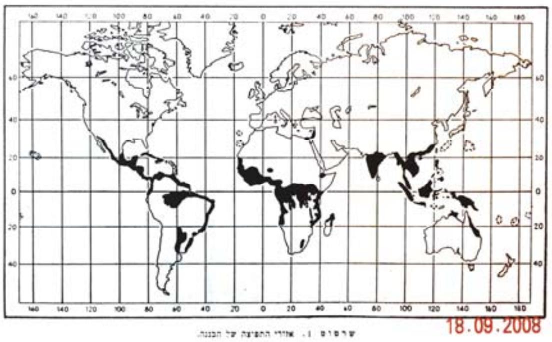

## World banana distribution

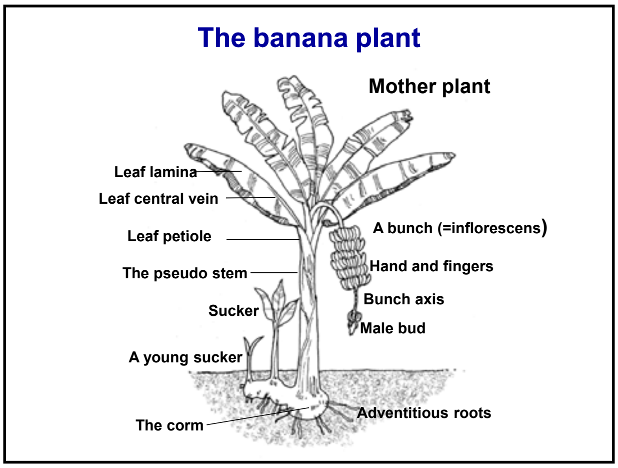



Philippines native banana: Cardaba (ABB); A typical backyard plantation.

A 1000ha export plantation (Cavendish, AAA, Philippines)


At shooting Stage


Typical high yielding banana plantation
(GN, AAA, Jordan Valley, Israel)


The banana plant
Mother plant
Leaf lamina
Leaf central vein
Leaf petiole
The pseudo stem
Sucker
A young sucker
The corm
A bunch (=inflorescens)
Hand and fingers
Bunch axis
Male bud
Adventitious roots


Banana diversity in India
Mysore, India

The banana root system of a GN mother plant and its suckers grown in perlite in 200 L container, sampled on Oct. 2012, 2nd cycle:
Total number of cord roots counted was 1202; Mother plant 244 roots, follower 176 roots, other rhizome parts (small suckers, old rhizome parts 682).
Total roots fresh weight: 14,850 kg,
Total roots length: 893 m
Percent roots dry matter: 6.2%

Banana roots mapping (10*10 grid, of 10*10cm squares)

## The banana response to plantation water stress

Banana branching cord root with lateral roots (primary, secondary, some tertiary. Hair roots are microscopic)

**Banana drought stress, Jordan Valley**


**Banana drought stress, Jordan Valley**


**Banana drought stress, Jordan Valley**


**Banana drought stress, Jordan Valley**

Water shortage effect, Philippines


Water shortage effect, Philippines

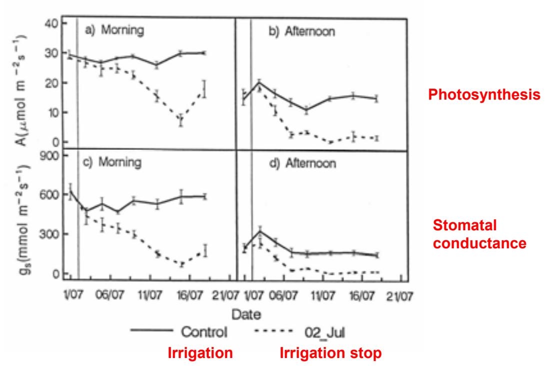
Water shortage effect, Philippines

Water shortage effect, Philippines

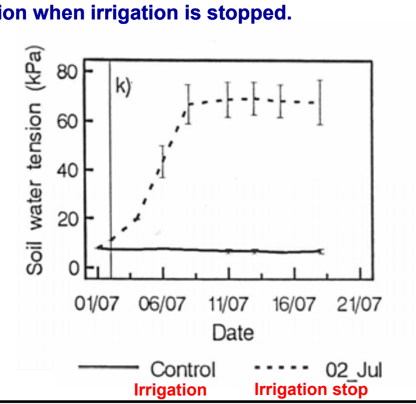
## The banana physiological response to water stress

**Banana behavior under high water availability: morning guttation**

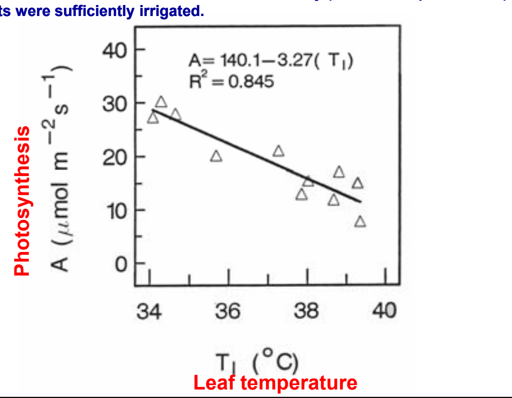
**The effect of withholding irrigation on rate of photosynthesis and stomatal conductance. The experiment was conducted on July 1993 (mid summer).**



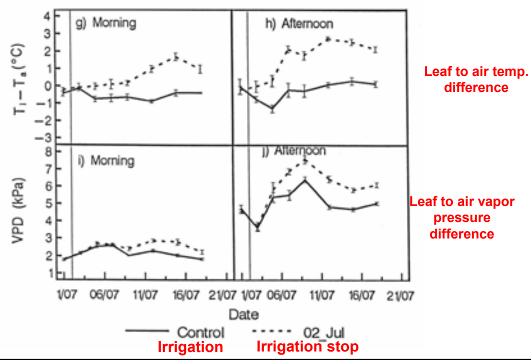

**The rate of change in soil moisture tension in a banana plantation when irrigation is stopped.**




**The relation between daily changes in leaf lamina temperature and rate of photosynthesis, on a hot summer day in the Jordan Valley, Israel. All measurements were taken at full Photon Flux Density (above 1300 μmol $m^{-2}$ $s^{-1}$). The plants were sufficiently irrigated.**




**The effect of withholding irrigation on the leaf energy balance (=the difference between air and leaf temperature) and on the leaf-to-air vapor pressure difference. The experiment was conducted on July 1993 (mid summer).**



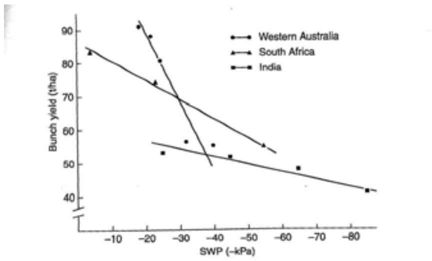
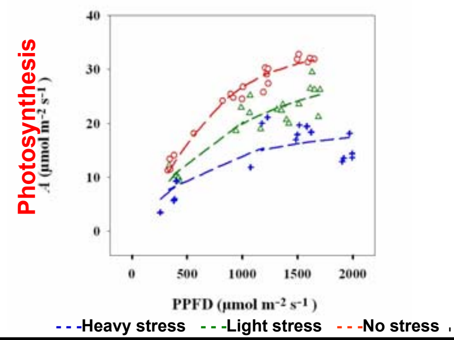



**Fig. 10.4.** Interaction between soil water potential (SWP), bunch yield (t/ha) and environment for AAA Cavendish subgroup bananas. Data from India are from a moist, tropical area in South India (Hegde, 1988), whereas data from Western Australia are from Carnarvon, a hot, dry area with no summer rain (Hill, 1990). Data from South Africa are from a cool, subtropical site with intermittent summer rain (Robinson and Alberts, 1986). Note that the yield response of banana to a reduced SWP is very severe in the hot, dry site, very mild in the moist, tropical site and intermediate in the cool, subtropical site.

Source: Robinson and Galan Sauco

**The effect of environmental stress conditions on banana carbon dioxide assimilation rate (A) under changing irradiance (Photosynthetic Photon Flux Density).**
**A was measured on leaves 3-4 from the top of plants at a late vegetative stage during the morning (0900-1100), in three consecutive days with much different environmental conditions: no-stress conditions: temp. 28.7º, RH 61%, VPD 1.44 kPa; moderate stress conditions: temp. 33.9º, RH 32%, VPD 3.27 kPa; and heavy stress conditions: temp. 38.1º, RH 25%, VPD 4.71 kPa. Different irradiance conditions were achieved by using shading screens.**




-The banana B genome that was originated in the more dry part of Asia, is relatively more tolerant to drought and to low temperature stress. This is, however, not relevant to the AAA Cavendish bananas that are in the center of our interest at this moment.

-The only anatomical tool (in addition to changes in stomatal conductance) that the banana can use to control leaf energy and water status balance is the function of the pulvinar bands that are situated along the junction of the two leaf lamina halves to the midrib.

-Specific cell layers that are part of these bands respond to a drop in the leaf cells turgor by shrinkage, which result in folding of the two lamina halves.

-The folded lamina receive less direct sunlight and may help to avoid lethal tissue temperature.

-A temporary leaf folding is common in banana plantations at noon time when transpiration may exceed the rate of water uptake, but its overall effect on the banana water status is limited.

## The banana morphological, anatomical and physiological characteristics that affect its response to limited water supply.

-The banana was originated in the wetland tropics of South East Asia, but secondary centers of origin took place in seasonal rainfall zones like India, Burma, etc.; and later in Africa and the Pacific islands.

-The banana is a giant herb: the high water content of the plant's tissue, the exceptionally large and thin leaves, with plenty of stomata on both leaf sides, cause a high rate of transpiration and consequently high water consumption.

-The high root pressure cause further 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 banana is highly sensitive to extreme climatic conditions. It is suffering at low temperatures but also at extremely high temperatures. It is very sensitive to wind stress due to its broad and easily shredded leaves. It is also very sensitive to drought stress.

-Being an isohydric plant, the banana close stomata under even slight water stress and keep them closed until soil moisture improves. This situation may impose problems with keeping the leaf energy balance, and consequently cause cease of growth and leaf scorch and desiccation, but the plant can survive a long drought. This characteristic is an important ecological adaptation, but would not help with regard to agronomy.

## Measurement of crop evapotranspiration

1) Crop evapotranspiration can be directly measured and calculated from soil water balance;

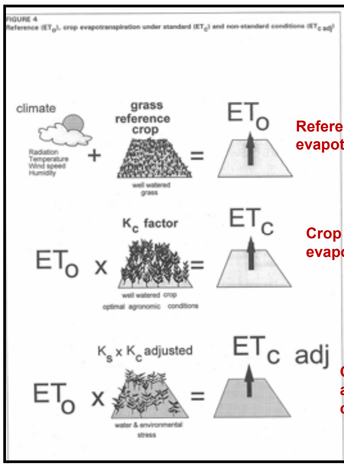
2) It can be directly measured using lysimeters;

3) It can be directly measured using mass transfer and energy balance (= Eddy covariance calculations);

4) Calculated indirectly by using crop data, meteorological data and the Penman- Montieth equation.
(FAO 56)

## Estimation of the banana water requirement

The basic formula used to calculate crop evapotranspiration
(FAO 56)




Reference evapotranspiration

Crop evapotranspiration

Crop evapotranspiration adjusted to stress conditions

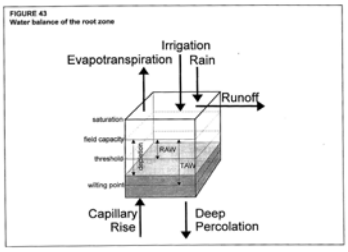
**Crop coefficient approach**

In the crop coefficient approach the crop evapotranspiration, $ET_c$, is calculated by multiplying the reference crop evapotranspiration, $ET_o$, by a crop coefficient, $K_c$:

$$ET_c = K_c ET_o \qquad (56)$$

where
$ET_c$ crop evapotranspiration [mm d$^{-1}$],
$K_c$ crop coefficient [dimensionless],
$ET_o$ reference crop evapotranspiration [mm d$^{-1}$].

(FAO 56)



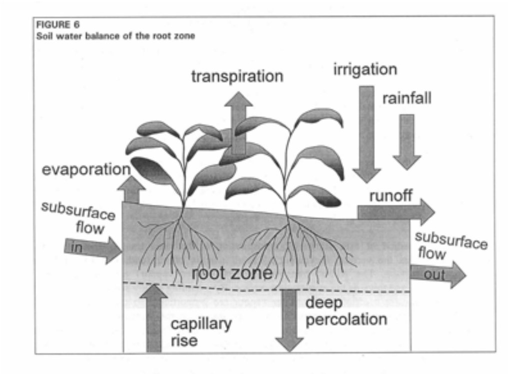

For $D_r$ > RAW, $K_s$ is given by:

$$K_s = \frac{TAW - D_r}{TAW - RAW} = \frac{TAW - D_r}{(1-p)\,TAW} \qquad (84)$$

where
$K_s$ is a dimensionless transpiration reduction factor dependent on available soil water [0 - 1],
$D_r$ root zone depletion [mm],
TAW total available soil water in the root zone [mm],
p fraction of TAW that a crop can extract from the root zone without suffering water stress [-].

After the computation of $K_s$, the adjusted evapotranspiration $ET_{c\ adj}$ is computed by means of Equation 80 or 81, depending on the coefficients used to describe crop evapotranspiration. When the root zone depletion is smaller than RAW, $K_s$ = 1.

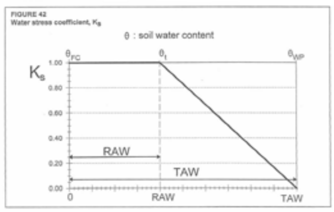
Source: FAO 56




(FAO 56)

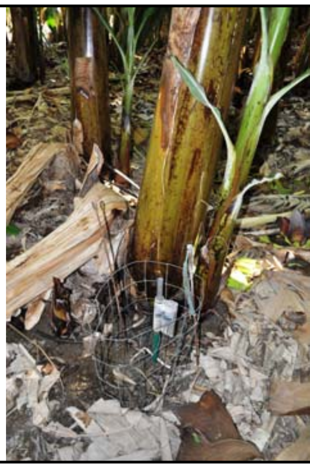
## The effect of soil water stress on the crop evapotranspiration (Etc)

**Etc adj = Ks Kc ETo**
**Where Ks is the water stress coefficient, that is changing from 1 (no stress) to 0 (maximum stress)**

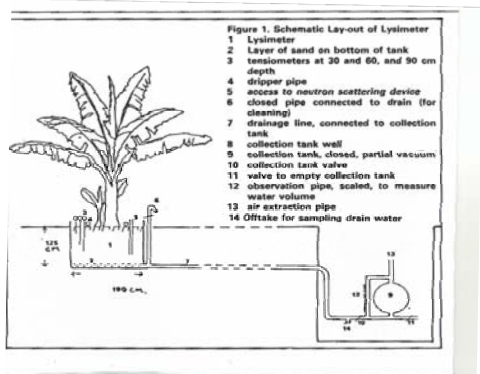



TAW (mm)- Total Available soil Water
RAW (mm)- Readily Available soil Water.
The fraction of TAW that may be depleted before moisture stress occurs.
TAW = 1000 ($\theta_{FC}$-$\theta_{WP}$) Zr
$\theta_{FC}$ = Water content at field capacity ($m^3\ m^{-3}$)
$\theta_{WP}$ = Water content at wilting point ($m^3\ m^{-3}$)
Zr = Rooting depth (m).

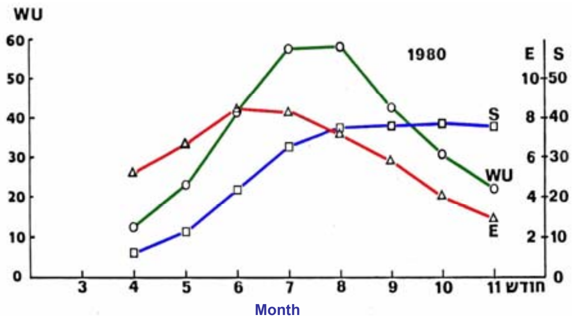
Source: FAO 56



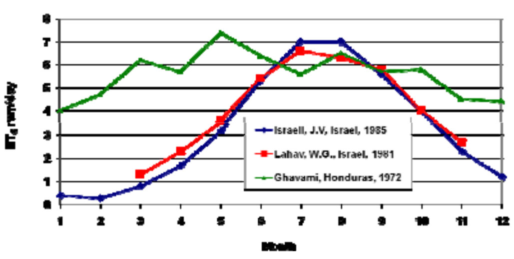
Schematic description of a drainage lysimeter equipped with a water suction system. The diameter of the round lysimeter was 190 cm and its height 125 cm, the volume was therefore 1.1 $m^3$. Two Williams plants were grown in each lysimeter.



**Seasonal variation in the banana leaf area (S, in m²/mat), in Pan A daily evaporation (E, in mm/day) and in the daily plants water use (WU, in Liter/day/mat). Two Williams mother plants (and two follower) were grown in each drainage lysimeter. Spacing was 3m*3m between mats; 1111 mats/ha and 2222 plants/ha. Data presented are for the 3rd cycle .**

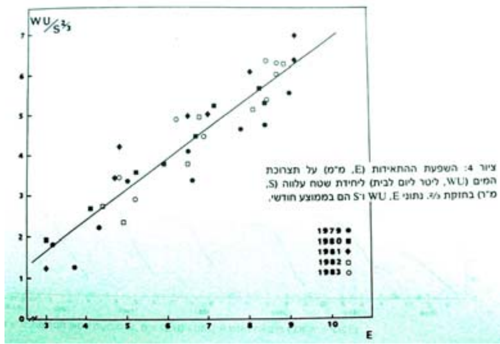



## Annual changes in daily banana evapotranspiration ($ET_C$) in the Jordan Valley and Western Galilee, Israel, and in Honduras




The effect of the Pan A daily evaporation (E, mm) on the daily banana lysimeter water use (WU, L/day)per unit of foliage area (S, m²) in 2/3 power.

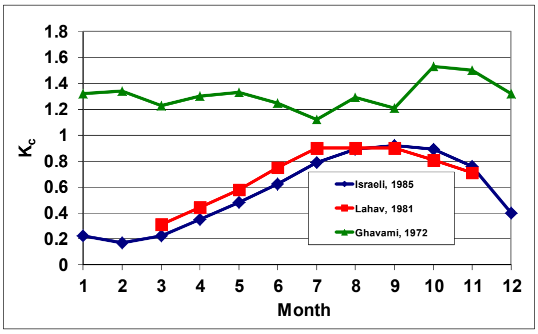
All data represent monthly averages of 5 years of observations with drainage lysimeters.



**Seasonal changes in the daily banana water evapotranspiration, $ET_c$ (mm) and the crop coefficient ($K_c$) when $ET_c=ET_o*K_c$ ($ET_o$= potential evapotranspiration measured with class A pan)**

| | Isr. (Jordan Valley) | | Isr. (Western Galilee) | | Honduras | |
|---|---|---|---|---|---|---|
| | Israeli, 1985, cycles 2-6 | | Lahav, 1981 | | Ghavami 1972 | |
| Month | $ET_C$ | $K_c$ | $ET_C$ | $K_c$ | $ET_C$ | $K_c$ |
| 1 | 0.4 | 0.22 | ---- | ---- | 4 | 1.32 |
| 2 | 0.3 | 0.17 | ---- | ---- | 4.7 | 1.34 |
| 3 | 0.8 | 0.22 | 1.3 | 0.31 | 6.2 | 1.23 |
| 4 | 1.7 | 0.35 | 2.3 | 0.44 | 5.7 | 1.3 |
| 5 | 3.2 | 0.48 | 3.6 | 0.58 | 7.4 | 1.33 |
| 6 | 5.3 | 0.62 | 5.4 | 0.75 | 6.4 | 1.25 |
| 7 | 7 | 0.79 | 6.6 | 0.9 | 5.6 | 1.12 |
| 8 | 7 | 0.89 | 6.3 | 0.9 | 6.5 | 1.29 |
| 9 | 5.6 | 0.92 | 5.8 | 0.9 | 5.7 | 1.21 |
| 10 | 4 | 0.89 | 4 | 0.81 | 5.8 | 1.53 |
| 11 | 2.3 | 0.76 | 2.7 | 0.71 | 4.5 | 1.5 |
| 12 | 1.2 | 0.4 | ---- | ---- | 4.4 | 1.32 |
| Sum | 1188 | | 1162 | | 2100 | |

**The seasonal changes in the banana crop coefficient ($K_c=ET_c$ / $ET_o$) under Tropical and Subtropical climate. The $ET_c$ (the banana daily evapotranspiration) was measured using drainage lysimeters and the $ET_o$ (the reference daily evapotranspiration) was measured with class A pan evaporation.**



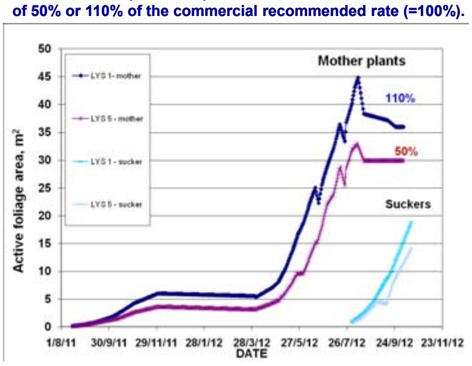

## Weighing Lysimeters, Jordan Valley, planted April 2011

**Seasonal changes in the banana daily water evapotranspiration, $ET_c$ (mm) and the crop coefficient ($K_c$) when $ET_c=ET_o*K_c$ ($ET_o$= potential evapotranspiration, measured with class A pan)**

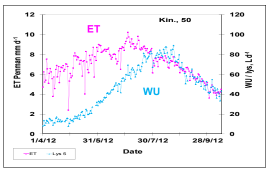
| | Isr. (Jordan Valley) | | | | Isr. (Carmel Chore) | | Isr. (Western Galilee) | | Lebanon | | India | | Honduras | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Israeli, 1985, cycles 2-6 | | Israeli, 1985, 1st cycle | | Peled | | Lahav, 1981 | | Saraf, 1973 | | Bhattacharyya, 1985 | | Ghavami 1972 | |
| Month | $ET_C$ | $K_c$ | $ET_C$ | $K_c$ | $ET_C$ | $K_c$ | $ET_C$ | $K_c$ | $ET_C$ | $K_c$ | $ET_C$ | $K_c$ | $ET_C$ | $K_c$ |
| 1 | 0.4 | 0.22 | ---- | ---- | ---- | ---- | ---- | ---- | 1.7 | 0.93 | 3.4 | 0.7 | 4 | 1.32 |
| 2 | 0.3 | 0.17 | ---- | ---- | ---- | ---- | ---- | ---- | 1.3 | 0.97 | 4.1 | 0.8 | 4.7 | 1.34 |
| 3 | 0.8 | 0.22 | ---- | ---- | ---- | ---- | 1.3 | 0.31 | 1.7 | 0.59 | 4.4 | 0.7 | 6.2 | 1.23 |
| 4 | 1.7 | 0.35 | ---- | ---- | 1.2 | 0.22 | 2.3 | 0.44 | 2.9 | 0.65 | 4.1 | 0.7 | 5.7 | 1.3 |
| 5 | 3.2 | 0.48 | 0.9 | 0.13 | 2.7 | 0.53 | 3.6 | 0.58 | 3.4 | 0.63 | 4.8 | 0.8 | 7.4 | 1.33 |
| 6 | 5.3 | 0.62 | 2.7 | 0.37 | 4.7 | 0.82 | 5.4 | 0.75 | 3.9 | 0.61 | 4.4 | 0.9 | 6.4 | 1.25 |
| 7 | 7 | 0.79 | 3.9 | 0.48 | 5.7 | 0.92 | 6.6 | 0.9 | 5.2 | 0.78 | 2.6 | 1.1 | 5.6 | 1.12 |
| 8 | 7 | 0.89 | 4 | 0.54 | 6 | 1.05 | 6.3 | 0.9 | 5.7 | 0.96 | 3.9 | 1.2 | 6.5 | 1.29 |
| 9 | 5.6 | 0.92 | 3.8 | 0.66 | 5.6 | 1.08 | 5.8 | 0.9 | 4.9 | 0.97 | 4.1 | 1 | 5.7 | 1.21 |
| 10 | 4 | 0.89 | 2.1 | 0.6 | 4.4 | 1.07 | 4 | 0.81 | 3.7 | 0.99 | 2.3 | 0.7 | 5.8 | 1.53 |
| 11 | 2.3 | 0.76 | 0.9 | 0.38 | ---- | ---- | 2.7 | 0.71 | 2.9 | 1.13 | 5.1 | 1.3 | 4.5 | 1.5 |
| 12 | 1.2 | 0.4 | ---- | ---- | ---- | ---- | ---- | ---- | 1.2 | 0.67 | 4 | 1 | 4.4 | 1.32 |
| Sum | 1188 | | 560 | | 928 | | 1162 | | 1178 | | 1441 | | 2100 | |

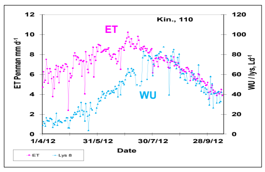
**Weighing lysimeters, Jordan Valley, 2011**

**Annual changes in leaf area per lysimeter with two plants during the 2nd cycle. Plants were planted on April 2011 (2 per lys.) and irrigated with Lake of Galilee (=Kinneret) water and desalinated water, at the rate of 50% or 110% of the commercial recommended rate (=100%).**



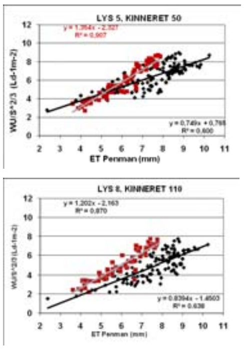

**Recording banana water use in the Jordan Valley using weighing lysimeters (2012). The annual course of change in the daily water-use (in liter per lysimeter per day; Blue line) and the concurrently measured reference evapotranspiration (Penman–Monteith equation; mm per day, Red lines). Second cycle, two plants per lysimeter, 1633 plants/ha.**



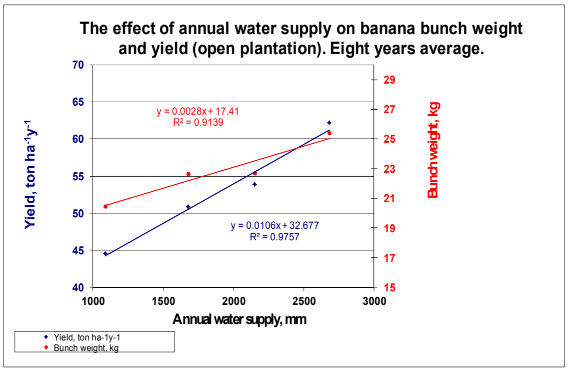
# Estimation of water requirement from results of field irrigation experiments

The relation between banana water use (calculated per unit of leaf area) and the reference evapotranspiration (calculated according to Penman–Monteith equation) during the 2nd year of the study (2012)

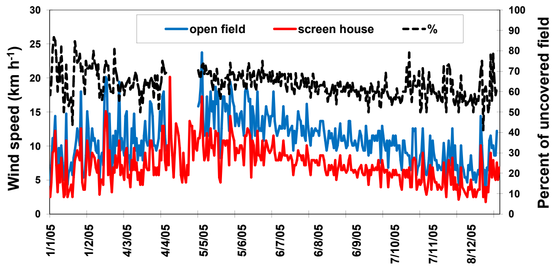



Class A evaporation pan installed at canopy level (about 4.5 m) in a screen house

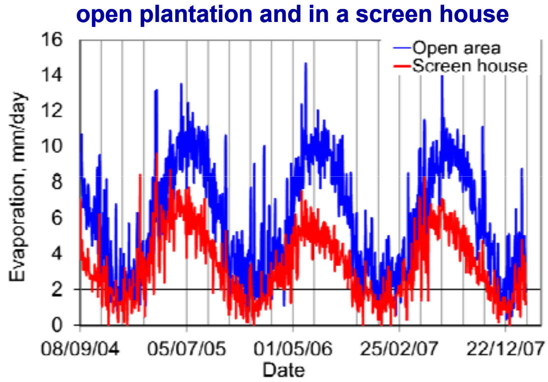
Initial research: The response of banana in the Jordan Valley to water quantity (open plantation; drip irrigation,1998).

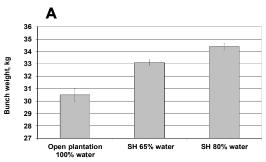


## Effect of screen cover on wind speed at canopy level




## Class A pan evaporation rate (Ea, mm/day) at an open plantation and in a screen house



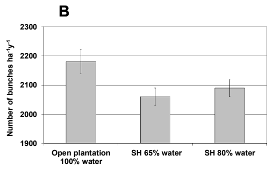

**The effect of reducing irrigation water application in screen houses (SH) into 80% or 65% of the control (open plantation, 100% irrigation ≈ 2100mm/year) on :**

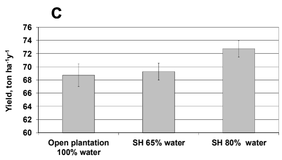
**A. Bunch weight, kg;**

**B. No. bunches harvested per ha per year;**

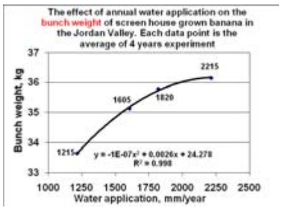
**C. Yield, ton/ha/year.**

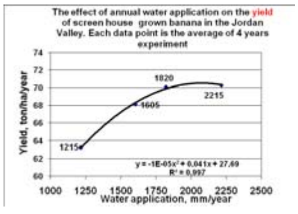
**Maagan study, Jordan Valley, four years averages.**




**The effect of water quantity applied to Screen House grown banana in the Jordan Valley on bunch weight (BW) and yield. Data presented is the average of four years (2005-2008) study. The quantities tested were 2215 mm/y (= 100%); 1820 mm/y (= 82%); 1605 mm/y (= 72%) and 1215 mm/y (55%).**

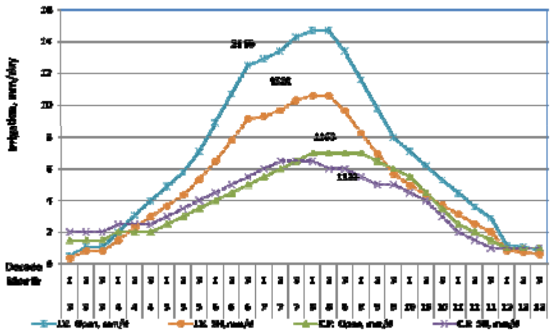


# Irrigation methods used in banana production:

- Surface (=flood) irrigation
- Over canopy (over head) "Cannon"
- Under-tree (under canopy) sprinklers
- Micro-sprinklers or micro-jets
- Drip Irrigation

**Banana commercial irrigation in the Jordan Valley and the Coastal Plain in open plantation and under screen house. The total annual water requirement (in mm) is indicated**



## The history: Banana flood irrigation

## Surface irrigation:

**The oldest method, that is still the most common in use for small banana holder.**

Advantages:
- Low cost of infrastructure and operation when utilizing local hand labor;
- Can use gravitation;
- save energy.

Disadvantages:
- High rate of water waste;
- uneven spread;
- quality depends on frequency only;
- impossible to combine fertilization;
- needs specific topography;
- enhance weeds.

## Under-tree (or: under canopy) sprinklers:

This is probably the most common irrigation method used to date in the banana export industry.

It started with sprinklers spaced at 17 x 17 m or so, but the distance between sprinklers was gradually reduced in order to improve distribution and reached spacing of 6 x 6 m in recently planted plantations; on the same time the sprinklers themselves changed for lower water discharge units and for lower water-emitting angle so that leaves and fruit are not wetted.

Irrigation efficiency was significantly improved.

## Over canopy 'cannons' (or big-size sprinklers):

The first high pressure irrigation systems that was in use in Central America during the 1st half of the 20th century. The system was composed of a 70 to 90m irrigation range overhead cannons connected to high volume high pressure water pumps.

Advantages:

- Simple technology;
- Each unit cover about 2ha or more;
- The units were portable;
- It is easy to supervise.

Disadvantages:

- High energy cost;
- Low efficiency (un even) irrigation coverage; surface runoff
- Strongly affected by wind;
- Reduces rate of vegetative growth;

All overhead irrigation systems for banana were stopped to be used when leaf and fruit diseases became a significant problem.

Advantages:

- Relatively simple to install, to operate and to maintain.
- Modern units are rigid, mechanically improved and gives (at low spacing) acceptably uniform coverage.
- Minimal leaves and fruit wetting.
- When coverage is good, may be used for fertigation.

Disadvantages:

- Wetting the top soil and the trash increases water direct evaporation losses. Irrigation of the drainage canals and roads adds to direct water losses.
- The evaporative cooling contribute to slower rate of vegetative growth and somewhat longer fruit hanging time.
- The high number of small sprinkler units make maintenance and supervision more difficult.
- The permanent wet soil surface enhance weeds growth and may contribute to phytosanitary problems.

Micro sprinklers irrigation in Brazil

## Micro-sprinklers or micro-jets:

**This irrigation method stands between the overall surface coverage of the under-tree sprinklers, and the localized irrigation with partial wetting of the drip system.**

**There is a great diversity in the type of units in use and in the spatial arrangement of the units in the field.**

Micro sprinklers irrigation in Brazil

## Drip Irrigation:

**This is the most technically and agronomically advanced irrigation method. It depends, however, on availability of relatively high level of technological capacity and on full cooperation of the plantation workers.**

**Advantages:**

- **The water coverage may be adapted to the local planting pattern, and water losses might be minimized.**
- **The system may be used for fertigation.**
- **When surface wetting is only partial, less weeds develop and water use efficiency may be maximized. This, however, depends on adequate irrigation application (both quantity and frequency).**

**Disadvantages:**

- **The maintenance of high number of emitters per unit of area is a challenge. There is a need for good water filtration and automatic irrigation control units.**
- **Losses from direct evaporation can not be avoided. The higher the frequency of irrigation, the higher the losses. Surface drainage may also contribute to losses.**
- **The evaporative cooling effect is close to the one mentioned with sprinklers (depending on the magnitude of surface soil wetting).**

Single drippers lateral per banana row (Ceara, Brazil)

**Advantages:**

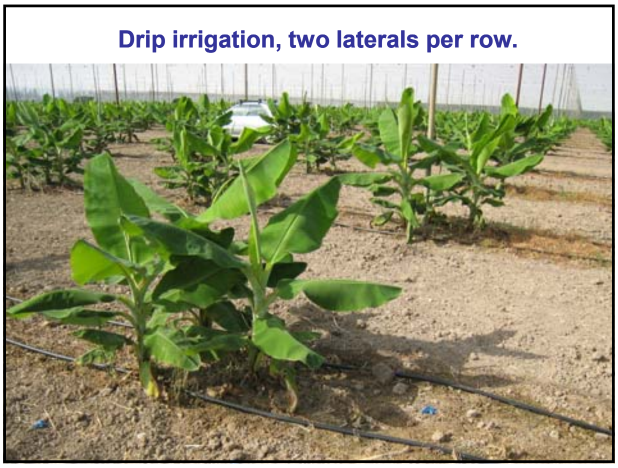
- **High water use efficiency. Maintaining high soil moisture in the root zone with minimal surface water evaporation and minimal other water losses.**
- **Drip irrigation is highly adequate for fertigation; may be operated in pulses; may operate at night hours (cheap energy); is not affected by winds; can be utilized in difficult topography; may be adapted to a variety of soil types (including sand).**
- **The water sources may be utilized in optimal way (≈20 hours a day); energy cost is minimal (high pressure is not necessary); the investment in water distribution installation is cheaper because of the low hourly discharge. It is specifically adequate for automatic operation.**
- **Drip irrigation can be used to irrigate with effluent water, and with partially saline water.**
- **Sub-surface drip irrigation may have specific advantage to tropical plantation.**

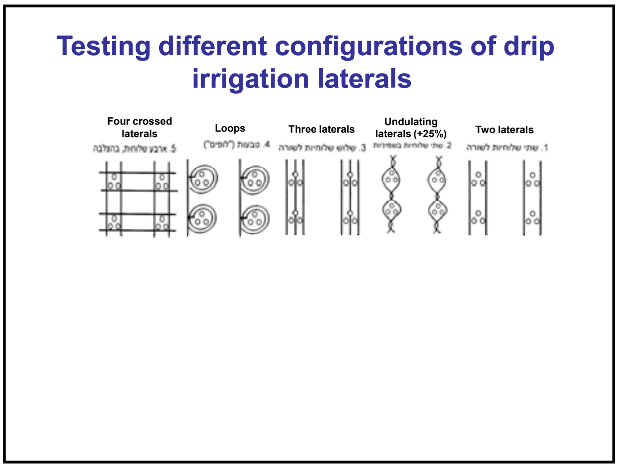
**Disadvantages (or limitations):**

- **The need for good technological level personnel and cooperating workers.**
- **The absolute need for adequate filtration systems and strict maintenance procedures (including chemical treatments) to avoid clogging.**
- **The drip laterals are highly prone to damage caused by workers using weeding or pruning sharp tools (Machete). Sub-surface systems may solve this problem.**
- **We are still studying the function of drip systems with regard to spatial arrangement and water discharge rate, in order to optimize its performance.**

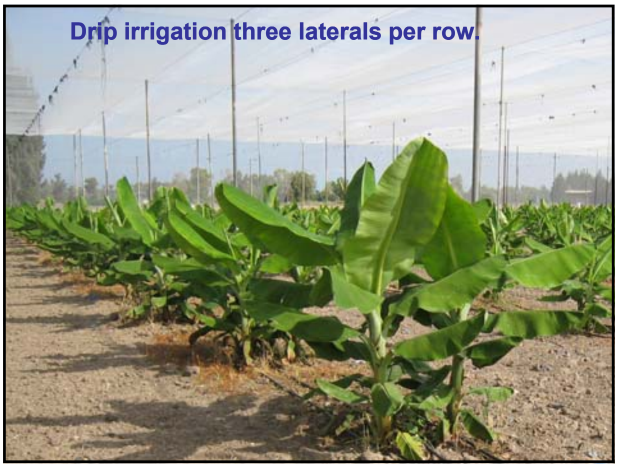
Single drippers lateral per banana row (Tanny, India)

**Studying the effect of the distance between the developing sucker and the drippers. In this case: 70cm distance.**


Drip irrigation, two laterals per row.


Testing different configurations of drip irrigation laterals
Four crossed laterals
5. ארבע שלוחות, בהצלבה
Loops
4. טבעות ("לופים")
Three laterals
3. שלוש שלוחיות לשורה
Undulating laterals (+25%)
2. שתי שלוחיות בשמיניות
Two laterals
1. שתי שלוחיות לשורה


rip irrigation, two undulating laterals, 25% extended le

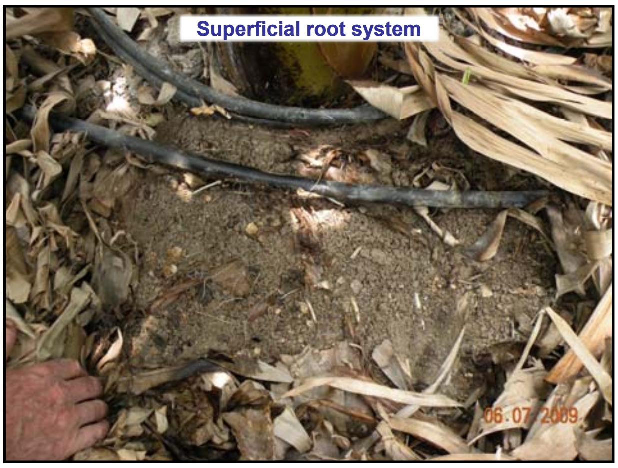

Drip irrigation three laterals per row.

Drip irrigation, two laterals at crossing directions per each mat.

Drip irrigation: one lateral but each mat is circled with a loop of dripper line.

'Per demand' Irrigation: the use of highly sensitive tensiometer to actively operate the irrigation system

'On demand' Irrigation: the use of highly sensitive tensiometer to actively operate the irrigation system in real time.


Superficial root system
06.07.2009


'Per demand' Irrigation: the use of highly sensitive tensiometer to actively operate the irrigation system


Superficial root proliferation under trash cover

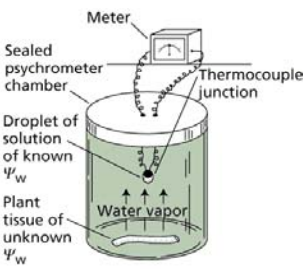
Banana corm on top of a subsurface15cm deep drippers lateral, exposed 5 years after planting. The bottom of the banana corm is just 10 cm deep, 5 cm above the lateral, and no limitations to irrigation functioning is observed. Advantages are the safety of the laterals and their optimal functioning. Disadvantage: the capillary upward water movement may cause topsoil salinity. Good for high rainfall / fresh water area.

A new concept being tested: ultra-low discharge (0.7 l/h) long duration of irrigation

**Psychrometer ($\Psi_w$ measurement)**

**Psychrometry** (the prefix "psychro-" comes from the Greek word *psychein*, "to cool") is based on the fact that the vapor pressure of water is lowered as its water potential is reduced. Psychrometers measure the water vapor pressure of a solution or plant sample, on the basis of the principle that evaporation of water from a surface cools the surface.

**Web Figure 3.6.A Diagram illustrating the use of isopiestic psychrometry to measure the water potential of a plant tissue. (Click image to enlarge.)**

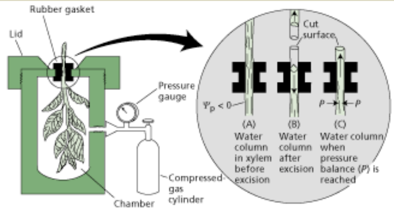



## Concluding remarks on banana irrigation:

1. Is it possible to grow banana without irrigation?
2. Are there any specific developmental stages or periods where water stress is specifically harmful?
3. How much water should be applied: to satisfy the plants demand? To leach excess salinity?
4. What are the common and what are the optimal irrigation systems?
5. Can the banana operate the irrigation by itself upon demand?

**Pressure chamber ($\Psi_w$ measurement)**

Web Figure 3.6.C The pressure chamber method for measuring plant water potential. The diagram at left shows a shoot sealed into a chamber, which may be pressurized with compressed gas. The diagrams at right show the state of the water columns within the xylem at three points in time: (A) The xylem is uncut and under a negative pressure, or tension. (B) The shoot is cut, causing the water to pull back into the tissue, away from the cut surface, in response to the tension in the xylem. (C) The chamber is pressurized, bringing the xylem sap back to the cut surface.




Interaction between irrigation and nutrition: acute potassium deficiency during bunch development