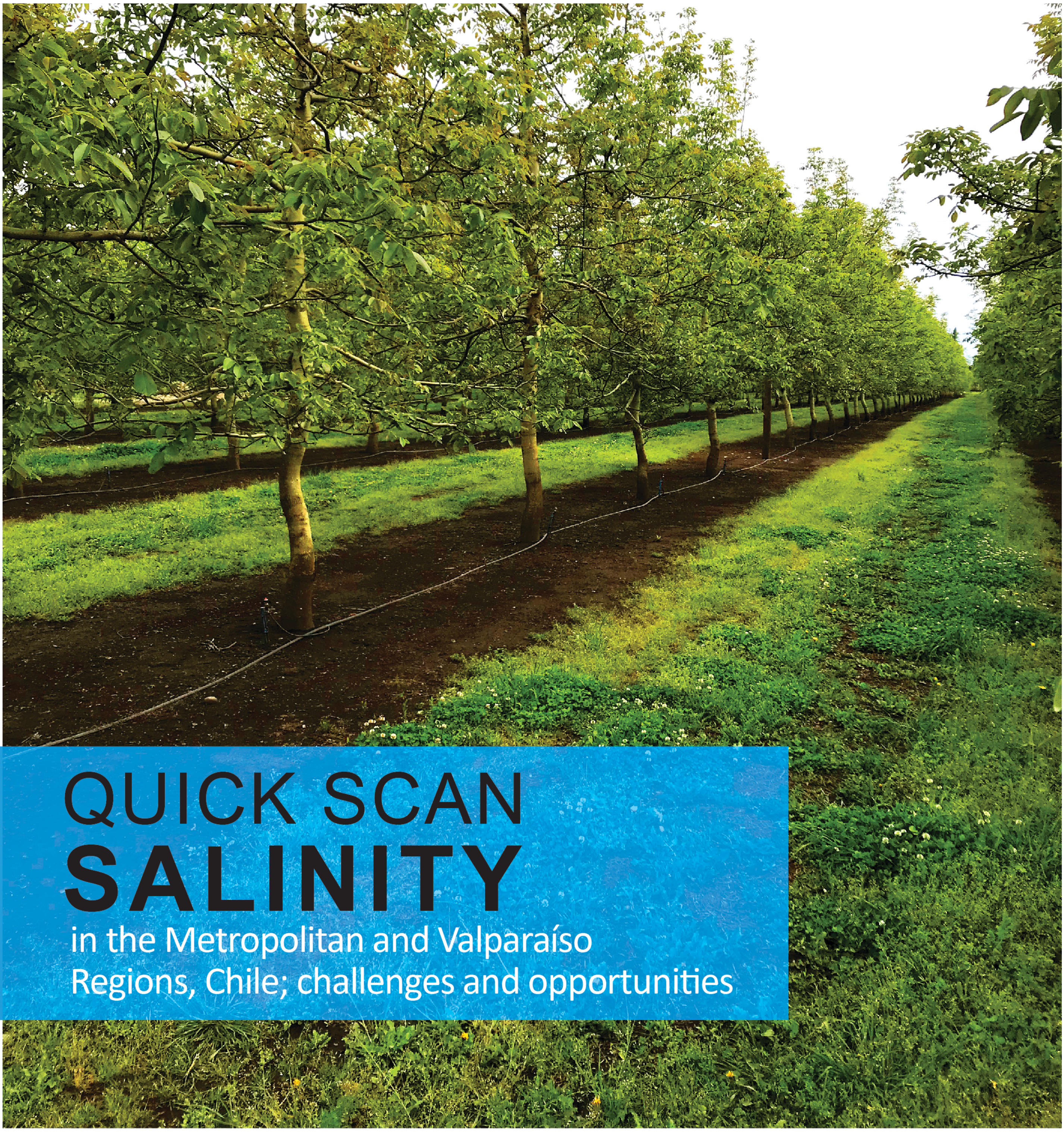

QUICK SCAN SALINITY

in the Metropolitan and Valparaíso Regions, Chile; challenges and opportunities

Bruning B[1]., Cleveland K[2]., Ramirez N[2]., Huizer, T[2]., Streef A[3]., de Vos, A[1].

Affiliations:

[1] The Salt Doctors B. V., The Netherlands

[2] Arcadis, Chile & The Netherlands

[3] Delphy B. V., The Netherlands

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Index

Executive Summary

Background

This report, financed by the Government of the Netherlands through the Partners for Water programme, provides the results of a quick scan on the salinity and water situation in agriculture in Chile, mainly focusing on two regions: Valparaiso and Metropolitan Regions. The project was performed by The Salt Doctors (lead), Arcadis and Delphy (all based in The Netherlands), and the local office of Arcadis in Chile. The overall objective of the study is to enhance the climate resilience of agriculture in water scarce and saline areas in Chile, by providing insight into salinity issues and by exploring the possibilities for improving agricultural practices in a saline environment. For this, a salinity and a needs assessment were performed, by means of interviews with several stakeholders, a literature review and field visits to two farms. Based on the results, different opportunities to improve the resilience of agriculture have been formulated.

Results

In Chile, the area of salt affected land is estimated at 76 million hectares, mostly found in the North where natural fossil salt crusts and numerous saline lakes are present. In the Northern Mediterranean zone, where the two focus areas are located, around 16% of the land is reported to be salt affected (>2 dS/m). Most farmers in the focus areas rely on river water for irrigation, due to the semi-arid climate and the recent droughts. The river water itself contains salts and the highest concentrations have been observed during the last five years during periods of extremely low flow of the river. The reported concentrations in electrical conductivity (EC) and chloride concentrations of both the river and irrigation waters at the two farms exceed the reported tolerance levels of avocado and walnut. In general, the origin of the presence of salts lies in the soil (former seabed) and the subsequent weathering of the soil which causes elevated salinity levels in the River Maipo. The mean salinity level of the River Maipo is 1,7 dS/m, with a maximum level reaching up to 2,2 dS/m, with maximum values linked to reduced water flow and droughts. Calcium is the main contributor to the elevated EC levels, followed by sodium. Salinity levels of the Aconcagua River have been reported to be lower (0,6-0,8 dS/m), although less information was found. Especially avocado is a very salt sensitive crop and it is recommended to use irrigation water with a salinity level of less than 0,6 dS/m. In this regard, the average salinity level of the Maipo River exceeds the tolerance level of avocado and salt damage, in the form of leaf burn, has been observed at the visited avocado farm. Different cultivars or rootstocks of avocado differ in salt tolerance, with the West Indian rootstocks showing the highest level of salt tolerance. The visited avocado farmer is already changing to this more tolerant rootstock. Salt damage in avocado is primarily a result of chloride ion toxicity, so it is important to ensure that rootzone chloride concentrations do not exceed the tolerance levels. The reported salinity levels of the Maipo River exceed the recommended salinity levels for the more tolerant avocado rootstocks as well, but only by a relatively small difference. In this regard, it should be possible to obtain high yields when also proper soil and irrigation management is taken into account (besides the general crop management). The soil type seems to vary significantly from place to place, ranging from coarse soils to clay soils. Salt accumulation in the soil must be prevented, since the salt concentrations of the irrigation water are already high. This can be achieved by regular leaching by supplying excess amounts of irrigation water. In more coarse, sandy soil natural drainage will most likely be sufficient to leach the rootzone, but with clay soil additional drainage will be needed. Improving and maintaining good soil structure, which can be negatively influenced by salinity, is vital for proper water infiltration and leaching, in addition to the drainage aspect. Salinity also affects the nutrient availability and uptake, so a balanced fertilizer strategy is also of great importance. So, only with an integrated approach that includes crop, soil and water management, it is possible to obtain cost-effective yields under saline conditions.

Needs and recommendations

Several needs and recommendations have been highlighted that are linked to:

- Data collection, mapping and monitoring at farm and regional level
- Tailor-made training and capacity building on methods to deal with salinity
- Water and irrigation management at farm level
- Water management and governance at regional level

Opportunities

Several opportunities are highlighted for preventing, mitigating and adapting to salinity. These opportunities are linked to crop, soil and water. On a crop level, this is mostly about adaptation. There are opportunities to select and use more tolerant rootstocks, but when salinity increases even further then changing to a completely different crop may be the only solution. But for soil and water, there are several opportunities regarding prevention and mitigation and these measures can also ensure that avocado cultivation can be maintained for a long time. These measures mostly focus on the water quality and quantity that can be implemented at farm and regional level. The soil itself can also be used in several ways to ensure good crop development. This is mostly linked to overall soil quality, at a chemical, physical and biological level, that can help the plant to withstand the salt stress, mostly by eliminating other stresses as much as possible.

1. BACKGROUND INFORMATION

In September 2021, the Embassy of the Kingdom of the Netherlands in Santiago commissioned the consortium to perform a quick scan, regarding the salinity challenges that farmers are facing in specific parts of Chile. The assignment is financed by the Government of the Netherlands through the Partners for Water programme. Since these salinity issues are strongly correlated to water management and overall farm practices, these aspects were also considered during the quick scan. The consortium consisted of the Dutch enterprises The Salt Doctors (lead), Arcadis and Delphy. Also, the local office of Arcadis in Chile was part of the consortium. Due to travel restrictions (COVID-19), the local activities were performed by Arcadis-Chile. The different activities consisted of field visits, interviews with various stakeholders and literature reviews, in order to achieve the overall objective.

a. Objective

The overall objective of the project is to enhance the climate resilience of agriculture in water scarce and saline areas in Chile, by providing insight into salinity issues and by exploring the possibilities for improving agricultural practices in a saline environment.

b. Activities and deliverables

The activities of this quick scan consisted of:

- a salinity assessment,
- a needs assessment of Chilean farmers and organizations and
- mapping of opportunities for prevention, mitigation, and adaptation, with regard to the management of crops, soil and water

Most of these activities have been performed in the form of literature reviews and interviews. Also, in the region of Metropolitan and Valparaiso, the consortium has visited two farms to specify the local conditions. In addition, there is the ambition to link the results of the project to specific Sustainable Development Goals, mainly in the form of:

- Which resilient agricultural practices can be implemented that increase productivity and production (SDG 2)?
- How can water-use efficiency be increased and sustainable withdrawals of freshwater ensured, to address water scarcity (SDG 6)?
- How can we strengthen resilience and adaptive capacity to climate-related hazards and natural disasters (SDG 13)
- How can we strengthen cooperation on land degradation and drought (SDG 15)?

c. Salinity in Chile

Due to the combination of rising temperatures and changes in rainfall patterns, Chile is one of the nations in Latin America that faces a decrease in water supply, especially in the northern half, and is expected to be the nation in Latin America to experience the worst level of water stress by 2040. Saline soils are one of the problems related to climate change and increased droughts. In the contacts of the Dutch Embassy in Santiago and in the initiatives of the Partners for Water program, the issue of salinity and agriculture has been addressed several times. Although it is not clear to what extent salinity is affecting agriculture, farmers and other organization indicate that salinity poses a threat to crop productivity in some areas of the country. For instance, in the Metropolitan Region, the salinity problem is arising in María Pinto, Mallarauco, Bollenar, Melipilla, Cuncumén and Puangue. In the coastal Valparaíso Region (from now on referred to as the Vth Region), it occurs in Santo Domingo. Santo Domingo is an important location for the production of fruit, mainly avocado, with a total of 2.692 hectares. This area has a lot of new producers. In comparison to other parts of the Vth Region, the production of avocado in Santo Domingo is 25-40% lower; 9-15 tonnage of avocado per hectare rather than 12- 25 tonnage per hectare in the rest of the region.

In the past years, some attention has been paid to this subject in Chile, for example by initiatives to generate fruits that are resistant to the effects of climate change, including more saline soils. However, to work towards resilient agriculture in a salinizing environment, organizations and farmers indicate that they lack clear insights into causes and action perspectives.

d. The consortium

Therefore, the Dutch embassy has reached out to The Salt Doctors (TSD) to perform a study to obtain a better insight into the extend of salinization in Chile, and what can be done to mitigate the negative effects of salinity, and to adapt to them where mitigation is no (longer an) option. The Salt Doctors in return have reached out to Delphy, an agricultural consultancy company, working on improving agricultural production worldwide for food and flowers. Delphy is responsible for the general agronomic advice in this study. Additionally, TSD reached out to Arcadis, a world leading company delivering sustainable design, engineering, and consultancy solutions for natural and built assets. Arcadis has an office in Chile and can therefore provide local, on the ground assistance. Arcadis has mostly overseen the water aspects of this study, in addition to doing the soil sampling and analysis. This report presents the findings of this study.

2. METHODS

Several methods have been applied to address the questions that are the background of this report. First, a literature study has taken place, reviewing the available and relevant (scientific) literature that was available to us, and provided by Chileans, experts in the field. Second, a questionnaire has been sent to two farmers and three members of the Agricultural Research Institute (Instituto de Investigaciones Agropecuarias, INIA). In addition, two interviews were held with farm administrators.

Figure 1. Impression of the two farms that were visited, with the walnut farm on the top left and the avocado farm on the top right. The bottom two pictures show an impression of the soil sampling at the two locations.

For on the ground soil salinity measurements, two orchards were visited by local staff from Arcadis where soil samples were taken (Figure 1). Both the topsoil (0-40 cm) and well as the subsoil (40-80 cm) have been sampled. Several subsamples were taken for the topsoil and the subsamples were mixed into one sample for the laboratory. These samples have been taken according to the soil sampling protocol of The Salt Doctors and were sent to Laboratory ALS.

a. Scouting for salinity effects in the field

As part of the field visits, a list of characteristics of salt-affected soils has been composed and shared with the Arcadis team in Chile. The following **visual symptoms** overview is based on the report of the Soil Survey Staff (2014) and has been used to inspect the visited locations.

Saline soils and plants grown on these soils may exhibit one or more of the following visual symptoms (Gupta and Arbol, 1990; Pearson and Waskom, 2007):

- Inhibited seed germination and irregular seedling emergence
- Symptoms of water stress even when soil is wet
- Fluffy appearance of soil surface
- Visible whitish salt crusts on soil surface
- Plants with leaf-tip burn, especially on young foliage, under sprinkler irrigation with saline water

Sodic soils and plants grown on these soils may exhibit one or more of the following visual symptoms (Gupta and Arbol, 1990; Pearson and Waskom, 2007):

- Cultivation problems related to (1) optimum soil water not uniform across field, with some areas wet and other dry; and (2) surface left cloddy, resulting in poor germination and variable crop stands
- Poor seedling emergence related to soil dispersion and crusting
- Stunted plants, often showing scorching and leaf-margin burn progressing inward between veins
- Shallow rooting depth
- Symptoms of water stress after irrigation or rainfall
- Variations in plant height across the field or yield variations upon harvest
- Dark, powdery residue on soil surface related to dispersed organic matter
- Soapy feel to soil upon wetting for texturing
- Poor drainage, crusting, or hardsetting
- Low infiltration rates; runoff and erosion
- Periodic stagnated water with cloudy appearance in low microrelief
- Soil wetness associated with only upper limits of soil; lower limits almost dry and hard in wetting cycle
- Upon drying, extreme hardening of soils and development of cracks, which vary in width and depth and close upon wetting.
- Dense hard subsoil with variable color; lime nodules possibly present
- Subsoil exposed or near to surface due to leveling or erosion
- Coarse structure (<20 mm), prismatic or columnar subsoil structure

High pH Soils: High pH soils may not necessarily appear any different from soils with neutral pH. Problems typically appear as nutrient deficiencies if pH >7.8. Plant symptoms can be useful indicators of sensitivity to high pH soils. Soils with high pH and plants grown on these soils may exhibit one or more of the following visual symptoms (Gupta and Arbol, 1990; Pearson and Waskom, 2007):

- Powdery substance on soil surface
- Evidence of plant nutrient deficiencies, e.g., reduced availability of Zn, Fe, P, and B as follows: (1) yellow stripes on middle to upper leaves (Zn and Fe deficiency); and (2) dark green or purple coloring of lower leaves and stems (P deficiency)

3. CLASSIFICATION OF SALT-AFFECTED SOILS

Salt-affected soils are often referred to as soils with elevated salt concentrations that interfere with normal plant growth and can include saline, sodic and saline-sodic soils (and many sub-categories depending on the type of salts). Salt-affected soils are more common in the arid and semi-arid regions of the world but have also been observed in humid and sub-humid climates, especially places where the entry of sea water can cause salinization (FAO, 2020; Abrol, 1988).

Saline soils contain excessive amounts of soluble salts that can reduce the ability of plants to take up water and can cause specific ion effects that negatively impact plant growth. So, saline soils can contain different salts and, in most cases, the major cations sodium, potassium, calcium and magnesium are responsible for the elevated salinity levels. The salinity level is generally expressed as the electrical conductivity (EC, in dS/m), measured in the water phase of a specific soil to water ratio. Often, a 1:2 or 1:5 ratio (soil:water) is used, although the more common international standard is to measure the EC in the extract of a soil saturated paste (ECe).

Sodic soils contain high amounts of adsorbed sodium ions which causes the degradation of the soil structure. Sodic soils are usually classified, based on either the sodium adsorption ratio (SAR) or the exchangeable sodium percentage (ESP) and/or the pH of the soil. There are several ways to calculate ESP, but often ESP=exchangeable ((Na/Ca+Mg+K+Na))*100 is used. For SAR, the calculation is SAR= exchangeable $((Na/(Ca+Mg)^{-0.5})$. In both cases, it is about the dominance of sodium (Na) which can cause soil structure to become unstable, which results in compact soils (in the case of soil high in clay content) with poor infiltration of water and air into the soil.

Recently, the FAO (2021) classified salt-affected soils according to

Table 1. As can be seen, there are several levels of salinity (<0.75 dS/m = non-saline, 0.75-2 dS/m = slightly saline, 2-4 dS/m = moderately saline, 4-8 dS/m = strongly saline, 8-15 dS/m = very strongly saline, > 15 dS/m extremely saline, based on ECe, so on the EC of the extract of a soil saturated paste). Additionally, also the ESP can be calculated and linked to a specific class. For sodicity, also the soil pH is often used, with pH>8.2=sodic. High soil pH can affect the nutrient availability of several elements, causing potential nutrient deficiencies in crops (mostly different micro-elements needed for optimal plant growth).

So, in short, to classify a salt-affected soil you need to know the EC, the pH and the concentrations of sodium (Na), calcium (Ca), magnesium (Mg) and potassium (K) to calculate ESP and SAR.

Table 1. The types of soil salinity and sodicity (FAO, 2021).

ECe (dS/m)	Salinity intensity	Effect on crop growth	ESP (%)	Sodicity hazard
<0,75	None	None	<15	None
0,75-2	Slight	None	15-30	Slight
2-4	Moderate	Yields of sensitive crops may be restricted	30-50	Moderate
4-8	Strong	Yields of many crops are limited	50-70	High
8-15	Very strong	Only tolerant crops yield satisfactorily	>70	Extreme
>15	Extreme	Only a few very tolerant crops yield satisfactorily		

4. CROP SALT TOLERANCE

Crops that grow under saline conditions are exposed to two major challenges: osmotic effects and specific ion effects. The osmotic effects are caused by the fact that salts reduce the osmotic potential of the soil solution, making it more difficult to take up water. Crops that have difficulties adapting to the osmotic effects often show signs of water stress or drought stress (wilting). The adaptation itself involves the accumulation and/or production of (organic) solutes, which requires energy, and this often results in reduced growth (even though crops appear to be healthy in all other regards). Specific ion effects can be directly toxic to the crop, due to excess accumulation of Na, Cl, or B in its tissue, or cause nutritional imbalances (Lantzke *et al.*, 2007; Munns, 2004; Hopmans *et al*., 2021). Ion toxicities are rarely observed in annual crops, but when sodium and/or chloride is dominant, accumulation in older leaves can take place and results in plant injuries such as burned sides of the leaf and yellowing around the veins.

Specific ion toxicities are particularly prominent in tree and vine crops and injury becomes more prevalent over the years. Often, chloride toxicity occurs in tree crops sooner than sodium toxicity as sodium (unlike chloride) is retained in woody tissue (Hopmans *et al*., 2021). In general, sodium can cause sodium-induced calcium or potassium deficiency in many crops and, thus, in the case of woody crops also chloride toxicity in leaves can be observed.

Figure 2. Various types of leaf damage on the avocado farm visited for this quick scan.

Crop salt tolerance is often based on the classical “threshold-slope model” (Maas and Hoffman, 1977), describing crop salt tolerance by a threshold value (maximum salinity level with no yield reduction) and a slope parameter (the yield decline for salinity levels beyond the threshold) (Figure 3. Division for classifying crop tolerance to salinity (Maas and Hoffman, 1977). On the left, the principle of the threshold and slope is illustrated, on the right the rating of salt tolerance is illustrated. In this model, a crop with a low threshold and a sharp yield decline at salinity levels beyond this threshold (steep slope) is referred to as a sensitive crop, and a crop with a high threshold and shallow slope is referred to as a tolerant crop. In this simplified model there is a distinction between salt sensitive, moderately sensitive, moderately tolerant and tolerant, and crop can be classified according to this division (also see Table 2). Although this simplified model can be improved (for instance, see Van Straten *et al*., 2019), the salt tolerance levels of crops are often reported by using this model and for this reason, it will also be referred to in this report. It should be noted that the yield data in this model is expressed as relative yield and these data serve only as a guideline to relative tolerances among crops. Absolute tolerance varies, depending on climate, soil conditions, and cultural practices. Also, it should be noted that crop salt tolerance is often linked to “salinity” (as in saline soils), but the effects of sodicity (poor soil structure, poor water infiltration, poor aeration, potential waterlogging, etc.) can have a large effect on crop growth and yield as well.

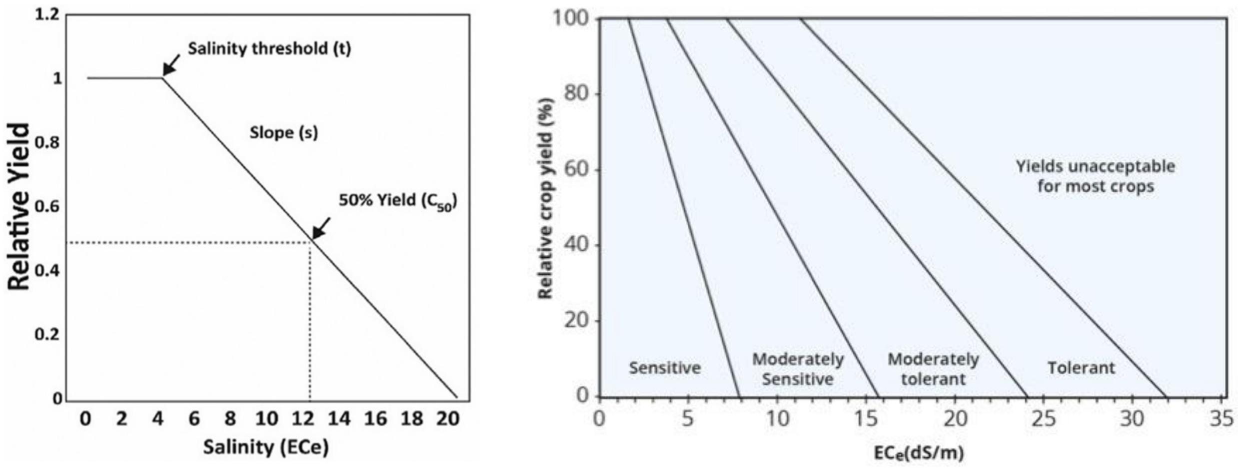

Figure 3. Division for classifying crop tolerance to salinity (Maas and Hoffman, 1977). On the left, the principle of the threshold and slope is illustrated, on the right the rating of salt tolerance is illustrated.

Table 2 provides an overview of the salt tolerance of some woody crops, including avocado and walnut (FAO, 2002). This FAO publication is often used as a reference of crop salt tolerance, although most of the cited literature is relatively old (see the last column in Table 2). Also, for most of these references the tolerance is based on shoot growth rather than the fruit yield, which makes it more difficult to link observed yield reduction in the field to the salt tolerance or salt stress. As indicated before, avocado is an important crop for the focus regions of this report, as well as walnut. Based on Table 2, both crops can be listed as salt sensitive.

Table 3, Table 4 and Table 5 provide more recent information on salt effects on walnut and avocado, not according to the threshold slope model but using other informative indicators.

Table 2. Overview of the salt tolerance of some woody crops (FAO, 2002).

Crop (Common name)	Tolerance based on	ECe Threshold (in dS/m)	Slope (% per dS/m)	Rating [1]	Year of reference
Almond	Shoot growth	1.5	19	S	1953, 1956
Apricot	Shoot growth	1.6	24	S	1956
Avocado	Shoot growth	--	--	S	1950
Fig	Plant dry weight	--	--	MT [3]	1954, 1983
Grape	Shoot growth	1.5	9.6	MS	1967, 1972, 1973
Grapefruit	Fruit yield	1.2	13.5	S	1978
Orange	Fruit yield	1.3	13.1	S	1958, 1988, 1991
Guava	Shoot & root growth	4.7	9.8	MT	1984
Walnut	Foliar injury	--	--	S [3]	1955

[1] Rating: S=sensitive, MS=moderately sensitive, MT=moderately tolerant, T=tolerant

[2] for full references, see http://www.fao.org/3/y4263e/y4263e0e.htm

[3] Rating is an estimate

Table 3. Growth restrictions of walnut trees as a function of the EC of the soil and the irrigation water (adapted from Ibacache, 2008).

EC (dS/m)	Growth restrictions for Juglans sp. (Walnut)		
	No Restriction	Medium	Severe
Root Zone soil salinity (ECe)	< 1.5	1.5 – 4.8	> 4.8
Irrigation Water (ECw)	< 1.1	1.1 – 3.2	> 3.2

Table 4. Growth restrictions of avocado trees as a function of the EC of the soil (ECe) and the irrigation water (ECw) (adapted from Ayers, 1977).

Crop	0 % Loss		10 % Loss		25 % Loss	
	ECe (dS/m)	ECw (dS/m)	ECe (dS/m)	ECw (dS/m)	ECe (dS/m)	ECw (dS/m)
Avocado	1.3	0.9	1.8	1.2	2.5	1.7

Table 5. Chloride tolerance of some fruit crop cultivars and rootstocks (Ayers and Westcot, 1985).

Crop	Rootstock or cultivar	Maximum chloride concentration (in meq/L) without leaf injury	
		Rootzone (soil)	Irrigation water
Avocado (*Persea americana*)	West Indian	7.5	5.0
	Guatemalan	6.0	4.0
	Mexican	5.0	3.3
Citrus (*Citrus spp.*)	Sunki mandarin	25.0	16.6
	Sampson tangelo	15.0	10.0
	Citrumelo 4475	10.0	6.7
Grape (*Vitis spp.*)	Salt creek, 1613-3	40.0	27.0
	Dog ridge	30.0	20.0
	Thompson seedless	20.0	13.3
	Perlette	20.0	13.3
	Cardinal	10.0	6.7
	Black rose	10.0	6.7

5. RESULTS

a. Current situation

WATER

Climate, Climate Change and Droughts

The climate of the Valparaiso and Metropolitan regions have been described as "Mediterranean" (semi-arid), with cool, (relative) wet winters and dry, warm summers. The two regions are often referred to as the "Northern Mediterranean Zone". Rainfall in the two focal regions of this report is highly seasonal, with most rain falling in June and July. The annual sum of precipitation is around 345mm (see Figure 4. Mean annual precipitation and temperature in Valparaiso, Chile (source: www.climate-data.org).). Because of this low amount of precipitation and highly seasonal nature of it, farmers irrigate their crops.

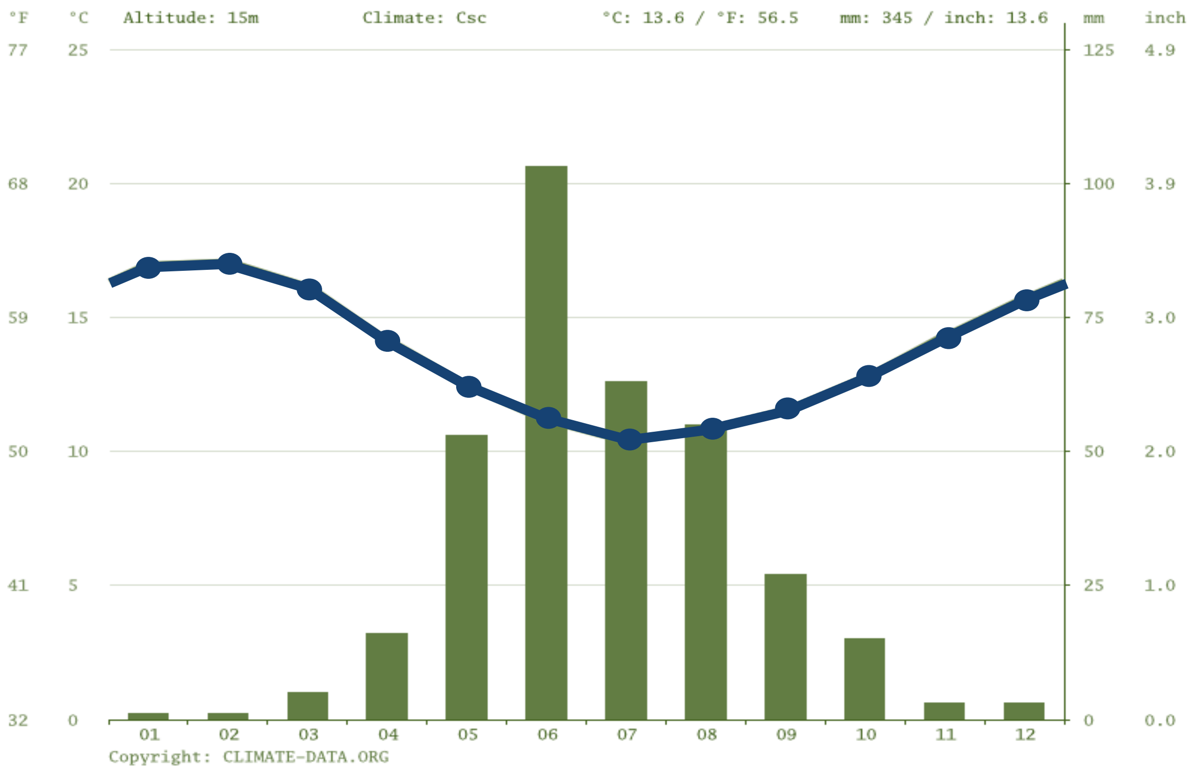

Figure 4. Mean annual precipitation and temperature in Valparaiso, Chile (source: www.climate-data.org).

Gradual warming has been experienced since the middle of the 1970's in central and northern Chile, which has been consistent with climate change caused by emissions of greenhouse gases into the atmosphere (CR^2, 2015). Currently, Chile is going through a mega-drought, with rain shortages recorded that exceed 30% from northern Chile down to the Araucania Region (Figure 5), with climate records unparalleled in the last 70 years. The return period for the driest year of the current drought has been calculated to more than 30 years in central and southern Chile (CR^2, 2015). In addition, this mega-drought has taken place during the warmest decade recorded in Central Chile, with records from weather stations registering maximum temperatures from 0.5 to 1.5 ^{o}C above normal values registered from the year 1970 to the year 2000 (CR^2, 2015).

The lack of precipitation in addition to the high temperatures has led to an increase in water loss from sublimation, evapotranspiration, and evaporation, worsening the current water deficit (CR^2, 2015).

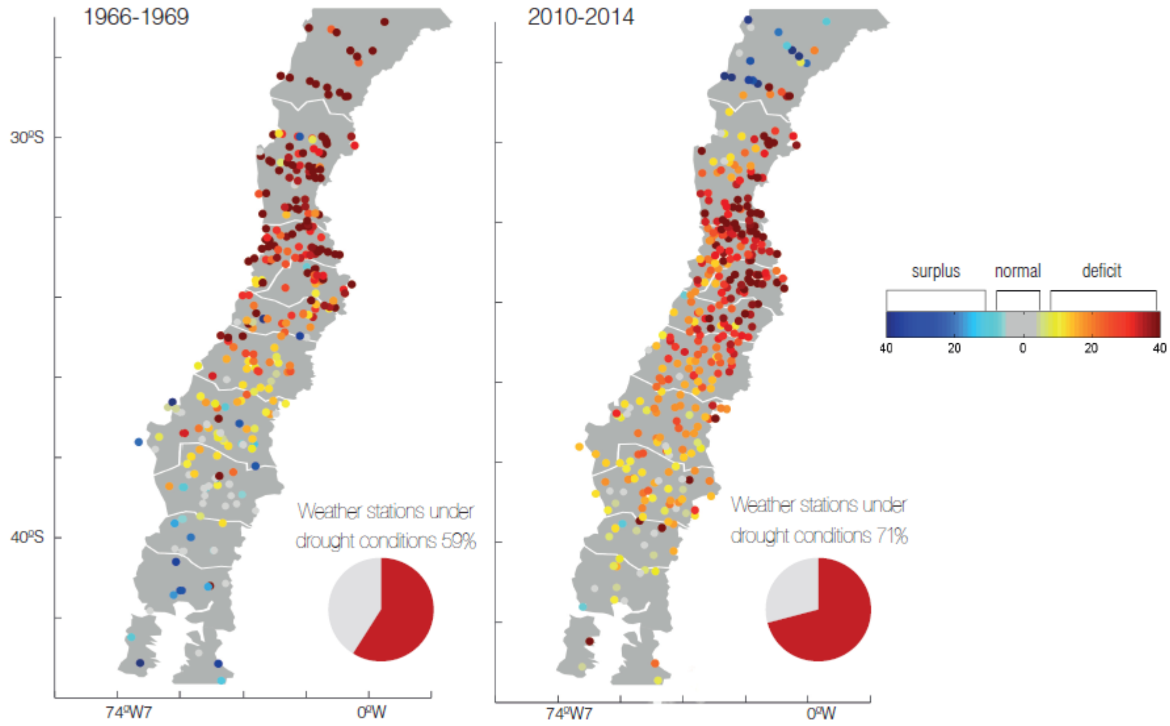

Figure 5. Average Rainfall Deficit or Surplus as a percentage for 1966 to 1969 and 2010 to 2014 (source: Image from the CR^2 Report to the Nation (2015).

By the end of the century, leading current averages of temperatures are expected to continue to rise by 2 to 4°C, along with the trend of decreasing rainfall. In addition, the wind regime, cloud cover and the frequency of critical events related to temperatures extremes, such as fewer frosts and more days of extreme heat, among others, are also expected to change. This could shift the current climatic zones to the south, affecting fruit production and forestry (Neuenschwander, 2010), and generating crop migration or switching of crops to mitigate the adverse effects (Sloat *et al.*, 2020; Rising & Devineni, 2020).

Water Rights in Chile

The current legislation for water rights in Chile is the Water Code (Código de Aguas) that was enacted in 1981. With water rights we refer to the legal right of a given person to use a certain volume of water, groundwater and/or surface water, at once, or over the course of a year, or other. The details are complex and specific per region, but it is central that they have once been awarded for free and can currently be sold on. Additionally, for ground water they have not been based on actual water availability.

The initial assignation of water rights was performed based on the historical use of water in the past (based on the old Codes of Water from 1951 and 1969). After that, if more water was needed, the one who pays most for it is chosen in an action among the interested parties, and the reallocation of the water rights occurs through the free transfer of rights (Figueroa, 1995).

Some of the important characteristics of the Water Code in Chile indicated by Ríos and Quiroz (1995), and grouped by Munchnik (1997) are listed below:

- Water rights are independent of land ownership rights and may be freely sold, bought, and transferred. Their private property character is guaranteed in accordance with the property rights established in the Civil Code.

- Applications for new water rights are not subject to the destination of the water or the type of use and there is no order of priorities regarding the use of the resource. Also in this sense, it can be said that this is the only legislation that does not impose as a condition of access to the water right its effective and beneficial use (Solanes, 1997).
- The State assigns water rights free of charge and, when simultaneous applications are filed for the same rights, these are awarded to the highest bidder. No taxes are levied on the right holders.
- The role of the state in dispute settlement is very limited, and disputes are resolved through private negotiations or through the judicial system.
- In addition to current consumptive uses, the Code defines the concept of non-consumptive use. This concept has been included in anticipation of the multiplicity of water uses, especially for the purpose of promoting the construction of hydroelectric plants in the upper reaches of river basins, without affecting new or existing consumptive rights granted in the lower reaches for irrigation purposes.
- In general terms, the right to use groundwater is governed by the same legislative rules as for surface water. However, the Code contains some special rules for this type of water (Rosegrant and Gazmuri, 1994).

User organizations include the following (Ríos & Quiroz, 1995):

- Surveillance Boards: committees in charge of overseeing the use of natural water sources
- Association of Canal Users: in charge of managing primary infrastructures, such as dams and main irrigation canals
- Water Communities: in charge of secondary infrastructures, such as distribution canals

Institutions that also play a role in the implementation of the 1981 Water Code and the Irrigation Laws (Rios & Quiroz, 1995) are the following:

- General Directorate of Water (Dirección General de Aguas, DGA): State agency under the Ministry of Public Works (Ministerio de Obras Públicas, MOP), in charge of general planning for water use and the development and exploitation of natural water resources.
- National Irrigation Commision (Comisión Nacional de Riego, CNR): State agency in charge of planning, evaluating, and approving investment projects in irrigation infrastructure works, which includes coordinating the activities of several public institutions and private organizations. Together with the Irrigation Directorate, it participates in the implementation of irrigation laws for large and small projects
- Irrigation Directorate (Dirección de Riego, DR): Government agency whose main function is the execution of technical and economic studies on irrigation works on investment projects financed by the State, once approved by the CNR, they are tendered to private companies

The water resource management model has been criticized by several multilateral agencies such as the OCDE (Neirot, 2018). In their report "Evaluaciones de Desempleño Ambiental: Chile 2016", the OCDE indicated that the model allows for the extreme concentrations of water rights, as well as observing the following issues (Neirot, 2018):

- Excessive allocations and extreme concentration of water rights persist
- There are cases of overexploitation and contamination in several aquifers in the country
- There is still a lack of knowledge of hydrological resources, a basic requirement for effective water management
- There is a need to improve the transparency of the public water registry

Hydrographic Description of the Metropolitan Region

90% of the Metropolitan Region is composed of the Maipo River basin, while the remaining 10% corresponds to fractions of the sub-basins of the Yali Estuary which is shared with the Valparaiso Region, the Alhue Estuary, and a minimal fraction of the sub-basin of the Rapel River, which is shared with the Libertador Bernando O'Higgins Region (Arrau, 2015). There are 15 rivers in this region, with two main ones, the Maipo River, and the Mapocho River (Figure 6).

The main river for this region is the Maipo River, originating in the Andes Mountains and ending in the city of San Antonio in the Pacific Ocean (Valparaiso Region), it crosses through three sub-basins: the Rio Maipo Alto, Rio Maipo Medio, and Rio Maipo Bajo. It is born from the confluence of the Yeso and Colorado rivers and has a mixed nivo-pluvial hydrological regime (Arrau, 2015; DIRPLAN MOP Región Metropolitana 2021).

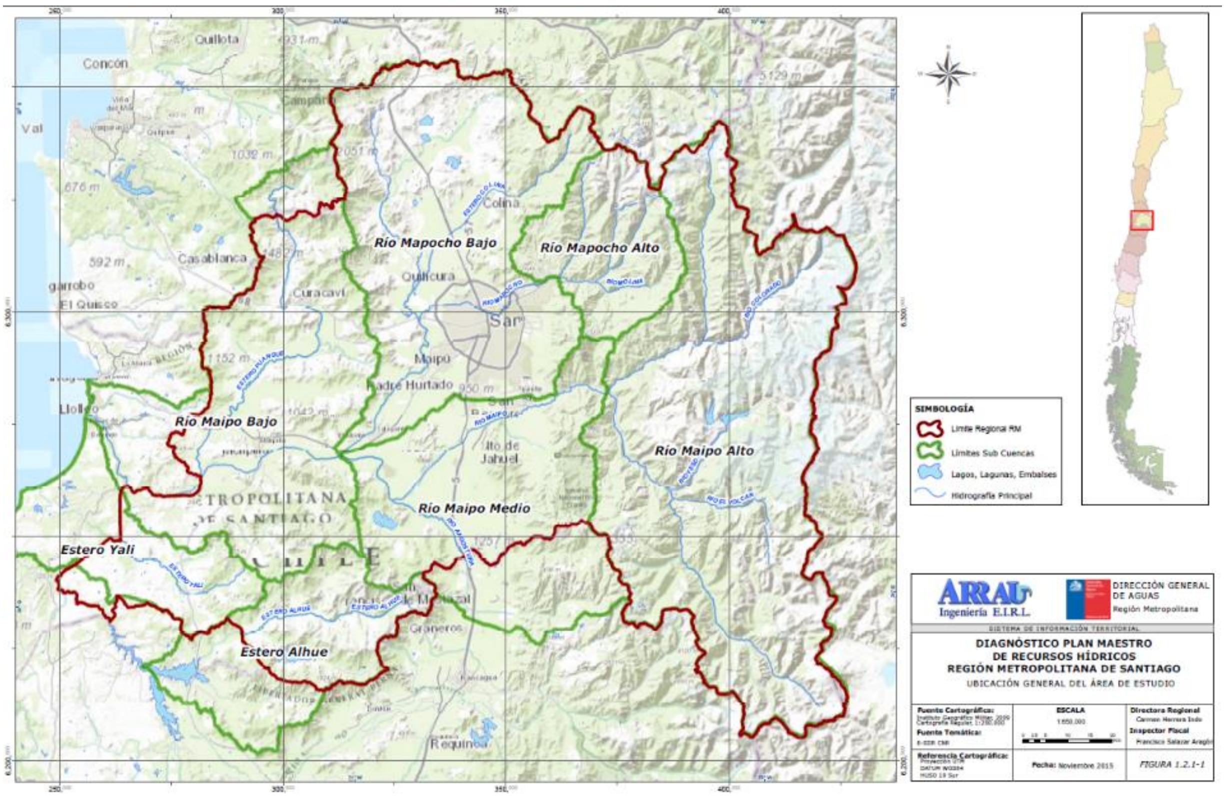

*Figure 6. Map of the Metropolitan region (*Source: Arrau, 2015).

The average annual surface supply between 2010 and 2014 for the region (sum of all sub-basins) was 123.5 m^3/s, and the average annual underground supply was 44.77 m^3/s, these do not consider the reuse between one sub-basin and another (surplus transfers; Arrau, 2015). The superficial water demand was 68.15 m^3/s, and the groundwater demand was 34.14 m^3/s (calculated from data presented by Arrau, 2015).

The main use for surface and groundwater is for irrigation (62% and 65%, respectively), with an average demand flow of 42.25 m^3/s for surface water and 22.19 m^3/s for groundwater, as presented in Table 5 with the other uses. The most recurrent problems are the availability of rural drinking water supply, the generalized lowering of groundwater tables and water shortages (for both surface and groundwater), which is also appreciated by the negative water balance in summer for superficial water (-19.74 m^3/s) and a negative water balance for groundwater (-4.98 m^3/s) in the spring and summer quarters (Arrau, 2015).

As mentioned before, the Maipo river is divided into three sections (also see Figure 6: Maipo Alto, Maipo Medio and Maipo Bajo), with the “Alto” section showing a significant increase of streamflow in spring months due to snow-melt in the Andes, the middle (“medio”) section showing two annual periods of higher discharge (in spring and winter due to precipitation and snow-melt), and the lower section showing mostly large volumes of streamflow associated with precipitation (Peña-Guerrero *et al*., 2020).

Table 6. Demand for Superficial and Groundwater in the Metropolitan Region of Chile from 2010 to 2014.

Demand	Irrigation (m3/s)	Urban Potable Water (m3/s)	Environmental Flow (m3/s)	Industrial (m3/s)	Mining (m3/s)	Rural Potable Water (m3/s)
Superficial	42.25	13.63	10.22	13.63	6.81	-
Groundwater	22.19	10.58	-	0.68	0.34	0.34

Source: Elaborated by Arcadis from data presented by Arrau, 2015.

Agricultural use in the Maipo River basin comprises 246,477 hectares of agricultural land, and 22,916 hectares of grassland crop rotation. The Maipo River is 250 km long and meets around 90% of the current demand for irrigation (DGA, 2004). The total area irrigated in the Metropolitan Region is 138,693.8 ha, mainly by furrow irrigation (41.5 %), as shown in Table 7.

Table 7. Irrigation systems used in the Metropolitan Region of Chile.

Irrigation System	Irrigated Area (ha)	Irrigated Area Compared to Total Area (%)
Flood	33,187.2	23.9
Furrow	57,547.3	41.5
Spray or sprinkler	881.5	0.6
Reel or Pivot	3,022.7	2.2
Drip or Tape	38,079.4	27.5
Flood	33,187.2	23.9
Furrow	57,547.3	41.5

Source: Elaborated by Arcadis based on information from the VII National Agricultural and Forestry Census of 2007 by INE.

Hydrographic Description of the Valparaiso Region

This region has four main rivers, all of a nivo-pluvial character (DIRPLAN MOP Región de Valparaíso, 2012), and all born from the Andes Mountains (Figure 7). They are the Aconcagua River, Petorca River, La Ligua River and Maipo River. For the Maipo river only the last stretch and mouth of the river are present in this region.

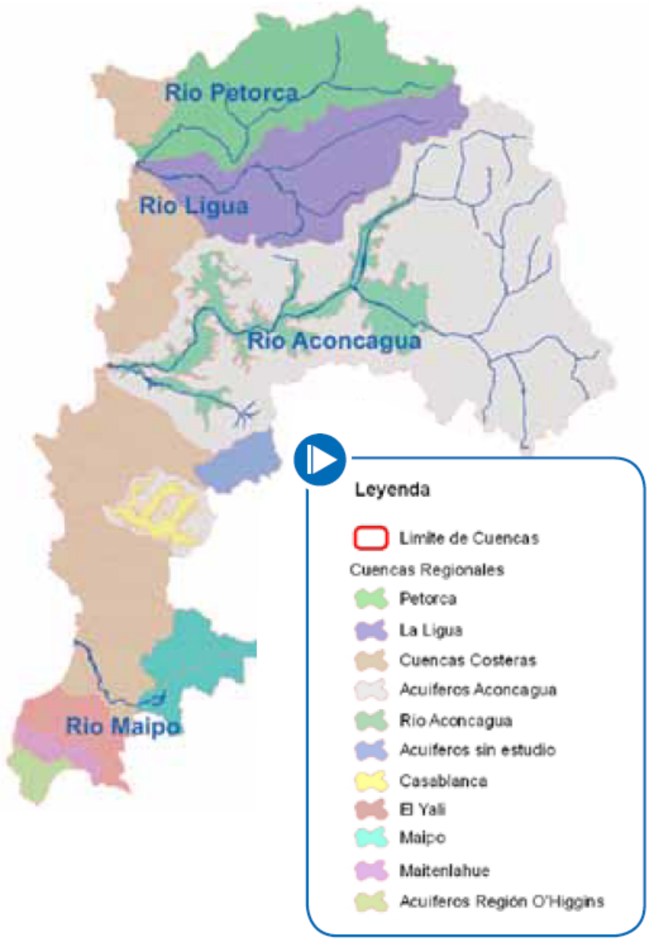

Figure 7. Basins and Sub-basins of the Valparaiso Region.

Source: DIRPLAN MOP Región de Valparaíso, 2012.

The Aconcagua River is the main river in the region, born in the Andes Mountains by the Juncal and Blanco rivers, since the intersection with the Blanco River, the Aconcagua River has a length of 142 km, up to its mouth in Concon in the Region of Valparaiso (CENMA, 2008). This river presents a noticeable seasonal fluctuation due to the melting of the snow in spring, and the rainfall in winter, which shows its mixed regime. This river drains a hydrographic basin of 7,4340 km^2 and is generated at the confluence of the Juncal and Blanco rivers in the Andes Mountains, with a length of 177 km (including the Juncal River), having an average flow of 79 m^3/s when draining into the sea (DIRPLAN MOP Región de Valparaíso, 2012).

The estimated demand until now (2021) for agricultural use of water is 35.6 m^3/s for the Valparaiso Region (DIRPLAN Region Valparaiso, 2007), and it is estimated that the Basin of the Aconcagua River has 71,000 hectares of land destined for agriculture (DCPRH, 2016). Table 8 shows the surface area of irrigated land in the region, and the relative contribution of the different irrigation methods.

Table 8. The surface area of irrigated agricultural land in the Valparaiso region and the relative contributions of the different irrigation methods.

Irrigation System	Irrigated Area (ha)	Irrigated Area Compared to Total Area (%)
Flood	16,721.7	19.2
Furrow	19,152.0	22.0
Spray, sprinkler	1,765.3	2.0
Reel or Pivot	1,085.2	1.2
Drip or Tape	32,925.7	37.9
Micro-sprinkler or Micro-jet	14,702.7	16.9
Other	535.0	0.6

SOIL

The geologic variety and diverse origin of surface sediments cause the soils of Chile to vary greatly in character from north to south. It can be stated that in the northern desert region saline soils, made up of gravel and sand cemented with calcium sulfate, alternate with alkali-rich soil, which are difficult to cultivate even with irrigation because of their surface salt accumulations. Within the Central Valley, the alluvial soils have developed over fluvio-volcanic deposits, which is the reason for their mineral and organic richness (source: https://www.britannica.com/place/Chile/Soils). In the Valparaiso and Metropolitan areas, the soil zones, from east to west, can be characterized as “Principal Andes range”, “Central Valley” to “Coastal Range” (Casanova *et al*., 2013). Due to the fluvial nature of the area, soil types can range from sandy soils to clay soils. The geology in the area shows a wide range of volcanic rocks to marine and continental sediments, often composed of gypsum (Peña-Guerrero *et al*., 2020). In most regions in Chile, the soil texture can be classified as sandy loam, with some loam, clay loam and clay (Casanova *et al*., 2013). The soils in the Metropolitan area are often fine-textured (contain clay) and the depth is limited by a cohesive dense horizon (by clay or cemented by carbonates) or a permanent water table (Casanova *et al*., 2013). Overall, soils in the Mediterranean zone are characterized by a low cation exchange capacity (Casanova *et al*., 2013) (indicating relative low clay content) and cation leaching is recognized as a major factor in limiting productivity in the Southern Mediterranean zone (Bernier and Alfaro, 2006). This indicates that many soils have good water infiltration and drainage. The soils of the Hyper-arid to Semi-arid zone and in the Northern Mediterranean often show a high pH which reduces the availability of especially micro-nutrients and crop deficiencies in iron (Fe), zinc (Zn), manganese (Mn) and copper (CU) are commonly observed (Casanova *et al*., 2013).

Figure 8 below shows the soil on the avocado farm visited for this report (image on the left) and the walnut farm (image on the right). The coloring on the hand is caused by the clay fraction of the soil sample (avocado farm), but larger particulate matter can also be observed.

Figure 8. Soil from the avocado farm (left) and the walnut farm (right).

CROPS

In Chile, family farms contribute to 54% of vegetable production, over 40% of annual crops and flowers and 30% of the vineyards in Chile, representing a total of 90% of the total number of farms in Chile. Less is known about these farms in terms of salinity problems, and usually they do not have the means to incorporate high tech or hire experts, unlike big farms.

Table 9 shows the ten most important crops in Chile over the years 2017-2019 (FAOSTAT data). We can see that for most crops, yields are slightly increasing over the years, and that the area cultivated is rather constant, except for oats, for which the cultivated area is reducing considerably. The area of Cherries is increasing.

Table 9. The ten most dominant crops on the surface of Chile in the years 2017-2019 (most recent data from FAOSTAT).

Irrigation System	Irrigated Area (ha)	Irrigated Area Compared to Total Area (%)	
Wheat	2017	225042	6,00
Wheat	2018	236415	6,21
Wheat	2019	222705	6,29
Grapes	2017	192821	12,36
Grapes	2018	193647	14,60
Grapes	2019	195357	13,83
Oats	2017	136818	5,21
Oats	2018	107528	5,31
Oats	2019	74617	5,16
Maize	2017	94668	11,22
Maize	2018	89058	12,47
Maize	2019	80428	12,10
Potatoes	2017	54082	26,38
Potatoes	2018	41268	28,67
Potatoes	2019	41811	27,81
Rapeseed	2017	46249	3,96
Rapeseed	2018	56533	3,89
Rapeseed	2019	48166	3,85
Walnuts, with shell	2017	35277	2,83
Walnuts, with shell	2018	36819	2,99
Walnuts, with shell	2019	40801	3,01
Apples	2017	35937	48,67
Apples	2018	34427	49,38
Apples	2019	32371	50,09
Cherries	2017	25109	4,78
Cherries	2018	30179	7,55
Cherries	2019	38392	6,09
Avocados	2017	30078	6,65
Avocados	2018	29166	5,83
Avocados	2019	29224	5,58

b. Metropolitan Region

The Metropolitan Region is the smallest and most populated region of Chile, with a total area of 15,403.2 km^2 (2% of the national territory). It has a warm temperate climate with a prolonged dry season. Most of the farms in this region are smaller farms of less than 20 ha, accounting for 73.2% of the total number of farms in the region, but equivalent to only 3.73% of the total farmland of the region. Farms of 100 or more hectares make up 9.6% of the total number of farms, but they account for 89.1% of the total farmed area. The rest of the details for farms of 20 to 50 ha, and 50 to 100 ha are presented in Figure 9, as well as the number of farms and the areas for each size class. For example, we can see if figure 9 that almost three quarters of all farmers (73,2%) have less than 20 ha, but all those farms account for only 3,7% of the agricultural land area in the region.

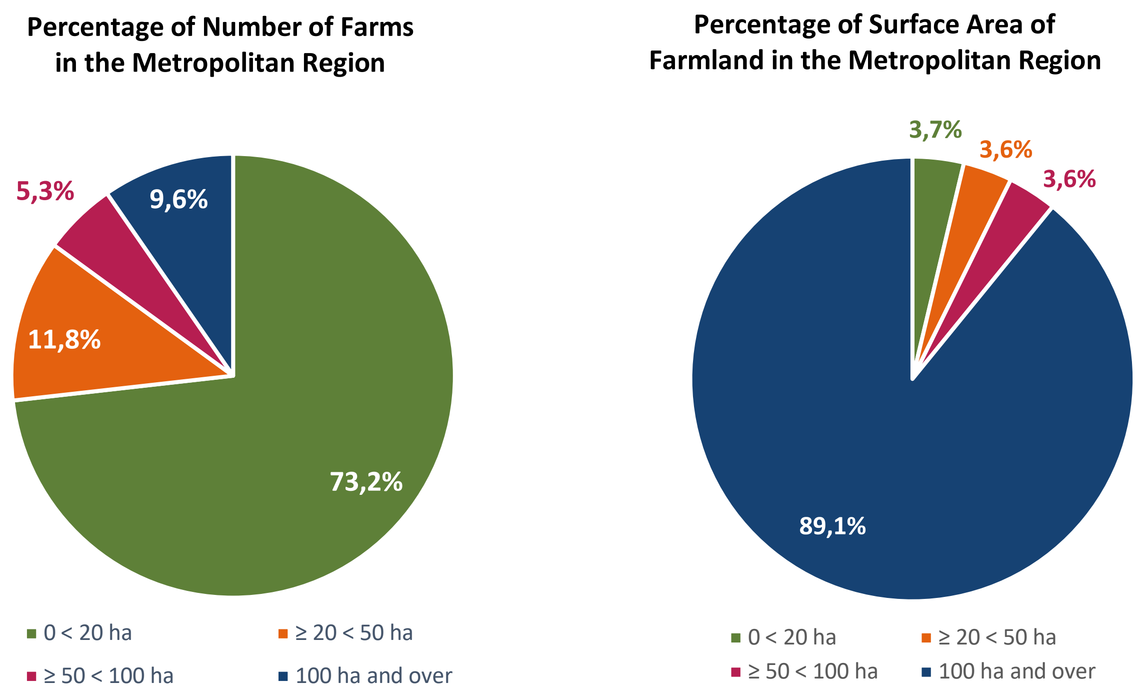

Figure 9. Size classes of farms in the Metropolitan area (left) and the percentage of total farmland occupied by the different size classes (right). Large farms (less than 10%) occupy the vast majority of farmland (89,1%) (source:adapted from ODEPA, 2021).

According to the 2007 Agricultural and Forestry Census, the main uses of soil for agriculture in the Metropolitan Region are destined to fruits (35.7%), vegetables (16.9%), forage plants (14.3%), cereals (10.7%), and vineyards and grapevines (8.2%) (INE, 2007). This census is being updated and the results are expected to be available by August of 2022 (INE, 2021). The regional fruit-growing area by species (Table 10) the regional horticultural area by species (Table 11) and the regional area of annual crops by species (Table 12) are presented below. The data in these tables were obtained from various sources and presented by ODEPA.

Table 10. Regional fruit-growing area by species (Source: Adapted by Arcadis and prepared by ODEPA based on the information from the fruit cadaster for the Metropolitan Region, ODEPA-CIREN 2020).

Fruit Species	Area (ha)
Walnut Tree	16,430.28
Table Grapevine	6,847.52
Olive Tree	4,945.64
Avocado Tree	4,229.33
Cherry Tree	3,681.28
Almond Tree	3,616.96
Lemon Tree	3,302.53
European Plum Tree	2,719.06
Orange Tree	2,506.36
Nectarine Tree	1,209.39
Others	5,173.36
Total	54,661.71

Table 11. Regional horticultural area by species.

Horticultural Species	Area (ha)
Corn	3,439.5
Lettuce	2,316.8
Onion (storage)	2,138.1
Onion (early)	1,571.7
Granado Bean	1,428.0
Carrot	1,362.7
Squash (early and storage)	1,129.9
Broccoli	1,010.4
Cauliflower	954.7
Faba Bean	929.9
Other	10,059.4
Total	26,341.0

Source: Adapted by Arcadis and prepared by ODEPA with information from the horticultural area survey by INE 2020.

Table 12. Regional area of annual crops by species.

Annual Crop Species	Area (ha)
Wheat Flower	2,075
Corn (human consumption)	1,841
Oats	1,296
Potato	1,254
Wheat	1,154
Corn (seed)	634
Sunflower	260
Bean	72
Barley (animal feed)	68
Other Industrial	26
Total	8,680

Source: Adapted by Arcadis and prepared by ODEPA with information from the survey of annual crops planted by INE 2020-2021.

c. Valparaiso Region

The Valparaiso Region has a total surface area of 16,693.1 km^2 (2,2% of the national territory). Insular territory is also included in its surface area, composed of the Easter, Salas y Gómez, San Félix and San Ambrosio islands, and the Juan Fernández Archipelago composed of the Alejandro Selkirk, Robinson Crusoe, and Santa Clara islands. It presents a temperate climate of the Mediterranean type, where rainfall has greater importance and regularity. Most of the farms in this region are smaller farms of less than 20 ha, accounting for 80.7% of the total number of farms in the region, representing 4% of the total farmland of the region. Farms of 100 or more hectares make up 7,7% of the total number of farms, accounting for 89,7% of the total farmed area. The rest of the details for farms of 20 to 50 ha, and 50 to 100 ha are presented in Figure 10, as well as the number of farms and the areas for each size class.

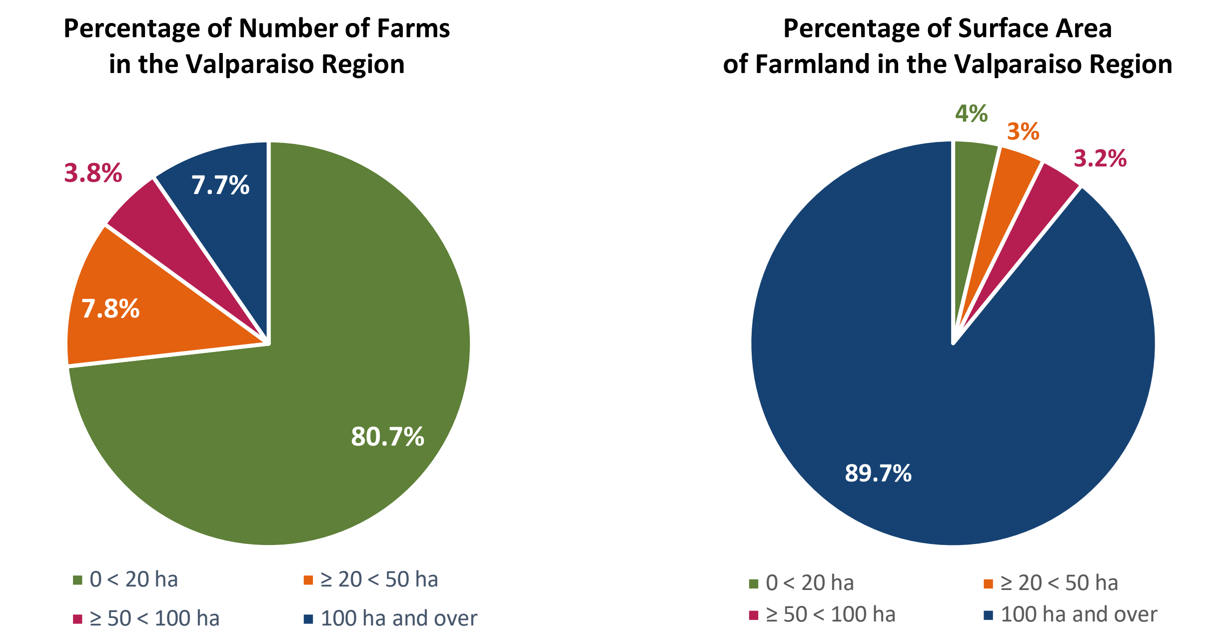

Figure 10. Size classes of farms in the Metropolitan area (left) and the percentage of total farmland occupied by the different size classes (right). Large farms (only 7,7%) occupy the vast majority of farmland (89,7%).

Source: Elaborated by Arcadis based on data presented by ODEPA (2021).

According to the 2007 Agricultural and Forestry Census, the main uses of soil for agriculture in Valparaiso Region are destined to forestry plantations (37.6%), fruits (34.1%), and forage plants (10.6%) (INE, 2007). This census is being updated and the results are expected to be available by August 2022 (INE, 2021). The regional fruit-growing area by species (Table 13) the regional horticultural area by species (Table 14), and the regional area of annual crops by species (Table 15) are presented below, this data was obtained from various sources and presented by ODEPA.

Table 13. Regional fruit-growing area by species.

Fruit Species	Area (ha)
Avocado Tree	20,317.80
Table Grapevine	9,969.77
Walnut Tree	7,003.30
Tangerine Tree	2,321.38
Lemon Tree	2,021.51
Peach Tree (canning)	1,990.15
Almond Tree	1,256.94
Orange Tree	1,186.01
Olive Tree	820.84
Nectarine Tree	295.41
Others	1,868.3
Total	49,051.4

Source: Adapted by Arcadis and prepared by ODEPA based on the information from the fruit cadaster for the Metropolitan Region, ODEPA-CIREN 2020.

Table 14. Regional horticultural area by species.

Horticultural Species	Area (ha)
Lettuce	1,652.5
Tomato	1,044.5
Granado Bean	820.2
Corn	786.2
Carrot	708.8
Cabbage	537.4
Garlic	302.7
Onion (storage)	263.9
Onions (early)	238.8
Celery	228.0
Others	2,196.0
Total	8,779.0

Source: Adapted by Arcadis and prepared by ODEPA with information from the horticultural area survey by INE 2020.

Table 15. Regional area of annual crops by species.

Annual Crop Species	Area (ha)
Barley (animal feed)	3,512
Potato	608
Wheat Flour	292
Corn (human consumption)	211
Wheat	87
Bean	14
Total	4,724

Source: Elaborated by ODEPA based on information from the VII National Agricultural and Forestry Census by INE, 2007, and modified by Arcadis (2021).

d. Salinity

Salinity of the water

As was mentioned before, farmers mostly use the river water for irrigation. The flow of the rivers, as indicated for the Maipo River, shows seasonal fluctuations and this can influence not only the quantity of the water, but also the quality. The electric conductivity of the Maipo River fluctuates from 800 to 1,300 µS/cm, with extreme values between 500 and 1,500 µS/cm, with the highest salinities registered at the origin of the river and at the end of the river (Arrau, 2015; Comisión Nacional de Riego, 1984). Peña-Guerrero *et al*. (2020) evaluated the impacts of drought on the water quality of the Maipo River in the period 1985-2015. The research showed that variables such as the electrical conductivity, SO_4 and chloride showed an exponential behavior while the streamflow decreased, and it reaches their maximum mean concentrations during hydrological drought periods. Most of these maximum concentrations were reached in recent periods of extreme low flows (2010-2015) and these results are listed in Table 16. Regarding the salinity of the Aconcagua River, a main river in the Metropolitan Region, a study by CENMA (2008) measured the electrical conductivity in the superficial water of the river, and demonstrated values that usually did not exceed 600 µS/cm (0,6 dS/m), with the highest measurement of 806 µS/cm. So, this river seems to be less saline than the Maipo River.

Table 16. Minimum, maximum and mean concentrations of the electrical conductivity (EC) and chloride measured at three separate hydrological stations in the Maipo River basin, in the period 1985-2015 (adapted from Peña-Guerrero et al. (2020)).

Sub-basin	EC (in dS/m)			Chloride (in mg/L)		
	min	max	mean	min	max	mean
Maipo Medio	0.83	1.51	1.27	85	202	137
Mapocho	1.15	2.21	1.66	101	324	211
Maipo Najo	1.31	2.18	1.71	143	292	204

In general, the geochemistry of the bedrock geology in the Maipo River is dominated by outcropping evaporites that are associated with high SO_4^{2-} level in the water and the water stream is further characterized by high concentrations of Ca, Cl, K and Na, with a pH range of 7 to 8.5 (Peña-Guerrero *et al*., 2020). In this regard, elevated level of the EC can be caused by increased concentrations of Na, but also Ca, Mg and K, since these four cations combined are responsible for the observed EC levels in most cases.

Salinity of the soil

Recently, the FAO (Global Soil Partnership) has launched the Global Map of Salt-affected Soils (GSASmap, see https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/global-map-of-salt-affected-soils/en/). Although Chile has not uploaded the results yet, based on the results of the neighboring countries, some trends can be seen, as is indicated in the maps below. In the GSAS database, there is a distinction between the salinity of the topsoil (0-30 cm) and the subsoil (30-100 cm), and both are presented below. Where the topsoil shows somewhat limited salinity concentrations (in the range of 2-4 dS/m, see Figure 11), it is especially the subsoil (30-100 cm) that show high salt concentrations in a vast area (Figure 11, right). In Figure 12, a more detailed image of the area around Valparaiso and the Metropolitan area is provided. Based on this figure, it appears that elevated salinity levels can be found to the east of the Valparaiso and Metropolitan area, in the elevated lands/mountains. This could be the source of salinity found in river waters flowing down the mountains, and possibly accumulating in the soil to some extent in the river area downstream. However, caution is advised extrapolating broadly since the Andes is between Argentina and Chile and forms a formidable geographical barrier.

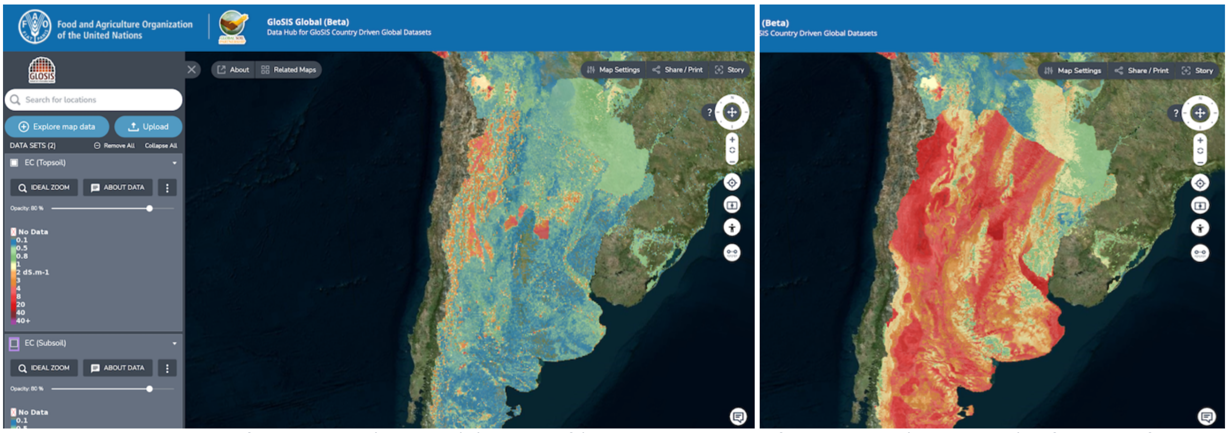

Figure 11. Soil salinity of the topsoil (0-30 cm) (image left), and soil salinity of the subsoil (30-100 cm), of a part of South America, as available from GSASmap (FAO, 2021). The orange color indicates a soil salinity level in the range of 2-4 dS/m (ECe), whereas the red color indicates salinity levels up to 20 dS/m.

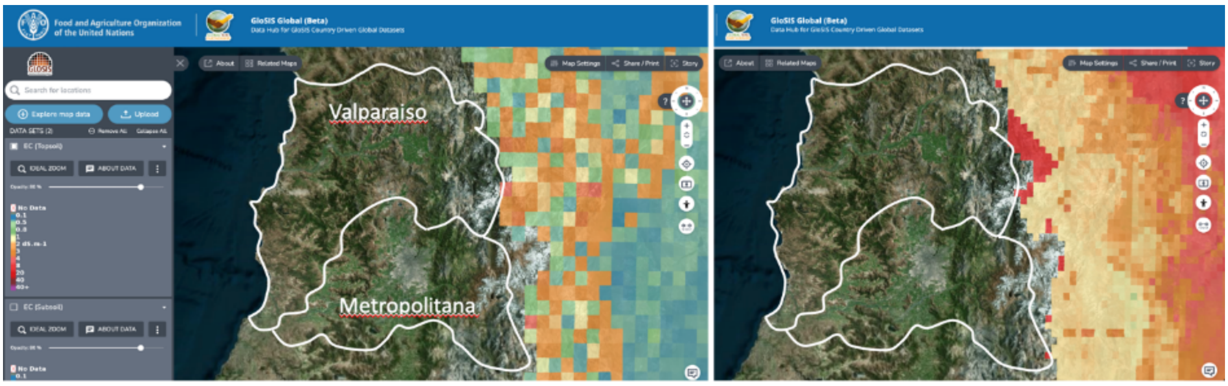

Figure 12. Soil salinity of the topsoil (0-30 cm) (image left) and soil salinity of the subsoil (30-100 cm), for the focus areas of the Valparaiso and the Metropolitan regions, as available from GSASmap (FAO, 2021). No direct soil salinity data is available, but based on this GSAS map it appears that the elevated land on the east of both areas are indeed salt-affected. However, caution is advised extrapolating broadly since the Andes are between Argentina and Chile and forms a formidable geographical barrier.

A more detailed study into the salinity aspects in Chile is provided by Casanova *et al*. (2013). Here, it is stated that around 759.000 km^2 in Chile is affected by salinity and an additional 33.000 km^2 by sodicity. These are mostly areas in the arid north of Chile and fossil salt crusts in the west of the extremely arid Central Valley. Among others, salts also accumulate in the semi-arid northern part of the Mediterranean zone, due to insufficient rainfall (<500 mm per year) to remove the salts from the topsoil. In general, the salt-affected areas are mostly located in the extremely arid to semi-arid areas, although in the northern part of the Mediterranean zone there are some pockets of moderately to strong saline soils that arise from confinement, created by a physical barrier to water flow out of a depression in the landscape (Casanova *et al*. (2013)). In Figure 13 and Table 17, the soil electrical conductivity of the topsoil (0-20 cm) in the hyper-arid, semi-arid and Mediterranean zone are presented. Based on Table 17 the majority of the soils in the different climatic zones can be classified as non-saline, although 31% of the soils of the Hyper-arid and Semi-arid zone can be classified as very slightly saline up to strongly saline. For the Mediterranean zone, around 16% of the soils are salt affected to some extent.

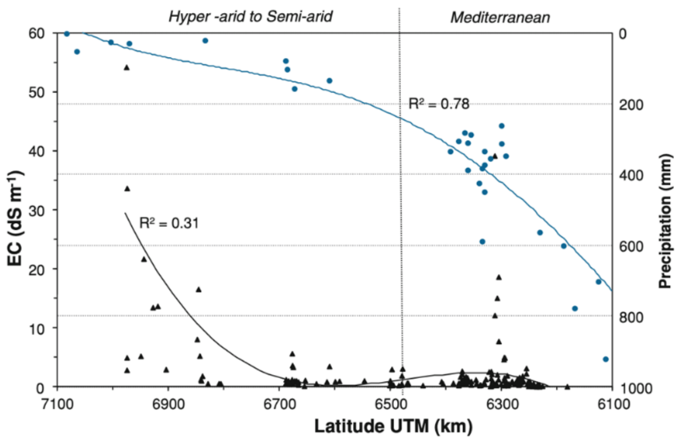

Figure 13. Soil electrical conductivity at 0-20 cm depth between the Hyper-arid to Semi-arid zone and Mediterranean zone. Triangles are EC in soil samples (N=173) and circles are mean annual precipitation obtained from 30 meteorological stations (Casanova et al. 2013).

Table 17. Range of soil electrical conductivity (EC) at 0-20 cm depth in Hyper-arid and Semi-arid zone (n=68 samples) and northern part of Mediterranean zone (n= 105 samples) (Casanova et al. 2013).

Class	EC (ds m - 1)	Hyper-arid to Semi-arid zone (%)	Northern Mediterranean zone (%)
Non-saline	0-2	69	85
Very slightly saline	2-4	12	8
Slightly saline	4-8	6	4
Moderately saline	8-16	4	3
Strongly saline	>16	9	1

e. Additional Information

ODEPA is the office of agricultural studies and policies, on their website it is possible to find information and statistics separated by region. They have online information regarding prices, costs per hectares of crops per region, census information, hectares of production, and others on their website at: https://www.odepa.gob.cl/. Another good source of information is the agricultural census by the National Statistics Institute of Chile (INE), the latest census available is from the year 2007, but is being updated now. The results should be available by August 2022 on their website at: https://www.ine.cl/censoagropecuario.

6. SITE VISITS AND INTERVIEWS

a. Farmers

Two farmers replied to the questionnaire sent, Helmut Engländer, a walnut producer (plantation of 47 hectares) from the Metropolitan Region, and Jaime Cruz, an avocado producer (plantation of 213 hectares) from the Vth Region. Both agreed to a site visit and allowed Arcadis to collect soil and water samples. The location of each surveyed farm is presented in Figure 14.

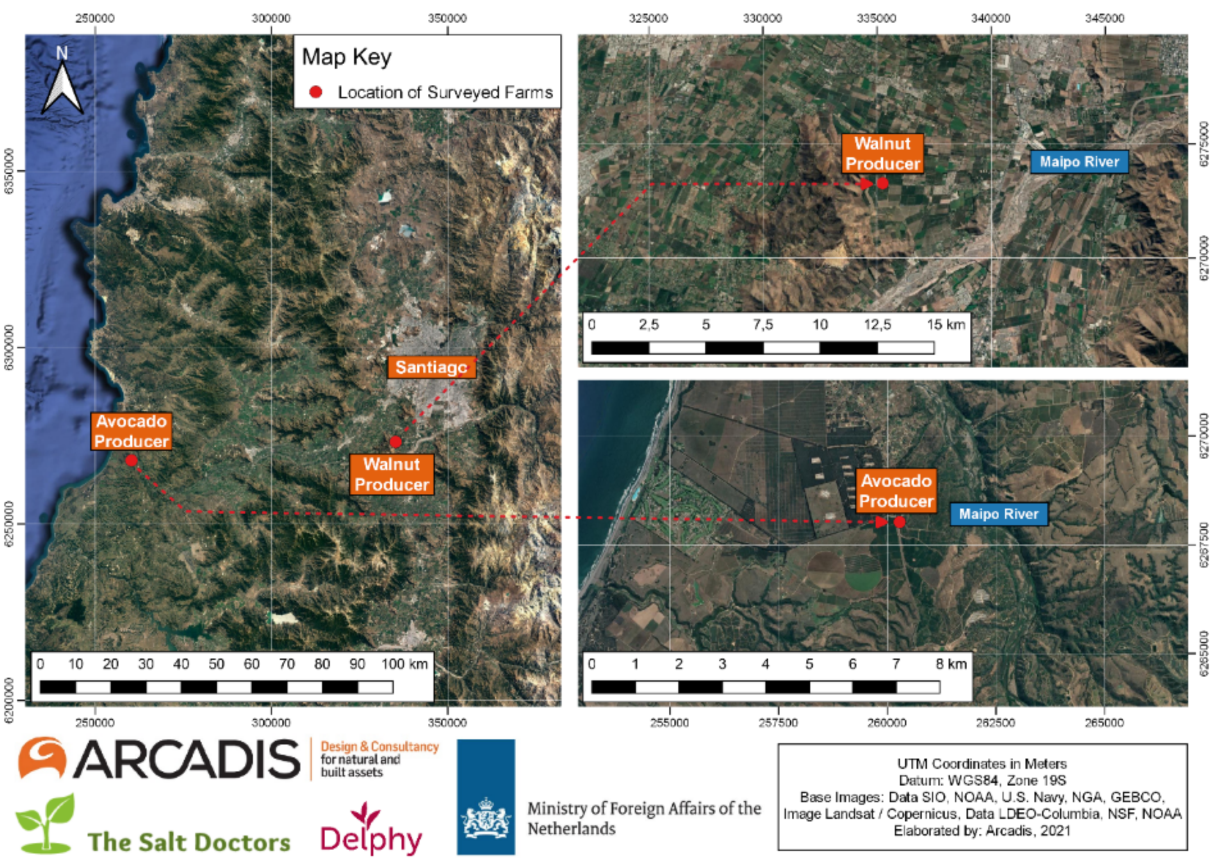

Figure 14. Location of the two farms visited.

Reviewing the information registered from the site visits, the interviews, and the questionnaires, it was observed that both producers believe they have some level of problem with salinity. Both receive water from the Maipo River as their source of irrigation water, the walnut producer was located closer to the Andes Mountains in the Metropolitan Region, and the avocado producer was located at the end of the river, close to the coast, in the Vth Region. Below follows a description of some of the technical details of the farms and data on the crops, soil and water. Results of the discussion with the farmers are outlined in the next chapter about the questionnaires.

Irrigation water and soil samples were taken at both locations. Table 18 shows some general aspects plus the macro nutrients of the irrigation water of both farms.

Table 19 shows the micronutrients and some other relevant variables of the same samples. Finally, Table 20 shows some calculations based on the four main cations in the irrigation water samples, the Sodium Absorption Ration (SAR) and the Cation Ration Of soil Structural Stability (CROSS).

The first value is an indicator of the relative dominance of Na compared to the other cations, which provides an indication of soil structural problems when the soil is irrigated with brackish water. The CROSS value incorporates the concentrations of all cations which is of importance since Na^+ and K^+ are both monovalent cations and thus tend to disperse clay soils, whereas Ca^{2+} and Mg^{2+} are both divalent cations that have a flocculation effect on clay soils (Rengasamy and Marchuk, 2011). Both SAR and CROSS can be used as an indication of potential soil structure issues when using this water as an irrigation source. SAR and CROSS values on those two locations do not indicate and risk of affecting soil structure negatively. Also, the elevated EC values of the water (as can be seen in Table 18) are actually mostly caused by calcium (Ca), followed by sodium (Na) (as can be seen in Table 20).

Table 18. General irrigation water characteristics and macro nutrients of the two farms visited.

	Unit				
	dS/m		mg/L	mg/L	mg/L
Farm	**EC**	**pH**	**Nitrate**	**Phosphorus**	**Potassium**
Walnut	1,19	7,8	14,5	< 0,005	4,50
Avocado	1,70	7,8	42,28	0,39	9,24

Table 19. Other irrigation water elements and heavy metals of the two farms visited.

	Unit					
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Farm	**Chloride**	**Sulphate**	**Boron**	**Calcium**	**Copper**	**Iron**
Walnut	157,7	351,2	0,16	139,8	0,008	2,48
Avocado	235,7	347,9	0,19	187,1	0,006	0,46
	mg/L	mg/L	mg/L	mg/L	mg CaCO3/L	mg CaCO3/L
Farm	**Magnesium**	**Manganese**	**Sodium**	**Zinc**	**Bicarbonate**	**Carbonate**
Walnut	13,2	0,081	86,3	0,018	77	< 1
Avocado	38,4	0,0381	119,3	0,009	160	< 1

Table 20. Concentrations (in meq/L) of the four main cations in the two farms visited. Also indicated are the values of EC (in dS/m), SAR and CROSS, see main body text for further explanations.

Farm	Cl	Na	Ca	Mg	K	EC	SAR	CROSS
Walnut	4,45	3,75	6,97	1,08	0,12	1,2	1,87	1,95
Avocado	6,65	5,19	9,34	3,16	0,24	1,7	2,07	2,24

On one of the farms, the farm of Jaime Cruz (avocados), laboratory analyses were available from previous years. This allows us to see if any changes have taken place over those years.
Table 21 shows us some relevant parameters plus the macro elements present in the irrigation water from 2016-2021. Table 22 shows the concentrations of some micro elements and some heavy metals.

Table 21. General water characteristics plus macro elements from 2016-2019 on the avocado farm.

		Units						
		dS/m	CaCO3	%	mg/L	mg/L	mg/L	mg/L
Date	**pH**	**EC**	**Hardness**	**Sodium**	**N (Ammonium)**	**N (Nitrate)**	**Phosphorus**	**Potassium**
08-09-2016	7,9	1,3	455	32,7	2	6,9	0,23	6
16-08-2018	7,4	1,8	640	28,9	1,3	15	0,6	9
27-09-2019	6,5	1,8	670	25,3	2	6,9	0,7	8
07-05-2020	7,7	1,9	660	26,7	1,4	8,5	0,07	9
03-09-2021	7,5	1,9	695	26,9	1	11,2	0,13	9

Table 22. Micro elements and heavy metals from 2016-2021.

	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Date	**Calcium**	**Magnesium**	**Sodium**	**Chloride**	**Sulphate**	**Bicarbonate**	**Arsenic**
08-09-2016	138	27	104	188	245	171	0,01
16-08-2018	202	33	122	238	365	195	< 0,01
27-09-2019	196	44	106	227	379	238	
07-05-2020	198	40	113	241	413	201	
03-09-2021	216	38	120	238	384	201	
Date	**Cadmium**	**Copper**	**Iron**	**Manganese**	**Lead**	**Zinc**	**Boron**
08-09-2016	< 0,01	0,02	0,13	0,05	< 0,01	0,01	0,17
16-08-2018	< 0,01	0,01	0,08	0,02	< 0,01	0,03	0,28
27-09-2019		0,02	0,03	0,11		0,02	0,73
07-05-2020		< 0,01	0,04	0,01		0,01	0,41

In addition to water samples, soil samples have also been taken on both farms at two different depths**.** Table 23 shows the results of the lab analyses for all macro and micro elements, plus some other relevant soil characteristics.

Table 23. Some soil characteristics and the concentrations of (some of) the macro and micro elements (total concentrations) in the soil at two depths of the two farms visited.

	Units								
	dS/m	dS/m	Meq/L	%		mg/kg	mg/kg	mg/kg	mg/kg
Farm and depth	**EC 1:5**	**ECe calculated***	**CEC****	**Organic matter**	**pH**	**Nitrate**	**Phosphorus**	**Potassium**	**Sulphate**
Walnut 0 – 40cm	0,18	1,23	18,6	35,5	8,3	15,0	1227	1928	452,1
Walnut 40 – 80cm	0,10	0,70	18,0	2,9	8,5	4,9	955	1400	166,9
Avocado 0 – 40cm	0,18	1,28	21,0	4,6	6,1	< 4,3	565	875	439,8
Avocado 40 – 80cm	0,20	1,40	16,2	5,8	6	51,1	546	690	376,3

* Assumed calibration factor of 7 (so, ECe= EC1:5 * 7)

** CEC= cation exchange capacity of the soil

Table 23 continued.

	Units								
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Location	**Boron**	**Calcium**	**Magnesium**	**Sodium**	**Chloride**	**Iron**	**Manganese**	**Copper**	**Zinc**
Walnut 0 – 40cm	<25	20515	8330	567	109	27738	723	56,4	105
Walnut 40– 80cm	<25	8016	7276	442	36	27234	676	45,6	74
Avocado 0 – 40cm	<25	2741	2634	86,8	86	61739	1039	25,9	173
Avocado 40– 80cm	<25	2567	2538	38,6	54	62828	1145	26,3	147

Conclusions from the water and soil analyses

Even though only two farms were visited to sample soil and water for this report, it allows us a good insight into the quality of soil and water along the Maipo River, the river from which both farms get their irrigation water. It seems that there is less information to be found about the salinity levels of the Aconcagua River, but the maximum salinity levels seem to be considerably lower, with maximum salinity levels reported in the range of 0,6-0,8 dS/m.

The EC of the irrigation water is around the values we expected based on the literature review, with an EC of 1,2 and 1,7 dS/m for the walnut farm and avocado farm, respectively (Table 18). On the avocado farm, where we have the time series available of irrigation water EC (Table 21), we can see that it fluctuates between 1,3 and 1,9 dS/m, with the value of 1,3 dS/m only occurring in 2016. This is also in line with the results presented in Table 16, where long-term results (1985-2015) of the salinity levels of the Maipo River show that the mean EC values are 1,7 dS/m in different parts of the river. The maximum values (2,2 dS/m) have been reported during the last years (linked with drought). The salinity threshold at which water is generally classified as moderately saline is 1,5 to 3 dS/m. These levels can affect salt sensitive crops and require careful management practices. In Table 24 an overview is provided of the water and soil analysis of the two farms. Based on the water analysis it seems that the avocado farm has more salinity challenges than the walnut farm. However, based on the soil analysis it seems to be the other way around, although some remarks have to be placed as well. First of all, the overall EC of the soil samples seems to be relatively low, compared to the salinity levels of the irrigation water. As said, in general, a factor of 1,5 is often used to "calculate" the EC of the soil. In the case of the two farms, this would imply that the soil salinity should be 1,8 and 2,6 dS/m (assuming the salinity levels of 1,2 and 1,7 dS/m) for the walnut and avocado farm, respectively. So, the reported EC values of the soil seem to be lower than expected, especially for the avocado farm. Soil samples represent the status of the soil at the time of sampling of course, so it could be possible that more frequent soil sampling and analysis will result in a different result. Also, the ECe had to be calculated since the lab results provide us with the results of a 1:5 method (1 part soil mixed with 5 parts water). Based on various literature and the experience of TSD we used a factor 7 to calculate the ECe, but it is advisable to also determine the exact calibration factor by also analysing the extract of the saturated paste of the soil itself. So, based on the EC values of the irrigation water of the two farms, it was expected that the avocado farm would show the highest soil salinity levels. However, based on the results from the lab, this seems to be the other way around. Looking at the soil concentrations of chloride and sodium, the concentrations are higher at the walnut farm, especially for sodium. This can possibly be linked to the very high concentration of organic matter in the topsoil at the walnut farm, which can bind the sodium and increase the total sodium concentrations of the topsoil. However, based on it seems that the soil of the avocado farm has a high clay content that can also bind the sodium. Other minerals at the walnut farm also show high concentrations (magnesium, potassium), which can be an indication that these high concentrations may be caused by fertilizer applications as well.

Table 24. Overview of the water and soil analysis of the two farms that were visited.

source	location	pH	EC[1]	Chloride	Sodium	Calcium	Magnesium	Potassium	Boron
			in dS/m	in mg/L	in mg/L	in mg/L	in mg/L	in mg/L	in mg/L
water	walnut farm	7,8	1,2	158	86	140	13	4,5	0,16
water	avocado farm	7,8	1,7	236	119	187	38	9,2	0,19
				in mg/kg	in mg/kg	in mg/kg	in mg/kg	in mg/kg	in mg/kg
soil	walnut farm	8,3	1,2	109	567	20515	8330	1928	<25
soil	avocado farm	6,1	1,3	86	87	2741	2634	875	<25

[1] EC soil as calculated ECe from Table 23

Looking at the high calcium concentrations at the walnut farm, it can't be excluded that high concentrations of various minerals have a natural cause (linked to the soil (origin) itself). The pH of both locations is also a point of attention, with the high pH of the walnut farm (potentially causing micro-nutrient deficiencies). The relatively low pH of the avocado farm is also noted, although this should cause fewer issues than the high pH at the walnut farm. Based on only the total concentrations of the various elements it is difficult to come to hard conclusions. It's recommended to analyze soil samples more often, focus on the available fractions of the minerals as well and possibly compare different laboratories operating in Chile.

Avocado, walnut and grape are considered to be sensitive for Boron, and Boron concentrations should not exceed 0.5-0.75 mg/L in the soil saturation extract (Ayers and Westcot, 1985). The reported concentrations of Boron are 0,16-0,19 mg/L for the irrigation water and for both locations the soil concentrations of Boron were reported as <25 mg/kg. In this regard, it seems likely that Boron is not causing the negative effects on the foliar development.

b. Walnut farm

The walnut producer presented some drier patches of walnut trees in some areas, he also showed Arcadis' personal what he believed to be a salinity problem, as seen in Figure 15 (top images). The damaged leaves of the visited walnut farm shown in Figure 15 were not easy to find and were not observed in the rest of the tree or trees nearby, they also appeared to be caused by a pathogen (possibly *Gnomonia leptostyla*, though further research and sampling is necessary to determine this). Figure 15 also contain images of reported salt damage in walnut and the leaf damage looks different. The walnut producer did not measure or have knowledge of the concentration of salinity or of the EC in the water used for irrigation. Arcadis personnel who visited the farm measured the EC in the water used for irrigation, registering 1.2 dS/m. Ibacache (2008), identified different toxicity levels for different EC values as shown in

Table 3 were 1.2 dS/m could cause some growth restrictions, but not many negative effects are expected. This seems also true for the measured soil salinity levels. Although these do show a somewhat elevated sodium level, the overall EC level of the soil should be below the reported maximum salinity levels reported for the threshold of walnut. Considering the information collected, and what was observed on the field visit and questionnaire, it is not possible to conclude if this walnut producer is affected significantly by a salinity problem, but the producer does apply a leaching fraction when irrigating to lower salinity levels in the topsoil. Additionally, he stopped fertilizing with mineral nitrogen fertilizers, replacing them with products of vegetable origin. The soil pH in this farm was 8,3 for the topsoil and 8,5 for the subsoil, which is a relatively high value. At these pH values, various trace elements will be difficult to take up and deficiencies can be expected. However, given the relatively low EC and SAR value of the irrigation water, in combination with high organic matter concentrations, no problems with soil structure are expected in the (near) future. In short, the reported salinity levels of the water and the soil should be below the threshold of the tolerance level of walnut, but careful soil and water management is needed to prevent salt accumulation (in the future).

Figure 15. Damaged leaves (top left, further zoomed in in the top- middle picture) and healthy looking leaves (top right) in a walnut tree from walnut producer in the Metropolitan region of Chile. In the bottom left image, the general leaf damage caused by chloride in walnut can be seen, and the bottom right image provides an indication of the leaf damage caused by "salinity" (source: Ibacache, 2008). So, the top three pictures were taken at the visited walnut farm and the bottom two pictures show the general leaf damage caused by chloride/salinity, but this was not observed at the visited farm.

c. Avocado farm

This farm is located at the end of the Maipo River, close to the coast. The EC measured in the water used for irrigation was 1.7 dS/m, which matched what the producer indicated in the questionnaire, where he stated that the EC of the water he uses for irrigation fluctuates during the year between 1.6 to 2.0 dS/m. This farmer provided us with several lab analyses of his irrigation water, from between 2016-2021. Table 25 shows the values of EC, pH and the four main cations in the irrigation water. We can see that the EC was lowest in 2016, which possibly reflects the mega drought of the last six to seven years.

Table 25. Trend in various parameters of the irrigation water between 2016 and 2021 on the avocado farm.

	Units						
	(dS/m)		(%)	(Meq/L)			
Date of sampling	EC	pH	Na^+ / ESP	Na^+	Ca^{2+}	Mg^{2+}	K^+
08-09-2016	1,3	7,9	32,7	4,5	6,9	2,2	0,15
16-08-2018	1,8	7,4	28,9	5,3	10,1	2,7	0,22
27-09-2019	1,8	6,5	25,3	4,6	9,8	3,6	0,21
07-05-2020	1,9	7,7	26,7	4,9	9,9	3,3	0,22
03-09-2021	1,9	7,5	26,9	5,2	10,8	3,1	0,23

Leaf damage was much more prevalent at the avocado producer's farm. The type of damage observed is shown in Figure 2. Compared to

Figure 16, which shows the general leaf burn caused by chloride and sodium, it appears that the leaves (on the left) in Figure 2 are indeed mostly affected by chloride. Based on the literature, it seems that avocado is very sensitive to salinity. Ayers (1977) indicates that losses of 10 to 25 % have been observed in avocados irrigated with water with an EC between 1.2 and 1.7 dS/m, as shown in Table 4, which could be one of the reasons that explains why the producer has a 20% lower crop yield (8 ton/ha) compared to the average crop yield for the region (10 ton/ha) as indicated by the Fruit Census for the Valparaiso Region for the year 2020, by CIREN and ODEPA (although these values do not correspond with the lower national yield average in Table 9, based on the FAOSTAT database). The reported salinity levels (EC values and chloride concentrations of especially the irrigation water) are close to or above the maximum salinity levels that avocados can tolerate without loss in yield or foliar damage. Based on Ayers (1977) the yield reduction should be around 25% when the EC of the irrigation water is 1,7 dS/m, as is the case at the avocado farm. But this maximum salinity level also depends on the cultivar or rootstock that is used. Ayers and Westcot (1985, see Table 5) concluded that West Indian rootstock is the most salt tolerant, tolerating up to 5,0 meq/L of chloride in the irrigation water (compared to the Mexican and Guatemalan rootstock that can only tolerate 3,3 and 4,0 meq/L of chloride, respectively). Castro *et al*. (2015) reported similar results, with a West Indian rootstock (called UCV7) showing the best potential for cultivation under saline conditions. As can be seen in Table 20, the chloride concentration (in meq/L) of the irrigation water of the avocado farm is 6.65, so this is still above the reported tolerance level of Ayers and Westcot (1985). Celis *et al*. (2018) evaluated the salt tolerance of 13 avocado rootstocks and concluded that there are differences in salt tolerance between the different varieties. In this research, the highest salinity concentration was 1,5 dS/m (ECw), which resulted in a soil ECe of 3-6 dS/m during the 3 years that the field trial was conducted. The yield and growth correlated best with leaf chloride concentrations, indicating that salt damage in avocado is primarily a result of chloride ion toxicity. It should also be noted that in this research none of the rootstocks performed satisfactorily when irrigated with water with an EC of 1.5 dS/m.

The producer at the visited avocado farm is already changing to West Indian ("Antillana") rootstocks, which are more tolerant to salinity, as shown by higher below and above ground biomass, lower sodium and chloride accumulation and a relatively low leaf are damaged by a high salinity treatment (Castro *et al*., 2015). The producer also indicated that his lower crop yield could also be due to unspecified poor practices in the past that he is trying to fix.

In Australia, the official recommendation is to use irrigation water containing not higher than 0,6 dS/m, with 80 mg/L chloride as a maximum (Queensland government, 2018). The various literature mentioned above, all show that the tolerance is closely linked to the ability of a specific rootstock to prevent the transport of sodium and chloride to the leaves.

It should be noted that excess chloride and sodium can have different causes:

- Saline irrigation water
- Poorly drained soils, resulting in salt accumulation in the rootzone
- Under-irrigation (no leaching) can also result in salt accumulation
- Over-application of manures and fertilizers that contain sodium and/or chloride
- A combination of the above

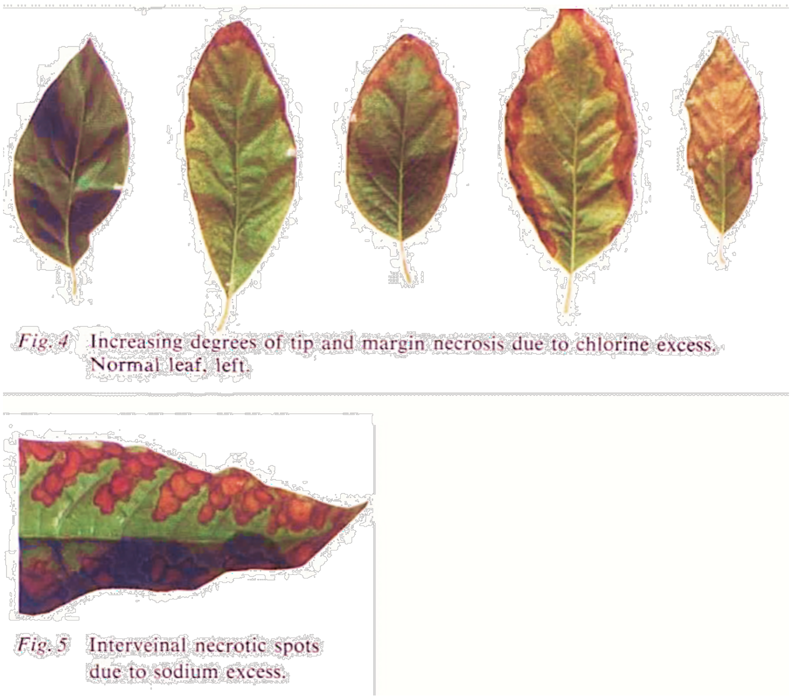

Figure 16. Typical leaf burn patterns in avocado caused by excess chloride (top image, "Fig 4") and leaf burg caused by excess sodium (bottom image, "Fig 5") (source: Lahav and Kadman, 1980).

7. RESULTS FROM INTERVIEWS WITH STAKEHOLDERS AND FARMERS

We have received two questionnaires from other stakeholders. The questionnaires were divided into different topics. Below, their responses are summarized following the topics of the questionnaire, and where the topics were also part of the farmers' questionnaires, their answers are also included in the summary below.

a. General questions

We have spoken to Ernesto Cortes (ECo) from the Universidad Catolica del Norte and to Francisco Meza Alvarez (FA) from Inias. ECo mostly works in an area outside of our focal area but both interviewees are well informed about the topics. Where relevant, the information of the two farmers Jaime Cruz (avocado, JC) and Helmut Engländer (walnut, HE) has also been added.

Both the interviewed scientists and the farmers know of several problems related to salinity in our focal regions and beyond. For example, FA mentions that north of Santiago, at the Lampa and Noviciado region, there are saline soils due to poor drainage. Both farmers draw their irrigation water from the Maipo river, which is also salt affected throughout the year and negatively affect their yields (JC, HE). Also, in coastal regions such as Sto Domingo, Mallarauco and Longotoma, there are different salinity levels of soil and irrigation waters. There, the problems are mostly due to bad drainage, and they are worse in dry years and dry times within years. ECo agrees with this, and he is currently working on the artificial recharge of a basin in the catchment of the Elqui river in the Coquimba region called Pan de Azucar, where EC values are around 1 dS/m in some areas, but between 4-5 dS/m in other parts (see Table 26).

Table 26. Salinity levels of different areas in the catchment of Pan de Azucar. The table is in Spanish but all EC levels indicate officially salt affected water (courtesy of Ernesto Cortes).

Criterio- subcriterio/ Campañas	Pan de Azúcar 13-11-18	Pan de Azúcar 26-04-19	Elqui Bajo 15-11-18	Elqui Bajo 24-04-19
Homogeneidad Piper- Hill	4	2	1	1
Homogeneidad Stiff	4	3	2	3
Grado homogeneidad	4	2.5	1.5	2
Estado homogeneidad	Muy alto	Medio-Alto	Bajo-Medio	Medio
CE	3.2	3.1	2.4	2.4
Dureza	4	4	4	4
Grado de salinidad	3.6	3.6	3.2	3.2
Estado de salinidad	Alto-Muy Alto	Alto-Muy Alto	Alto	Alto
Grado de salinización	3.8	3.1	2.4	2.6
Estado salinización	Muy Alto	Alto	Medio-Alto	Medio-Alto

This aquifer is used both for drinking water as well as for irrigation. It is in these two sectors, irrigation water and drinking water, that the decreasing availability and increasing salinization of surface and ground water is most felt. It is already observed that this increasing salinization has led farmers to adapt by choosing more salt tolerant cultivars (FA, JC), but in some cases it has also led farmers to change their crops, for example, from lettuce to olive plantations (ECo). The decreasing availability of water is affecting farmers by restricting the amount of water they have for irrigation, and to be able to leach salts away from the rootzone. (FA). One of the responses to the diminishing availability of fresh water is desalinization of groundwater, and another is covering up the irrigation channels such as they do in California (HE). He also mentions the use of products that displace salts and that improve the soil moisture.

When asked about the availability of soil- or water salinity maps, both interviewees indicate that there is information, but scattered. There is no centralized body that has a good overview of the salinity problems. However, it is clear that there are problems around this topic, and also around water availability, since Chile is currently in a mega-drought, where precipitation has been less than average for seven years in a row.

b. Agriculture

Most information on the salinity and water problem effects on crops are described under the section of the two farmers (avocado and walnut), here we focus more on the answers of the two interviewed scientists.

Both interviewees agree that yields are decreasing as a result of the salinity problems and lack of available fresh water. However, FA notices that disappointing yields are not only a result of those two abiotic factors, but also because of heat stress. Long, hot droughts probably intensify the salinity problems (FA). Every ten years, an extensive census is carried out on which crops are cultivated and what area, and what the yields are etc. This census has been carried out in 2021, and the results should be available mid next year (2022).

There is a distinction between large and small farmers in that the small ones mostly produce annual crops, whereas the large farms mostly have trees. Because the large farms have more means to invest in their business, mostly in proper irrigation systems, small farmers generally suffer more from salinity problems and lack of irrigation water (FA).

As for the availability of external inputs, mostly this is not a problem. However, not always high-quality seeds are available and this directly affects yields (FA). Fertilizers are available but the right one may be too expensive for smallholder farmers. There are programs that stimulate and support the use of organic inputs such as manure and compost for degraded soils, and both farmers that we interviewed also mentioned that they incorporate their prunings into the soil. However, it is possible that there is more to be gained by improving the organic matter content on farms affected by salinity.

c. Governance and administration of water

The distribution and management of water is governed by the Chilean water Code, in place since 1981 (FA). According to FA, the code is effective but not perfect since it does consider environmental aspects, and it is also separated from the management of groundwater. ECo agrees with the latter part, that the system is ineffective since it does not incorporate the whole hydrological system. ECo mentions, as an example of a properly integrated management body the region of Copiapo. Here, water problems are even larger than in the focal area of this study, and thus the local authorities were forced to improve the system. According to ECo there is hope in that message: when the stress on the system becomes too large, the authorities will respond effectively. In this regard, he also mentions the recharge of Pan de Azucar as a successful example of management.

The government supports a number of projects that aim to optimize freshwater use and that work on desalinization of waters, but those projects are too few to have a large impact (FA). The same is said by both stakeholder respondents about projects that aim to address problems generated by climate change. ECo adds that it would be smart to focus more on the restoration of the natural ecosystems since this will have a trickle-down effect on the stability of the whole system, also of those parts used by humans.

In the focal region of this study, numerous irrigation channels exist to administer the water to where it is needed, and during normal years, water availability is less of a problem here (JC, HE). Additionally, reservoirs have been built for the administration of water. The DGA is responsible for the management of this, and the management is executed by the River Vigilance Boards and the irrigation canalists' associations (FA). The system has proven itself over the years but of course, it gets harder when there is no water available, which is an increasing trend as both interviewees point out.

In Coquimbo, outside of our focal area (north), large basins have been constructed to catch the precipitation when it falls and make it available to the dry season. ECo mentions a reservoir of 200 Mm^3 in the valley of the Elqui river and one with a capacity of 700 Mm^3 in the valley of the Limari valley. However, because precipitation has been much lower than average for many years in a row now, as mentioned above, these reservoirs have less and less water in them and people get rationed a smaller quantity of water every year. A large part of the water that normally supplies water to these reservoirs usually falls in the form of snow, which has also reduced significantly during the years of the current mega-drought.

d. Water quality

Water quality is measured every three months by the DGA in the focal region of this study, and they should have information on this (FA). However, the information on surface waters and groundwater are not unified and it will take considerable time to compile and combine all the information. One of the farmers mentioned that the only information on water quality he has access to is to those analyses that he does himself (JC). Although we could not get any data on the salinity levels of the region and the focal region of ECo, both respondents as well as the two farmers we interviewed agree that salinity levels are increasing in time, so this also includes the salinity levels in the Maipo River.

Recently, in some locations farmers close to the sea experience salinization through seawater intrusion, but this happens very locally (FA, ECo). An example outside of our focal region is seawater intrusion in the Elqui river, in Coquimbo. However, in general in Chile, the origin of salts lies in the soil, since most of Chile has been seabed until relatively recently, when tectonic plates lifted the seabed and created the Andes in the process. In general, seawater intrusion and/or flooding is not a large problem in Chile since most of the country is on a slope.

To conclude, both interviewees indicate that currently, Chile is under water stress since they have had six or seven years of below average precipitation levels. Partly as a result of this, the available water is of increasingly worse quality. According to the farmers we interviewed, this also leads to conflict over water resources. This is widely recognized, and several projects are underway to address these issues.

8. NEEDS ASSESSMENT AND RECOMMENDATIONS

a. Salinity

The most obvious piece of information missing while writing this report is a *clear overview of the salinity issues* in Chile. This is also exemplified by the fact that Chile is not in the recently reduced global soil salinity map as shown in Figure 11 and Figure 12. Both soil and water salinity are *not centrally monitored*, and we were therefore unable to find a *good salinity map* of Chile, or of the two regions highlighted in this report.

Recommendation: Data collection and mapping on regional level

Following this need of salinity maps, we recommend developing a stepwise approach to map the salinity in Chile, starting with mapping the two regions highlighted in the report. The purpose of the maps is to determine salinity issues, risks and potential locations for saline agriculture to boost the current situation where they face challenges. The following steps are required:

- Define the type of maps to be developed in detail e.g. land use map, groundwater map, surface water salinity map, groundwater salinity map (classes and salinity risks), soil map
- Interview relevant research institutes, universities and governments to see what maps and data do exist but are not yet known
- Check availability of open-source data. Google Earth Engine (GEE), satellites, sensors and open data allow information to be gathered on the weather, how much water is in the soil and how crops are faring.
- Perform a gap analysis on what data is still missing to be able to propose detailed locations in the two regions
- Develop a measurement and monitoring plan focusing on the data parameters (for soil and water salinity: minimum is ECe, pH and available Na, Ca, Mg and K (to calculate ESP/SAR). For soil samples should be taken of the topsoil and subsoil), frequency, relevant moments in the year/month, and minimal required locations to fill the gaps. Ideally in collaboration with relevant government departments in the field of agriculture and water management. A relevant starting point could be SWOT analysis to understand the strengths, weaknesses, opportunities and threats of 1) current data collection activities 2) available instruments and labs and their quality and 3) capacity in terms of expertise and experience as well as number of people at government departments working on data collection
- Analyze the data and develop the maps, based on the needs and relevance for future planning of activities
- Share and discuss the maps and measurement & monitoring plan with relevant government departments (like the General Directorate of Water, the Ministry of Agriculture and the Agricultural Research Institute [INIA], among others) and farmer associations. This will create awareness and at the same time provide feedback. Ideally, it results in collaboration for future measuring and monitoring.
- While discussing the maps and proposed measuring and monitoring plan
- Composed maps can also be used to indicate specific areas that are suitable for specific crops, and areas where specific crops are best avoided (based on water availability and needed quantity and quality for instance)

Similar steps can be considered for other regions in Chile.

Recommendation: Data collection and monitoring on farmer's level

As a lack of data is an overall issue, it could be considered to discuss with farmers whether it would be worth considering the development of a data collection network at farmer's level using an App to record and share the data. This could focus on a wide range of parameters. The following steps are suggested:

- Prepare a quick scan on what parameters could be considered in relation to what is most relevant
- Interview farmers on the added value to them, their willingness to be involved, and practical aspects to take this into account
- Consider organizing a small scale, year-round group of enthusiastic farmers, to evaluate and use the lessons learned to extend the group of farmers and area or to conclude that it's not successful.

Some farmers are well aware of the salinity issues of their soil and irrigation water, and they have accurate knowledge on this and measure regularly, although this mostly focuses on the water aspects (and less on the soil properties). Because they irrigate with slightly saline water, they also apply a periodic leaching fraction to wash accumulated salts to deeper layers, away from the rootzone. However, the exact details of the irrigation management remained unknown. First indication is that the overall water balance on a seasonal basis is in line of the crop water need. But when irrigating with saline water, precision irrigation is needed, based on the crop water demand and the required leaching. For instance, more frequent irrigation is needed under saline conditions in order to maintain the field capacity above 80%. This is needed to prevent salt accumulation when the soil is drying up in between irrigation events. This is especially critical when the salinity levels are already close or just above the threshold limits of the crop, as is the case for avocado when irrigation with water of 1,7 dS/m. On the other side, leaching should take place in balance with nutrient uptake (prevent the leaching of nutrients, especially nitrate which is very mobile) and waterlogging should be prevented at all costs. The best way to control the exact amount of water that is applied, is drip irrigation. However, based on Table 7 and Table 8, it seems that only around 28% and 38% of the total irrigated area uses drip irrigation for the Metropolitan and Valparaiso Region, respectively. Both the visited farms use drip irrigation, as can be seen in Figure 17. It should be noted that, under certain circumstances, using flood irrigation can be an efficient way to ensure proper leaching of the entire soil profile.

Both farms that we visited for this report were large. Large farms occupy, by far, most of the farmland as shown in Figure 9, but the majority of farmers own less land. Much less is known about their *awareness of the salinity issues* on their farms, and their methods of dealing with it.

When we look at the measures taken by farmers to combat the salinity, many good practices have come to light. The measures taken by the farmers include:

- The use of more salt tolerant rootstocks
- Applying a periodic leaching fraction to leach accumulated salts
- Apply organic matter to the soil (in the form of prunings and leaves)
- Apply liquid humic acids to the soil to boost soil life
- Regularly measure and monitor soil and irrigation water quality
- Using the right irrigation methods

Figure 17. Impression of irrigation system of the walnut farm (left) and avocado farm (right). Both farms use drip irrigation, with the drip lines placed on top of the soil.

Recommendation: Tailor-Made Training on methods to deal with salinity issues on farmer's level

Following the fact that some farmers are experienced with applying a periodic leaching fraction to leach accumulated salts to deeper layers, opportunities for knowledge sharing as well as insights into the needs of fresh water and water management are relevant to consider. Therefore we recommend to:

- Collect more detailed information on their practices and data on water demands of the farmers in general and split per activity like irrigation and leaching accumulated salt, if possible.
- Collect needs of issues that are yet experienced.
- Collect insights into the awareness level of salinity programs of the farmers with less land
- Develop a tailor-made training for smallholder farmers on methods to deal with salinity issues and water management in Chile, based on (or even in collaboration with) best practices of experienced Chilean farmers and worldwide examples from The Salt Doctors, Delphy and Arcadis. Ideally, the training can be applied as a train the trainer concept in Chile, from farmer to farmer.
- Develop a 'toolbox' of potential measures that can be used in the tailor-made training and support the train the trainer concept.

As part of the training, it can also be of great added value to implement a first pilot in the field that incorporates some of the recommendations, so:

- Set up pilots at one or several existing farms to develop and showcase the best practice cultivation strategy, regarding improved crop, soil and water management
- Improve the organic matter content in the soil to boost soil life and stabilize/improve soil structure
- Apply mulch to reduce evaporation from the soil
- Test products available on the market that claim to help under saline conditions

So far, it was not possible to analyze exactly which fertilizers are available, which fertilizers are being used, what the exact composition of these fertilizers are, when, how and how much is applied and how much should be applied. This overall fertilizer strategy may further improve the farming practices and overall quality and quantity of the fruits. Possible, this can be part of a next phase as well. The same is true to some extent for the irrigation strategy.

As was indicated before, *irrigation is a critical factor in dealing with salinity*. Interestingly, the leaf damage as spotted on the walnut farm may indicate infection with a virus, which is more common on trees suffering from water stress (too much water), which can be caused by waterlogging. During the interviews it also became clear that at some locations poor water infiltration and waterlogging occurs. This is an indication that the soil structure is sub-optimal (can be caused by salinity that affects the soil structure of clay soils). Unfortunately, we have (very) *little information on soil type and structure* in Chile. However, a whole range of soil types exists in Chile (Arcadis Chile, personal communication), including (heavy) clay soils. On the other side, poor water infiltration and waterlogging can be a direct cause of sub-optimal drainage. Additionally, avocado is very sensitive to poorly-drained conditions and are also susceptible to Phytophthora root rot which thrives in poorly-drained soils. Proper irrigation can only take place in combination with proper drainage (at field and farm level, but also at region level). It appears that drainage is mostly based on the natural capacity of the soils and little or no drainage systems are actively developed and installed (like surface drainage canals or sub-surface drainage pipes). Also, it became clear that the salinity levels of the river water fluctuate. In this regard, it makes sense to monitor the salinity level of the river water closely and only use the water when salinity is relatively low. The construction of water reservoirs at farm level can also be advisable, in order to store water at times of low salinity and use it during times of high salinity in the river. These reservoirs can also be used for rainwater harvesting. Some additional points regarding water and irrigation management at farm level are given below.

Recommendation: water and irrigation management at farm level:

- Construct water reservoirs at farm level to collect water when salinity is low and use when salinity is high
- Harvest rainwater if possible and mix with river water
- Use subsurface irrigation (more water efficient and can prevent irrigation water from becoming too hot) and apply frequent but small quantities of irrigation water
- Install drainage, to allow for salt leaching
- Focus on improving soil structure by adding organic matter and calcium to improve water infiltration and leaching
- Focus on the details of irrigation and crop water demand (during the season). In many cases, there is room for further improvement regarding the water use efficiency, both of the irrigation system, as well as the water application itself.

Recommendation: Study causes of problem and interaction water and soil types

More in depth study on the soil types and structures in Chile, starting in the 2 regions would be required to indicate what happens in the interaction between water and soil. In other words, what is causing the problem with salinity? It is the waterlogging itself, resulting in degraded soils with lower productivity? A study of the causes based on more in-depth information on soil types, soil structures, irrigation and drainage will be required to provide further recommendations on saline agriculture potential in the two regions and/or Chile as a country.

b. Water

Regarding water, the most noticeable problem is a *water governance issue* concerning the water rights and the water rights distribution. Historically, the system for awarding water rights allowed speculation since in some cases they were awarded to people who originally did not use them and now they sell those rights to those who need them. However, there is no correlation to the number of water rights those owners have, and how much they need the water they have a claim on, i.e. how much land they own. As such, there is a discrepancy between those who have access to water and those who need it, leading to a market for water.

In addition to the lack of correlation between those who have the right to water and those who need it, water rights (especially for groundwater) were granted independently of catchment water budget or special weather conditions. Also, former calculations underlying the amount of water to be distributed have also proven not accurate and do not consider a sustainable use of the resources in the long term. Additionally, it has to be noted that they are becoming more and more outdated now that precipitation quantities are decreasing as a consequence of changing weather patterns.

Groundwater extractions are not properly controlled by the government nor water communities. As a result, farmers pump up groundwater also unsustainably, which leads to diminishing groundwater resources in aquifers. Consequently, it leads to deteriorating water quality, such as increasing salinization.

When water tables go down in aquifers there is an inequity in groundwater access since large farmers have resources to drill new wells and pump from lower depths. This is not the case for small farmers, as these drilling costs are prohibitive for them.

Those large-scale farmers have advanced knowledge, equipment and technology on their farms and run their businesses in a professional way. Also, they have the means to invest in new interventions when this is needed. However, much less is known about the land farmed by smallholder farmers. Also, those farmers are less knowledgeable than the large ones and lack the means of investing in modern technology that would help them increase their production and/or sustainability.

Groundwater is regulated but lacks control by the authorities. As a result, farmers pump up groundwater also unsustainably, which leads to diminishing groundwater tables. However, it also leads to deteriorating water quality, such as increasing salinization. This is mostly done by large farmers. When the water table drops too much or when the quality is becoming too poor, they simply drill a new well some distance away.

Recommendation: water availability and demands (water quantity)

Freshwater availability requires an understanding of the system and therefore analysis of the water system, groundwater aquifers, etc. is required. A first step is to be able to map the water availability for example in a water system or region for specific seasons in the year (being aware that water crosses administrative boundaries, at the surface but also in the ground). Then, mapping of water demands, related to functions / users / landownership and locations on annual or seasonal basis is required. Once the balance is clear with regard to availability and demand it would be relevant to map the water rights at the current situation and at the ideal situation and see what would be needed to get there.

Additionally, a SWOT analysis on the management of the government on this could be performed, to understand success factors like the recharge of Pan de Azucar when a water availability problem seems to occur. The SWOT, which can be filled based on desk studies and interviews, will also contribute to new opportunities on water use and sustainability as well as technical and governance solutions. It is required to the entire hydrological system into account in this analysis (so including groundwater).

Recommendation: water pollution and salinity (water quality)

Similar steps for water quantity can be done for water quality, by focusing on the SWOT analysis and mapping current water quality issues. The water quality aspects are important to take into account when providing the governance advice as below.

Recommendation: water governance from system understanding

The 'water rights businesses' seems to be lucrative and not clearly monitored or managed yet although improvements are happening already in accurate response when water is scarce. It could be considered to develop directives or guidelines on how to proceed with the water rights now and in the future. Recommendations could be formulated based on the results of the water quantity and quality analysis and an in-depth analysis of the current water governance system. Governance related recommendations include policy development, coordination and collaboration and specific on water rights, e.g. system-based zoning plans, prioritization of water needs (for consumption, for food production, for industries etc.). Lessons learned from projects worldwide can be translated to the Chilean situation as well.

COASTAR: relevant example on fresh water and the 'Water bank'

The COASTAR project involves a collaboration between several district water boards and the province of Zuid-Holland to develop an innovative concept for meeting freshwater requirements. In densely populated areas such as Zuid-Holland, increasing periods of severe precipitation call for additional efforts. The efficient storage of large volumes of rainwater takes up valuable square metres of land. The innovative COASTAR concept (COastal Aquifer STorage And Recovery) involves a robust, large-scale subsoil freshwater supply, enabling temporary freshwater storage in the soil. The project also looked into governance solutions like the concept of a Water Bank. The extraction of groundwater costs a farmer 'money or rights', while injecting rainwater yields 'money or rights'. This ensures a better balance between supply and demand of water. The current research focuses on various aspects of feasibility, such as calculations of possible effects on the subsurface, the legal and the financial aspects.

Recommendations for capacity building on water governance by serious gaming

Besides analysis and advising, a tailor-made training on water governance could be developed for the government of Chile and/or regional governments involved. Tailor-made because of the need to really dive into the situation in Chile with regard to water governance and relate it to the challenges of farmers and salinity. A serious game, or a policy simulation, could be developed involving the government officials and/or farmers as a tool for capacity building. The game creates an interactive learning experience and can be used for collaborative decision making and design processes. Based on experiences with serious gaming it requires a good explanation of the purpose, added value and importance of the interactive approach to the participants. The development of a serious game aims to:

- create a shared feeling of urgency and a focus on the management of time pressure related to case-specific challenges.
- the transfer of knowledge: which mechanisms are in play? who has which responsibilities, who can influence etc.?
- work towards a solution that organizes knowledge and data with (ultimately) a wide application.
- do so in a way that empowers local actors and enables a constructive dialogue.

- make sure that local actors become the owners of this solution, i.e. this toolbox of game modules and other co-creative tools. It should be recognizable and case specific
- an understanding of the conflicting goals and possible traps related to the various solutions.
- and finally, the development of possible governance pathways.

The game contributes to an increase of problem-solving capacity of involved government officials and/or stakeholders.

Those large-scale farmers have advanced knowledge, equipment and technology on their farms and run their businesses in a professional way. Also, they have the means to invest in new interventions when this is needed. However, much less is known about the 50% of land farmed by smallholder farmers. Also, those farmers are *less knowledgeable* than the large ones and also lack the means of investing in *modern technology* that would help them increase their production and/or sustainability.

9. OPPORTUNITIES FOR PREVENTION, MITIGATION AND ADAPTATION

Based on the data obtained from literature, from the interviews, from the field visits we see several opportunities to enhance the climate resilience of agriculture in water scarce and saline areas in Chile. These opportunities are linked to crops, soil and water and are also based on the needs and recommendations of the previous chapter. Due to COVID-19 it was not possible for The Salt Doctors and Delphy to visit Chile and discuss in detail with the farmers in the field. Because of this, it was difficult to really pinpoint the details for the opportunities for improving the overall cultivation strategy. But the challenges and problems of the farmers are clear and based on this we can identify several opportunities that can improve the overall resilience and crop production.

a. Crops

For crops, it is difficult to formulate opportunities to prevent and mitigate the effects of salinity, since these aspects are more related to the soil and water opportunities (see below). Both walnut and avocado are very sensitive for salinity. For avocado it is known that different rootstocks also differ in salt tolerance, so one way to adapt to salinity is to use the more salt tolerant West Indian rootstocks.

In short, opportunities in relation to crops can be:

- Selecting and using more salt tolerant cultivars/rootstocks. In the case of avocado, the West Indian rootstocks appear to be more tolerant
- Applying foliar fertilizers can ensure proper uptake of essential (micro) nutrients and in that way prevent or mitigate some salinity effects. Applying a calcium based foliar fertilizer can also improve the overall fruit quality. Also, there are several products that claim to improve the overall resilience of a crop (make it more robust) and this could be tested under the local conditions
- Hot, dry winds intensify leaf burn in avocado orchards, due to increased transpiration and a higher rate of absorption and accumulation of chloride in leaves. In this regard, it can make sense to realize wind breakers around the orchard, possibly in the form of a line of trees (so an additional form of agroforestry)
- The ultimate form of adaptation is selecting crops that are suitable for the given salinity levels of the soil and irrigation water. In practice, this will mostly imply that avocado and walnut are not the best crops to cultivate under saline conditions (very salt sensitive) and, for instance, it makes more sense to switch to olive which is much more salt tolerant

b. Soil

For soil, many aspects of the opportunities lie in the order of preventing salts from negatively affecting soil conditions (from a chemical, physical and biological point of view) and mitigating the effect of salinity of crop growth, mainly in the form of the presence and availability of various nutrients. In this regard the opportunities are:

- Many of the opportunities mentioned below should be based on a reliable soil analysis that should take place every four years as a minimum. It should be known which nutrients are present and the concentrations. Based on this, a balanced fertilizer strategy can be composed.
- Soil pH can be high, due to “salinity” (when sodium carbonate is the main source of salts, the (bi)carbonate can result in very high soil pH). Adding (organic) acids can greatly improve crop performance in that case.
- By using organic matter and/or calcium (gypsum if soil pH is high and sulphate is not present in the soil in excess amounts already, use lime if pH is low) as a soil additive, the overall soil structure can be improved.

Also, lime pallets are available that work well under wet and "waterlogged" conditions. By improving the overall soil structure, also water infiltration and leaching can be improved.

- Make sure that the organic matter that is used is low in salt content. If the pruning and leaves of the salt affected orchard is used, it is likely that this contains salts as well. Investing in salt free organic matter can be a cost-effective solution in that case.
- Apply organic mulch (a layer of 5 cm of, for instance, the straw of wheat or barley) to the area that is irrigated. This will limit the evaporation from the soil and reduce the water need. When less water is used, then less salts are added. Also, this makes leaching more effective in times of heat and drought.
- Leaching is only possible with proper drainage. In many cases, the instalment of sub-surface drainage is a suitable way of ensuring leaching of salts below the rootzone in a cost-effective way (often avocado roots mostly in the top 30 cm of the soil, so ensure salts are leached below this level). Drainage can also prevent "waterlogging" in a deeper layer of the soil. The drainage can be installed in such a way that it becomes a "closed system"
- The instalment of suction cups can be a quick and easy way to sample the water in the soil (pore water) at different depths to check the salinity levels of the different layers and fine tune the timing and amount of leaching (in combination with measuring nitrate)
- Use only fertilizers that are free of sodium and chloride. Sending some samples to the lab to check for the actual content of sodium and chloride is recommended when using local brands. Also, in many cases, the magnesium concentrations are high in salt affected areas. In that case also fertilizers free of magnesium should be used. By analysing the minerals present in the irrigation water and adding exactly the nutrients that are missing, all fertilizers can be added by means of irrigation (fertigation). This balanced fertilizer application can also be an effective way to reduce overall soil EC
- The analysis of the soil samples did not give quality information that we needed. For instance, it should be known what the available fractions of the different nutrients are, which minerals (and percentages) occupy the CEC, and also one of the results of the organic matter analysis seems unlikely (although this was rechecked). Also, more information is needed on soil microbial activity, in order to know how and how much this should be improved (bacteria, mycorrhizae fungi, ...)
- Using cover crops in between the rows of trees (see picture below) can also greatly improve overall soil conditions/structure, water infiltration and leaching
- Salt stress can be relieved to some extent by various soil additives and foliar applications (amino acids, humic/fulvic acid, various enzymes,). By understanding the local conditions, it is often possible to identify a product that can improve crop quality and quantity in a cost-effective way. It is recommended to test this in the local setting
- It's good to mention that sodium can be bound to the clay-humus complex (CEC, mainly in the form of clay and organic matter), whereas chloride usually remains in the soil water solution. This makes it easier to leach chloride, in comparison to sodium, although uptake can also be higher compared to sodium.

Figure 18. Example of an orchard with cover crops to improve water infiltration and soil fertility (left) and one of the visited farms in Chile without cover crops (right).

c. Water

Opportunities for prevention, mitigation, and adaptation for water management:

At field/farm level:

- Create water reservoirs for rainwater harvesting and collection of river water in times of low salinity
- Mixing rainwater with river water can also be a cost-effective way of ensuring low salinity levels of the irrigation water
- Monitor the salinity level of the irrigation water and, where possible, keep the salinity level below 0,6 dS/m
- Desalinating irrigation water, by reverse osmosis, can be cost-effective for high value crops. This can be explored further for the local conditions, although it should be noted that the brine fraction (with high(er) salinity concentrations should also be handled in a sustainable way
- Magnetically-treated water is sometimes reported to improve salt leaching from the topsoil, but at the same time reported results are inconsistent
- Install weather station and/or soil moisture sensors to determine the exact level of evapotranspiration and crop water demand so precision irrigation is possible, including the timing and quantity of leaching that is required
- Ensure of proper functioning of the irrigation system and maximize the water use efficiency, especially when the irrigation water contains salts (the less water you need to apply, the less salts you add to the soil)
- Sub-surface drip (placing the drip lines in the soil) are more efficient and commonly installed in new plantation in dry areas.
- Irrigation should be more frequent but apply less per irrigation event under saline conditions. Leaching could be needed every few irrigations with excess water, exceeding by 30-50% of the standard irrigation need (so a leaching fraction of 30 up to 50% may be needed)

At region/national level:

- Create “catchment” government departments that are responsible for water monitoring. These departments must exist under a new frame of institutions.
- Study the sustainability of drinking water sources in the region, know to what extent the aquifers can continue to be stressed.
- Generate more research to know the real contribution to the water supply provided by glaciers.
- Have updated information regarding the geographical location of the Water Rights.
- Legal advice to the organizations of users within the regions who claim the historical use of the waters.
- Constitution and registration of groundwater communities in aquifer sectors.
- Carry out a program to control extractions from aquifer sectors.
- Implement a subsidy system to correct the increase in the cost of pumping due to the decreased groundwater levels. Such subsidies should be properly monitored to avoid an increase in pumping and the consequent drawdown of aquifers.
- Promote artificial recharge of aquifers
- Declare areas of restriction or areas of prohibition, in aquifers according to their level of exploitation or overexploitation.
- Improve quality and quantity of rainfall, fluviometric and water quality information
- Improve the quality and quantity of groundwater level information.

- Improve information and analysis of the current state of surface and groundwater quality.
- Install a groundwater quality monitoring network.
- Improve the surface water quality monitoring network.
- Encourage user organizations to update their information and data and integrate them into a common system.
- Study the promotion of the deepening of wells in critical sectors.
- Improve control in the activity of extraction of aggregates, to avoid adverse effects in the rivers.
- Greater control and supervision of compliance with environmental regulations and commitments.
- Increase the technical capacities of public officials in each region for water resource assessment, field testing and the relationship with water user organizations, along with improved inter-agency coordination.
- Improve the communication channels of the institutions with the citizens.
- Take immediate action to ensure future supply in the face of climate change.

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