Soil salinity: common mistakes and how to avoid them

An agronomist's experience from the field

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Have you ever seen white crusts on soil? Yes, it is what you think. Soils can be salty. Salts are present naturally in soils and water, and they move freely through the soil. Naturally saline soils may support rich ecosystems, but droughts and human activities, especially improper irrigation, can increase how many salts are in soils, a process that is called salinization. Soil salinization and sodification are major soil degradation processes recognized as being among the most important problems at a global level for agricultural production, food security and sustainability in arid and semi-arid regions.

Salt-affected soils have serious impacts on soil functions, such as in the decrease in agricultural productivity, water quality, soil biodiversity, and soil erosion. Salt-affected soils reduce both the ability of crops to take up water and the availability of micronutrients. They also concentrate ions that are toxic to plants and may degrade the soil structure.

It is estimated that there are more than 833 million hectares of salt-affected soils around the globe (8.7% of the planet).

The global annual cost of salt induced land degradation caused by salinization is estimated to be of US$ 27 billion related to lost crop production.

From: https://www.un.org/en/observances/world-soil-day & https://www.fao.org/fileadmin/user_upload/world_soil_day/WSD_2021/SM_cards/GSP_GSSAS21_Twitter_004.jpg

Today, the areas that are undergoing salinization due to various reasons are increasing and the process takes up to 1.5 million ha of farmland per year from production. But often, farmers don't realize that the salinization process has already begun.

What is the salinization process?

When there's more salt input to the soil than what is washed away to below the root zone, by rain or by irrigation.

What is salinity?

Soil salinity is the salt content in the soil; A soil is classified as saline once its saturated paste extract reaches 4.00 deciSiemens/meter (dS/m). People usually think that salinity is sodium, but it is not necessarily the same thing. There is sodic soil, there is saline soil, and there is saline-sodic soil.

Soil sodicity is measured through either its Exchangeable Sodium Percentage ESP) or its Sodium Adsorption Ratio (SAR). Both measure the sodium content of the soil in relation to calcium and magnesium. Sodic soils are low in total soluble salts but high in exchangeable sodium, which tends to disperse soil particles and destroys soil structure. A soil is classified as sodic if it has an ESP of 15 or more, or has a SAR of 13 or more.

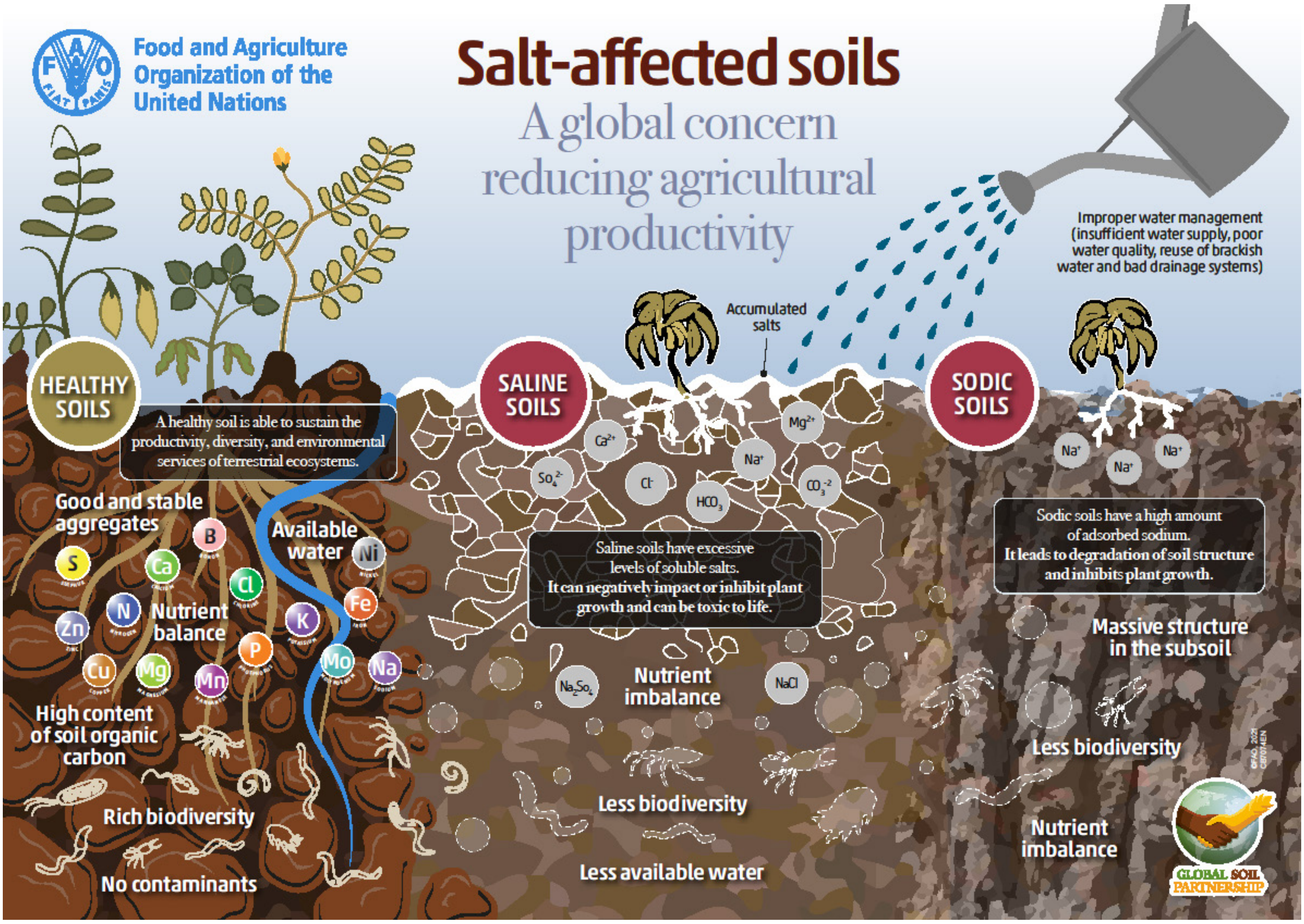
Soils which are both saline and sodic are classified as saline sodic and have characteristics of both.

Table 1: Distinguishing features of saline and sodic soils

Salt affected soil classification	EC_e (dS/m)	Soil pH	SAR	Soil physical condition
Normal	<4	<8.5	<13	Good
Saline	>4	<8.5	<13	Normal
Saline-Sodic	>4	<8.5	>13	Normal
Sodic	<4	>8.5	>13	Poor

Ec_e = Electric conductivity of saturated soil extract
SAR = Soil Adsorption Ratio

The cations in the water are calcium, magnesium, potassium (potassium from the fertilizer). The anions are chlorides, sulfites, carbonates, and nitrate.



What's the problem with salinity?

The problem with salinity is that the more salts there are in the soil solution, the higher the osmotic pressure in the soil. When osmotic pressure is higher in the soil solution than in the plant roots, the plant is unable to draw water from the soil.

The second problem is, sodium causes the dispersion of the soil aggregates and breakdown of soil structure, reducing soil permeability and decreasing water infiltration into the soil.

The third possible problem is that there are certain ions that can be toxic to crops.

Therefore, the diagnosis of what causes the salinity problem is critical to the success of the crop.

Where do the salts come from?

The natural cause for salinity and sodicity is the naturally occurring salts in the soil. Rains dissolve the minerals from the bedrock and they move with the water into the soil. This is a slow process, but when you use these soils for conventional agriculture, salts from the irrigation water and the fertilizers are added at a quick rate. If the amount of water from precipitation is not enough to wash away the salts, they add up and thus the salinization process begins.

We will not refer to natural salinization, but only to agricultural soils.

The development of soil salinization in this example is generally without sodium, because there are no salts in the rain and the fertilizer does not supply sodium. This happens with small farmers who use fertilizers and have no irrigation and rely only on the rains.

The second source of salts is brackish and/or sodic brackish irrigation water. Even when you start farming in non-saline soil, we always ask for a water test including EC, which is the indication of the salinity status. This is to understand if the water may affect the future soil EC. It is very important to start every project to start with laboratory analysis for soil and water salinity.

Soil and water tests

If you ask for a water test and don't specify what you want, the laboratory may test the water like drinking water, which is a much more expensive test, with many components, not necessarily the ones we want. Therefore, when we do a water test, and want to know what the EC is, and whether there are ions that could cause toxicity, we have to talk about it with the grower and give a list of all the indicators we want: EC, pH, cations and anions. It's important to send sample only with a specific list. Agricultural laboratories often have different packages, so you should always ask and choose a package.

Many people, growers who don't have a deep understanding of the salinization issue, ask for soil tests and get an EC value. But this index gives only part of the information. It says if a problem might arise, but not what is the cause.

Understanding the analysis

The tests provide information on soil fertility, and from this it is very difficult, if not impossible, to draw conclusions about the salinity situation. Therefore, when there may be an issue of salinization, it is necessary to do not only a soil fertility test but also a soil salinity test. It should be done on the solution of a fully saturated soil sample (paste). Here, too, there is an issue that not everyone knows, that not all laboratories perform the test on saturated soil solution (soil paste). Why is this important? Because the saturated solution is created from different amounts of water for different types of soil. But there are different accepted methods in different countries, some of which use a fixed ratio between soil and water either by weight or by volume. These ratios are 1 soil: 1 water, 1:2 or 1:5, regardless of the type of soil. The results of course differ between the ratios and between them and the saturated paste. Therefore, you always need to know the extraction ratio in order to calculate accordingly and correctly understand the salinity analysis.

Table 2:

LABORATORY DETERMINATIONS NEEDED TO EVALUATE COMMON IRRIGATION WATER QUALITY PROBLEMS

Water parameter	Symbol	Unit	Usual range in irrigation water	
SALINITY				
Salt Content				
Electrical Conductivity	EC_w	dS/m	0 – 3	dS/m
(or)				
Total Dissolved Solids	TDS	mg/l	0 – 2000	mg/l
Cations and Anions				
Calcium	Ca^{++}	me/l	0 – 20	me/l
Magnesium	Mg^{++}	me/l	0 – 5	me/l
Sodium	Na^{+}	me/l	0 – 40	me/l
Carbonate	CO^{-}_3	me/l	0 – .1	me/l
Bicarbonate	HCO_3^-	me/l	0 – 10	me/l
Chloride	Cl^-	me/l	0 – 30	me/l
Sulphate	SO_4^{--}	me/l	0 – 20	me/l
NUTRIENTS[2]				
Nitrate-Nitrogen	NO_3-N	mg/l	0 – 10	mg/l
Ammonium-Nitrogen	NH_4-N	mg/l	0 – 5	mg/l
Phosphate-Phosphorus	PO_4-P	mg/l	0 – 2	mg/l
Potassium	K^+	mg/l	0 – 2	mg/l
MISCELLANEOUS				
Boron	B	mg/l	0 – 2	mg/l
Acid/Basicity	pH	1–14	6.0 – 8.5	
Sodium Adsorption Ratio[3]	SAR	(me/l)[1], [2]	0 – 15	

* Note: the “usual range” encompasses levels from the very best to the worst

So many people get this wrong, it’s a cause for many misunderstandings. For example, in a project in one of the Latin America countries, the EC was fine according to a ratio of 1:5 in sandy soil, which is a lot of water in the solution. (In sandy soil, saturated paste is reached with 30-35% water of soil volume). When you convert it to saturated soil values, it turns out that the soil is very salty (for example see conversion table below).

- For sands multiply the $EC_{1:5}$ value by 15
- For loams multiply the $EC_{1:5}$ value by 9.5
- For clays multiply the $EC_{1:5}$ value by 6.5
- Or use values in between for 'intermediate' soil types

Table 12 shows the Australian classification for soil salinity based on EC_e values, with conversions for $EC_{1:5}$ values in soils of different textures

Table 12: Australian classification system for classification of soil salinity

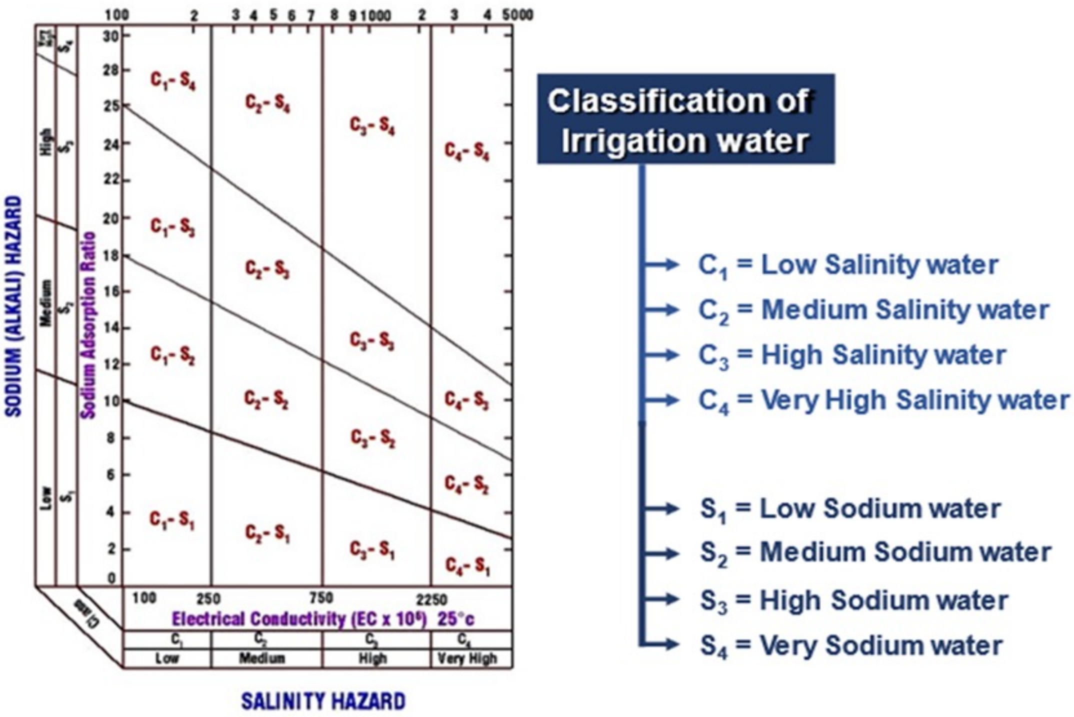
Term	EC_e Range		$EC_{1:5}$ Range	
		Sands (dS/m)	Loams (dS/m)	Clays (dS/m)
Non saline	0-2	0-0.14	0-0.18	0-0.25
Low salinity	2-4	0.15 - 0.28	0.19-0.36	0.26 – 0.50
Moderate salinity	4-8	0.28 - 0.57	0.37-0.72	0.51 – 1.00
High salinity	8-16	0.58 – 1.14	0.73-1.45	1.01 – 2.00
Severe salinity	16-32	1.15 – 2.28	1.45-2.9	2.00 – 4.00
Extreme salinity	>32	>2.29	>2.9	>4.01

I learned from this that it is not enough to get an oral report of the EC, you have to see the lab analysis, as each laboratory states the method it used.
If it isn't stated, we may not understand the results properly. If a region does not have a conversion table, we must do the conversion ourselves, from the values using constant ratios to the values of saturated paste, because the literature is based on this.

When we get the results of the specific ion levels, we have the information whether the soil is non- saline, or with saline without sodium, or sodic- saline, or sodic only. The treatment for each problem is a different treatment, at least partially.

Guidelines for Interpretation of Irrigation Water Quality

Potential irrigation problem			Units	Degree of restriction on use: None	Slight to moderate	Severe
Salinity (affects crop water availability)						
EC_w			dS/m	< 0.7	0.7 – 3.0	> 3.0
TDS			mg/L	< 450	450 – 2000	> 2000
Infiltration (infiltration rate of water into the soil) Evaluate using EC_w & SAR together						
SAR =	0 – 3	and EC_w	=	> 0.7	0.7 – 0.2	< 0.2
	3 – 6		=	> 1.2	1.2 – 0.3	< 0.3
	6 – 12		=	> 1.9	1.9 – 0.5	> 0.5
	12 – 20		=	> 2.9	2.9 – 1.3	> 1.3
	20 – 40		=	> 5.0	5.0 – 2.9	> 2.9



What can we do about salinity?

First of all, flushing with water. And if there is sodium, you can add gypsum, then the calcium from the gypsum can replace the sodium bound to the clay. It's important to understand what type of salinization we have in order to choose the appropriate treatment.

Sodium can come from the bedrock, which contains sodium, from alluvial soils or from brackish irrigation water that contains sodium.

When you start using water with a medium or high EC and you don't recognize it, the problem begins and it progresses according to the amount of salts in the water, the amount of irrigation water applied, the sensitivity of the crop irrigated by that water, and the amount of effective rain, which is needed to wash away the salts. Take into account that all the water is taken up by the evapotranspiration process and does not remain in the soil. But not all the fertilizers and minerals are taken up. The remaining salts that came with the water and fertilizers, remain and accumulate in the soil if there is not enough rain to flush them out.

A sodic soil does not have to have a high EC, but a high ESP the ratio between the adsorbed sodium in relation to all the cations in the soil solution. The other cations are calcium, magnesium and potassium.

Other ions

A very important issue is that of specific ions in water which cause problems. Boron, chlorides, sodium, and carbonates.

Carbonates will cause a problem to the soil over time, but the first three are ions that are toxic to the plant.

It is thought that there is a connection between climate and precipitation, and the presence of boron and chlorides in the water. For example, in Brazil in areas with a lot of rain throughout the year, you do not encounter the presence of boron and chlorides. But since we do not really know what is beneath the surface, if you take water from a well, you should check at least once every few years for the presence of boron and chlorides.

The water in wells may come from rainwater in higher areas. It happens that this underground water passes through places that are sources of salts that dissolve easily. Thus these ions arrive with the groundwater. So don't rely on your logic that says that there shouldn't be excess boron or chloride. You should always check to remove all doubt, because the damage to the soil and the plant can be very severe, and the test is not expensive.

Salinity prevention and management: best practice

The agricultural activity when preparing for a project and during a project includes the following:

1. Monitoring

2. Salinization preventing crop rotation

3. Gypsum application

Before each project, a soil survey should be done as well as soil tests, where the first soil tests should include not only soil fertility but also soil salinity. Salinity problems of all kinds.

There can be salinity problems in certain places and not in others, in the same project. It depends on various factors such as height differences between the areas, soil drift from place to place and the presence of high saline groundwater in certain areas.

Therefore, before any new project or even an existing project for which there is no information regarding these points, it is recommended to carry out these tests so that we can better manage the crops and agricultural activity in the project.

According to the types of water that are used, it is necessary to decide when or how often soil salinity tests should be done.

When there is a presence of certain (not necessarily high) salinity in the water and/or soil, it is useful to establish a soil salinity monitoring program. It can be done more than once a year. For example, at the end of the growing season and before the beginning of the next season. If the rainy period is between the seasons, we can see how the season ended in terms of salinity, and after the rains, before the beginning of the next season, understand how much of the applied salt is washed away and how much remains, and plan accordingly.

The importance of seeing not only the numbers but also the salinization trend, is making decisions according to the expected future situation, not only the existing one. From my experience, this is something that is not often done and brings surprises after a few years, when the salinity problem begins to become serious. The treatment is of course more difficult, and may perhaps include changing the crop for a few years, or adding water to flush down the salts.

For example, in the western Negev desert in Israel, sodic brackish water was used in the past to grow summer cotton, and after about three years of growing cotton, salinity would accumulate. Then they would leave the field fallow for a year, or only grow wheat as a cover crop, and let the rain over two winters (during the winter wheat crop and again the next season before sowing a spring cotton variety) flush out the salts. There was a regional salinity monitoring program, which shows that the water of the Western Negev region was sodic-saline (excess calcium, magnesium, sodium, chlorides and boron); it also gave us information about the increase in the presence of sodium in the soil and we treated it with gypsum (calcium sulphate) on the soil surface before the beginning of the rains.

The example of cotton in the Negev desert shows that with proper treatment, it's possible to prevent long term or irreversible damage to the soil. When water quality and availability improve, it is possible to continue using the soil for many years and grow other crops, not resistant to salinity. Today, when other crops are irrigated with non-saline or less saline water in the Negev desert, it is proof that the soil can be protected from salinity if there is constant monitoring and correct decision-making.

Even in arid to semi-arid places where there are summer rains, but it is necessary to supplement the amounts of water through irrigation, the well water is usually of a certain salinity. Though the salts are leached out during the growing season, the precipitation is often not enough to remove the salts applied by irrigation, and there is a trend towards salinization. Then at some point you have to decide to let the soil rest for a year or two, a decision that is not easy to make. Or, alternatively, to temporarily switch to a crop that is resistant to saline conditions and that hardly needs irrigation and fertilization, so that the limited amount of rainwater will allow some flushing of the salts. If one year is not enough, you have to continue for a second year, for example growing wheat, or growing leafy crops.

Gypsum application

Where the salinity problem is mixed with sodicity we can treat it with gypsum. Monitoring the soil solution SAR (from saturated paste) and ESP shows us the state of sodium in the soil. From this, we can decide on the amount of gypsum (calcium sulfate) that should be spread as uniformly as possible on the soil surface before the rains begin.

Knowledge is Power

Monitoring not only gives the salinity status of cations such as calcium and sodium, but also the amount of chlorides remaining in the soil from the irrigation water, and information about the presence of boron.

The importance of having the information is in knowing and understanding the salinity situation in the soil in order to devise the necessary action plans towards prevention of salinization.

Preventing salinization of soilless substrates

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Salinization is an excessive accumulation of water-soluble salts including various compounds of sodium, potassium, calcium, magnesium, sulfates, chlorides, carbohydrates, and bicarbonates.

Salinity becomes a problem when enough salts accumulate in the root zone to negatively affect plant growth. Excess salts in the root zone hinder plant roots from withdrawing water from surrounding substrate. This lowers the amount of water available to the plant, regardless of the amount of water physically in the root zone.

Growing in soilless media is challenging in regards to salinity since the volume of the substrate is relatively limited. This means that the root system cannot grow towards more comfortable conditions, as happens in earth-grown plants, but necessarily remains in the conditions of the space within its container, even if they're sub-optimal. For this reason, it's important to create and maintain optimal growing conditions in the growing media (or, in the root zone) at all times. One method is Proportional Fertigation, where every irrigation event supplies a full spectrum of nutrients to ensure their constant availability.

The small volume of the growing media also reduces its buffering capacity and hence limits our margin of error. For this reason, precise fertigation and well-timed, uniform water distribution are highly important to the prevention of substrate salinization.

Table 1: A limited volume of growing media = a limited buffer of available water and nutrients

Substrate	Root volume (l)	Water content (%)	Available water (l)	N g/l
Soil	500	30	150	52
Peat moss (organic)	25	50	12	3.4
Rockwool (mineral)	15	60	10	2.1

Table 1 shows the relationship between substrate volume and availability of water and nutrients, and consequently, the buffering capacity of the solution. The smaller the growing substrate volume, the more sensitive the plants are to imbalances. As excess salinity is a detrimental factor for plant growth, successful cultivation in soilless media depends on maintaining a good balance of water and nutrients in the root zone.

Start at the source

A high-quality water source with a low EC is an essential starting point for creating a well-balanced nutrient formula. It's important to know the water's EC and pH levels, as well as the ratios of its elements, as stable EC and pH levels enable to precise irrigation. Carry out water analysis to know your initial situation.

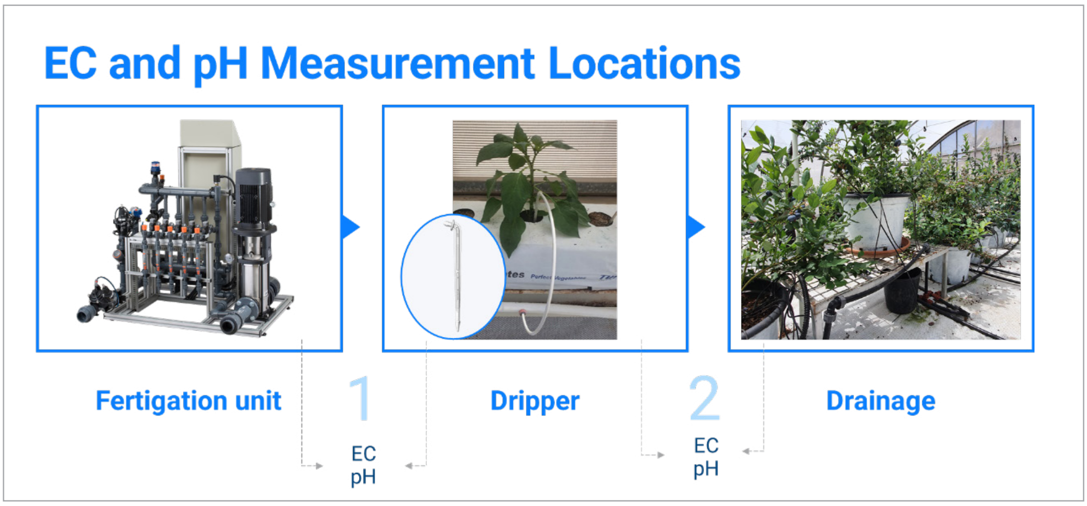
Use of high-grade fertilizer with low sodium and chlorine content is also important in achieving this goal. Sodium are not only salts themselves, but they compete with calcium, potassium and magnesium which are important to the plant.

Salinization results from accumulation of high concentrations of salts. This can occur when irrigation is insufficient to flush them out of the substrate or when uneven water distribution enables their accumulation in dry areas.

Monitoring

As a rule of thumb, 30% drainage should keep the EC at a correct level most of the time. However, constant monitoring is required to keep track of the situation in the root zone and make corrections in real time.

Water volume, EC and pH are monitored in the irrigation solution as well as the drainage. To prevent salinization, we must keep track of the changes in the drainage with time and take care it remains within the required range.



If the measurement shows an accumulation of salts beyond a predetermined limit (usually 0.5mS), a rapid response is necessary to prevent damage to the crop. Action is needed when EC levels in irrigation solution and drainage differ, as indicated in Table 2.

Table 2: Comparison of EC levels between irrigation and drainage indicates when corrective measures must be taken.

EC measurement results			Action
Dripper EC level	=	Drainage EC level	None required
Dripper EC level	>	Drainage EC level	Inspection and appropriate action
Dripper EC level	<	Drainage EC level	Immediate action required

If there's a difference which is smaller than 0.5mS/cm, follow to ensure that the gap does not increase.

When dripper EC is higher than drainage EC, it is often because the plants consumed nutrients. In this case, increase fertilizer in the irrigation solution. Another situation which can cause a lower EC in drainage than in irrigation solution is unintended washing. This will usually be accompanied by a high drainage volume, i.e., above 40%.

When dripper EC is lower than drainage EC, it's usually due to a smaller than necessary irrigation volume. In this case, increase irrigation time. In some cases, a flushing process may be necessary. Flushing is done with a relatively high volume of water, with the required pH but without fertilizer (salts), until the drainage EC target is reached.

Rapid response irrigation system

In order to prevent salinization and to minimize damage once salinity has been detected, a hydraulic system which can provide the necessary response must be in place. The hydraulic system must be designed a priori to supply not only the day-to day water needs of the crop, but also the exceptional demands for in case EC drainage monitoring show unwanted values:

A relatively high flow, pressure compensated, non-leakage dripper (PCJ CNL for example) enables keeping the system (including the main and submains) pressurized at all times, to get the required flow immediately and simultaneously.

To summarize

Remember that when you fertigate in soilless media, you give your plants the best chance to fulfill their potential, but at the same time, you decrease your margin of error. Being aware, monitoring, and making adjustments is the key to success.