Salinity

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Hi all, good to see you again.

The agricultural seasons keep moving in their natural, reasonable way, unlike some unreasonable political changes in the neighborhood.

The first good rains in Israel have germinated the sown winter crops, painting the fields in a fresh green color, creating brown-green square plots.

It's quite a dry winter, not enough rain. It's cold, and we had some snow. Everybody loves the white, fresh, clean snow, it gives an amazing feeling.

This Agronet is dedicated to another white crust on the soil: salt, and salinity problems.

We speak a lot about food security. The fact that every year we have 1.5 M ha less land to cultivate due to salinity issues, does not create enough noise and awareness.

We, at Netafim, are experiencing salinity and fighting it at many different locations in the world. Drip irrigation + good cultivation and drainage practices, are the best solution to deal with it.

Let's deep dive into this Agronet, and this is what you'll see:

1. Dr. Itamar Nadav, our Agronomic Research & Innovation leader, will give us an overview on the threat of salinity to food security.
2. Boaz Guy, our Americas regional agronomist will share with us the double success story of Lala: one side is the Services model, but not less important is the agronomic success in fighting the salinity problem there.
3. Guy Reshef, our R&D agronomist (among other titles), will take us 2.5 meters below the soil surface, into the root zone of date trees. A very exciting and simple way (but a lot of work!!! taking hundreds of soil samples in 20X20 cm pixels) to see the salt distribution under different irrigation regimes and emitters.
4. Besides the surprising results, it was very nice to see the whole Agronomy unit (including the writer (+ the POD team, working like ants underground to extract the soil samples.
5. Yoram Krontal will take us to Tanzania, to the TPC sugarcane project. Yoram has succeeded in a very long and hard journey, to grow an amazing yield under salty conditions that nothing but drip & Yoram could overcome.... This project became a Mecca for sugarcane growers, who came to see the "miracle". As we always say – seeing is believing.
6. Michi Uner, our legendary Latin America agronomist, will share with us his vast experience with salinity, from his kibbutz close to the Gaza strip, and all through South America. There is a nice saying that says: No one is wiser than the one who has rich experience. In some cases – it's not true...., but Michi is the exact confirmation of this saying. Let's learn from him how to avoid common mistakes.
7. Orian Shalev, our greenhouse agronomist will take us to another direction of salinity: in soilless media. Although it is protected agriculture, the plants are not protected from mistakes in the irrigation & fertigation regimes. It's a very small volume and could easily become too saline for the plants. Let's learn how to do it right.
8. Udi Bar, a capsicum/bell pepper grower from Moshav Paran in the Negev desert, will take us

into their local practical solution, to overcome soil and water salinity. Udi is definitely a partner for success, and a true believer in drip irrigation. His yield results are the proof of concept of the local solution. (Thanks to Adaia & Shahar Dayan for the interview).

9. Eran Rave, head of Gilat Research Center, in the Negev desert, Israel, will brings us the story of an applied research. In his article he brings an overview on the results of desalination in Israel and the long-term influence of irrigating soils with water that has high salinity levels. From the interview (thanks to Itamar Nadav), I would like to pick a few important lessons and share them with you, it will summarize this long introduction:

We can live with and manage soil and water salinity.

But – it should be monitored **frequently** and not once a year.

It's true that each region has different problems and solutions, but these practices are always best:

- Frequent monitoring to avoid salt build-up
- Soil flushing when needed – don't reach irreversible situations.
- Use salt resistant rootstock, if available.

Many thanks to the Agronet team headed by Adaia Shiboleth.

Enjoy your reading

and

A happy, healthy year to you and your families.

Yours,

Dubi

The impact of soil salinity on our food security

Dr. Itamar Nadav, head of research and innovation, Agronomy unit

Soil is a vital resource for feeding the burgeoning global population, expected to reach over 9.8 billion people in 2050 (United Nations, 2020), and is a controlling variable of the hydrological processes of the planet, supplying products and services fundamental to maintaining life and prosperity. Presence of excess salts in the soil make it saline, and pose a significant threat to farm productivity, environmental health and financial welfare. Salt accumulation in the root zone or soil surface results in loss of soil fertility and alters the soil properties, thus harmfully impacting the soil's environmental functions and its ability to support plant growth. For instance, it restricts water intake and the soil-water capacity limit, which causes surface runoff and erosion, leading to soil degradation, worldwide. Based on the FAO/UNESCO soil map of the world, the total area of saline soils is 397 million hectares (Mha) which is approximately 3.1% of the world's land area (FAO, 2005). Moreover, future projections of climate change and human population growth suggest that the extent of saline soils will grow accordingly.

Saline soil includes saline, alkaline and saline-alkaline soils characterized as elevated salt concentrations, elevated pH and high sodium concentrations, respectively. Saline soils have EC (of the saturated paste extract) values of >4 dS/m, ESP <15 and pH values <8.5, while alkaline soils have the corresponding values as less than 4 dS/m (EC), more than 15 (ESP) and more than 8.5 (pH) (Table 1). The high pH level in alkaline soils is mainly the result of high carbonate concentrations.

Soil salinization prompts the change or even disturbance of the characteristic natural biochemical and erosional properties. Therefore, elevated salinization levels would result in the loss of the available soil resources, affecting agricultural development and ecological well-being.

If left unattended, this condition could develop into a socio-economic and human health problem in the long run.

Table 1: Classification of salt effected soils.

TABLE 1 Classification of salt-affected soils

	Soil property		
Classification	**EC (dS/m)**	**ESP**	**pH**
Saline soils	>4	<15	<8.5
Alkaline soils	<4	>15	>8.5
Saline–alkaline soils	>4	>4	>8.5

There are two major causes of soil salinity: natural (primary salinization), and human-made (secondary salinization). The occurrence of parent materials and physical or chemical weathering of minerals and seawater intrusion is the leading natural cause of soil salinization. Utilization of low-quality water for crop irrigation because of prolonged dry spells, in conjunction with heavy chemical fertilizers is the principal human-made practice bringing about soil salinization. The human-made salinization conditions are aggravated under poor drainage settings. Irrigated areas are more susceptible to land degradation, and over 14 km2 of fertile areas are lost per day due to soil salinization.

Over 23% of overall farmland is assessed to be saline. Information and mapping of soil salinity at temporal and spatial scales are vital for the water system and seepage management.

Impact of salinity on plant yield

Raised soluble salts such as sodium and chloride in soils are a significant risk to agriculture globally, predominantly in dry areas. In these areas, salts are inclined to build up in the soil profile because of elevated evaporative conditions that raise the osmotic stress and negatively influence soil water availability to plants. A surplus of salt in the rootzone relates to a decreased capacity to extract water. Salts alter the water's osmotic potential and restrict water movement through the root. Therefore, plant development, transpiration and productivity are diminished when soil salinity reaches the threshold. If saline environments endure, the limited quantity of salt that penetrates a plant alongside water builds up in due course and becomes toxic. These effects cause asymmetrical plant development and plant wilting. Moreover, high Na in the soil may also influence soil water correlations, bringing about the scattering of soil colloids that change the water and air movement, decreasing infiltration rate, promoting waterlogging and possibly causing anoxic situations in the rootzone. In any event, even in limited quantities, soluble salts lessen yields for some crops.

Table 2: water salinity classification

Salinity class	Salinity level (dS/m)	Effect on plant yield
Non-saline	<2	Insignificant
Slight saline	2–4	Affects only sensitive plants
Moderate saline	4–8	Affects many plants
High saline	8–16	Affects all plants except salt-tolerant ones
Very high saline	>16	Affects almost all plants except some highly tolerant ones

Different plants vary in their response to saline conditions, also within the same species (Table 3). The two main mechanisms of salinity impact on plants are the osmotic and toxicity effects. The osmotic effect occurs when salt concentrations outside the root membrane exceeds the in-root concentration, which limits the plants' ability to extract water from the soil, which in turn leads to wilting. On the other side, some of the water extraction by the plant is an active action by specific water channels in the root cells. This active water extraction along with active ion extraction pumps on the root cells, increases the total ion concentration within the plant tissues. Plants have different methods to adapt to increasing ion concentrations, by storing the excess ions in specific cells or flushing the salts through the water vascular to the leaf tips. This is why in many cases the effect of salt can be seen by burnt leaf tips.

The accumulation of salts in the root zone has adverse effects on plant growth, not only due to the low osmotic potential of the soil solution resulting in decreased availability of water to plants, but also due to the ion imbalance and ion toxicity.

Table 3: Sensitivity and tolerance level of some key crops

TABLE 3 Sensitivity and tolerance level of some key plants

Sensitive (up to 2 dS/m)	Moderately tolerant (up to 6 dS/m)	Highly tolerant (up to 10 dS/m)
• Blackberry	• Guava	• Spinach
• Tangerine	• Sunflower	• Barley
• Cherries	• Pineapple	• Date palm
• Deciduous orchard	• Maize	• Sugar beet
	• Onion	• Asparagus
• Pummelo	• Carrot	• Bermuda
• Boysenberry	• Fig	• Rye
• Avocado	• Olive	• Swiss chard
• Lemon	• Cucumber	• Cotton
• Grapefruit	• Pomegranate	• Kenaf
• Lime	• Rice	• Rapeseed
• Apple	• Oats	• Triticale
• Orange	• Grape	• Wheat, durum
• Almond	• Alfalfa	• Wheat, semi-dwarf
• Peach	• Tomato	
• Apricot	• Potato	• Wheatgrass
• Prune	• Flax	
• Pear	• Sudangrass	
• Beans	• Rye-grass	
• Peas	• Harding grass	
• Plum	• Coconut	
• Sugarcane	• Wild rye	
• Red clover		

Soil salinity and organic carbon content

Salinity affects microorganisms mainly by decreasing osmotic potential, which reduces their activity and alters the composition of the microbial community. These changes have implications for soil organic matter decomposition. Recent studies projected the loss of soil organic carbon (SOC) from saline soils across the globe due to a reduction of plant growth and reduction in microbial activity which will reduce the SOC inputs and increase the emission of the remaining carbon from these soils. This research suggests that saline soils can lose up to 17% of their SOC stock, which can reach up to 3.99 tons h^{-1}.

Projected soil salinity in drylands up to the year 2100

While we know the dispersion of salty soils around the globe today, there is a need to know what will happen in the near and far future to plan and act accordingly. To this end, a research group has developed several models to predict the global changes in saline soil distribution according to a few possible scenarios. The models, based on the output of Global Circulation Models (GCMs) were applied to new input predictor data to estimate the annual soil salinity level for each grid-cell (0.5° spatial resolution) of the global soil base map of the drylands between 1904 and 2100.

Figure 1 shows the spatial distribution of the projected change in primary soil ECe in the mid-term (2031–2060), relative to the reference period (1961–1990).

According to our long-term predictions based on all multi-model ensembles, the dryland areas of South America, southern Australia, Mexico, south-west United States, and South Africa are generally at the highest risk of increased soil salinity, compared to the reference period. The threat of climate-induced soil salinity is also projected to increase in the drylands of Spain, Morocco, and northern Algeria.

In a wider perspective, given the current and projected climate change and land use, it seems that mostly the southern hemisphere will be subject to increasing land area under saline conditions. In some regions in the northern hemisphere, the total area under saline conditions seems to decrease over time, given the projected conditions (Fig. 2).

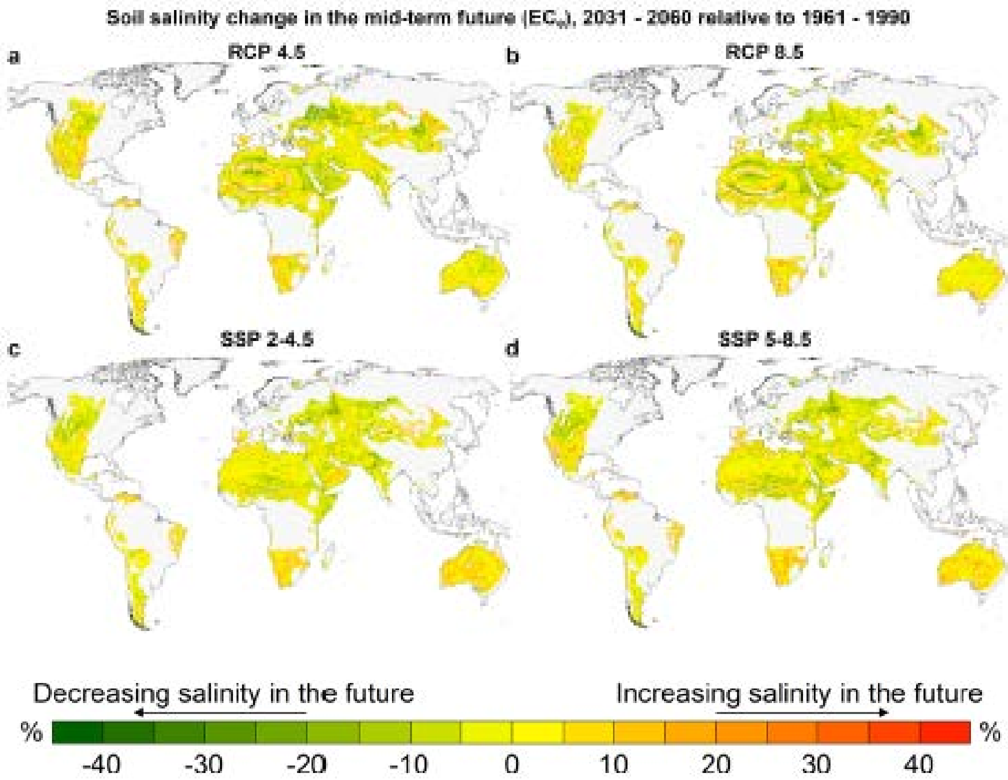

Fig. 1: Spatial distribution of the change in primary soil ECe projected by the multi-model

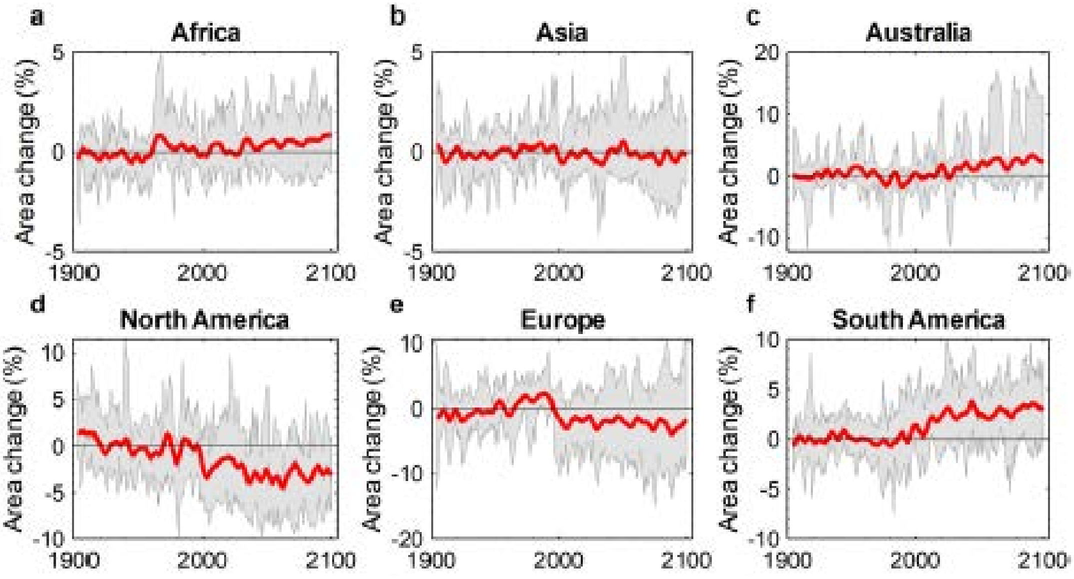

Fig. 2: Continental-level predicted annual change in the total area of soils with an ECe ≥ 2 dS m−1 relative to the 20th century average (1904–1999)

Looking forward, the future looks salty. The recent studies show various trends in salt accumulation across the globe where some gain and some lose. Those trends threat the capacity of agriculture to supply the future food demand for the rapidly increasing population. In addition, as a result of climate changes, water availability and soil degradation, the main cropping areas of today might not be as fertile tomorrow, while other areas would be the main global food suppliers. That would affect the entire global political and economic map as we know it today.

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Growing alfalfa in the saline-sodic soil of Torreon, Mexico.

The Lala project success story

Boaz Guy, head agronomist, Americas division

In December 2018 we established 2 IAAS projects of 90 ha each in the alfalfa farms of LALA, a big dairy company in Torreon, located in the arid northeast of Mexico. When we received the water and soil analysis, we understood that it is going to be a challenge, since the soil contained high levels of salts, sodium and carbonates, and water quality wasn't good either.

Alfalfa is usually grown in arid areas, despite the soil and water challenges, but why?

Alfalfa has been called the "queen of forages" with the highest crude protein content of 22-26%, compared for example, with corn 7-10%, bermudagrass 7-16% and Vicia (vetch) with 18%.

Crude protein is the potential of the forage to provide protein to the livestock and reflects the quality of the forage (not the energy value). It is calculated by multiplying the N content by 6.25. But, if alfalfa is not harvested on time, before flowering starts, it loses protein (CP) and gains fibers (ADF), which reduce its quality (see table below).

Rain just before harvesting is problematic, since machinery can't enter the field, harvesting is delayed and quality starts decreasing. The low amount of rain in the desert allows to cut just on time and get high quality alfalfa. But arid areas put alfalfa up for a challenge since water is usually scarce and salty, and soil is saline, sodic, calcareous or a combination of them.

Saline soil is characterized by a high concentration of soluble salts, high EC, pH lower than 8.5, low SAR (Sodium Adsorption Ratio,) good soil structure and good water infiltration.

Sodic soil is characterized by a low concentration of soluble salts, low EC, pH higher than 8.5, SAR > 13, ESP (Exchangeable Sodium Percentage) >15%, RSC (Residual Sodium Carbonate)>2mM, poor soil structure, low infiltration and aeration and crust formation.

Calcareous soil is characterized by high Active calcium carbonate (> 10% p/p), Total calcium carbonate >35%, high pH (7.5-8.5), poor soil structure and crust formation.

In one of the projects, we had a saline-sodic soil and in the other a calcareous one.

Table 6. Change in alfalfa quality with advancing plant maturity.

Maturity	TDN (%)	CP (%)	ADF (%)
Pre-bud	65	21.7	28
Bud	62	19.9	31
1/10 bloom	58	17.2	34
1/2 bloom	56	16.0	38
Full bloom	54	15.0	40
Mature	52	13.6	42

Abbreviations: TDN = total digestible nutrients, CP = crude protein, ADF = acid detergent fiber. All values are expressed on a dry matter basis.

Source: Nutrient Requirements of Dairy Cattle, National Academy of Science, Publ. 1349.

"When the percentage of crude protein is low, the bacteria responsible for digestion cannot sustain adequate levels to process forage. Ultimately, the animal's intake and digestibility are reduced". (Anderson, Forage Nutrition 101).

The challenge

Alfalfa has a moderate tolerance to salinity (2.0 dS/m 100% of yield potential; 3.4 dS/m 90%; 5.4 dS/m 75%; 7.6 dS/m 50%, according to Ayers and Westcot 1976), but at the early stage of germination, the young root has difficulty to take up water from the saline soil and dries out.

SDI is the only drip solution possible for alfalfa, because of the frequent cuts and the possible damage to on-surface driplines. But in saline soil, SDI moves salts to the soil surface where germination occurs, therefore this is an issue that needs special attention.

Since alfalfa seeds are small, sowing is done on surface, and germination takes place in a hostile environment exposed to the sun, birds, and salts.

Calcareous and sodic soils form a hard crust on the surface and make it difficult for the roots to penetrate the crust and reach the soft and moist soil beneath. Corn that is grown on these farms in rotation with alfalfa, has the opposite problem: It is sown at a depth of 5.0-6.5 cm and must cross the crust upwards to emerge.

To identify a calcareous soil in the field, we used the vinegar test. Vinegar, or acetic acid has a pH of 3, so when applied to the soil surface it reacts with the carbonates, releases CO2 bubbles, and leaves holes in the soil.

Alfalfa originated in the arid area of Southwestern Asia with Iran as the geographic center, so it has evolved to seek water in the depth. For this purpose, it needs a deep and not too compact soil. Sodium and carbonates compact the soil and make it difficult for the roots to go deeper.

When using SDI in a sodic or saline soil, sodium and other salts accumulate between two driplines, causing plants to suffer from low water availability. Since soil becomes compact in that area, water doesn't infiltrate easily, and the soil becomes dry. The result is an uneven growth with higher plants along the driplines and shorter in between.

So, how did we deal with the complex soil conditions?

- Deep soil tillage, the first step in soil preparation allowing good root penetration and salt leaching.
- Closer distance between driplines (75 cm between driplines and 30 cm between drippers). To create a continuous, wide wetted strip that reduces salt accumulation in between the driplines and allows uniform water distribution throughout the plot.
- Shallow dripline installation, at 25 cm, to reduce salt accumulation in the root zone.
- We used an overhead irrigation method (flood or sprinklers) for germination.
- We applied carboxylic acid through the drip system (Promesol 5X, 12 l/ha) that reduces the negative effect of salts on soil structure and plants.
- We regularly use fertilizers with high percentage of ammonium to help lower soil pH, and a higher dose of phosphorous (10 kg P2O5/harvest) and micronutrients that have low availability in alkaline soils. Phosphorous application is done by phosphoric acid which also helps in decreasing soil pH and cleaning the drippers from carbonate residues.
- In the calcareous soil we applied sulfuric acid through the drip to soften the crust during germination. We continue applying sulfuric acid once every cycle (22-30 days normally), with a pH 4.0-4.5 for 2 hours.

Applying compost to increase the soil organic matter can also be helpful in such cases, but we chose not to do so in these projects. For sodic soil it is recommended to apply gypsum (calcium sulfate) before sowing, but since the soil in these projects contains high levels of calcium as calcium carbonate, we decided to apply sulfuric acid which helps in releasing the calcium into the soil solution. The free calcium in the soil solution could then exchange with the sodium attached to the soil particles and release it into the soil solution to allow its leaching deeper into the soil.

Alfalfa plants often live in symbiosis with the Rhizobium bacteria, which forms nodules in its roots and fixes atmospheric nitrogen. However, in our projects in Torreon, because of soil conditions, there is very little nodulation, so our alfalfa is usually fertilized also with nitrogen (4-5 kg N/harvest).

Success!

Taking all the actions described above, alfalfa is grown and irrigated successfully by SDI even in challenging soil. Moreover, SDI has a big advantage in these conditions compared with sprinklers or

flood, since it allows to irrigate with high frequency (every 4 days), maintaining high soil water potential and achieving high quality alfalfa with tall and thin stems, that are low in fibers, and with wide leaves rich in proteins.

The fact that the soil surface remains dry, significantly reduces weeds which could compete with the alfalfa for water and nutrients and decrease the overall forage quality.

In the region of Torreon in the north of Mexico, alfalfa farmers were used to maintaining the alfalfa crop for only 2 years, with an average yield of about 20 tons of dry matter per hectare per year. With SDI we extended the life of the alfalfa crop up to 4 years till now, with yields of 25-30 tons/ha/year. The 30-50% of the water saved by drip irrigation was used to expand the cultivated area. The water use efficiency increased from 1.5 kg dry matter/m3 of water with flood irrigation, to 2.3 kg dry matter/m3 of water with drip.

The good results helped us expand our activity with Lala and reach 780 ha. Next year we are expecting to expand the Lala IAAS with another 1000-1200 ha.

Date palm irrigation with saline water
experiment summary

Guy Reshef, Netafim Agronomy unit; Ephraim Tsipilevich, Jordan Valley Agricultural R&D station; Benny Alksalasi, date grower, Kibbutz Gilgal

Objectives

Reassessment of irrigation recommendations for Mejhoul dates under the conditions of the Jordan Valley.

Examine whether irrigation can be optimized by using integral drip irrigation along the length of the row.

Examine the effects of the irrigation method and the water amounts on the root system and salt distribution in the soil.

Abstract

To examine the effects of water quantities and irrigation methods on dates in the Jordan Valley, 2 irrigation methods and two water quantities were tested for 4 seasons between 2015 and 2018: commercial irrigation - 2 sprinklers near the tree, versus 2 laterals of integral drip. Both irrigation methods were tested with 2 water amounts relatively to the recommendations: 100% of the recommended amount compared with 75% of the recommended amount. In addition, the treatment of 75% drip irrigation was examined also according to 75% of the recommendations in an interval determined according to tensiometer readings and a predetermined soil EC threshold (an average of 40 Centibars for the readings at 30 and 60 cm depths). The results show that the treatments did not significantly affect the crop, but the removal of salts was better and the root system was larger and denser with drip irrigation at 100% of the recommendation. Due to a large accumulation of salts and damage to the number of date stalks with drip irrigation according to 75% of the recommendations, we canceled the irrigation treatments at 75% of the recommendation and

instead examined for two more years drip irrigation at 120% and 140% of the recommendation. The results of this experiment show that drip irrigation at 120% of the recommended volume can improve the yield and the size of the fruit under the conditions of saline soil and brackish irrigation water.

Introduction

Dates are the main branch of plantations in the Jordan Valley and its scope in the current season reaches 3,000 ha. According to the accepted irrigation recommendations, water amount for irrigation of a ha of mature dates (starting at the age of 8) is 12000-13000 m3 per season. The accepted stand for planting dates is 9x9 m and in the first years it is acceptable and correct to water the plantation with 2 sprinklers placed near the tree (photo 1). Today it is customary to continue to irrigate mature trees using this method. Exposing the roots of mature trees clearly shows that the roots cover the entire wetted area with varying density, even in places where the electrical conductivity is very high, even though the area wetted by the sprinklers is quite limited.

About 60% of the date plantations are irrigated with brackish water that comes from the Tirzah reservoirs, which supply about 26 million cubic meters per year. The water plant in the Tirzah reservoir is fed by 3 water sources: sewage water that comes from East Jerusalem (Kedron effluents), Jordan river water and flood water. The average electrical conductivity of this water (seasonal average) has been 4.0-6.0 dS/m in recent years. When irrigating with water with such electrical conductivity, borders of salt are formed at the edges of the wetted bulb which can reach 20-30 dS/m. In addition, due to the desire to expand the plantations, date palms are now being planted in marginal areas where the entire area was not flushed before planting. In such areas the level of electrical conductivity of the soil can reach 80-100 dS/m in the soil solution. And the farmers are content with flushing the planting pit only, so that the salt walls at the edges of the pit can reach a conductivity of higher than 100 dS/m.

The irrigation recommendations accepted today for Mejhoul date plantations are: from fruit set to the stage when all the fruit is yellow, irrigation according to a coefficient of 90% of pan evaporation; When all the fruit is yellow, 50% of pan evaporation, until the next season's fruit set. In light of the above, it seems that it should be possible to optimize irrigation, improve salt removal and possibly save water if we switch to integral drip irrigation along the entire row and increase the wetted soil area.

Course of research and working methods

The experiment was carried out in the date plot in Kibbutz Gilgal. Mejhoul variety, planting 2006. Until the experimental treatments were applied in 2014, all plots were watered by 2 micro sprinklers near each tree. A soil survey was carried out on 4 pits: 2 near the tree and 2 in the center between 2 trees. The average EC, salinity components and nutrient levels in the upper soil layers is summarized in Table No. 1.

Treatments

1. Irrigation of 100% of the recommendation using 2 SuperNet™ micro-sprinklers near the tree, each sprinkler 58 liters/hour. 116 liters/hour/tree. Set irrigation frequency.
2. Irrigation of 75% of the recommendation using 2 SuperNet™ micro-sprinklers near the tree, each sprinkler 58 liters/hour. 116 liters/hour/tree. Set irrigation frequency.
3. Irrigation of 100% of the recommendation, 2 laterals of integral drip, Uniram™ drippers every 0.5 m, 3.5 liters per hour per dripper. 126 liters per hour per tree. Set irrigation frequency.
4. Irrigation of 75% of recommendations using 2 laterals of integral drip, Uniram™ drippers every 0.5 m, 3.5 liters per hour per dripper. 126 liters per hour per tree. Set irrigation frequency.
5. Irrigation of 75% of recommendations using 2 laterals of integral drip, Uniram™ drippers every 0.5 m, 3.5 liters per hour per dripper. 126 liters per hour per tree. The irrigation frequency was determined by a threshold value, according to tensiometer readings.

Methods and Materials

Location: 32,00,33N 35,27,37, E. Central Jordan Valley, Israel (Near Kibbutz Gilgal(.

Desert climate:

- Average maximum temperature in August = 41°C.
- Average minimum temperature in January = 9°C.
- Average annual rainfall = 150-180 mm.

Calculated evapotranspiration (average):

Jan =1.7mm	Feb = 2.5mm	March = 4.8mm	April = 5.7mm
May = 8.1mm	June = 9.6mm	July = 10.5mm	Aug = 9.5mm
Sept = 7.6mm	Oct = 5.2mm	Nov = 2.9 mm	Dec = 1.7mm

Soil type: silty clay.

Irrigation water: Recycled sewage water. Salinity: 4.3-5.2 dS/m without added fertilizers.

Variety: Majhoul.
- Planting year: 2006
- Planting distances: 9X9 meters.

- Five treatments x six repetitions. Repetition size = 9 trees (729 square meters). Entire experimental area = 2.2 hectares.
- The amount of irrigation water was determined by multiplying the accepted coefficients (Ministry of Agriculture) with the local evaporation data measured by pan evaporation class A.
- Per treatment, two tensiometer stations, with three tensiometers each, were placed at 30, 60, 90 cm depth.

Image 1: Two micro-sprinklers per tree

Image 2: Two drip laterals per row

Image 3: Aerial photograph of the experiment area

Table 1: An example of the actual annual water quantities used by treatment (31/10/2017 to 1/10/2018)

Treatment No.	Treatment	% of the recommended dose	Actual water quantities (mm)
1	sprinklers	100	1228
2	sprinklers	75	874
3	drip	100	1207
4	drip	75	863
5	drip + tensiometers	75	947

At the end of the fourth season (11.2018), pits measuring 4.5 meters in length, about 2.5 meters deep, were dug along the line and perpendicular to the row, two pits per treatment. At distances of 50 cm by 50 cm, soil samples were taken to characterize the electrical conductivity. A total of 900 samples were taken.

Results

Table 2: Fruit yield (kg per tree), in four harvests

Treatment Year	Sprinklers 100%	Sprinklers 75%	Drip 100%	Drip 75%	Drip + Tens 75%
2015	65.4	82.5	75.9	80.4	65.7
2016	65.6ab	67.5ab	86.1a	59.4b	57.8b
2017	83.1ab	82.8ab	107.5a	78.9b	85ab
2018	89.8	86.8	83.8	62.8	75.6
Average	71.0	70.4	88.3	79.9	76.0
% Difference from sprinklers100%		99	124	113	107

Table 3: Average weight (gram) per fruit, in four harvests

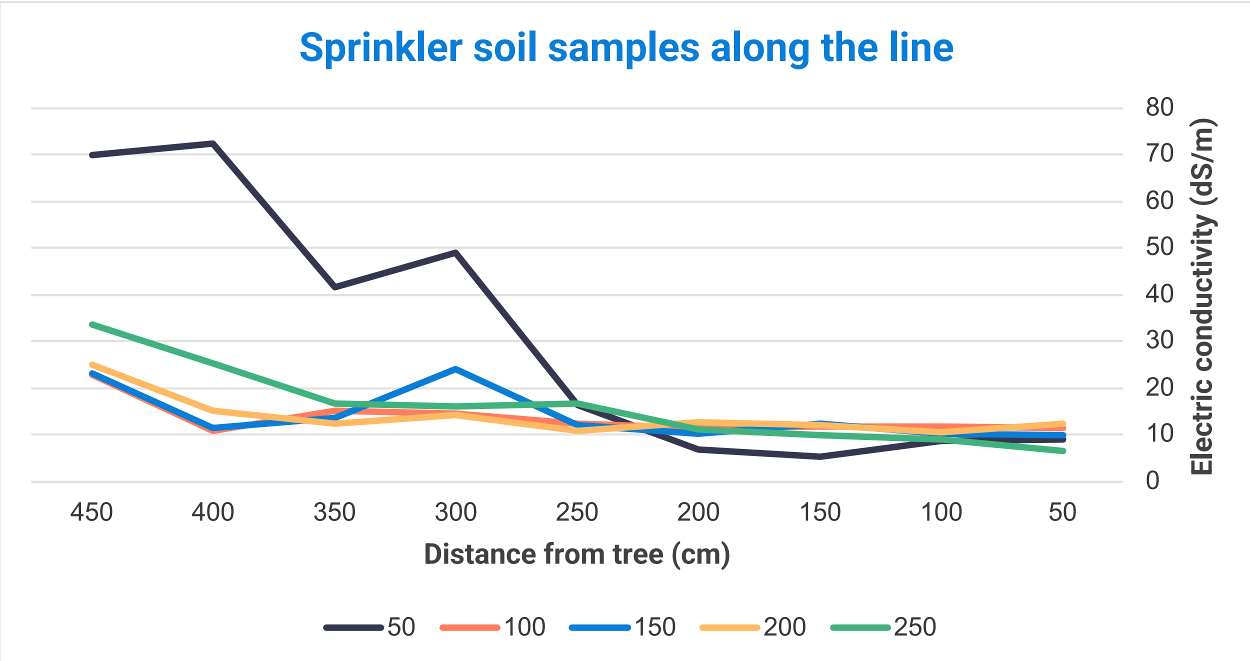
Treatment Year	Sprinklers 100%	Sprinklers 75%	Drip 100%	Drip 75%	Drip + Tens 75%
2015	20.7	20.8	19.8	21.6	19.6
2016	17.3	19.7	17.1	19.3	19.3
2017	17.2	17.7	18.3	17.4	17.8
2018	23.5ab	23.2ab	20.6b	23.2ab	25.2a
Average	19.7	20.4	19	20.4	20.5
% Difference from sprinklers100%		103	96	104	105

Table 4: Percentage of blistering, in four harvests

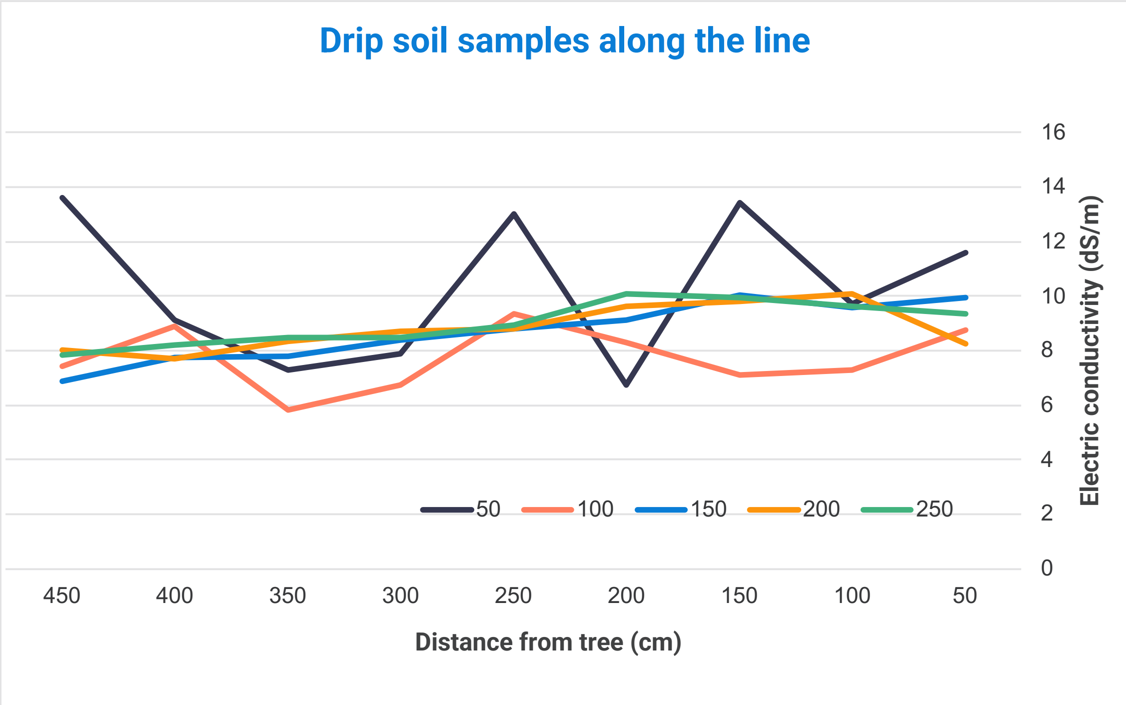
Treatment Year	Sprinklers 100%	Sprinklers 75%	Drip 100%	Drip 75%	Drip + Tens 75%
2015	22.8	27	25	23.9	22.4
2016	15.6a	7.7b	13.6ab	13.6ab	11.3ab
2017	10.3	9.7	11.1	11.8	8.1
2018	24.4	27.9	25.2	30.8	23.9
Average	18.3	18.1	18.7	20	16.4
% Difference from sprinklers100%		99	102	110	90

Image 4: The sampling pit with the coordinate grid and the central root layer 30-60 cm deep.

Image 5: The sampling operation

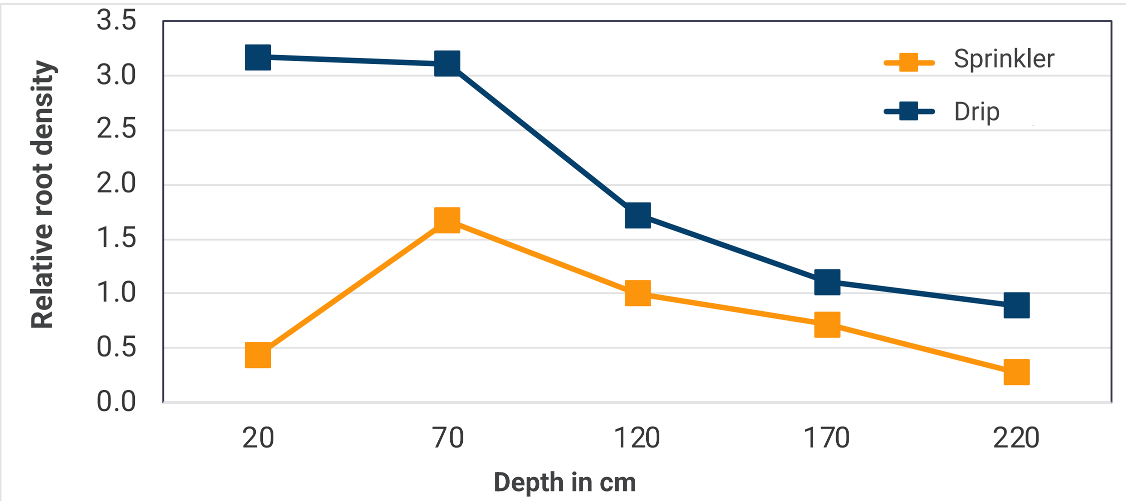


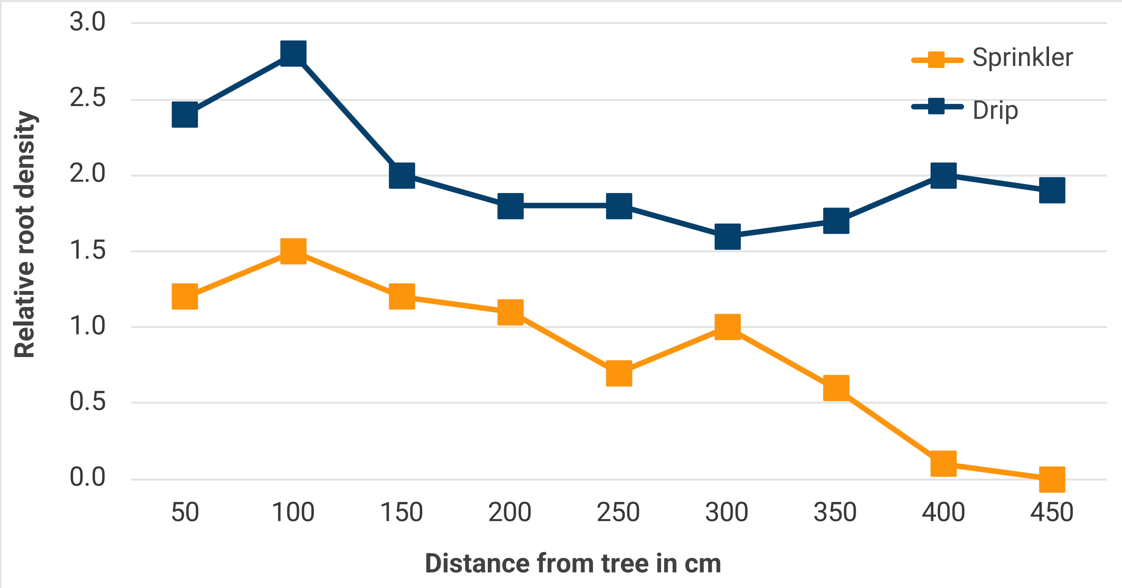
Depth of sampling layer (cm)



Depth of sampling layer (cm)

In the graphs above, the continuous salt deposition distributed evenly along the drip line can be seen, while salt deposition by sprinklers is concentrated at a radius of up to 2.5 meters away from the tree.





In the graphs above, the decrease in root density with depth and distance from the trunk can be seen in the 100% irrigation treatment, in both irrigation methods. Root density in the drip treatment is higher, relatively to the sprinkler treatment, up to a depth of 1 meter. Root density in the drip irrigation method, is significantly higher, relative to the sprinkler method, along the drip lateral and away from the trunk.

Conclusions

1. In sprinklers, a decrease in water volume did not damage the crop.
2. In drip irrigation, decrease in water volume, damaged the crop.
3. Deposition of salts to the depths of the soil, was better by drip than by sprinklers, especially in the larger water dose.
4. No commercial advantage was found to determining the irrigation interval according to tensiometer readings.
5. In view of the results, it will be worthwhile to examine an increase in the water dose in drip irrigation. On the other hand, there is room to examine a decrease in water dose in sprinklers.
6. Although the roots of the date tree reach a distance and a depth of several meters, most of the roots are at a depth of 30 to 60 cm.
7. In general, the roots are in the upper soil profile. In sprinklers, the roots are concentrated around the trunk at a radius of up to 1.5 meters. With the drip method, the roots are found along the drip laterals.
8. The wetted area of two continuous drip laterals, is 2.5 to 3 times larger than the wetted area of two sprinklers. As a result, the effective root zone is larger.


Image 6: Typical wetted area of a drip line placed 20 cm deep.


Image 7: Typical wetted radius of sprinklers in similar soil.

Following the results, in the 2019 season, it was decided to increase the irrigation water dose, in both drip treatments with the low water dose (75%), to 120% and 140% of the recommendations. The three additional treatments remained unchanged.

Table 5: The annual amount of water applied in 2019 (by treatments)

Treatment	Irrigation coefficient relative to recommendations	Annual water dose (mm)
Drip	100%	1049
Drip	120%	1235
Drip	140%	1481
Sprinklers	100%	1055
Sprinklers	75%	791

Table 6: Impact of irrigation method and quantities of water on the 2019 crop and quality

Treatment	Yield (Kg/tree)	Blistering (%)	Dry fruit (%)	Average fruit weight (g)
Drip 100%	a120	a13.1	18.4	b18.5
Drip 120%	a110	ab10.7	17.0	a22.2
Drip 140%	a108	ab12.7	19.5	a21.6
Sprinklers 75%	b85	b8.2	18.6	b18.8
Sprinklers 100%	b81	ab10.2	25.8	ab20.8

Discussion

To our surprise, the 75% drip treatments, with the lower yields from the previous seasons, closed the gap with the leading treatment (100% drip) as early as the first season with increased irrigation volumes.
Apparently, the limiting factor for tree development was the salinity in the soil. The increase in water dose improved salt flushing and positively affected the crop.

This experiment is in its seventh season and towards the sixth harvest. We intend to continue for two more seasons in the hope of preserving the emerging trend.

Sugarcane drip irrigation in saline and sodic soils under problematic water conditions

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Abstract

Salt accumulation in irrigated soils can severely impair yields, irrigation efficacy and soil structure. Many farms are limited in expanding their growing area due to marginal soils, which raises the need to adapt irrigation methods for saline/sodic soils. The demonstrative case study of an estate called TPC Ltd is presented below.

TPC Ltd. is situated in a semi-arid region of Northern Tanzania with saline/sodic soils on about 3000 ha, which represent a third of the estate. The irrigation water quality is highly variable in terms of salinity and sodicity, depending on the source and season. Previous work suggested that soil reclamation was possible with overhead sprinklers, while reclamation with furrow irrigation proved unsuccessful. The consideration of subsurface drip irrigation is described below.

The trial consisted of five treatments: a) pre-planting overhead soil flushing, drip irrigation 1 l/h; b) pre-planting gypsum application and overhead soil flushing, drip irrigation 1 l/h; c) no pre-planting treatment, drip irrigation 1 l/h; d) pre-planting overhead soil flushing, drip irrigation 0.6 l/h; e) no pre-planting treatment, standard furrow irrigation (control). The trial was designed as a field observation of 1 ha per treatment with no replicates. Yield, soil chemical properties and dripper performance were analyzed for three years after planting.

Drip irrigated treatments maintained an average yield of 167 tons/ha for the three years, with no differences between the reclamation treatments, while furrow irrigated yields dropped from 140 t/ha in planted cane, to 86 tons/ha for the first ratoon and 66 tons/ha for the second ratoon.

Overhead flushing before planting was most effective at maintaining EC and SAR values within threshold values (EC 100-200 mS/m, SAR 5–10) throughout the trial. Low flow drippers (0.6 l/hr) were less effective at flushing salts. No drop of EC and SAR was noted in subsequent years under drip irrigation.

During the first year, some of the drippers - mainly low flow - showed sedimentation of organic matter and bicarbonate. Filtration method was replaced and recommendations for system maintenance were established. However, bicarbonates remain problematic due to low water quality. Injection of acid is recommended to dissolve precipitates.

Drip irrigation facilitated optimal cane growth though salts were not flushed from the soil. The efficacy of drip irrigation results from a high irrigation frequency, maintaining high soil moisture and matrix potential near optimal conditions, thus reducing water potential. For future application of drip irrigation in saline/sodic conditions it is recommended to use 1-2 l/h drippers and keep high soil moisture levels

Introduction

The accumulation of excessive salt in irrigated soils can reduce yields, irrigation efficacy and soil structure (Horneck et al., 2007). When soil salt concentration increases, cane growth is reduced, and the effect on yield is relative to the soil threshold level; the threshold level for sugarcane is between 1.7 and 2.0 dS/m (Copland et al., 2011). The expansion of agriculture to marginal soils, as in the case of sugarcane, raises the need to adapt appropriate irrigation methods for saline/sodic soils.

TPC Ltd. is situated in a semi-arid region of Northern Tanzania with saline/sodic soils on about 3000 ha, which represent a third of the estate. The irrigation water quality is highly variable in terms of salinity and sodicity, depending on the source and season.

Irrigation on TPC is mainly conducted through sprinkler and furrow irrigation and some drip irrigation in the non-saline soils. Previous work suggested that soil reclamation was possible with overhead sprinklers, while reclamation with furrow irrigation proved unsuccessful. (Noel, 2009, unpublished data).

Drip irrigation is considered an effective irrigation system that removes salts from the active root zone in trees (Burt & Isbell, 2005; Hanson et al, 2010). This is effective mainly due to a high irrigation frequency, keeping a high moisture level and reducing osmotic potential.

Previous work done in Swaziland by Nixon & Workman (1987) tested the impact of soil leaching in Sugarcane, by placing the drip line on the soil surface every inter-row or alternate inter-row; a good response was found only when the dripline was placed every inter-row.

However, since in sugarcane the drip line is installed subsurface at approximately 20cm depth, salts move not only downwards but also towards the soil surface.

Following is a field observational trial that evaluated growing sugarcane in saline/sodic soil using subsurface drip irrigation.

Objective

The following objective was set: Evaluate performance of drip irrigation in saline/sodic soils and poor water conditions:

- Is soil flushing prior to planting required when using sub-surface drip irrigation?
- Chemigation through drip system as a means of White Grub control
- The implications of managing drip irrigation

Materials and methods

Location: The field observational trial took place on TPC Estate, which is located near the town of Moshi in north Tanzania.

Climate: The region is characterized as semi-arid, with a yearly rainfall of 400-700mm and ET ~1500mm. The local climatic conditions are presented in the table below:

Table 1: Farm climate conditions (TPC met. Station, Sept. 1974 - Aug 2002)

	Min Temp	Max Temp	Humidity	Wind	Rad	ET_o	Rain
Month	°C	°C	%	km/day	MJ/m²/day	mm/day	mm
January	17.6	33.0	68	199	17.4	4.7	42
February	17.8	33.3	65	199	18.9	5.1	46
March	18.6	32.3	52	178	17.4	5.1	113
April	19.1	29.6	81	156	16.3	3.7	318
May	18.4	26.8	86	111	13.4	2.8	141
June	16.7	26.0	82	111	13.9	2.8	29
July	15.7	25.6	75	133	13.4	2.9	22
August	15.5	26.6	71	156	15.7	3.5	14
September	15.7	28.7	66	200	17.3	4.3	15
October	16.8	30.8	61	245	18.5	5.1	37
November	17.6	31.9	62	289	17.1	5.3	81
December	17.6	32.0	69	222	16.0	4.5	58
Total					195.3		916

Soil: the site soil is classified as saline/sodic loamy sand; Soil chemical properties are described in Table 2. The soil analysis shows that salinity was not a major threat, the soil had low Ca and Mg and high Na levels.

Table 2: Soil chemical properties taken from the trial location prior to initiation

Depth	pH	EC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	SAR
(cm)	1:2.5	(mS/m)	(me/l)			(me/ 100g)	
0 - 30	8.3	64.3	0.69	0.01	4.4	4.0	8.3
30 - 60	8.7	73.0	0.23	0.01	6.0	2.4	17.3
60 - 90	8.7	66.6	0.18	0.01	5.6	2.6	18.6

The threshold values are described in the table below:

Table 3: Desirable values.

Element	pH	ECe	Ca^{2+}	Mg^{2+}	^{+}Na	^{+}K	SAR
Unit	(1:2.5)	(mS/m)		(me/l)		(me/ 100g)	
from	7	100	2	1	2.5	1.5	4
to	9	200	4	2	5	5	8

Irrigation water source: the southern part of the estate is based on 2 water sources: the old intake (high-quality source) and the Kikuletwa River (low-quality). As the year progresses, the flow in the old intake decreases and water is added from the new intake at the Kikuletwa River in the south (saline water) and mixed in to make up for any missing volume to irrigate the furrow irrigated area in the southern part of the farm.

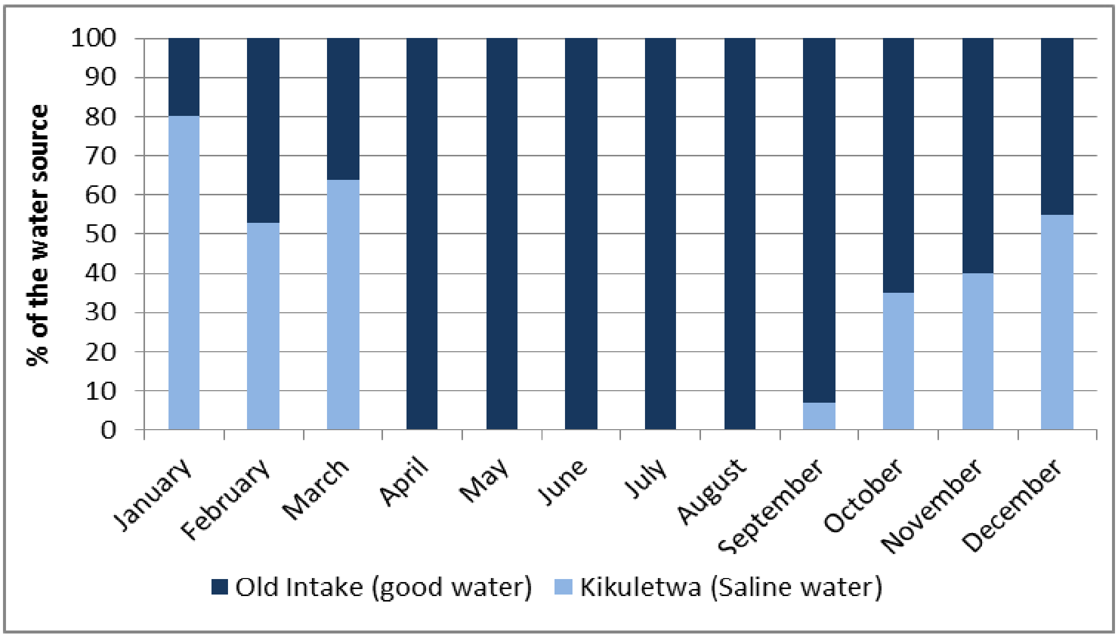


Figure 1: Water source mixture along the year

The chemical properties of the different water sources is shown in the table below

Table 4: Irrigation water chemical properties

Source	Type	pH	Ec	Ca_2^+	Mg_2^+	Na^+	K^+	CO_3^{2-}	HCO_3^-	SAR
		water	mS/m	me/l						
New Intake	River	7.8	20	0.5	0.4	0.9	0	0	2.4	1.3
Kikuletwa	River	8.4	134	1.5	3.8	8.3	0.5	0	12.2	5.1

Trial design: the field trial is designed as a field observation at a size of 1 ha per treatment with no replicates

Table 5: Trial treatments

	Treatments		Plot size
	Irrigation system	Prior to planting	(ha)
1	Furrow	Not flushed	1
2	DripNet PC 16150; 1.0 l/hr @ 0.3m	Not flushed 6 mm/day	1
3	DripNet PC 16150; 1.0 l/hr @ 0.3m	Not flushed	1
4	DripNet PC 16150; 1.0 l/hr @ 0.3m	Flushed	1
5	DripNet PC 16150; 0.6 l/hr @ 0.4m	Not flushed	1.6

Soil Reclamation and flushing: The flushing system was designed as a mobile MegaNet, 550 l/hr sprinkler system that uses the drip irrigation system by connecting to a bypass from the main line. After flushing, the sprinkler system is removed and the drip irrigation goes into operation. Should soil salinity and sodicity levels require repeating the flushing treatment, the sprinkler system can be reinstalled and activated. The system can be removed after flushing and installed in a different area; In this manner, one system can cover a significant area, following the harvesting and planting pattern.

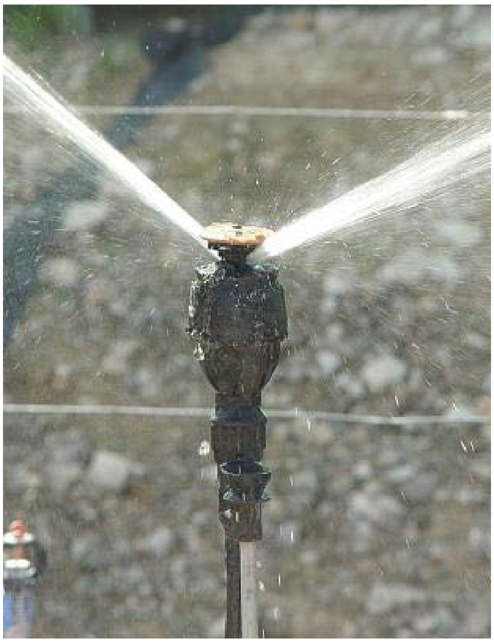


Figure 2: Sprinkler flushing system

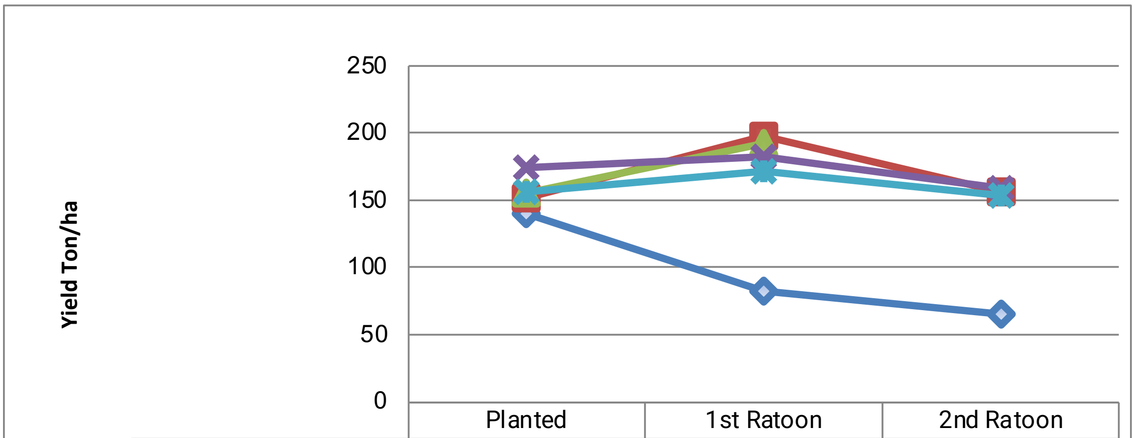
The crop: in March 2011, the cane variety N 25 was planted in a dual row configuration of 40cm x 140 cm. The drip line was placed in the center of the dual row 20 cm below the surface. The furrow treatment was planted at single row configuration of 150cm.

Irrigation was applied on a daily basis of 4mm/day and in the event of rain greater than 10mm, irrigation was suspended for 4 days. Nitrogen (fertigation) was applied through the drip system once a month till the 5th month.

Results

During the trial different aspects were analyzed: yield, soil reclamation, white grub control and dripper performance.

Yield: the first harvest took place when the cane was 10 months old. From the second year on, the cane was harvested at 12 months. At the 3rd harvest during loading, heavy rains caused a pause in the loading and the cane from treatments 3 was eliminated.



	Planted	1st Ratoon	2nd Ratoon
Furrow	140	83	66
Drip 1L - 6 mm/day	151	197	157
Drip 1L	155	193	
Drip 1L Flushing	174	183	159
Drip 0.6L	156	171	154

Figure 3: harvest results for 3 years

Furrow yield sums at 288 ton/ha (96 ton/average), while drip irrigation yield sums at 502 ton/ha (167/average), a 74% yield increase with drip. Among the drip treatments the differences are minor as compared to furrow irrigation. While the drip treatment maintained high yield during the 3 years, furrow irrigation yields dropped at a rate of 40%/year to a level where the crop needed to be renovated.

Effect on soil salinity: Higher levels of salinity were found in the low flow dripper, 0.6 l/hr. As the crop progressed the furrow irrigation showed increasing levels of salinity. The flushing treatment shows high levels for about 1 year and then a decrease, drip without flushing showed the lowest levels.

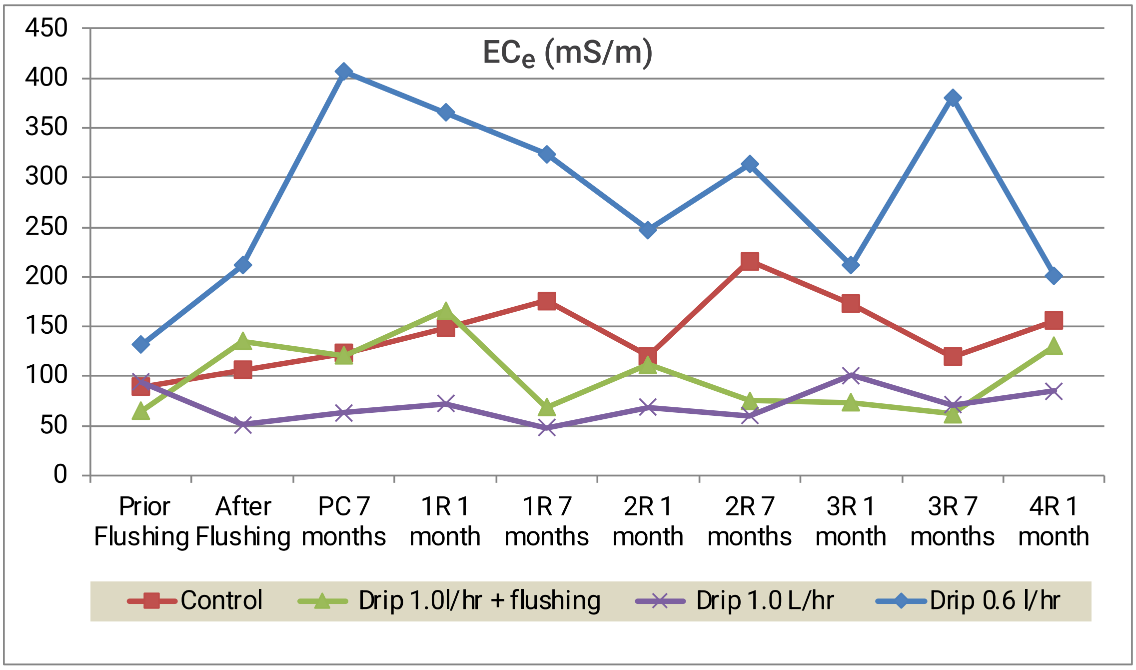


Fig 4: Soil solution electric conductivity in the various treatments

In the flushing treatment, SAR and EC are high during the first year due to release of cations into the soil solution, while in the furrow irrigation treatment SAR increases as the crop progresses. Better values found in the drip treatment without flushing.

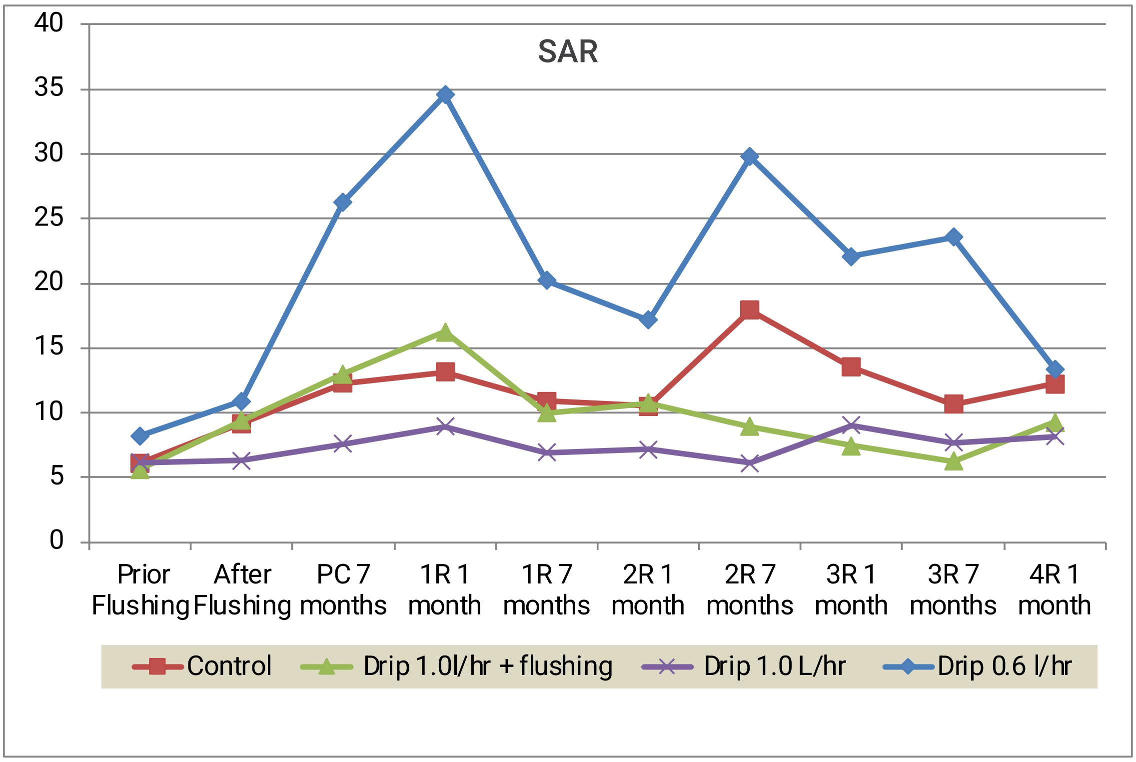


Figure 5: soil solution SAR in the various treatments

Although the soil analysis was aimed for salinity (soil solution) and not for soil fertility, the K levels under drip were lower by 0.3 meq/l compared to furrow, probably due to higher yields; fertilization recommendations for drip should be updated.

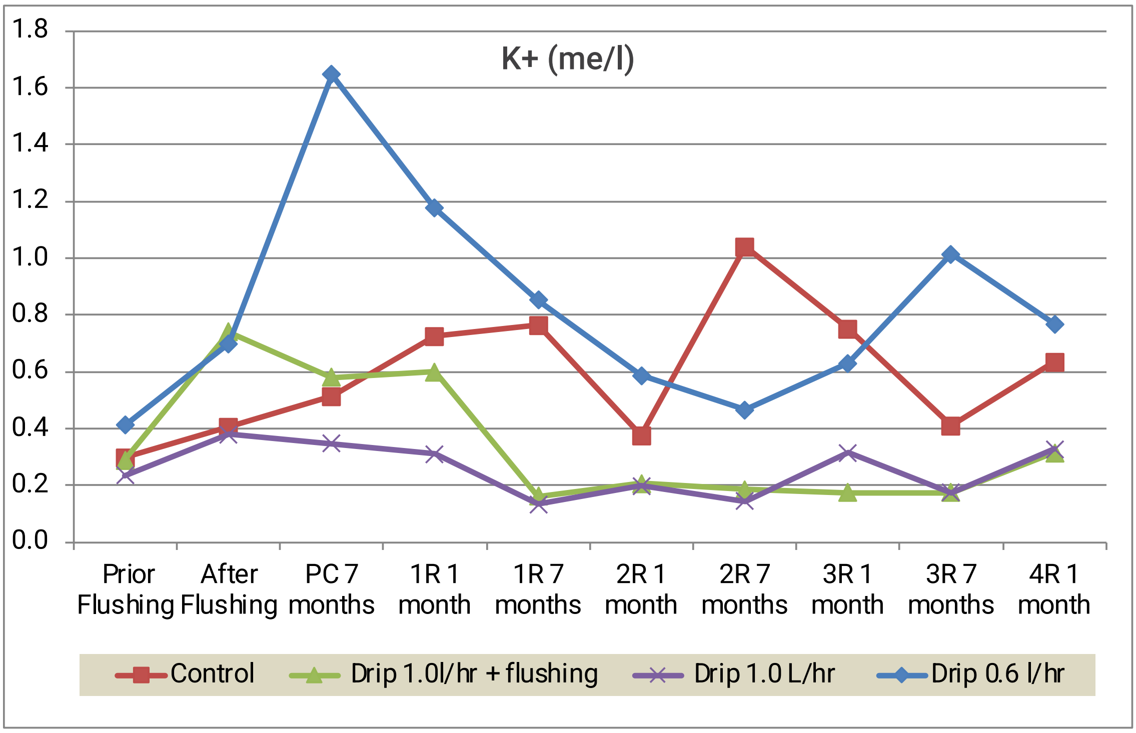


Fig. 6: soil solution K levels in the various treatments

System performance: towards the end of the first year, the system showed some serious performance problems: around 30 – 40% of the drippers showed sedimentation of organic matter and bicarbonate. As a result, significant flow reduction occurred and segments of cane began drying out. Dripper samples were taken to a laboratory where it was found that the sediment was composed of 65% mineral matter and 35% organic matter.

Fig.7: Segments of cane drying out due to drip clogging at the end of the first year

Fig. 8: Uniform cane development at 1st ratoon after system restoration, flow rates back to normal

As a result of the system's poor functioning, several steps were taken:

- The filtration system was replaced with a gravel filter instead of the simple screen filter that had been in use.
- Clogged segments of drip lines were replaced shortly after harvest.
- New recommendations for system maintenance were established, including flushing, peroxide, acid and pendemetelin injections, and performance monitoring.

Within a few months the problem was overcome. The system with the 1 l/h drippers is performing and the flow rate is back to normal values; with the 0.6 l/h the flow rate was recovered but is still at 85% of the normal rate, but the field and plant development are uniform.

Table 6: drip performance analysis prior and after treatments

Treat-ment	Dripper flow	1st Year		2nd Year		3rd Year	
	l/hr	Clogging rate	%	Clogging rate	%	Clogging rate	%
T2	1	0/4	0.00	0/12	0.00	4/16	0.25
T3	1	5/7	0.71	2/12	0.17	5/15	0.33
T4	1	0/6	0.00	1/12	0.08	0/16	0.00
T5	0.6	2/3	0.67	19/25	0.76	11/23	0.48

White grub control: toward the beginning of the fourth year, White Grub (cochliotis melolonthoides) infestation was observed. The grubs feed on the roots of the sugarcane plant, reducing growth and crop yield.

As the pest infected all the treatments, it was decided to treat the whole trial. For grub control 4l/ha ATTAKAN (SC Imidacloprid 350) was injected via the drip system.

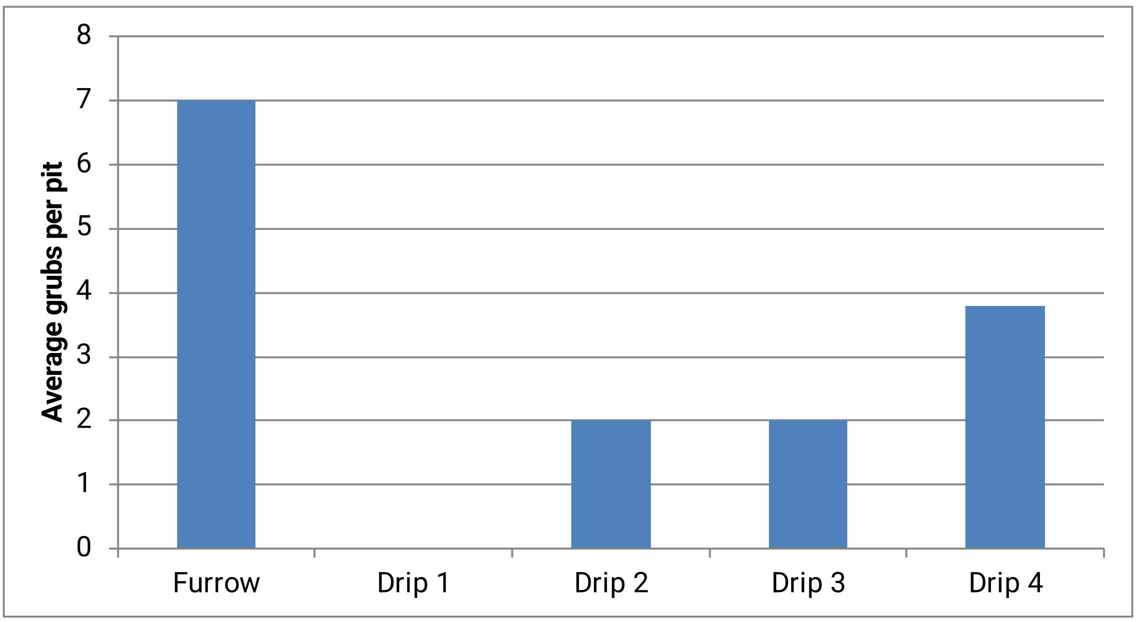


Fig. 9: White Grub levels at the various treatments after application

Grub counts showed that Attakan injection (liquid Imidachloprid) had a beneficial impact, with a dramatic drop in grub counts. It was concluded that injection of Imidacloprid for control of white grub should be done as a preventive measure soon after harvest.

Discussion

Subsurface drip in saline soil:

The soil Water Potential (ψt) is the sum of two potentials

$\Psi t = \Psi h + \Psi o$

ψo - The osmotic potential, and ψh = hydraulic potential.

While the hydraulic potential is the sum of pressure gravitation potentials: $\Psi h = \Psi p + \Psi g$

the osmotic potential is constant, results from the salts in the soil solution, and was apparently low, as shown by the soil analysis values. Applied daily, Drip irrigation kept the hydraulic potential high thus increasing plant water potential, and reducing the effect of the osmotic potential, so that the overall of both potentials stayed high in the SDI treatments thus allowing optimized water uptake and subsequently improved growth.

How to ensure high yields using subsurface drip in saline/sodic soil:

- Drip does not flush the soil, it keeps a small bulb with optimal conditions (high hydraulic potential)
- Irrigation must be applied daily to keep the high hydraulic potential
- In case of rain, up to 15mm irrigation should be applied to avoid backwashing of salts from surface into the root zone
- In the case of TPC, yearly rainfall of 500mm is sufficient to flush the soil
- In case of less rainfall, the flushing system should be applied when salinity increases

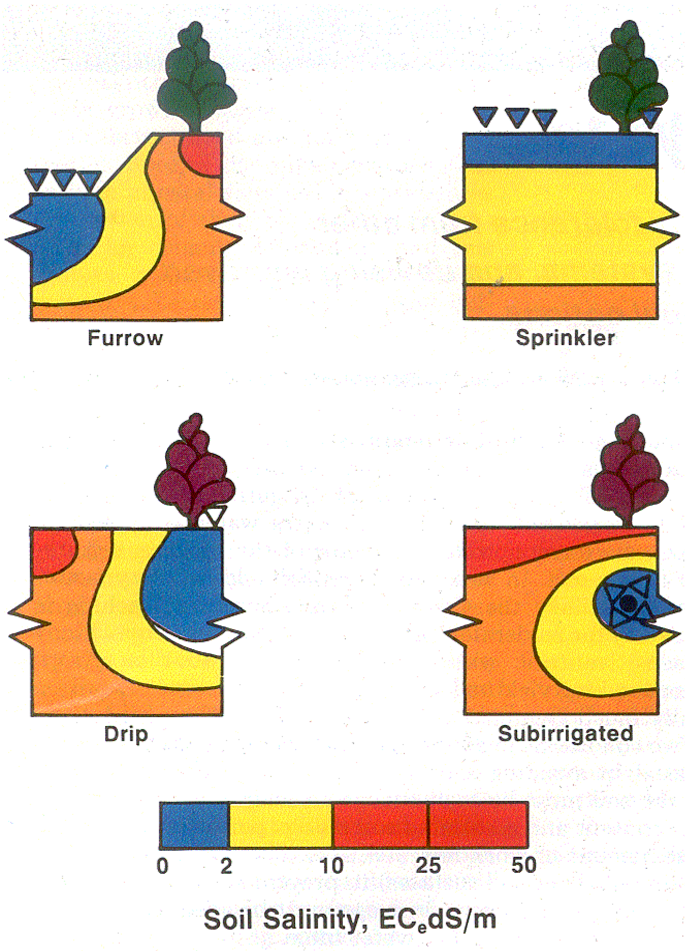


Fig. 10: Effect of soil salt flushing by different irrigation methods

The trial showed again the beneficial use of subsurface drip as a delivery system (besides water and fertilizers for: pest & diseases such as: White Grub, nematodes, borers, aphids.

Use for mill effluent or vinasse, and a vast variety of other products (under development), mycorrhizza.

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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.

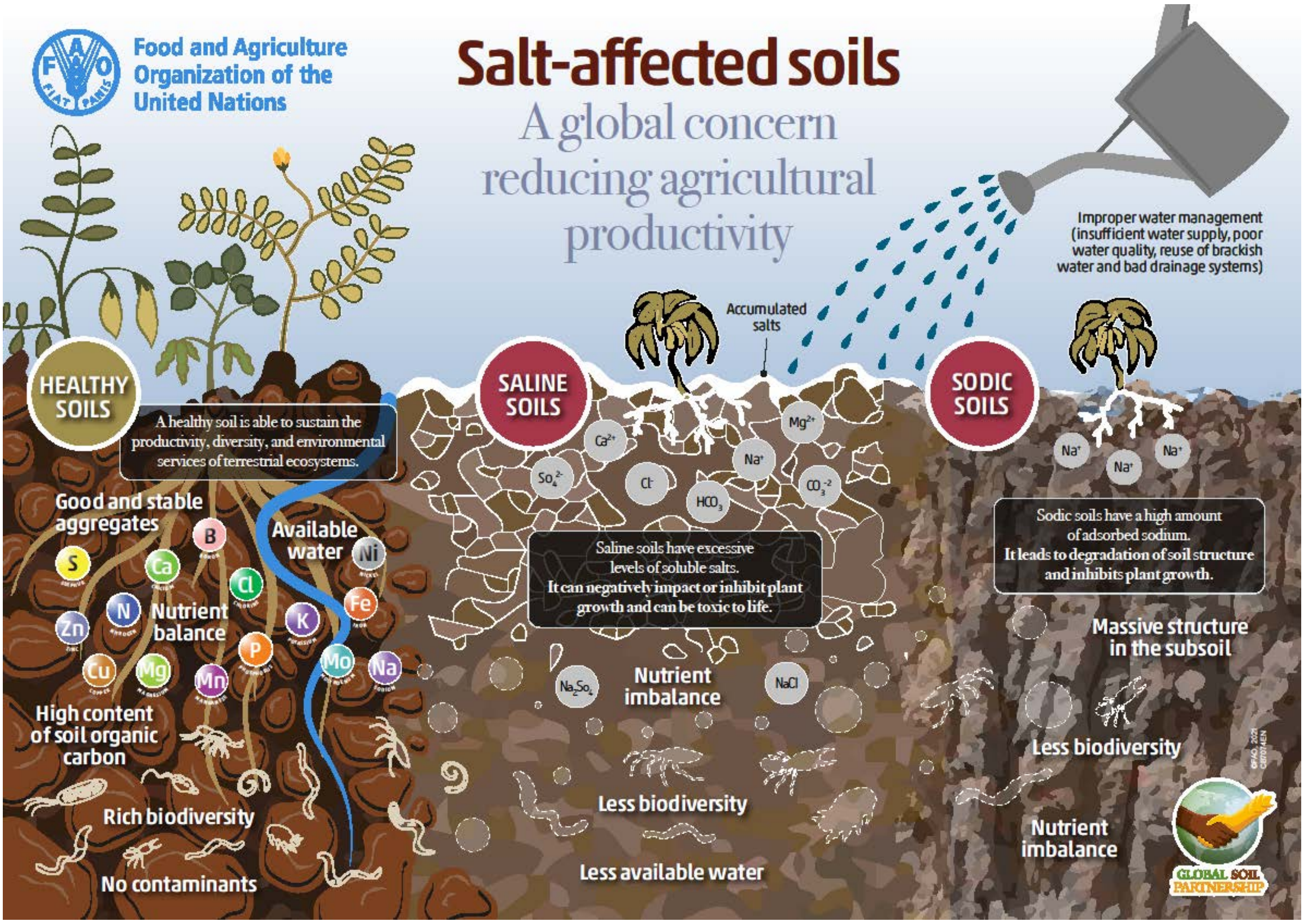
Soils which are both saline and sodic are classified as saline sodic and have characteristics of both.

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

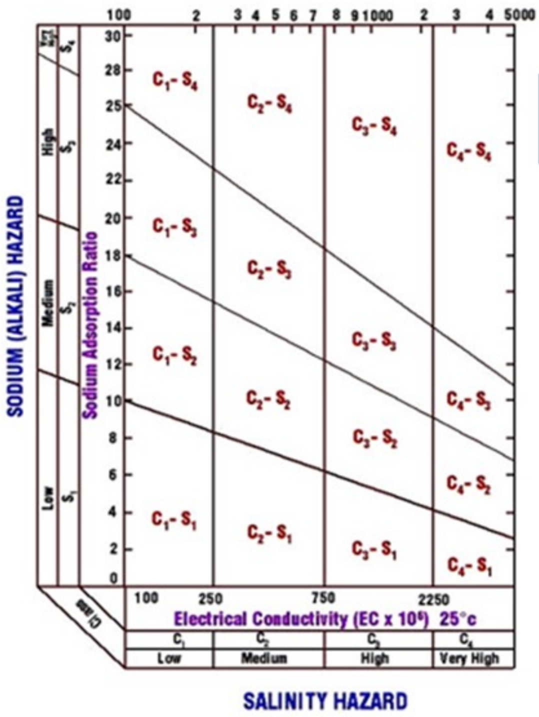
Term	EC_e Range		$EC_{1:5}$ Range	
		Sands (dS/m)	Loams (dS/m)	Clays (dS/m)
Non saline	0-2	0-0.14	0-0.18	0-0.25
Low salinity	2-4	0.15 - 0.28	0.19-0.36	0.26 – 0.50
Moderate salinity	4-8	0.28 - 0.57	0.37-0.72	0.51 – 1.00
High salinity	8-16	0.58 – 1.14	0.73-1.45	1.01 – 2.00
Severe salinity	16-32	1.15 –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

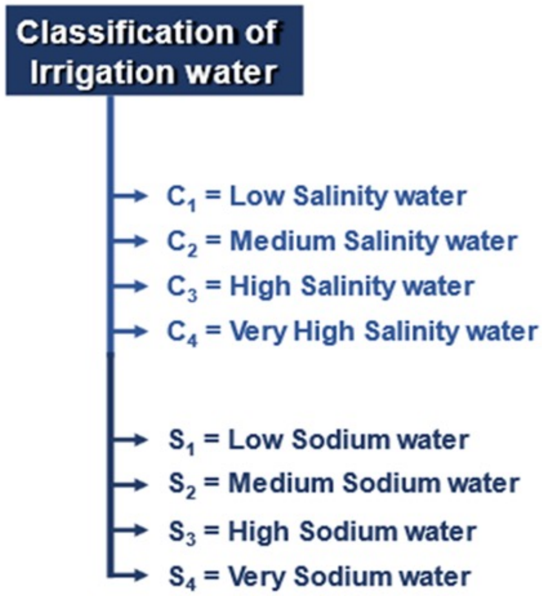
I learned from this that it is not enough to get an oral report of the EC, you have to see the lab analysis, as each laboratory states the method it used.
If it isn't stated, we may not understand the results properly. If a region does not have a conversion table, we must do the conversion ourselves,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

Orian Shalev, senior greenhouse agronomist, Agronomy unit

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.

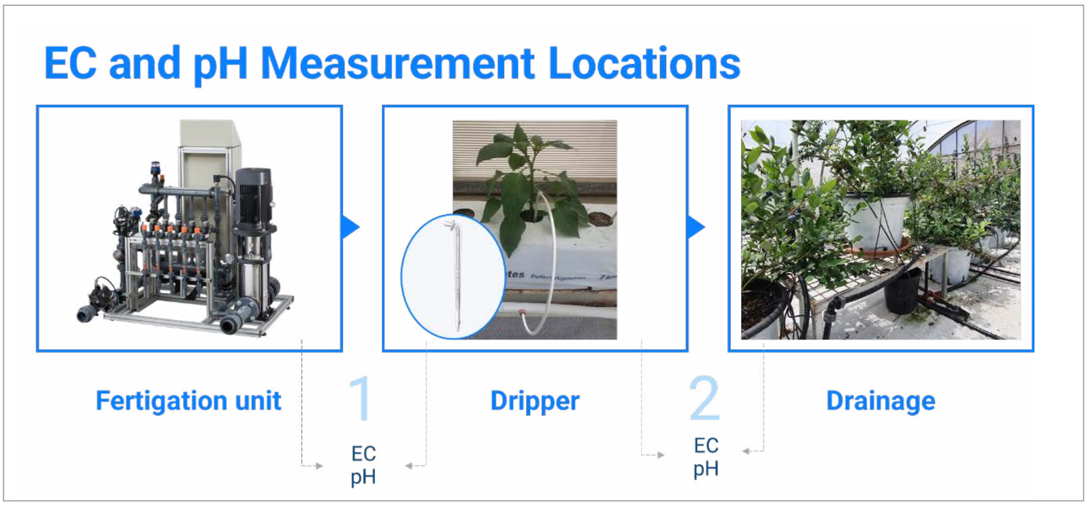
Use of high-grade fertilizer with low sodium and chlorine content is also important in achieving this goal. Sodium are not only salts themselves, but they compete with calcium, potassium and magnesium which are important to the plant.

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.

How do they do it?

Growing peppers under saline conditions in the Negev Desert

Adaia Shiboleth & Shahar Dayan, Agronomy unit

Udi Bar, bell pepper grower, Moshav Paran, Israel

Paran is a small moshav located in the Aravah desert in southern Israel with a population of around 500. Each family farm unit covers 5 ha. The main crops are high quality peppers and flowers for export. In addition, 14 families run a cowshed of 40-45 dairy cows each.

Among the smaller farm branches are a date palm orchard and turkey production.
Most of the surface of the southern Negev has a stony and sterile cover. The average annual rainfall is below 50 mm. A boring located close to a geologic fault provides water from a considerable depth, close to 1600 m. This is fossil water originating in the Nubian Sandstone formation. It is, therefore, a non-renewable resource, but at present rates of utilization the supply should last for at least 200 years*. Salinity in this water results mainly from calcium sulfate and reaches an EC of 2.8 dS/m.

**From: Arid Zone Agriculture in the Aravah in Israel: Unconventional Agroclimatic Resources and Risks*

To understand how farmers manage to grow high quality crops in these difficult conditions we talked to Udi Bar, a bell pepper grower, born and raised in Paran. Udi is a veteran grower, very professional and one of the largest growers in the area with 10 ha of pepper greenhouses.

Udi, tell us about your pepper farm

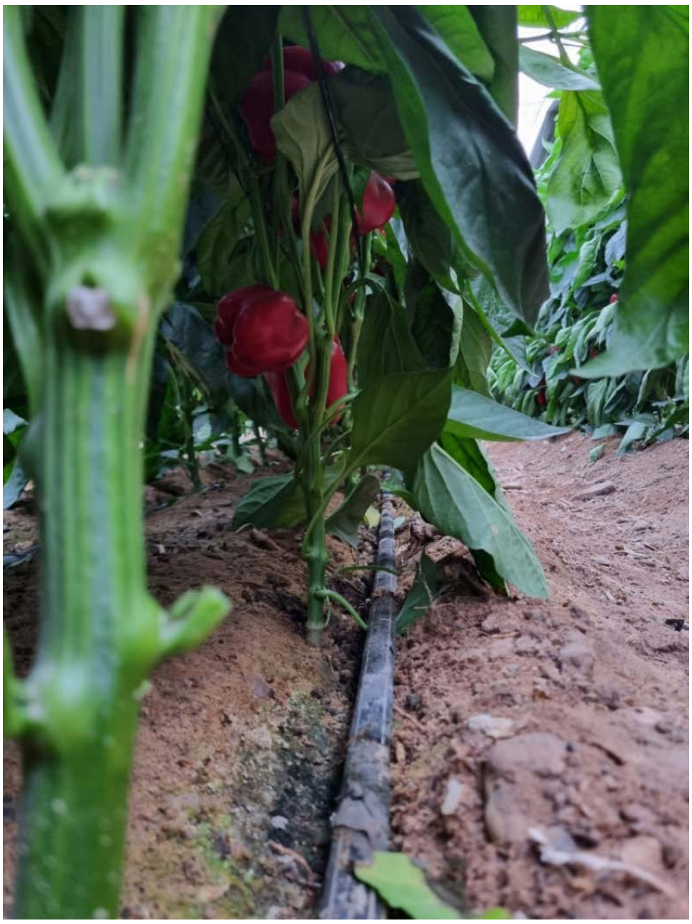
We're having a good season, good weather. In the first harvest this season the fruit was a bit small, perhaps because of the August heat waves. I'm not worried about growing the crop, but about marketing and sales. We depend on export as the local market is too small, mostly to Russia. But there's a big reduction in export: in 2014 Israel exported 70,000 tons, and now less than 50,000 tons: the sanctions on Russia affect us as well as growers in Turkey and Morocco. We plant the peppers in July and harvest in several waves between November and April or the beginning of May latest. We use cultivars which are not especially salinity tolerant but were developed in the country and grow well in the local conditions.

We Paran farmers specialize in growing high quality peppers for export. We grow them directly in the soil, but as the local loess soil is impenetrable and stony and saline, it's covered with a 40-50 cm layer of sand we brought in from elsewhere. The sand has the additional advantage of having no indigenous salinity. Each season, before planting we flush the soil with 1000-1500m3/ha to begin with a less saline soil.

Water quality is low. Other than salinity, it has sulfur and bacteria. The quality has reduced with time, as pumping raises salinity and as higher salinity water from new boreholes is added to the reservoir. Due to the high salinity, there are crops that it is no longer possible to grow in Paran, such as grapes. The plants degenerate and the vineyard must be uprooted after only 5-8 years.

With higher water quality we could get much better results. We use 1.5 X the amount of water we would need with better water, just to flush the salts to below the root zone. Even so, the plant manages to uptake less water and nutrients and this is a disadvantage in the competitive market. The dairy farm began desalinating their water, resulting in a significant increase in productivity.

Fertilizer is applied according to plant requirements and no more. In the beginning of the season, when very little water is applied, we are wary of salinization. Tap water including fertilizer can get to an EC of 3.5 dS/m. We use a soil solution extractor and test the EC and nutrients in the soil, which can get to 7-8 dS/m in the root zone. Every few days we halt the fertilization and flush the soil.



Drip equipment lasts for years as a result of good maintenance. Of course, salts damage the equipment. There's a lot of scale deposit, and bacteria and salts clog the drippers. Regular acid treatments aren't always enough, we also do maintenance with hydrogen peroxide and still suffer a lot of damage to the equipment.

We do maintenance treatments every season. At the end of the season we apply sulfuric acid and a couple of months later we apply hydrochloric acid.

Thin wall equipment such as Super Typhoon™ lasts only two years in Paran. We used to use it for three years but the damage to the crop was too big. Uniram™ is very successful and lasts up to 7-8 years with high pressure and strict maintenance.

Each farm in Paran has its own water storage tank. So water is pumped when available and irrigation is applied when the crop needs it, in the morning.

Yield is high in Paran, at 120 tons/ha, while in the rest of the Arava desert it's normally around 70-80 tons/ha. The result of high professionality of the farmers, agricultural R&D and cultivar development is maximal yields under the present conditions. We only need better water!

sustainability

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Article

Leveraging Sustainable Irrigated Agriculture via Desalination: Evidence from a Macro-Data Case Study in Israel

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Abstract: Israel has been a global frontrunner in (a) irrigation water application efficiency; (b) utilization of non-conventional (recycled and brackish) water supplies containing salts for irrigation; and recently (c) large-scale seawater desalination to provide water. Irrigation with water high in salts in many dry regions has been shown to be non-sustainable, mostly due to contamination of soils, subsoils, and groundwater resulting from the application and leaching of salts. We hypothesized that the move to desalination would reverse prior problematic trends of salinization and provide a path to sustainable irrigated agriculture in Israel and similar environments. To investigate effects of desalination in Israel on the status of salinity trends, we evaluated citrus leaf sodium, chloride, and magnesium in the years since the onset of large-scale national desalination in 2008 and examined fresh produce in the country for sodium and magnesium. We found remarkable reversal of previous trends until 2006, when salinity was found to rise consistently, in the recent data showing decreases of 20, 34, and 30% for Na, Cl, and Mg, respectively. A tendency for Israeli produce to be high in concentrations of salts compared to international standards was also reversed following large-scale desalination. Sodium in Israeli fresh produce is no longer much higher than that expected in equivalent sources in the USA while magnesium is lower in Israel fruits and vegetables compared to USDA standards. We present these results and trends to support the argument that desalination can allow and promote sustainable irrigated agriculture in the world's dry areas.

Keywords: seawater desalination; recycled wastewater; salinity; sodium; magnesium; chloride; citrus

1. Introduction

It is generally acknowledged that providing global growing needs for food, fiber, and bio-energy necessitates expansion of agriculture into the world's more arid regions. The hot and dry nature of such regions slated for increased agricultural activity themselves necessitate irrigation to allow production. Water-scarcity in the dry areas of the world, in turn, has led to utilization of non-conventional water sources for irrigation. Moreover, these water sources, namely recycled wastewater and brackish groundwater, are characterized by high levels of minerals and contaminants, almost universally including problematic salts.

Salts in irrigation water reduce a crop's ability to take up water and, via combinations of osmotic and toxic stresses, inhibit growth and production [1,2]. Farmers irrigating with water containing problematic salts must insure at least periodic leaching of the soil where roots are active to enable sufficient plant health for successful agricultural production [3]. Contrary to wetter areas, in dry regions, rainfall and natural hydrologic systems are insufficient to remove added salts and, after leaching the root zone, deeper soils and groundwater are contaminated with accumulating salinity [4,5].

Due to the basic need for leaching and the nature of arid ecosystems, irrigation with water high in salts in such regions is fundamentally not sustainable [6–8]. Rising saline groundwater tables, resulting from excess irrigation allowing continued irrigation and production, has been the ruin of civilizations in drylands throughout human history [9]. Tales of ruined civilization linked to this narrative have been repeated throughout history, from Mesopotamia to the Indus Basin, and continue to be part of the dialogue in locations including California, Australia, and Pakistan. Modern strategies for coping with the phenomenon often include costly and complicated systems for collection and disposal of drainage water from the irrigated agricultural areas [10].

In Israel, the story has taken a markedly different and unique turn. Most of Israel has deep soils and deeper aquifers, and therefore rising water tables are not an issue. Nevertheless, Israel has been a pioneer of a combination of highly efficient delivery of irrigation water via drip systems on one hand, and large-scale utilization of relative salty water sources for irrigation on the other [8]. Between 1970 and 2004, irrigation water to Israel's agriculture moved from being dominated by fresh water to almost 50% irrigation with saltier water, mainly as recycled municipal wastewater [11]. Almost simultaneously, Israel developed and moved from surface and sprinkler irrigation to the more efficient drip technologies and methods [8]. Unique to the world, Israel's adoption of drip came early and was nearly absolute and today all irrigation is via pressurized sprinkler and drip systems with the latter covering about 80% of Israel's irrigated land. Between the 1970s and the early 2000s, Israeli irrigation was thereby characterized by concurrent movement towards: (a) use of non-conventional water high in salts; (b) efficient irrigation due to drip and smart, data driven (meteorology plus crop factors, water status monitoring, etc.), scheduling; (c) pricing to enable/encourage application of water for leaching; and (d) leaching of salts leading to contamination of groundwater with salts and nitrates.

The ramifications of these actions were investigated in a previous study [7] focusing on national trends between during the period of utilization of recycled wastewater and adoption of drip irrigation. An evaluation of national scale historical data to define trends in Israeli soils and citrus leaves revealed increasing salinity over time (mid 1990s until early 2010s). The sodium (Na) fraction of cations in soils was shown to increase 50% over the course of period for which data was collected. Sodium and chloride (Cl) in diagnostic leaves of citrus trees both doubled over the same period. Additionally, Na in Israel's then current (2012) fresh produce was found to be well over USA standards. In a comparison of values found in a large sample of 24 fresh, edible products (crops) sampled from farms and markets from all over Israel, 20 were found to have higher Na compared to USDA reported standard values. Some of the produce reached levels four to five times those expected according to the US database. For example, oranges in Israel were found to have around 4 mg/100 g fresh weight which is some five times greater than the level reported as normal or expected in the US.

However, Israel's story does not end there. Since 2007, Israel has addressed water scarcity by adding seawater desalination into its water budget and has done so massively. As of 2010, more than 40% of Israel's fresh water supply has moved from surface and groundwater sources, all with some component of salinity, to desalinated water essentially void of salts [12]. The repercussions of such large-scale movement from lower to higher quality water to the overall hydraulic and hydrological systems in the country are multifaceted. First, the quality of fresh water has changed, with significantly less salts reaching the 50% of irrigated agriculture using Israel's national water carrier as a supply. The move to desalinated water was naturally received positively by farmers realizing potentially higher yields with less water and opportunity for increased water and fertilizer efficiency [6]. Management of desalinated water for irrigation proved to come with its own set of challenges though, most particularly following the realization for need to supply minerals such as calcium (Ca), magnesium (Mg), and sulfate (SO_4) that had traditionally been components of delivered water but are not present in the desalinated water [13]. An additional important ramification of the desalination of municipal water supply was the decreased salinity in the wastewater stream and significant lowering of salts in recycled effluent used for irrigation [14].

Post-desalination era irrigation water in Israel indeed has significantly less salts than previously was the case. Mineral content of both tap water and effluent of course vary widely over time and especially by location, depending on variables including original water source and treatment methods. The following numbers are therefore very general but should provide a fairly reliable comparison of irrigation water quality in Israel pre- and post-large scale desalination of sea water. Pre-desalination tap water supplied by Israel's national water carrier would typically have 60–100 mg/L Na, 50–70 mg/L Ca, 5–10 mg/L K, 25–30 mg/L Mg, and 200–220 mg/L Cl with electrical conductivity (EC) of around 1 dS/m. Today, with the addition of desalinated water containing low to no concentrations of these minerals, tap water is better characterized by 10–30 mg/L Na, 30–45 mg/L Ca, 0–4 mg/L K, 0–10 mg/L Mg, and 40–140 mg/L Cl, with EC of 0.2–0.5 dS/m [13–15]. The salinity and character of municipal wastewater effluent after treatment is largely a function of local background tap water quality plus typical additional concentrations of 70–80 mg/L Na, 100–120 mg/L Cl, 25–40 mg/L K, and only ~10 mg/L Ca and Mg. As a result of the influx of desalinated water to municipal supplies, Na in effluent from recycled municipal wastewater has roughly decreased from over 150 mg/L to under 150 mg/L, Mg from more than 40 mg/L to under 15 mg/L, K from as much as over 40 to under 30 mg/L, and Cl from over 300 mg/L to under 220 mg/L [14,16,17].

The driving hypothesis of this study is that the move to desalination would reverse prior problematic trends of salinization in Israel and provide a path to sustainable irrigated agriculture. Our objective therefore was to evaluate effects of desalination in Israel on the status of salinity trends. To do this, we revisited the original approach of using a national macro-data set by reevaluating citrus leaf Na and Cl from 2008 until 2015. We additionally took new samples of edible crops and reevaluated their Na concentration compared to USDA standards. Since desalinated water in Israel is universally devoid of the mineral magnesium, the trends of Mg since 2007 in citrus leaves and its concentration in fresh produce were evaluated as well.

2. Materials and Methods

To explore trends in Na and Mg levels in citrus, we investigated a database summarizing ~13,500 citrus leaf samples collected by Israeli growers between 2008 and 2016 and sent to national laboratories for mineral analysis. Samples, tested for Na, Cl, and Mg concentrations, were typically taken in October–November from around four to six month old 'diagnostic' leaves from fruiting branches. List of varieties and orchard location included in the database can be found in Raveh (2013) [18]. The database was received from the Israeli Field Services Laboratories and included samples from commercial citrus orchards from all over the country; about 42% of the analyses came from orchards located along the coastal area of Israel, another 31% from the western Negev, and about 27% from the north of the country. For Mg analysis, leaves were washed in distilled water, dry ashed, extracted with HCl and analyzed by ICP (Spectrociros ccd, Spectro Analytical Instruments, Kleve, Germany). For Na and Cl analysis, the washed leaves were oven dried at 65 °C for 72 h, pulverized and analyzed using water extract [19]. The database included samples from all parts of the country. Since growers may not routinely request leaf Na and Cl analysis for orchards that appear healthy, it is likely that the mean values found over the years in the databases do not necessarily represent absolute mean nationwide values. Assuming that the samples represent more problematic areas than not, the values for all of the parameters tested are likely to be higher than actual averages. Leaf salt concentrations could also be influenced by differing or changing meteorological conditions. While actual annual rainfall in Israel fluctuates widely, during the period that the samples were taken the average annual rainfall was 8.6% below the long-term yearly average [20].

In order to assess a more current picture of the effects of desalination water on Israeli agriculture, 550 samples of 29 different fruits and vegetables (20–25 samples of each product) were acquired from all over Israel during 2017. The edible part (2 to 4 g) of each product was dry ashed (550 °C), extracted with HCl (18.5%), and analyzed for Na and Mg concentrations by atomic absorption spectrometer (Pinaacle 500; PerkinElmer, Waltham, MA, USA).

The Na and Mg in Israeli crops was compared to that found in the USDA National Nutrient Database for Standard Reference Food and Drug Administration [21].

3. Results and Discussion

Annual levels of Na, expressed as percentage of dry weight (% DW), in leaves of citrus trees have steadily and linearly decreased by some 20% from concentrations of over 0.18 to less than 0.14% dry weight since the introduction of large-scale seawater desalination in Israel in 2007 (Figure 1A). Leaf Cl followed this trend with an even stronger, nearly 35% decline, reducing from over 0.5% in 2008 to 0.34% in 2015 (Figure 1B). Magnesium in the diagnostic citrus leaves declined nearly 30% as well, from nearly 0.4% in 2008 to 0.28% (Figure 1C).

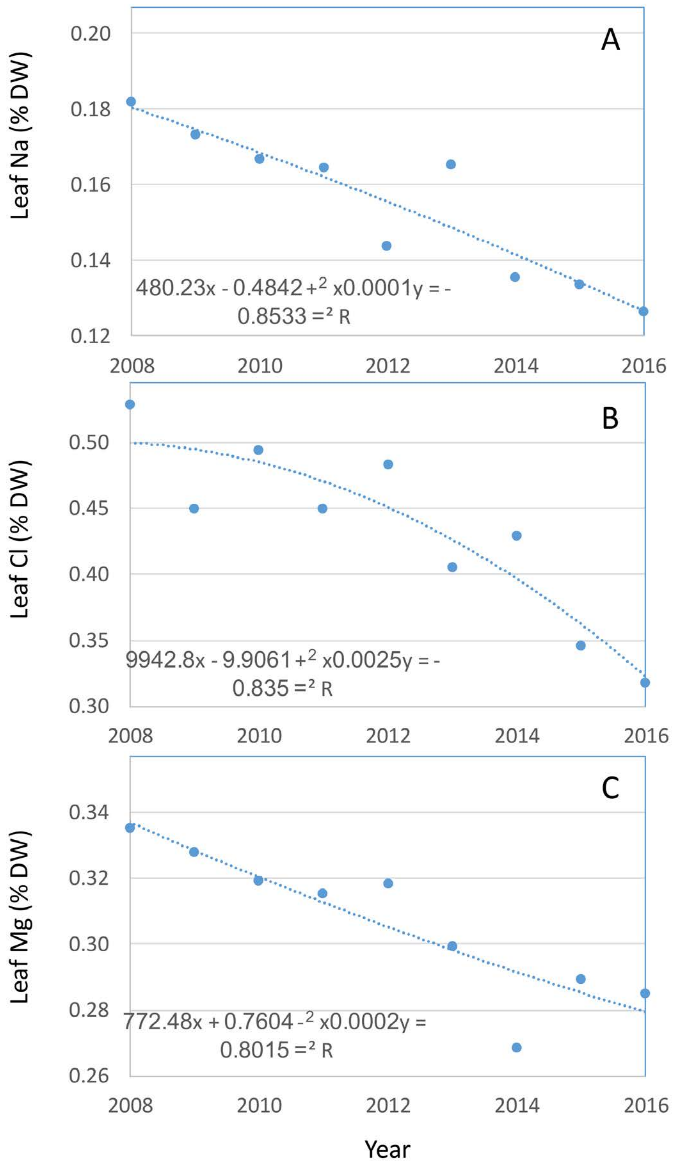

Figure 1. Average annual sodium (**A**), chloride (**B**), and magnesium (**C**) in diagnostic citrus leaves from Israel national database. n = 1200–1800 per year. p of best-fit regression curves < 0.001.

Absolute concentrations of Na in sampled fresh produce is shown in Figure 2A. None of the concentrations reported, even in the root and tuber crops tending to have relatively high levels, are considered dangerous or unhealthy for human consumption. Shown normalized to concentrations expected in the same products in the USA (Figure 2B), the data reveals that, of the 28 products tested, about a third are very similar to the standards of the USDA, a third significantly higher, and a third lower. The difference between this data and situation in 2017 to the parallel analysis published by [7] from 2012 is remarkable. In 2012 only 4 of 26 crops were found to have lower Na than US standards and more than half had concentrations of Na more than double the standards.

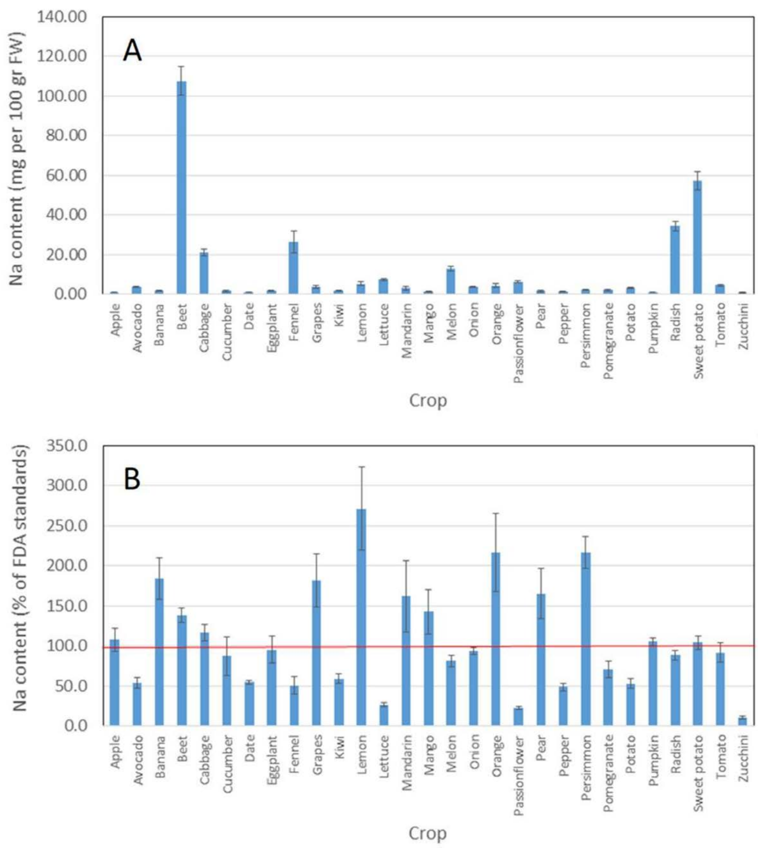

Figure 2. Sodium in fresh produce in Israel. (**A**) Absolute content, and (**B**) normalized to USDA/FDA National Nutrient Database for Standard Reference. Error bars signify standard error for each crop.

The move to desalination is expected to be particularly influential on Mg in agricultural systems [13,14]. This is supported by the data of Mg in edible products and its comparison with USA standards (Figure 3A,B). In 2017, Mg concentrations were found to be universally lower in Israeli produce compared to levels in each of the products in the United States found in the USDA database.

Similar to our previous macro-data case study for Israel showing trends over time [7], the strength of the current data set lies in its indication of large-scale trends and a consequential enabling to rethink big-picture paradigms. Each data set and its statistical consideration could admittedly be questioned, especially since control for uniqueness and balance in sampling is not feasible in such a study. That said, we find the trends and the clear and absolute reversal of the previous findings to be compelling. The fact that negative trends of increasing salinity for more than 20 years were completely reversed following the move to desalination for water supply in Israel is more than promising and indicates hope for sustainable irrigated agriculture beyond Israel and into additional dry areas. The concept and belief that desalination may be a viable strategy instead of irrigation with low quality water is not new [6–8,22], but the new large scale confirming evidence is truly reassuring.

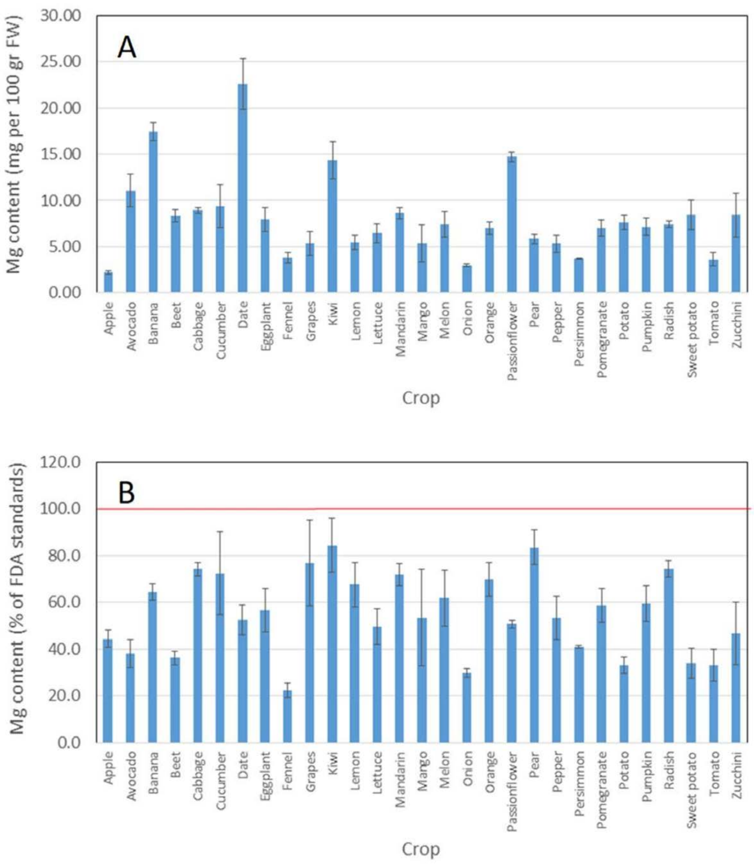

Figure 3. Magnesium in fresh produce in Israel. (**A**) Absolute content, and (**B**) normalized to USDA/FDA National Nutrient Database for Standard Reference. Error bars signify standard deviation error for each product.

Of course, desalination, as a water supply in general—and for irrigation purposes specifically—is not without issues needing consideration and treatment beyond those of soil and groundwater contamination and management of minerals. The environmental impact of desalination plants, particularly regarding energy consumption and disposal of brines, needs to be addressed in scenarios for long-term sustainability [23,24]. This we leave to engineers, designers, and decision makers but are hopeful in the realization that water scarcity today appears to be solvable and expected to become a non-issue as soon as accessible (affordable) sustainable energy will become available. The economics of desalination for irrigation must constantly be evaluated and will be a function of local price scheduling and markets and expected costs and benefits. Today, there is increasing evidence for the economic feasibility for agriculture to support desalination. Examples have recently been shown for Israel [25], California [26], Spain [27], and Australia [28].

4. Conclusions

The influx of large amounts of desalinated seawater into Israel's water economy appear to have reversed trends of problematic buildup of salinity in agro-ecosystems caused by the combination of utilization of poor quality water for irrigation and adoption of methods for very efficient water delivery and use. Trends found by analyzing national macro data of minerals in citrus leaves and of salt concentrations in edible produce which showed increasing salinity from the 1990s until the end of the first decade of the 21st century were reversed during the country's consequent and continuing post-desalination age. Prior fears that policy and practice in Israel were not sustainable due to the threat of salinity buildup and need to leach salts from agricultural fields have therefore been largely dissipated. We expect this to be of interest globally suggesting desalination as a component of sustainable models for irrigated agriculture in other dry regions.

Author Contributions: Eran Raveh directed data collection and processing. Alon Ben-Gal and Eran Raveh together were responsible for concept, design, interpretation, and writing.

Conflicts of Interest: The authors declare no conflict of interest.

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Long term irrigation with saline water - the Israeli perspective

An interview with a local researcher

Dr. Itamar Nadav, head of research & innovation, Agronomy unit

Dr. Eran Rave, head of Gilat Research Center, ARO.

We are pleased to host Dr. Eran Rave for a discussion on the past, current and future use of saline water in Israel. Dr. Rave is a whole-plant physiologist, specializing in the effects of environmental conditions on plant development, photosynthesis and assimilate transport, and CAM photosynthetic plants. Dr. Rave also works closely with citrus growers in Israel dealing with treated wastewater irrigation. Today, Dr. Rave is the head of Gilat Research Center which is a part of the Agriculture Research Organization (ARO) of Israel.

What is your perspective on the use of saline water in Israel along the years?

Since its establishment, two major problems have arisen in the water sector in Israel - a decrease in the amount of water suitable for drinking, and a constant deterioration in its quality. The level of salinity in the Sea of Galilee, Israel's main freshwater source, and in the aquifers rose constantly and decreased the quality of the water.

Until 1990, the water used for agriculture was drinking water. Only from the 1990s did the process of water recycling and the use of effluent water begin. About 70 percent of the sewage water in Israel is purified and used for irrigation purposes. In the nineties the quality of recycled water was not as high as it is today and it was more saline.

Also, over-pumping of water from aquifers in the Negev desert increased salinity until it became undrinkable and unsuitable even for agriculture.

It took time to understand that there is a problem with the use of saline water for irrigation. During the first years, between 1992-1997, no effects were observed, and only after 5-10 years of saline water irrigation, some indicators of negative effects were observed. There were no immediate yield losses at first. The water used for irrigation had 230-250 mg/l of Cl,- which is not very high, but over the years, and with very little leaching, the effect of long-term salinity build-up was observed in both soils and plants.

Does the purpose justify the risk?

The use of saline water came from pure necessity of water for irrigation. The main water source for irrigation back then was from the largest treated wastewater facility in the Dan region (central Israel), that was used for irrigation in the south of Israel. Looking back, the use of that water saved the Israeli agriculture, since no other water source was available. The use of saline water for irrigation in Israel was drastically reduced following the acknowledgment of its negative effects. There are still some places that use saline water for irrigation but it's not as common as before. Since then, the quality of the treated wastewater has improved, and the salinity levels were decreased, mainly by using sea water from the desalination project. Also, many farms have their own desalination systems.

How does water salinity affect the plants' ability to take up nutrients from the soil?

High soil salinity has a secondary effect on nutrient uptake by plants. High salinity reduces the plants' water consumption and consequently the water flow from the soil and through the plant is reduced. Since most of the nutrients are taken up and flow in the plant with the water flow, any reduction in water flow leads to reduction in nutrient uptake.

Primarily referring to nitrogen uptake, which can be reduced x4 under saline water irrigation. As for other nutrients, there is a competition for uptake between cationic nutrients and high concentrations of sodium.

Is the damage to the soil following the long-term saline water irrigation irreversible?

There is no conclusive answer for that. The soil SAR was increased but the soil EC was reduced after moving to low salinity water irrigation and natural leaching by rains. The soil SAR can be recovered with the right treatment.

Is there any direct correlation between soil/water salinity and increasing salt content in the plants and edible parts?

Salts accumulate in all plant organs, from roots to leaves and fruits. In most cases, the roots accumulate most of the salts, and in some crops, like carrots, that's the edible part. Salts can also accumulate in edible leaves like lettuce, or in fruits, such as in citrus. High irrigation water salinity will eventually lead to salt accumulation in all plant tissues.

In addition to the damage to plants, is there any hazard for human consumption of high salt content of fruits and vegetables?

In root vegetables we have reached near risky levels, but there was never any risk for the public. The salinity level in carrots, for example, can reach 80 mg\l following saline water irrigation. In citrus, the salt levels reached levels which are toxic to the tree itself, but the salt concentration in the fruit remained lower and it was nontoxic for human consumption.

Is the salt accumulation in plants reversible?

In vegetables and rotational crops, it's not an issue since they are harvested at the end of the season. Soils with high salt content can be leached to reduce salt levels and sail SAR can be treated by Ca amendment. In tree crops it takes more time. Leaves of trees are replaced every year or two, so they will become clean eventually. There is some salt accumulation in the roots and trunk that will be flushed by water flow over time when irrigating with fresh water.

Is there any practice you can recommend for reducing or monitoring the salinity level in soils and crops?

Keep your finger on the pulse! Don't wait for a scheduled lab analysis at the end of the season or a visit from the extension service. Do frequent soil salinity analysis - at least once a month - by simple means of sampling small amounts of soil (such as a laundry detergent spoon), 1:1 dilution with water and measuring with an EC meter;

Occasionally flush soil salts by non-saline irrigation and monitoring;

Soil mulching to reduce evaporation and salt accumulation in the topsoil layer;

Reduce pulse irrigation and maintain long, deep irrigation to expand the moisture bulb around the dripper as much as possible and drive the salts away from the root zone.

Does the future depend on genetically modified salinity resistant plants?

When no other option exists, we must irrigate with saline water. But eventually even desert plants that are salt tolerant, will die as a result of high salinity. A genetic solution is too farfetched since it takes 10-20 years of research, so it won't be relevant enough. The salts need to be removed one way or another. It's better to treat the water beforehand, than to treat the soil later, but it's not always possible. On the other hand, irrigation with desalinated sea water also poses a few problems. The lack of crucial ions in the water can also do damage to plants.

Based on the Israeli experience and your personal experience, what can you recommend when dealing with saline water?

There is no global silver bullet. Every region needs its own solution according to the local conditions, available water sources, and resources for addressing the problem.

The basics would be to constantly monitor the salinity built-up in the soil by simple means. Conduct soil flushing occasionally. Use salt resistant rootstocks if available.

The red line is irreversible damage from long term irrigation with salty water. Usually, it will be soil damage, as plants can be easily replaced. Soil remediation might take time, good quality ware and resources. The bottom line is the economic cost-effective solution per local conditions.

Considering the above perspective by Dr. Rave, we can conclude that irrigation with saline water sources is not recommended, since it might cause long-term damage to soil and plants. When no other water is available and it's the only option, caution needs to be taken. Monitoring the salinity levels and correct salt management can sustain growth under saline conditions.

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