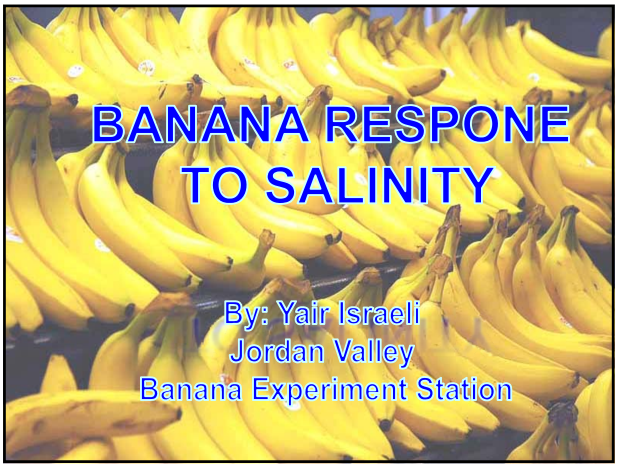
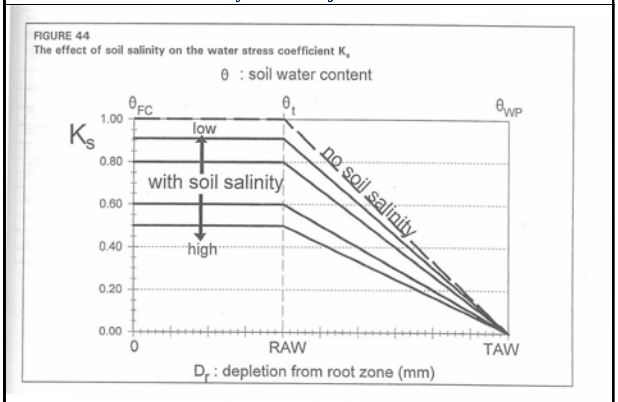
- **What is the source of water salinity?**
- **Plants are frequently exposed to soil water salinity;**
- **The main source of salinity is the irrigation water;**
- **Weathering soil minerals contribute dissolvable salts;**
- **Underground salty water may also be a source of salinity (typical for desert Salinas);**
- **Sea water can contribute salts to nearby area as aerosols (wind carried microscopic sea water droplets) or through underground sea water;**
- **Effluent water used for irrigation are also a source for salinity;**
- **Animal manure and composts may contain high concentration of salts and when used without the necessary cautious may become a source for soil salinity.**



The effect of soil salinity on readily available soil water



- **What is the problem with water soil salinity?**
- **The main effect of soil salinity on plants is the increase in osmotic pressure of the soil water that makes it more difficult for the plants to extract water from the soil. The gravitational potential, the chemical potential and the matric potential are additive. The higher (=the more negative) the osmotic potential the lower the water availability.**
- **Saline irrigation water reduces root growth and may cause a reduced root system.**
- **Some specific ions have toxic effect: Sodium and Boron are the most common examples.**

- **Most bananas are produced in wet lowland area. Is banana production facing, in reality, salinity problems?**

- **Surprisingly, in reality, bananas do face quit frequently salinity problems on variable environments. Examples of photos are given from all over the world, where salinity problems were evident.**

- **How do plants respond to salinity?**
- **Some plants can tolerate salty soils by special physiological tools; like the secretion of excess of salts through special glands in the leaves; some others may isolate salts by isolating them in specific cellular compartments, like vacuoles; some may use selective membranes to avoid uptake and spread of certain elements, etc.**

- **The banana, that was originated and domesticated in the wet tropics, does not have specific adaptations to help the plant to face salinity problems (but see later more about the banana response to specific toxic ions).**

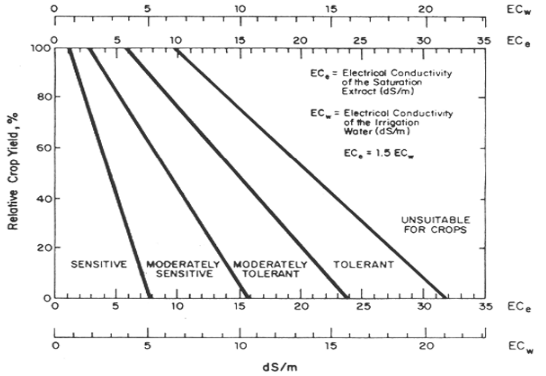
The Mass & Hoffman model

The following equation (Maas and Hoffman 1977) expresses the straight line salinity effect on yield

$$Y = 100 - b\,(EC_e - a) \qquad (10)$$

where:	**Y**	**=**	**relative crop yield (percent)**
	EC_e	**=**	**salinity of the soil saturation extract in dS/m**
	a	**=**	**salinity threshold value (EC, crop specific))**
	b	**=**	**yield loss (in %, crop specific) per unit increase in salinity**

Fig. 10 Divisions for relative salt tolerance ratings of agricultural crops (Maas 1984)



http://www.fao.org/docrep/003/t0234e/t0234e03.htm

i. **The leaching requirement**[1]

The necessary leaching requirement (LR) can be estimated from Figure 7 for general crop rotations. For more exact estimates for a particular crop, the leaching requirement equation (9) (Rhoades 1974; and Rhoades and Merrill 1976) should be used:

$$LR = \frac{EC_w}{5\,(EC_e) - EC_w} \qquad (9)$$

For JVBES: 5*1.0-1.4=3.6;
LR=1.4/3.6=0.39

where:	LR	=	**the minimum leaching requirement needed to control salts within the tolerance (ECe) of the crop with ordinary surface methods of irrigation**
	EC_w	=	salinity of the applied irrigation water in dS/m
	EC_e	=	average soil salinity tolerated by the crop as measured on a soil saturation extract. Obtain the ECe value for the given crop and the appropriate acceptable yield from Table 4. It is recommended that the ECe value that can be expected to result in at least a 90 percent or greater yield be used in the calculation. (Figure 7 was developed using ECe values for the 100 percent yield potential.) For water in the moderate to high salinity range (>1.5 dS/m), it might be better to use the ECe value for maximum yield potential (100 percent) since salinity control is critical to obtaining good yields.

The total annual depth of water that needs to be applied to meet both the crop demand and leaching requirement can be estimated from equation (7).

$$AW = \frac{ET}{1 - LR} \qquad (7)$$

For JVBES: AW=1000/(1-0.39)=1640mm

where:	AW	=	**depth of applied water (mm/year)**
	ET	=	total annual crop water demand (mm/year)
	LR	=	leaching requirement expressed as a fraction
			(leaching fraction)

How can we minimize the damage of soil salinity?

Since irrigation water is the most common source of salinity, we may improve the quality of the water we use (which is not very easy),

Or: we may add additional amount of water in order to leach the accumulating salts.
How much to add?

Relative crop salinity tolerance rating	Soil salinity (ECe) at which yield loss begins
Sensitive	< 1.3 ds/m
Moderately sensitive	1.3 – 3.0 ds/m
Moderately tolerant	3.0 – 6.0 ds/m
Tolerant	6.0 – 10.0 ds/m
Unsuitable for most crops (unless reduced yield is acceptable)	> 10.0 ds/m

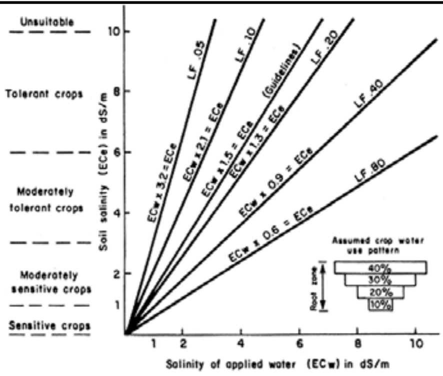


Fig. 7 Effect of applied water salinity (EC_w) upon root zone soil salinity (EC_e) at various leaching fractions (LF)
http://www.fao.org/docrep/003/t0234e/t0234e03.htm

Desert saline soil, near the Dead Sea (Jericho)

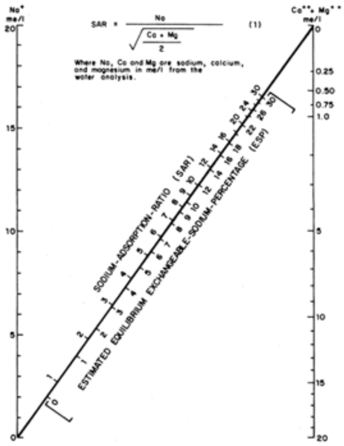


Fig. 1 Nomogram for determining the SAR value of irrigation water and for estimating the corresponding ESP value of a soil that is at equilibrium with the water (Richards 1954)

The plantation planted on that area (after leaching with plenty of fresh water), first cycle

Desert soil salinity in Senegal

Individual plant, suffering strong Sodium toxicity

Salinity of irrigation water (Ceara, Brazil)

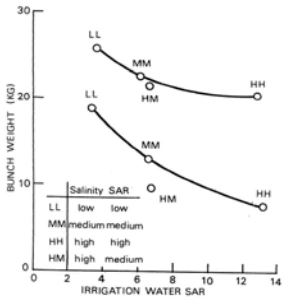
Underground water salinity (Guangzohu, China)

Marginal scorch caused by high Boron in the irrigation water, Western Galilee, Israel
(Field study, Lahav et al. in press)

Early study of the banana response to soil salinity conducted in the JVBES during the eighties (Israeli et al. 1986)

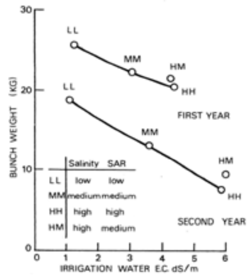
The experimental treatments were four combinations of irrigation water salinity and levels of SAR, achieved by the addition of NaCl, KCl and $CaCl_2$ in different proportions to the fresh Lake of Galilee water, and arranged in a partial factorial design, four treatments in four replications.
We used specific experimental method ("micro plots") that allowed us to separate the root system of neighbor banana mat (Dwarf Cavendish, two plants per mat) so that every mat could serve as an experimental replication.

The relationship between bunch weight and sodium adsorption ratio in the irrigation water. (Israeli et al., 1986)



Further increase in SAR from 6.6 to 13.2 also affected growth and production parameters (Data for the 2nd year are given): shooting date was delayed from 4/9 to 26/9, follower height reduced from 73cm to 67cm but Fingers/bunch number was not changed but relative mean finger weight was reduced from71% of the control (on SAR=6.6) into only 56% of the control (on SAR=13.2; control SAR was 3.7).

The relationship between bunch weight and electrical conductivity of the irrigation water during two growing seasons. (Israeli et al., 1986)



Pronounced effect of the water salinity was also recorded on other growth and production parameters (Data for the 2nd year are given): shooting date was delayed from 30/7 (Low Sal.) to 4/9 (High Sal.), follower height reduced from 135cm to 73cm and fingers/bunch number was reduced from 202 to 144(!).

The conclusion from our 1st salinity response study were as follows:

1. The banana may suffer a decrease of more than 50% in production before any external symptoms are evident!

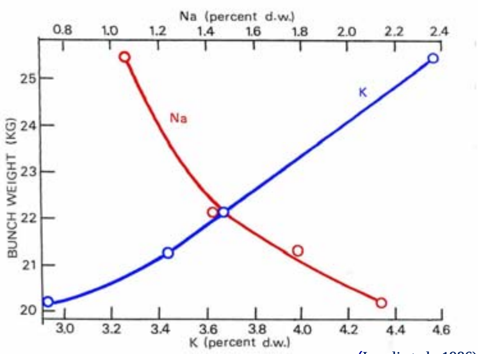
2. The effect on rate of growth (mother plants and suckers) is as pronounced as the effect on the fruit.

3. In addition to general salinity, the Sodium has a specific negative effect on banana.

Indirect conclusions are as follows:
-Since the salinity effect is firstly the osmotic effect, the damage to the plant is aggravated under higher environmental stress (higher temperature, higher VPD, stronger wind, stronger evaporative demand). Both water stress and salinity stress effect may have different magnitude under different climatological conditions.

-Soil type may also have an effect on leaching or accumulation of salts in the roots zone, and on sodium damage (this aspect will be shortly discussed later).

The relationship between root Sodium and Potassium concentrations (% dry weight) and bunch weight in bananas that were irrigated with saline water



(Israeli et al., 1986)

Desalination apparatus

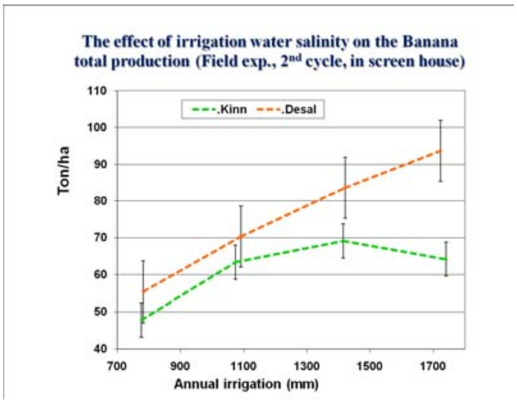
Recent study of salinity effect was planted in JVBES on spring 2010 and managed by A. Silber.

This time the effect of water with salinity lower than the Lake of Galilee (=Kinneret) was tested. The higher quality water were produced by a compact desalination (reverse osmosis) apparatus.

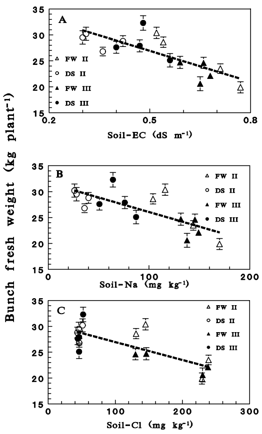
The two types of irrigation water quality, Fresh Water (FW) and Desalinated Water (DS), are compared in four rates of irrigation: 50%, 70%, 90% and 110% of the common rate in use (=100%, 1600-1700 mm/year). The EC of the FW is 1.4 dS/m and the DW 0.3 dS/m. The experiment is conducted in an open plantation and in screen house, but just the initial screen house results are presented here. Data are in preparation for press or already in press by A. Silber.

The FW/DW experiment just after planting

	Irrigation water content (including fertilizers)	
	FW	DS
EC (dS/m^{-1})	1.5	0.3
Na ($mg\ L^{-1}$)	140	15
Cl ($mg\ L^{-1}$)	300	30
Ca ($mg\ L^{-1}$)	60	10
Mg ($mg\ L^{-1}$)	30	4



The FW/DW experiment on 2nd cycle

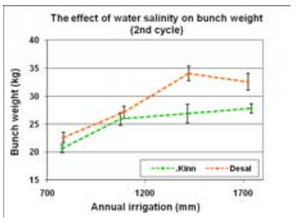


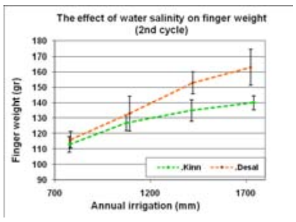
The relationship between bunch fresh weight and: soil-EC (A), -Na (B) and –Cl (C) during yield cycles II and III.

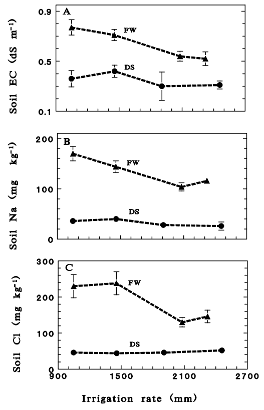
Symbols represent experimental data± SE (not shown when smaller than the symbol).

Silber et al. 2013 in press

The effect of water salinity on banana bunch weight and finger weight (Field exp., 2nd cycle, in screen house)



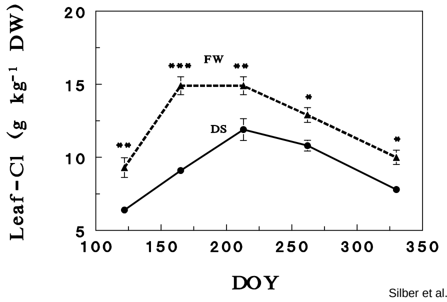




Effects of irrigation rate and water salinity on: (A) EC; (B) Na; and (C) Cl concentrations in soil samples (soil:water 1:2 extracts, 24 h) obtained on 4 October 2011. Symbols represent experimental data± SE (not shown when smaller than the symbol).

Silber et al. 2013 in press

The effect of water salinity on leaf-Cl concentration during 2011. DOY is the day of the year. Symbols represent experimental data± SE (not shown when smaller than the symbol). *, ** and * above each symbol denote the significance (for water quality) at $P \leq 0.05$, 0.001, and 0.0001, respectively.**



Silber et al. 2013 in press

How much water do we use in the J.V. for salts leaching ?

	Open area	Screen house
a. Irrigation, mm/y	2200-2300	1500-1600
b. Evapotranspiration (mm/y)	1200-1400	900-1000
c. Leaching factor ($^a/_b$)	2200/1200=1.83	1500/900= 1.67
d. Leaching requirement	45%	40%

Silber et al. 2013 in press

Leaching requirements for the Kinneret water

Water composition (mg/l)

	EC, dS/m	Na^+	Cl^-	Ca^{++}	Mg^{++}
Fresh (Kinneret) water	1.5	140	300	60	30
Desalinated water	0.3	20	50	10	4

Silber et al. 2013 in press

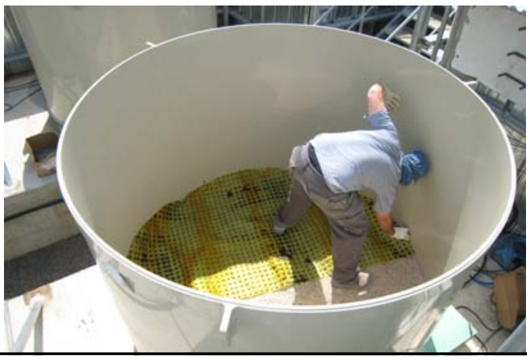
Study of the effect of FW and DW using weighing lysimeters. The container is placed on electronic scale and is freely drained into a collector equipped with a pressure sensor. change in weight are continuously Irrigation, drainage and collected. The volume is 4.5 m^3

Who is the “bad guy”?

- The concentrations of Na^+ and Cl^- are much above the plants needs.
- The concentration of Ca and Mg are within the range of the plants needs.
- Both Cl^- and Na are “bad”, but Na^+ is more above the plants needs,

  and in addition is also toxic, and has a very negative effect on the soil itself.

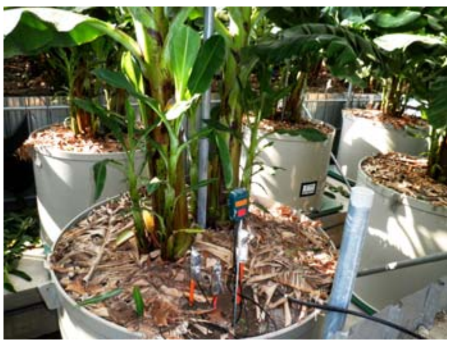
CONCLUSIONS: the option of using desalination in order to eliminate the salts before reaching the field is highly recommended!



The lysimeters two weeks after planting

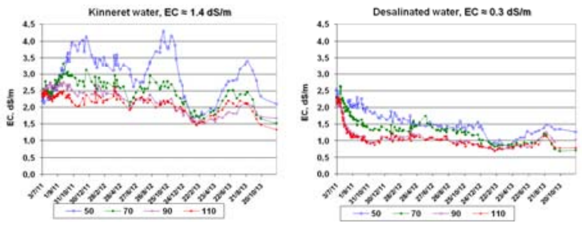
A steel floor is installed to facilitate horticultural work.
It is not touching the lysimeters themselves.

Ready to shoot for plant crop

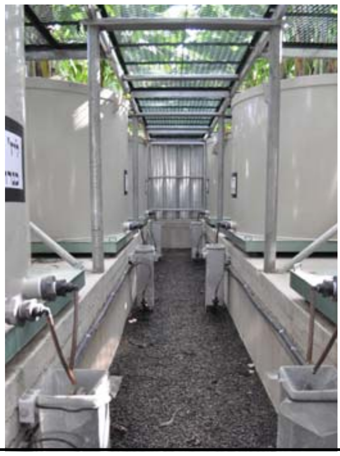


The effect of irrigation water salinity and quantity on the leachate salinity

The course of change in the EC of the lysimeters drainage water when irrigated with Kinneret lake water (EC ≈ 1.4 ds/m) or desalinated water (EC ≈ 0.3 dS/m; including fertilizers) during 3 irrigation seasons. The lysimeters received different rate of irrigation water: 50, 70, 90 or 110 percent of the commercial recommended quantity.



Silber, in press



2nd cycle DW, 110%, 52kg

Second cycle bunches

On the left: DW, 70% On the right: FW, 70%

Hoffman, G.J., Shanon, M.C. Salinity. 2001. In: Micro irrigation for Crop Production: Design, Operation and Management, Eds: Lamm, F.R., Ayars, J.E., Nakayama, F.S. Developments in Agricultural Engineering 13, Elsevier, Amsterdam

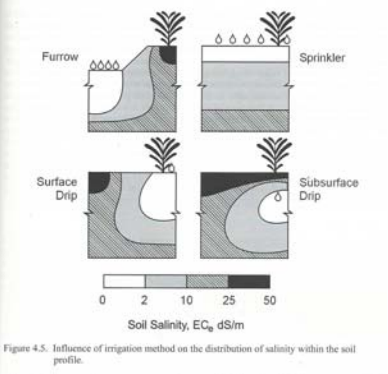


Figure 4.5. Influence of irrigation method on the distribution of salinity within the soil profile.

What is the effect of different irrigation systems on soil salinity?

Irrigation with brackish water

- **Brackish water in the form of saline or treated effluent water could provide a substitute for fresh water for irrigation.**
- **The main concern for crop irrigation is mineral content, due to its osmotic and specific toxic effects.**
- **Extensive research has been carried out in the last decade on these topics.**

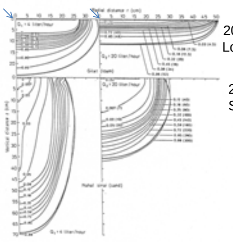


Fig. 2. Model computations (eq. [3]) of two-dimensional axisymetrical nonreactive salt concentration distribution during infiltration from a trickle source for two trickler discharges (Q1, Q2), and two soils. The cumulative infiltration = 12 liter. The numbers labeling each curve indicate relative concentration expressed as (C-Co)/Cn. The numbers in parentheses are salt concentrations (C) in soil solution (mmol(+)/liter); Co is the inlet salt concentration, and Cn is the initial C in the soil (mmol(+)/liter). Heavy lines represent the wetting fronts. Source: Bresler, 1977. Bresler, E. (1977). Trickle-drip irrigation: principles and application to soil-water management. Adv. Agron. 29,343-393.

Irrigation with brackish water

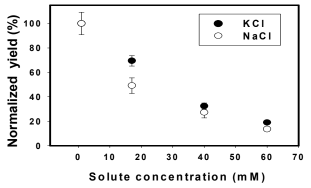
- Marginal chlorosis (A) followed by necrosis (B) was found with increasing sodium concentration.
- Plants treated with increasing KCl concentration showed no visible damage to the leaf.
- Chloride does not contribute to leaf scorch and thus its effect is mainly osmotic.

Shapira et al. 2010

Irrigation with brackish water

- The osmotic effect was studied under controlled conditions.
- Results confirmed that banana is sensitive to increased solute concentration.
- The differences in response to NaCl and KCl were analyzed and traced to the specific toxicity of sodium.

Shapira et al.

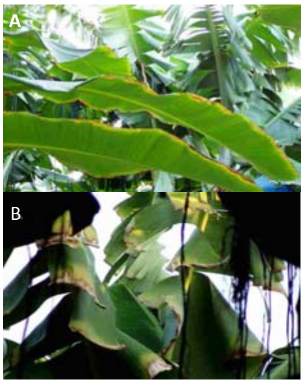


Irrigation with brackish water

- As was the case with sodium, leaf scorch appeared only at the leaf margins.
- Symptoms increased in severity along with increasing boron concentration: (A) 2 ppm boron; (B) 6 ppm boron.

Shapira et al.

Boron toxicity symptoms



Irrigation with brackish water

- Another notorious element found in brackish water is boron.
- A field study was set up to follow the long-term effect of irrigating bananas with effluent water of low salt content, containing increasing boron concentrations, up to 6 ppm.

Long-term effect of boron on banana production in the Western Galilee (Coastal Plain)

Boron (ppm)	Marketed yield (t ha^{-1})	Plant density (plant ha^{-1})	Plant height (cm)	Bunch weight (kg)
0.5	63.7	2010	317	35.5
1	64.0	1870	319	36.8
2	60/5	1850	312	34.4
6	60.7	1830	301	35.7

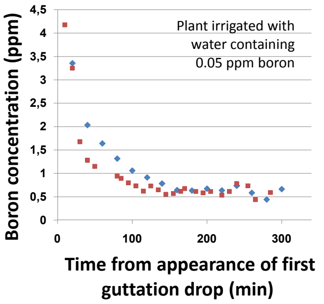
Shapira et al. Lahav et al. in press

Irrigation with brackish water

- In addition, a significant amount of boron is normally removed from the leaf by the process of guttation.
- Repeated guttation along with sequestration of boron in the leaf margins contribute to the banana's ability to produce commercial yields under high boron levels.

Shapira et al.

Removal of boron from the leaf in guttation fluid

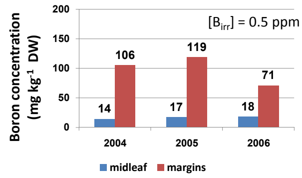


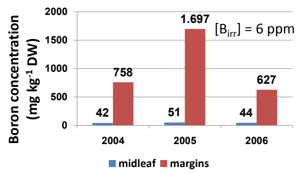
Irrigation with brackish water

- Mineral analysis revealed accumulation of boron in the marginal tissue of the leaf where leaf scorching appeared.
- We found that the anatomy and venation of the banana leaf "directs" toxic molecules to the leaf margins, protecting most of the photosynthetic tissue.

Shapira et al.

Boron concentrates at the leaf margins





Banana guttation

Banana guttation

-The high root pressure of the banana cause water movement from the roots to the leaves lamina even during the night. Water exude from the leaf through the marginal hydatodes in a process called guttation.

- The guttation is a mean to decrease damage of toxic elements, like Sodium, that is secluded close to the leaf margins and Boron that is released to the outside at the leaf margins.

-So, the banana do have some specific adaptations in the level of the leaf anatomy and function, and is able to protect itself from some toxic elements. But for the future, the developing of higher drought and salinity tolerant bananas by genetic improvement is of a high priority.

Thank you