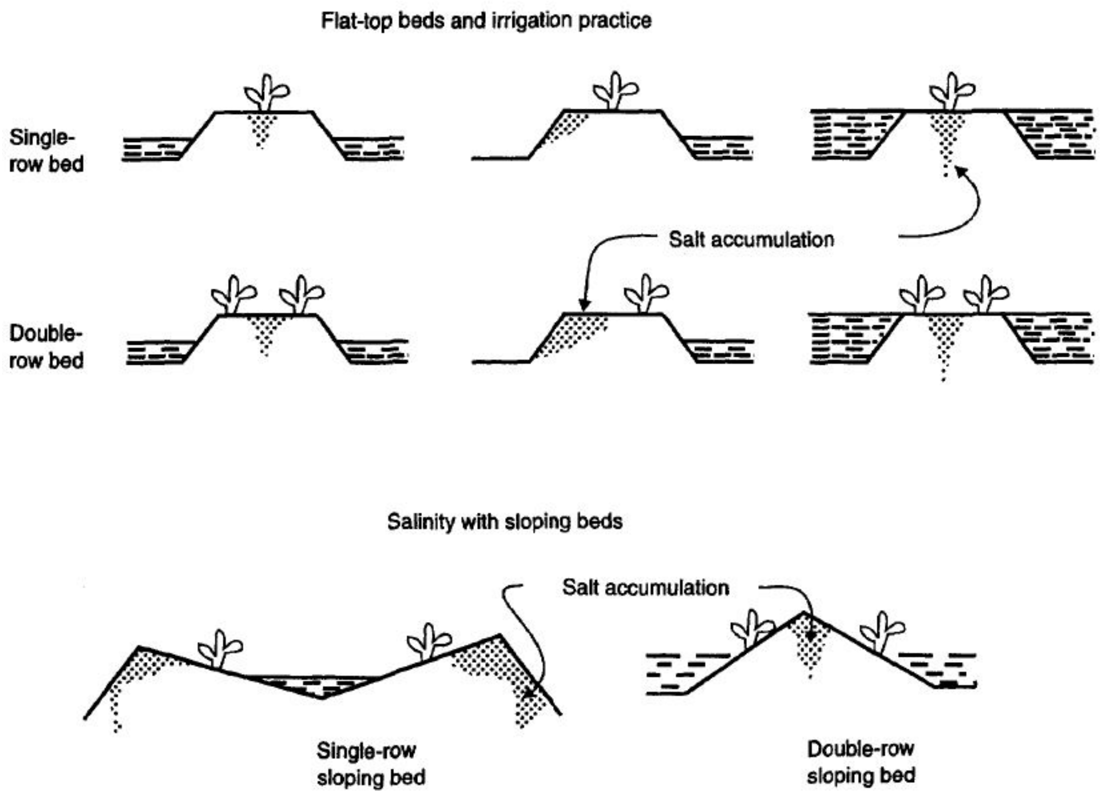

Figure 19. Salt accumulation patterns in potato growth under furrow irrigation (Hillel, 2000).

For a row crop such as potato, surface drip irrigation has the advantages that water can well be saved and depending on the drip schedule salt ions can permanently be leached from the root zone.

For this case study some explorative simulation studies for potatoes grown on ridges and irrigated with drip irrigation were carried out with the FUSSIM2 model of Heinen and De Willigen (1998) and Heinen (2001). A full description of this study can be found in Heinen (2014). The system was considered to be a two dimensional system and following comparisons were done:

- Effect soil type: sand, sandy clay loam, silty loam.
- Effect soil frequency of irrigation: daily (for all soils), after 20% of the available water content was depleted (different per soil type).
- Effect root distribution: with or without roots along the slope and underneath the gully.
- Effect of an extra drip line in gully.
- Effect of a ridge versus no ridge situation.
- Effect of the *EC* (dS m^{-1}) of the irrigation water.
- Effect wide versus small ridges for three soil types and for two levels of irrigation frequency.

The focus was on the *EC* distribution in the root zone, on reduction in root water uptake either due to osmotic hindrance or due to dryness, and on the penetration depth of the *EC* front at the end of the growing season.

The *EC* in the sand soil was much larger than that in the other two soils. Remarkably, the reduction in Root Water Uptake (RWU) was the least for the sand. The high *EC* values resulted in low EC_e (= *EC* in the saturated extract) values since low water contents (θ) were present in the sand: $EC_e = \theta/\theta_s * EC$. Apparently for the sand the reduction in RWU due to EC_e was less than for the other two soils. This can be ascribed to the specific shape of the water retention characteristic of the sand used in this study. It indicates that a good knowledge of the soil hydraulic properties is important when optimizing drip irrigation strategies.

The study showed following results:

- The effect of irrigation frequency was small with respect to RWU and the EC distribution in the soil. However, the penetration depth of the EC front was larger for the less frequent irrigation situation.
- The EC distribution pattern in the root zone was different for two different rooting patterns considered. That means that a good knowledge of the rooting pattern, including root growth, is needed when optimizing drip irrigation strategies.
- The presence of an extra drip line in the gully caused lower EC values underneath the gully. Since slightly more water was added compared to the standard situation this also caused more leaching and thus a deeper penetration of the EC front. This scenario could be improved by lowering the water delivery of the main drip line at the top of the ridge.
- In case wide beds are used, plumes with high EC were seen between plant rows caused by evaporation from the soil surface during the first half of the growing seasons and by RWU occurring throughout the root zone (Figure 21). The EC values inside the plumes in the middle of the bed were slightly higher than those in the plume underneath the gully. This may have been due to the slightly higher amounts of roots in the middle of the bed compared to the gully.

The explorative study revealed that for the calculation of optimal drip irrigation strategies it is important to know the soil hydraulic properties, the rooting pattern and to pay attention to root development (which was not done here). In this explorative study only a single growing season was considered. Future analysis should take into account long-term effects.

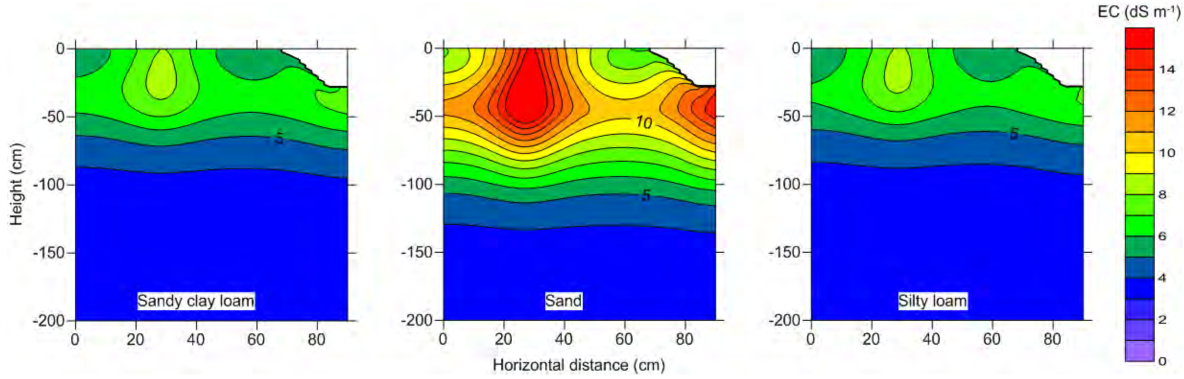

Figure 20. The EC distribution in wide beds at the end of the growing season for 3 soils with daily irrigation. Plant rows and drip lines were present at horizontal positions 0 and 60 cm.

In the water resources management as described above, salt ions are removed. As shown from the Figures 19 and 20, salt will accumulate either in the subsoil or in the deeper soil layers. So, we must apply more water to leach out salts. This is not only contradictory to our aim to save as much water as possible, but applying too much water may also raise the water table and thus bring back the salt from below (Hillel and Vlek, 2005; Hillel, 2000). Therefore, the amount of water applied must be optimized so as to allow leaching without water-table rise.

A more sophisticated irrigation regime can be considered in which plants are forced to adapt and to increase their salt tolerance. An example is the earlier described Alternate partial Root Drying irrigation management (ARD, Jacobsen *et al.*, 2012). For potato such an intermediate saline-fresh drip irrigation with intermediate salinity in the root zone has indeed been shown to result in smaller yield losses than with continuous saline drip irrigation (Levy, 1992). However, it appeared that the type of soil is important. Ahmadi *et al.* (2010) showed that water saving irrigation in potato was not recommended on a loamy sand soil due to considerable yield losses, but sandy loam or coarse sand soils showed high water productivity.

4.5.2 Mulching

Apart from a well-chosen irrigation strategy, application of a soil coverage or mulching treatments may also improve crop performance under saline conditions. Positive effects of straw mulch (Figure 21) have been reported for potato cultivation with the grass species Setaria in Rwanda (Devaux and Haverkort, 1987), with chopped grass in the Czech Republic (Dvorak *et al.*, 2012) or with rice straw in India (Kar and Kumar, 2007). The studies reported significantly higher leaf area index, water use efficiency, intercepted photosynthetically active radiation (IPAR) and finally tuber yields in the mulched plots compared to the non-mulched plots under the same irrigation treatment due to a reduction in soil temperature by 4-6 °C and preservation of soil humidity.

Figure 21. Winter potatoes covered by rice straw in India (Anderson, 2010).

The effect of mulching for a no-ridge situation (i.e. the effect of preventing evaporation from the soil surface) has also been studied in the explorative simulation studies by Heinen (2014).

The simulation showed that preventing evaporation from the soil surface via mulching has a huge effect on the *EC* distribution in the soil, resulting in lower *EC* levels (Figure 22). This was especially seen during the first part of the growing season when soil evaporation is dominant. At later stages evaporation from the soil surface is generally low as the soil coverage by the crop canopy is about 100%. The penetration depth of the *EC* front for the mulched situation was significantly lower than for the non-mulched situation.

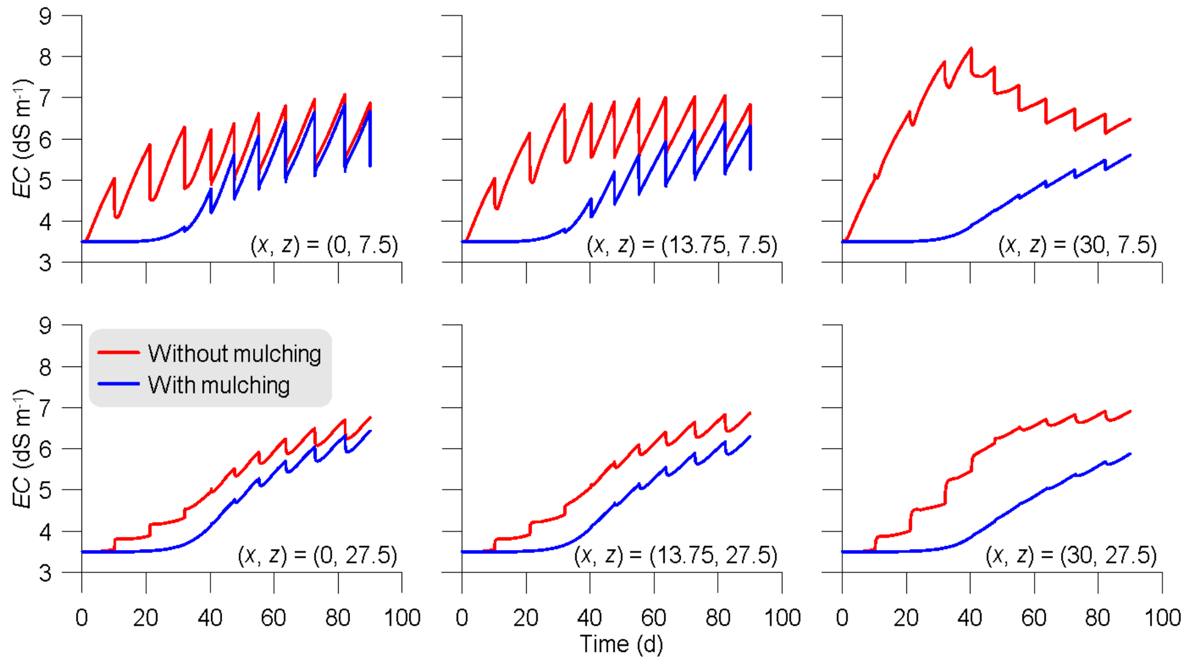

Figure 22. Time course (hourly data) of EC (dS m[-1]) with not frequent irrigation for non-ridge situations without and with mulching in a silty clay loam for 6 indicated positions (x,z) in the root zone.

The results indicate that mulching is a very effective way to have moderate *EC* levels in the soil and to prevent deep penetration of the salinity front. In this explorative study we only considered a single growing season.

4.5.3 Intercropping

Intercropping, i.e., growing two or more crops at the same time on a single field, is an ancient practice still used in much of the developing world. This type of farming with a combination of moderately salt tolerant, like broccoli, and salt tolerant crops, like barley (see Table 1) can especially be practiced on slopes as a way to reuse drain water (Figure 23).

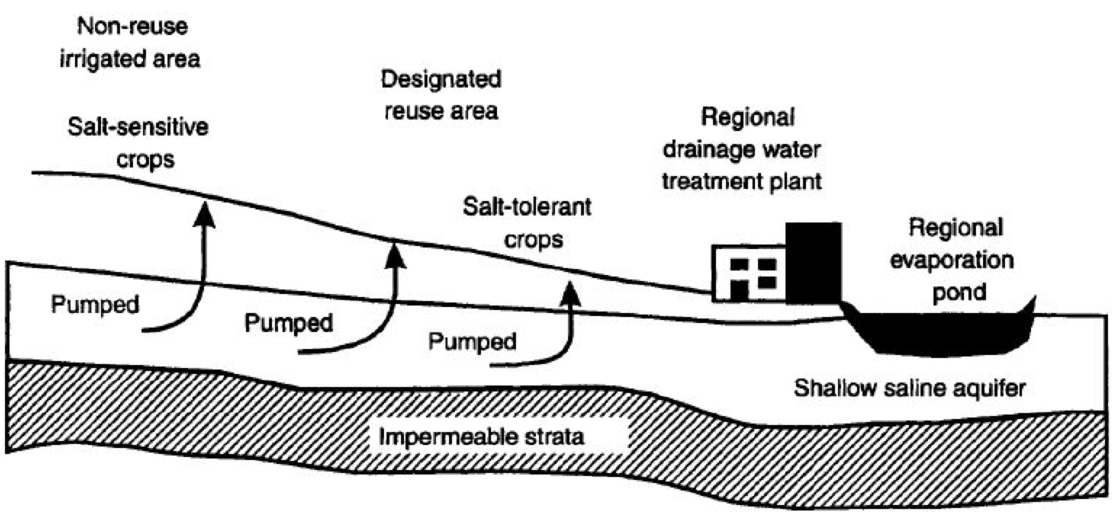

Figure 23. Drainage water reuse and disposal for an irrigation region (Hillel, 2000)

A combination of crops is an alternative farming system which can be very well practiced, when the growing calenders of the different annual crops are in one line. An example is the cultivation of potato Which has a crop calender from November until May in combination with f.e. beet or the extreme salt tolerant quinoa (Sun, 2013), which has a crop calendar from March until September.

The choice for an adequate combination of crops is important as shown in the studies by Hillel (2000) and Hillel and Vlek (2005). They compared estimated income losses for kibbutz (collective) and moshav (small-holder cooperative) farms in the Negev region of Israel (Table in Figure 24). Their calculations represent existing crop mixes and irrigation practices, which were not adapted for salinity. The salinity-induced losses in moshav farms turned out to be about double those of kibbutz farms, due to the larger share of salt-sensitive fruit and vegetable crops grown on moshav farms. The magnitude of the salinity damage appeared to be highly dependent on the composition of the crops. They conclude that adjustments of the crop mix and irrigation treatments to salinity have the potential of significantly reducing these damages. Because the initial installation costs are high for drip irrigation, field crops together with horticultural crops in rotation might be also considered (Jacobsen *et al.*, 2012).

Salinity Level	*Income Loss (percent)*	
Ppm Cl	*Kibbutz farms*	*Moshav farms*
200	5	10
300	14	30
400	23	45

***Note:* Estimates are for the Negev region of Israel.**

Figure 24. Estimated income losses for various salinity levels of irrigation water (Hillel, 2000).

4.5.4 Integrated aqua - agriculture

Integration of aquaculture with agriculture is a perspective combination to reuse the effluent from the cultivation of fish for the cultivation of cash crops. Roest *et al.* (2013) investigated the feasibility of real-life integrated, brackish groundwater - aqua-agriculture farming for potato in the Egyptian desert environment (Figure 25). Fish farming has shown tremendous growth during the last decade in Egypt and has turned the country into a world-player in this field. As it is legally impossible to use fresh water for aquaculture but the possibilities of increasing water productivity in this way are appealing, the government allows the use of brackish water, a non-conventional water resource. As large pockets of (brackish) groundwater are available in certain locations in the desert, the combination of fish farming with agriculture using brackish water has a high potential for future economic cooperation activity between Egypt and the Netherlands.

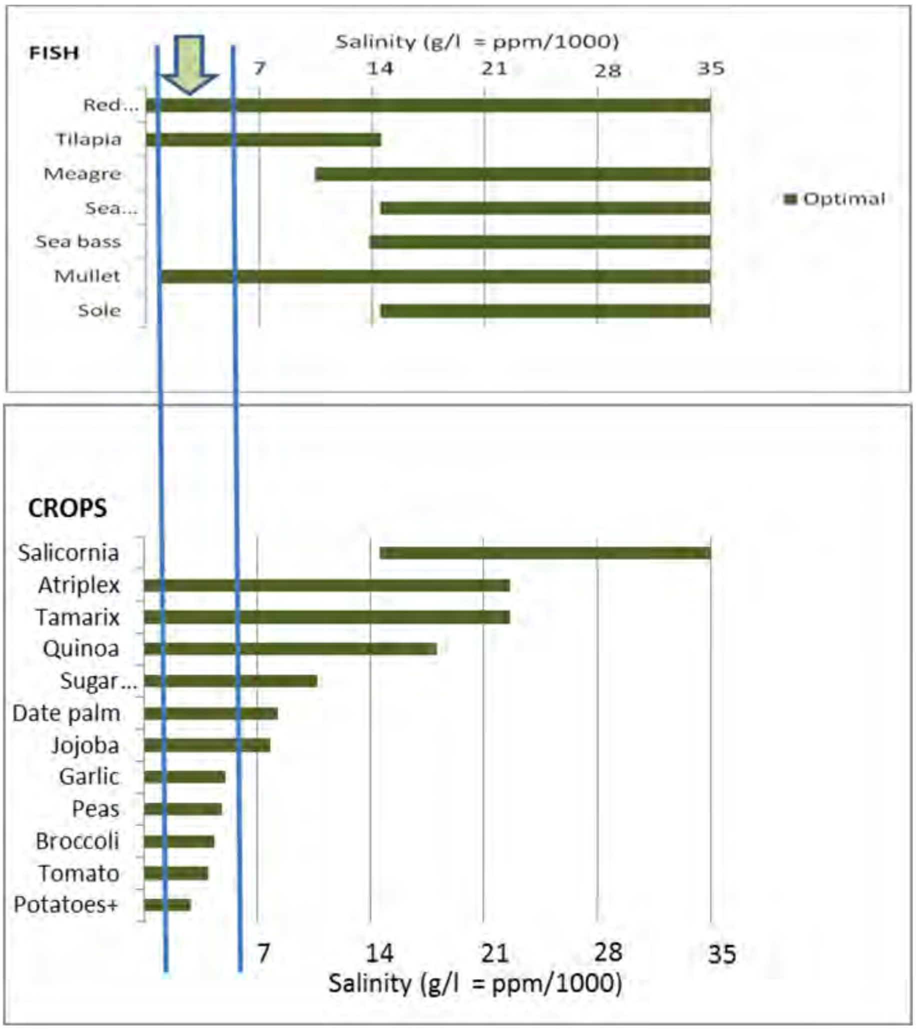

Figure 25. *Combination of aquaculture and agriculture. The EC trajectory between the blue lines represents EC values becoming common in brackish environments (Roest et al., 2013).*

4.6 Sustainability of irrigation management and the confrontation with dilemma's

Continued population growth and rising living standards are likely to require an increase of agricultural production in the coming decades. In this task, irrigation will play a decisive role. As (Hillel, 2000) stated:

> *'An important aspect of long-run management of water resources, under conditions of gradual deterioration in their quality, is related to intergenerational equity. Farm income and food security of future generations may suffer if the stock of groundwater and the water quality they inherit from the present generation decline. In other words, the actions of the current generation may impose negative costs on the next generations via inconsiderate depletion and contamination of groundwater. While negotiations between polluters and victims can often yield a socially optimal resource allocation, negotiations between the current and next generations are impossible. Furthermore, water quality for generations yet unborn cannot depend solely upon intergenerational altruism at the individual level. In the absence of corrective actions, the damage to future water-users may be irreversible as salinized areas are unsuitable for agriculture expansion. Thus, governments of today have a responsibility to fulfil in regulating water usage to ensure adequate water quantity and quality as well as sustainable food production and public health, in the long-run'.*

It should be obvious that any attempt to leach without adequate drainage is not merely doomed to fail but can indeed exacerbate the problem. (Hillel, 2000) states that this principle is too often ignored in irrigation projects. In many areas where natural drainage is slow and artificial drainage is not provided, it becomes impossible to sustain irrigation in the long run, and the land must sooner or later be abandoned owing to progressive salinization. So, all techniques available to cope with salinization must be used to develop optimal farm management and water saving strategies.

4.7 The way forward

It is well understood that application of the "Golden Triangle" Government - Research - Business is highly useful in further advancing the "more crop per drop" opportunities, including the cultivation of salt-tolerant crops.

Every partner in the Triangle has to contribute from its own mandate:

- The Government is able to contribute with e.g., taking away legal, institutional, and trade hurdles. It might also consider to provide seed-funding where Business would not be the logical funder. As incentives, Governments can also provide subsidies to stimulate desired developments or they may introduce taxes to discourage unwanted developments;
- Business is highly required in the cooperation as it has the power to implement and to insert research findings into real-life business opportunities. It also may have access to venture capital and capital providers, if so required;
- Research can expand the knowledge required to make it happen. That will include agricultural research (e.g., integrate current advances in the molecular sciences, in biotechnology and in plant and pest ecology with a more fundamental understanding of plant and animal production in the context of optimizing soil, water and nutrient use efficiencies and synergies, etc.) but it will also need to find other answers related finding the earlier mentioned location-specific solutions.

So, we plea to formulate future proposals with respect to PPP issues together with the public and private sector.

Research must increasingly integrate current advances in the molecular sciences, in biotechnology and in plant and pest ecology with a more fundamental understanding of plant and animal production in the context of optimizing soil, water and nutrient use efficiencies and synergies. And especially the development of sustainable hands-on solutions to save the environment for future generations should be emphasized.

We suggest to draw attention in future research to following themes:

- Smart rotations. Crops differ in their responses to external circumstances. In order to optimize soil and water use and to provide a balanced year-round cropping pattern with a steady requirement for labor and stable production level, smart crop combinations have have to be made and fine tuned to daily temperatures, water demand and water supply.
- Smart and sustainable integrated agricultural systems in which water can optimally be used and reused. This requires an optimized water demand - water supply fine tuning. As an example can be mentioned the combination of fish Tilapia with and potato-quinoa growth (Roest *et al.*, 2013).
- Valorization of secondary metabolites and beneficials from salt tolerant plant species. In some crops salinity stimulates the production and accumulation of economic interesting metabolites, e.g. pharmaceuticals, cosmetics, nutraceuticals or precursors for technical applications (Buhmann and Papenbrock, 2013). An example is the accumulation of flavonoids in *Salicornia europaea* (Kong *et al.*, 2012) which component is considered to act as an anti-obesity agent. Before making use of the metabolites, several biological and technical problems need to be solved, such as constant production of the respective compounds, establishment of suitable extraction methods, transfer of of preliminary promising results to application and regulatory aspects of bringing new products on the markets.

- Attention to the effects of irrigation frequency. The salinization rate of the soil and concomittant plant response will highly depend on the irrigation strategy and the combination between frequency, irrigation period and flow rate. The relationship between frequency, irrigation period and flow rate and its effect on salinizatin rate has nog been studied in detail. In order to develop a sustainable farm management and minimal salinization, this aspect needs to be studied further.
- Attention to the question whether the saving of the environment for the long run (thousands of years) might need the use of extra water at the moment. Short-term conservation measures differ from long-term measures in terms of implementation time, long term effectiveness and influence on water need planning. Long term measures are substitutes for new water supplies while short-term measures are applied to quickly fix temporary water shortage problems. A long-term measure such as a landscape design change may require increased watering at first, thereby reducing short-term savings available through outdoor irrigation restrictions.
- Smart technologies to prevent pollution of water resources (under arid conditions). Salinization of the root zone is still prevented by leaching and smart irrigation schedules. However, a more sustainable way of preventing salt accumulation in the subsoil and in the groundwater has not been well developed. In order to prevent an unwanted situation on the long run, more attention should be paid to develop smart technologies to monitor contamination and to get rid of the salts in a sustainable way.

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