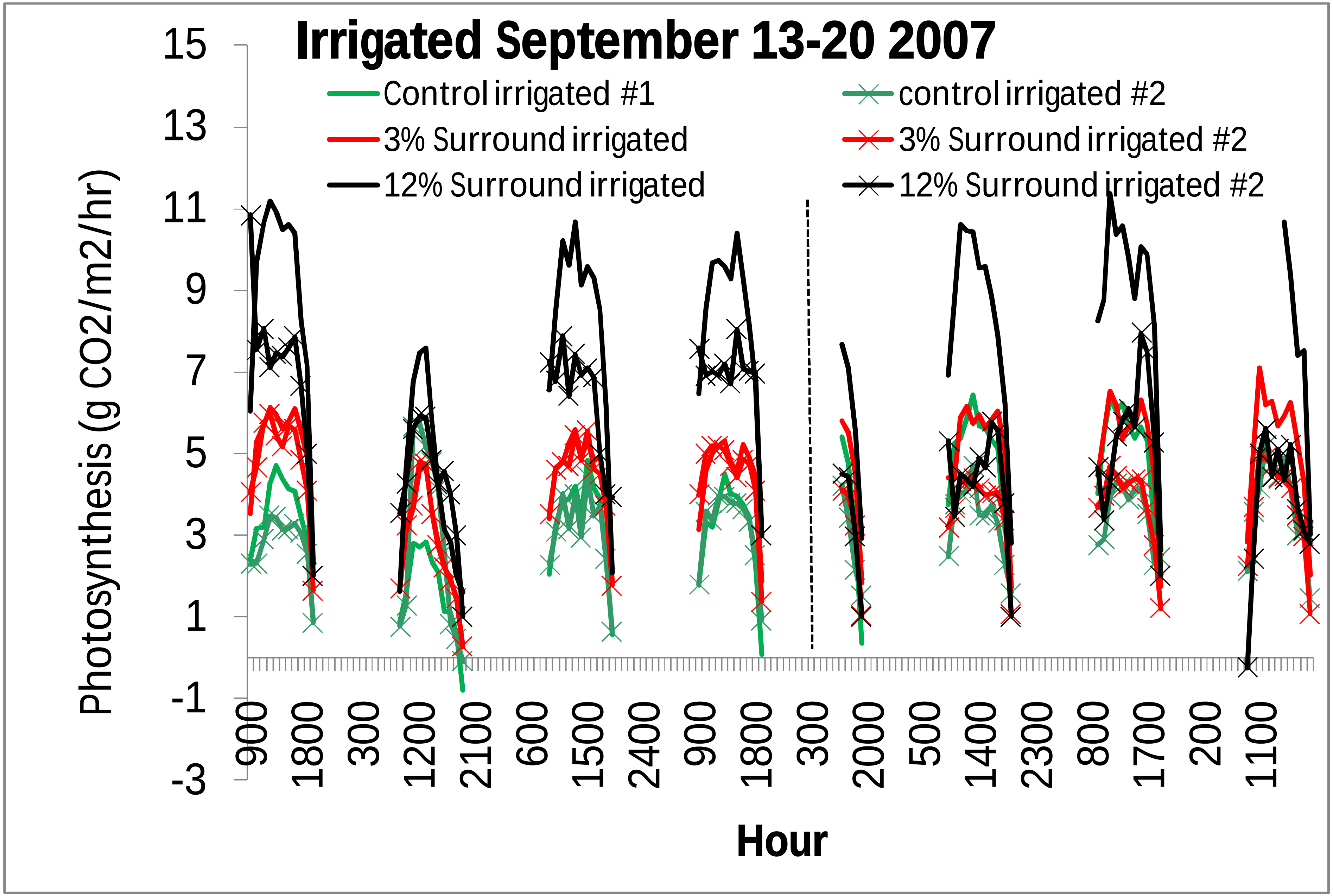

Source:
Dr. David Michael Glenn USDA, ARS, West Virginia, USA
12% Surround
Control
3% Surround

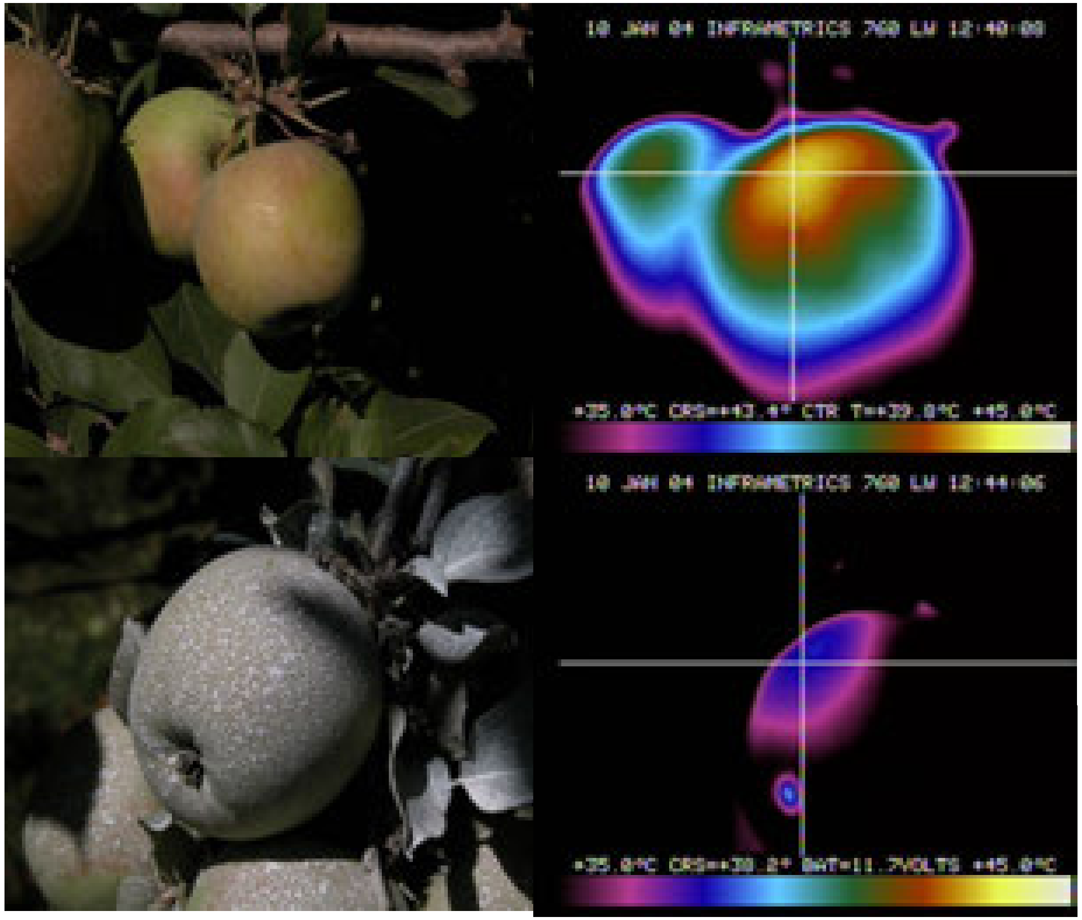
Source:
Dr. David Michael Glenn USDA, ARS, West Virginia, USA



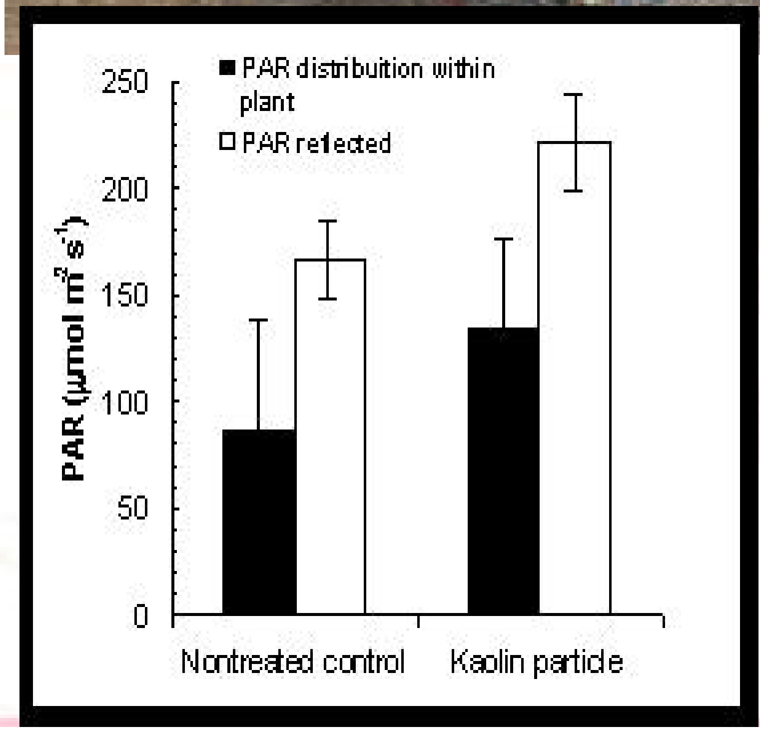
In summer the use particle film (kaolin particles) applied in high light condition (clear sky)

- **Increase reflection of UV and IR**
- **Reduce leaf temperature**
- **Increase stomatal conductance**
- **Increase whole-canopy photosynthesis and transpiration**

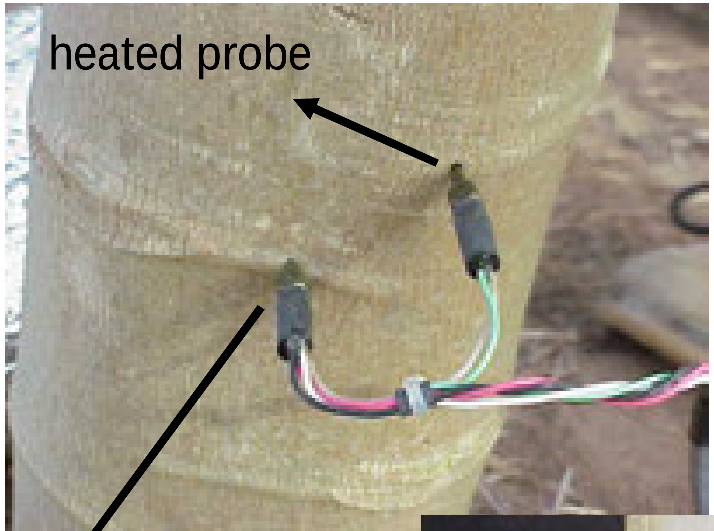
Concentration: 10%/12%



12kg = 38US$

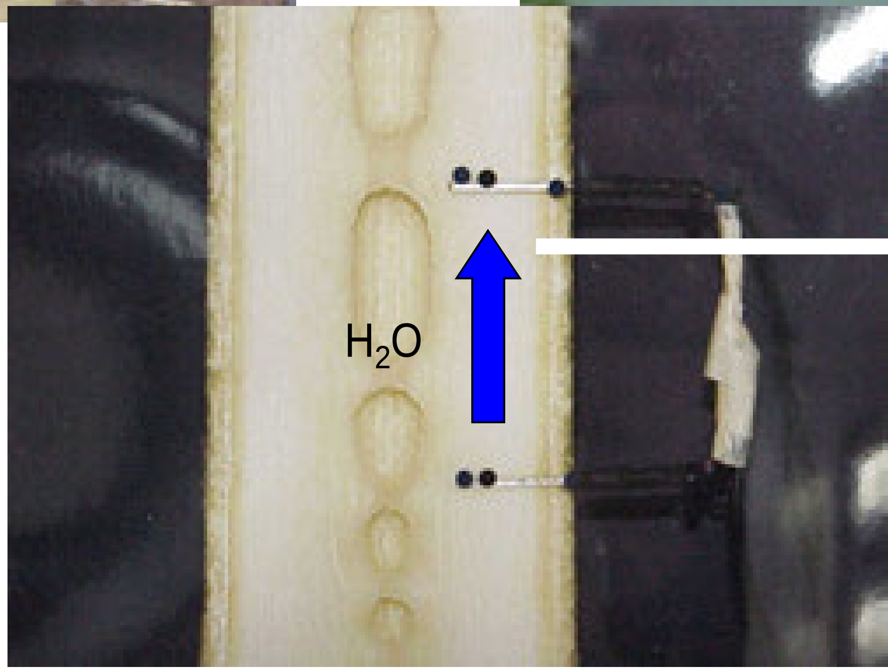

PAR distribution within plant
PAR reflected
PAR (µmol m-2 s-1)
0
50
100
150
200
250
Nontreated control
Kaolin particle

Effects on sap flow

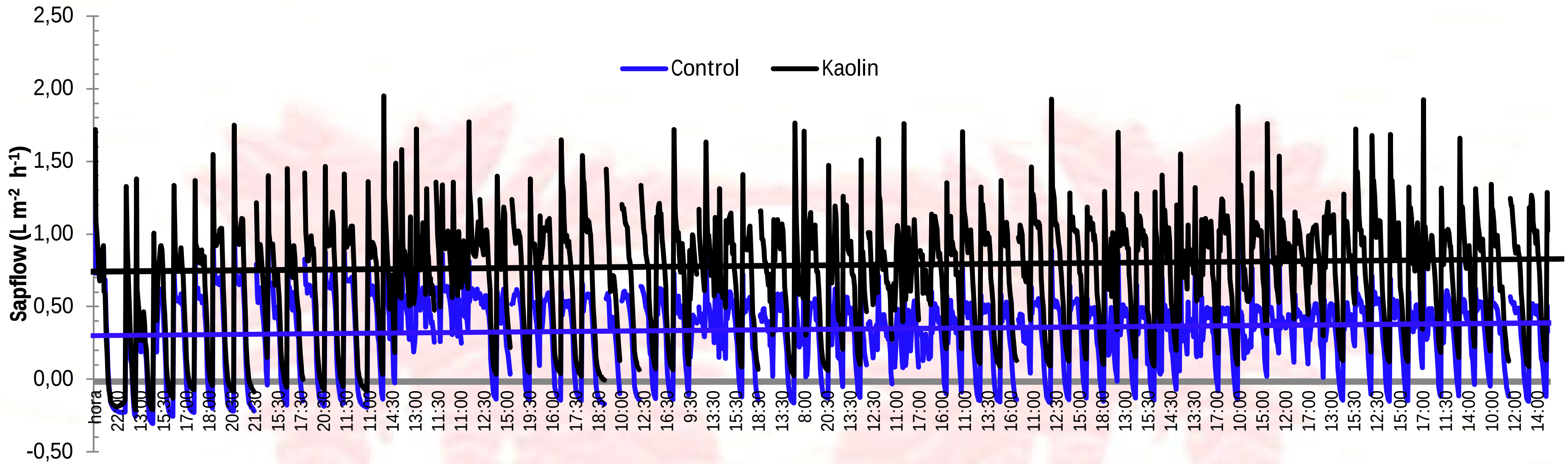


non-heated probe

Sap flow measure differences between heated and non-heated probe



Water reduce temperature



May to July (winter dry season)(104days)

Plant leaf area: **5m²**

Kaolin particles:
0.70 L h m^{-2} x $5m^2$ = 3.5 L h^{-1} $plant^{-1}$ x 8h = **28 L H_2O $plant^{-1}$ day^{-1}**

Control:
0.32 L h m^{-2} = 1.60 L h plant x 8h = **12.8 L H_2O $plant^{-1}$ day^{-1}**

Maximum light = 2300µmol m^{-2} s^{-1} = 1000 W m^{-2}

I think that Kaolin particles is important to papaya:

- Can reduce midday photosynthesis depression (stomatal effects is so important to increase yield in papaya). The photosynthetic capacity of a papaya genotype also influences papaya fruit quality (Salazar, 1978).

-Can control aphids (Aphids are the predominant means by which papaya ring spot virus (PRSV) is transmitted)

-Reduce canopy temperature (Prolonged droughts, associated with high temperatures, adversely affect fruit production because the condition induces abortion of floral and fruit structures, leading to sterile phases or fruiting skips along the stem)

-Increase scatter light inside the greenhouse

-Kaolin particles reduce dew formation on leaves

Salazar, R. 1978. Determination of photosynthesis in commercial varieties of papaw (*Carica papaya* L.) and its possible relationship with the production and quality of the fruits. Revista ICA. Bogota 13(2):291–295.

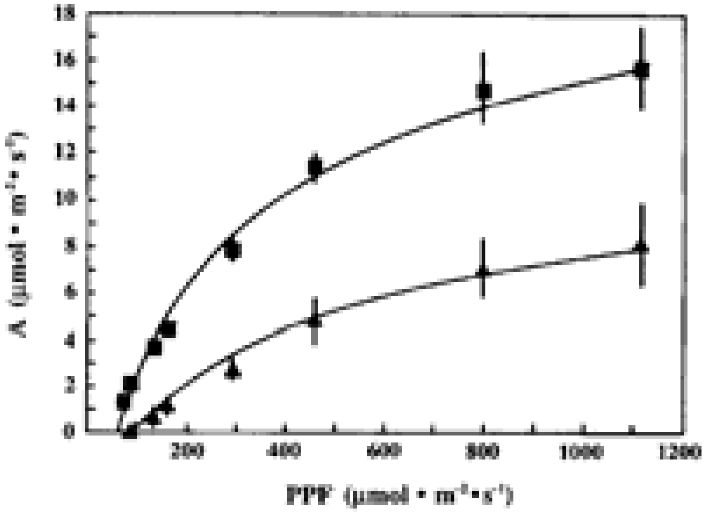


Fig. 1. Net CO_2 assimilation (A) of leaves from control (■) and papaya ringspot virus-infected (▲) *Carica papaya* plants as a function of incident photosynthetic photon flux (PPF). Each point represents the mean of six replications ±se determined on 5–6 Jan. 1992. Equations for the response curves are $A = (-21.67) + 5.32 \ln PPF$, $r^2 = 0.98$ (control); and $A = (-15.77) + 3.37 \ln PPF$, $r^2 = 0.98$ (diseased); se was smaller than symbols where no bars are visible.

Table 1. Influence of papaya ringspot virus on net CO_2 assimilation at saturating light and ambient CO_2 (A_{max}), internal CO_2 partial pressure at A_{max} (C_{im}), CO_2 use efficiency, apparent quantum yield (ø), the ratio of variable to maximal fluorescence (F_v/F_{max}), and dark respiration (R_d) of 'Kapoho' papaya plants. Measurements were made on systemically infected leaves, 7 to 8 weeks after inoculation (n = 7 for F_v and 6 for others).

Variable	Control	Diseased
A_{max} (μmol CO_2/ m^2 per sec)	15.7	8.9^{**}
C_{im} (μbar CO_2)	273	267^{NS}
CO_2 use efficiency (μmol CO_2/ μbar CO_2)	0.053	0.030^{***}
ø (μmol CO_2 / μmol photons)	0.039	0.016^{***}
F_v/F_{max}	0.80	0.76^{*}
R_d (μmol CO_2/ m^2 per sec)	1.79	2.94^{**}

^{NS,*,**,***}Nonsignificant or significant at $P = 0.05$, 0.01, or 0.001, respectively.

Symptoms of Papaya Ringspot Virus
(photo credit: John McHugh)

Action of Particle Films Against Insects and Mites

1. Repellent
2. Oviposition Deterrent
3. Feeding Inhibitor
4. Acute Mortality
5. Chronic Mortality
6. Impedes Grasping (Fall-Off)
7. Paralysis or Altered Behavior
8. Host Camouflaging
9. Restricts Movement or Infestation Process

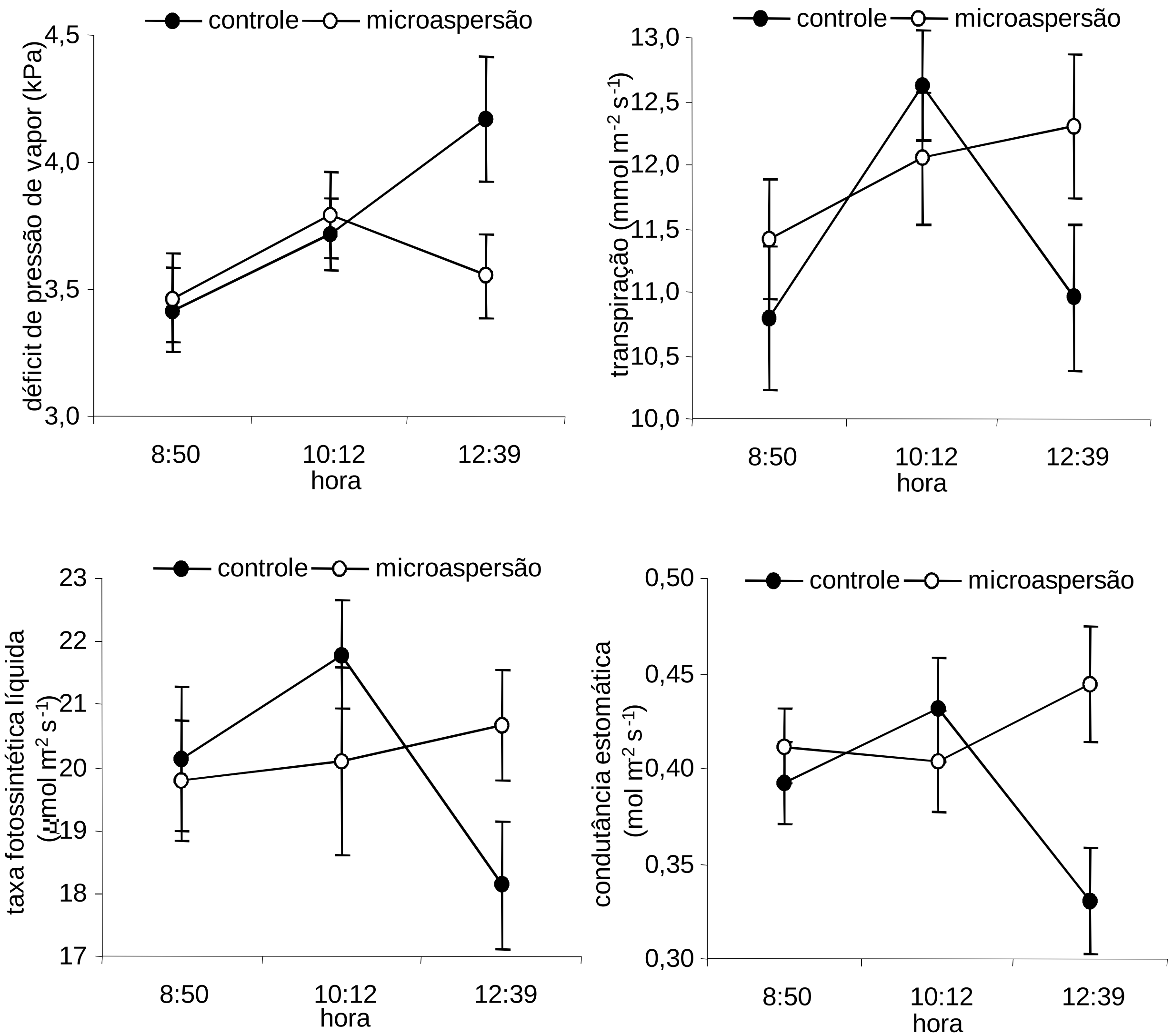

Inside the greenhouse light is very limitant


Kaolin particles reduce dew in papaya leaves

Can reduce disease!

Microspray irrigation applying above the canopy during summer (12h to 14h).
Evaporative cooling reduce $VPD_{leaf\text{-}air}$, increase stomatal conductance, increase transpiration and photosynthesis

When the air temperature inside the canopy reached 35ºC the microspray irrigation system was turned on

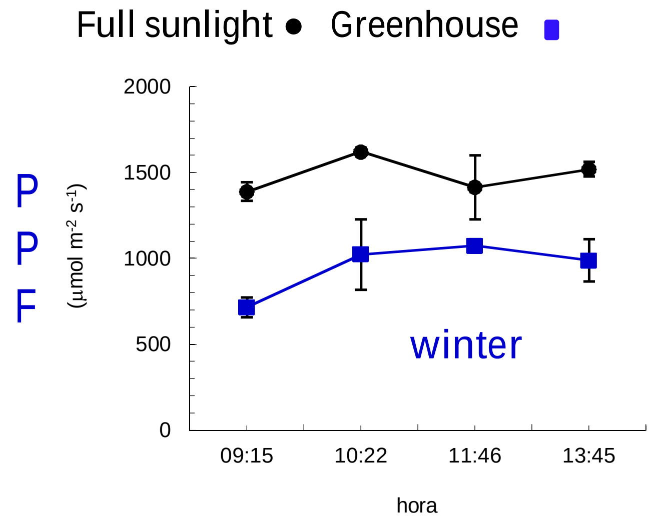


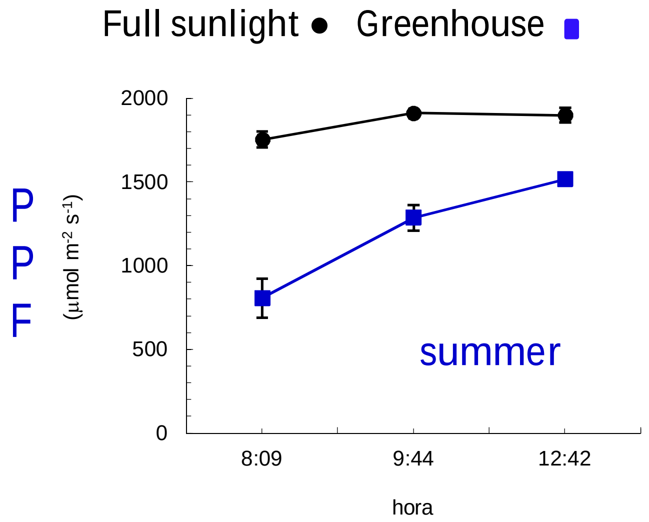
Microspray irrigation increased

5 fruits plant^{-1}

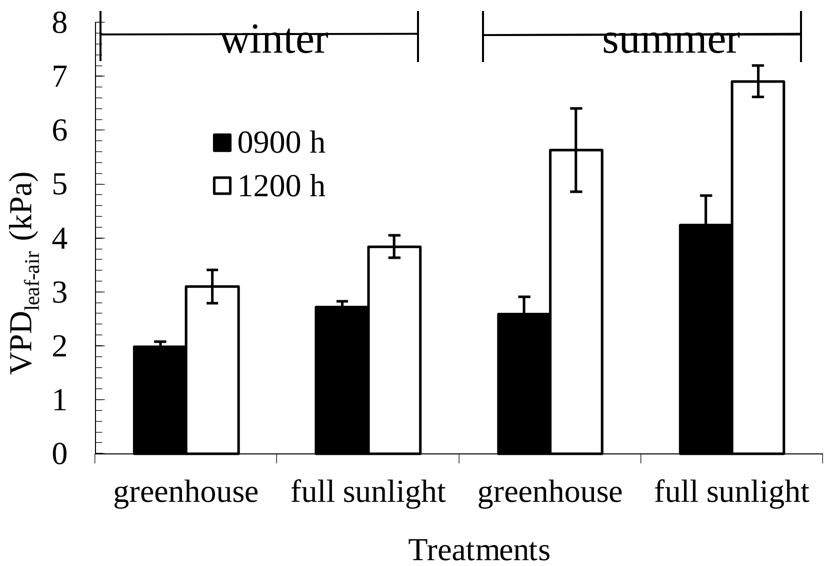
Greenhouse can provides adequate environmental conditions to cultivate papaya.
-protection against excessive light (sunburn, photoinhibition, high leaf temperature, high $VPD_{leaf\text{-}air}$)
-protection against wind and hail
- Exclusion of PRV vector

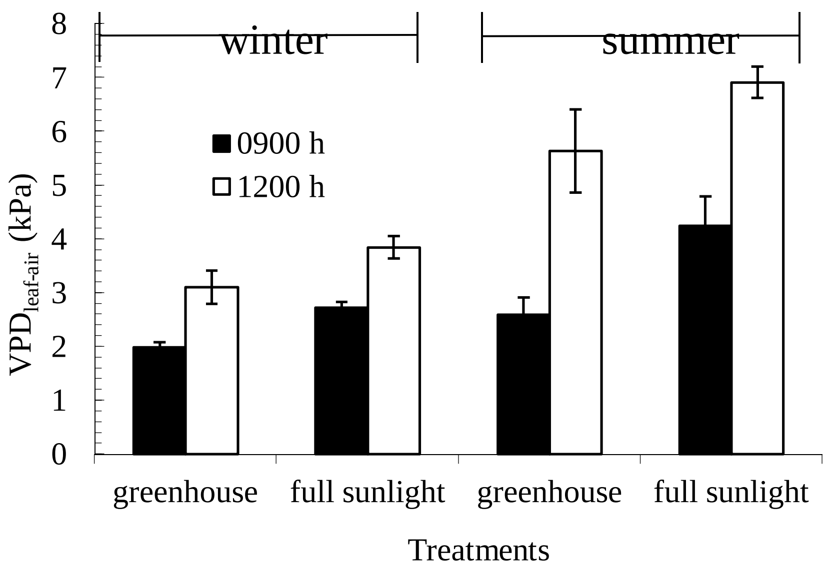
Baixinho de Santa Amália genotype



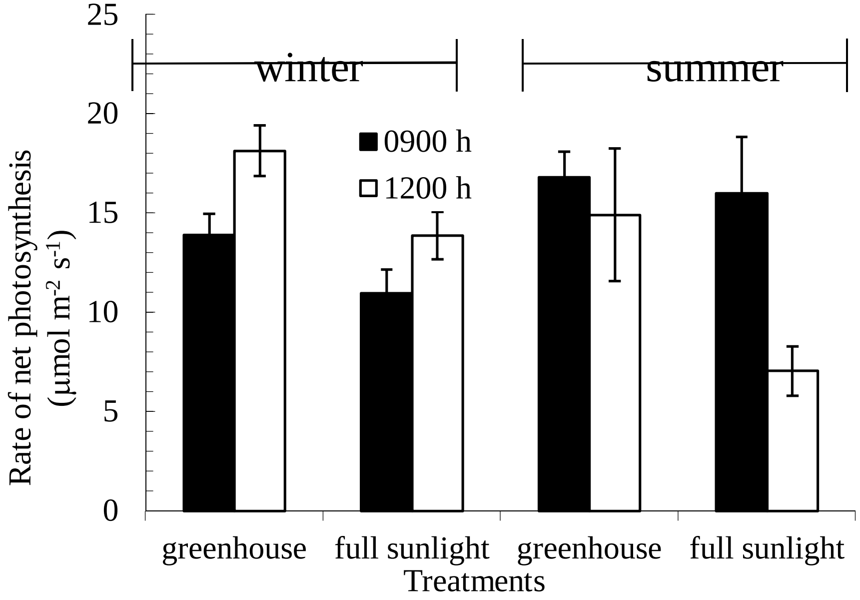


30% Light reduction

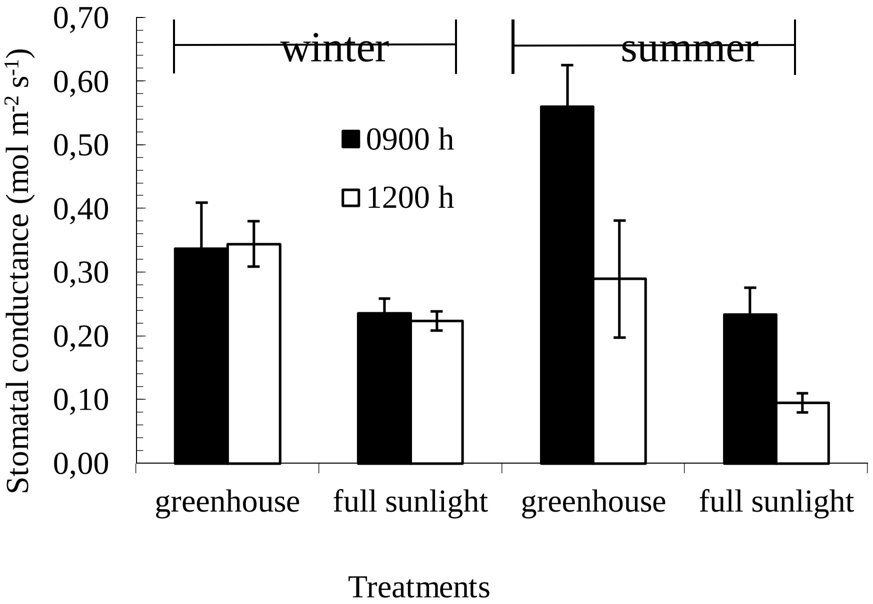




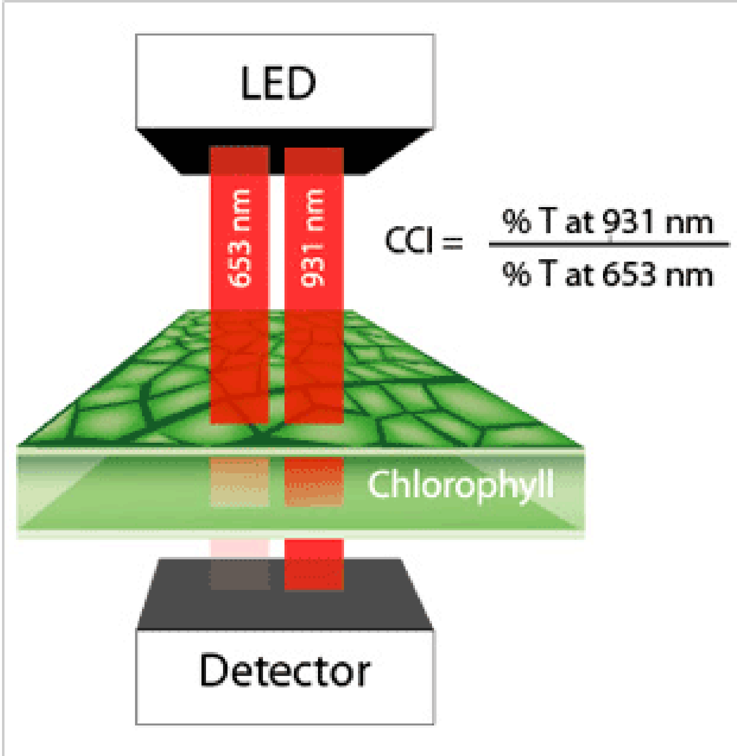
winter
summer
0900 h
1200 h
VPD$_{leaf-air}$ (kPa)
8
7
6
5
4
3
2
1
0
greenhouse
full sunlight
greenhouse
full sunlight
Treatments



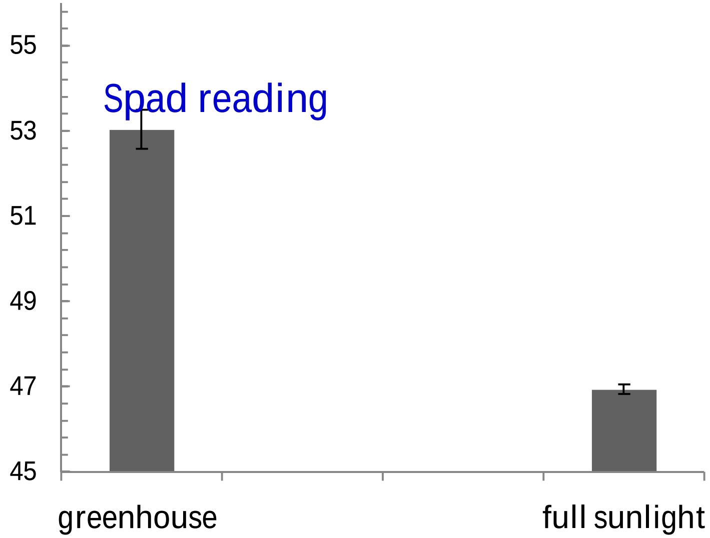
winter
summer
0900 h
1200 h
Rate of net photosynthesis
(µmol m^{-2} s^{-1})
25
20
15
10
5
0
greenhouse
full sunlight
greenhouse
full sunlight
Treatments



winter
summer
0900 h
1200 h
Stomatal conductance (mol m^{-2} s^{-1})
0,70
0,60
0,50
0,40
0,30
0,20
0,10
0,00
greenhouse
full sunlight
greenhouse
full sunlight
Treatments

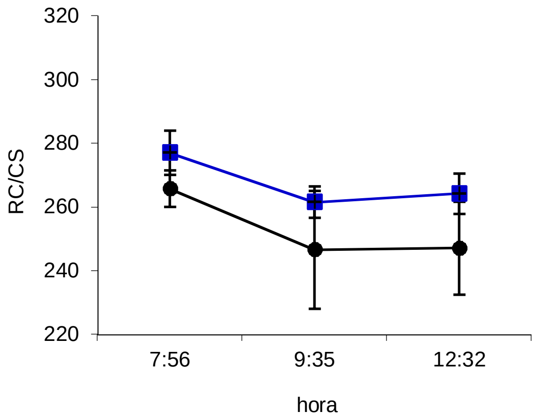


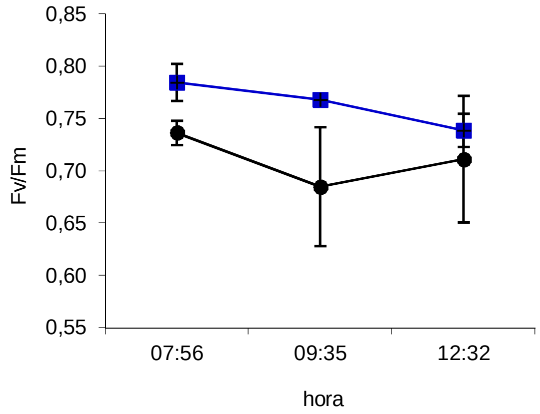
LED
653 nm
931 nm
CCI = % T at 931 nm / % T at 653 nm
Chlorophyll
Detector

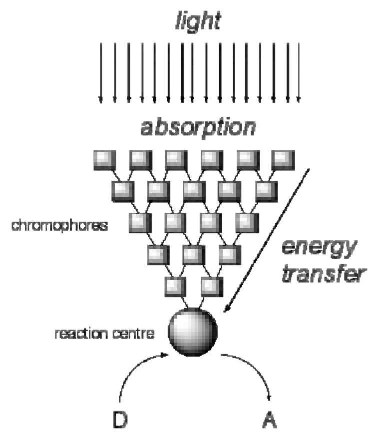


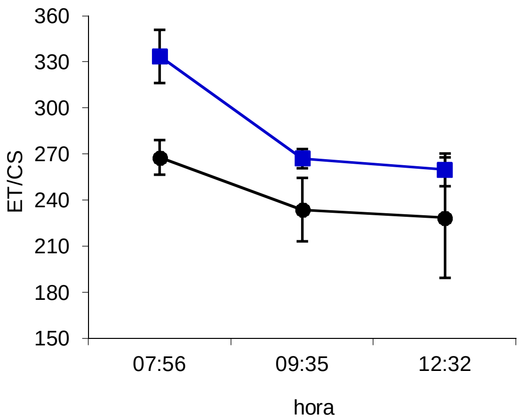
Spad reading
55
53
51
49
47
45
greenhouse
full sunlight

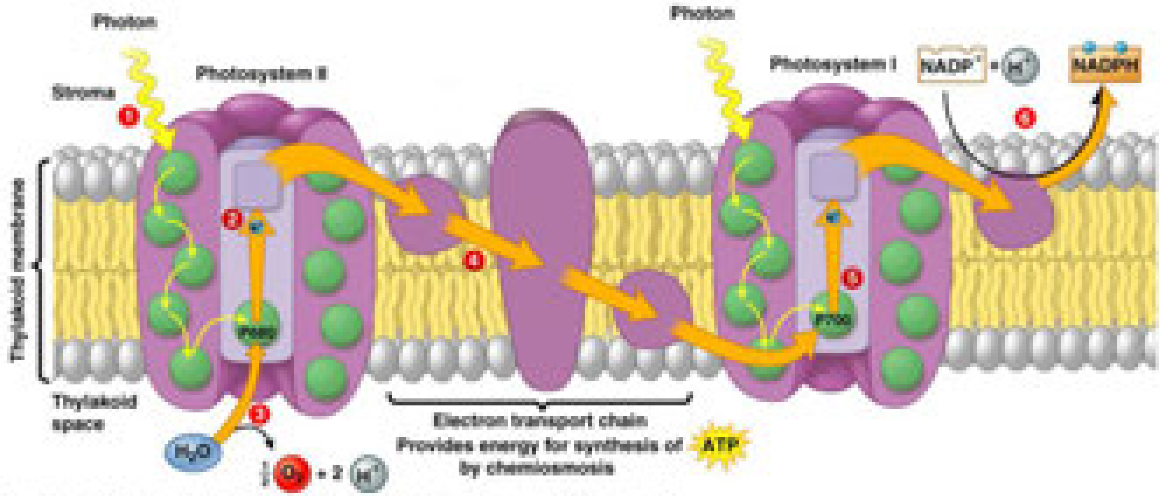
Full sunlight ● Greenhouse ■







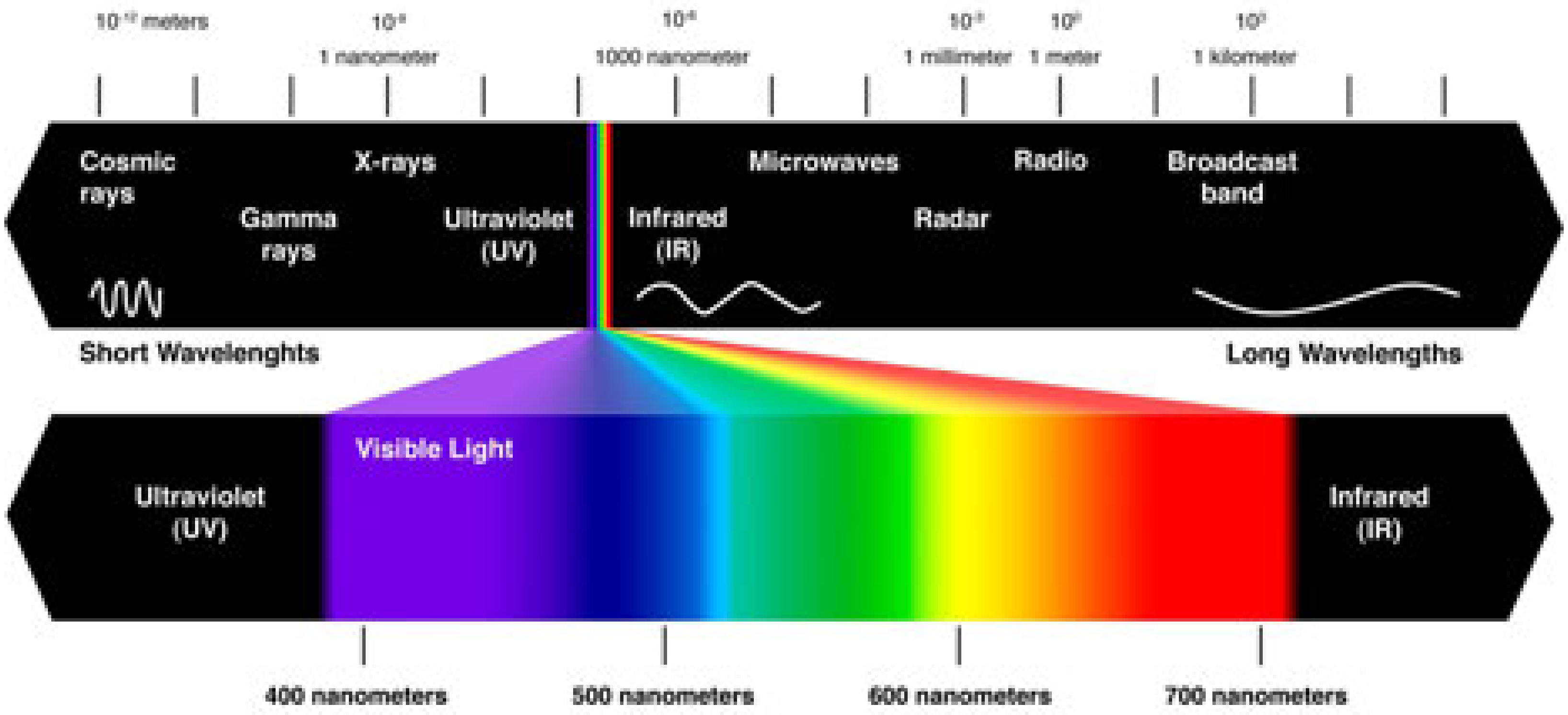




Commercial production

2004/2005	Greenhouse	Full sunlight
Plant Height (cm)	**183.8** a	144.2 b
Trunk diameter (cm)	**13** a	10 b
Leaf number plant^{-1}	**35.3** a	29.4 b
Leaf area plant (m2)	**0.2** a	0.15 b
Number of fruits plant^{-1}	**9.7** a	6.5 b
Fruit weight plant^{-1}	**3.53 kg** a	2.12 kg b
Average fruit weight	**364.7 g a**	326.1g b
Martelleto et al 2008		

Light quality and intensity can affect leaf anatomy in papaya plant

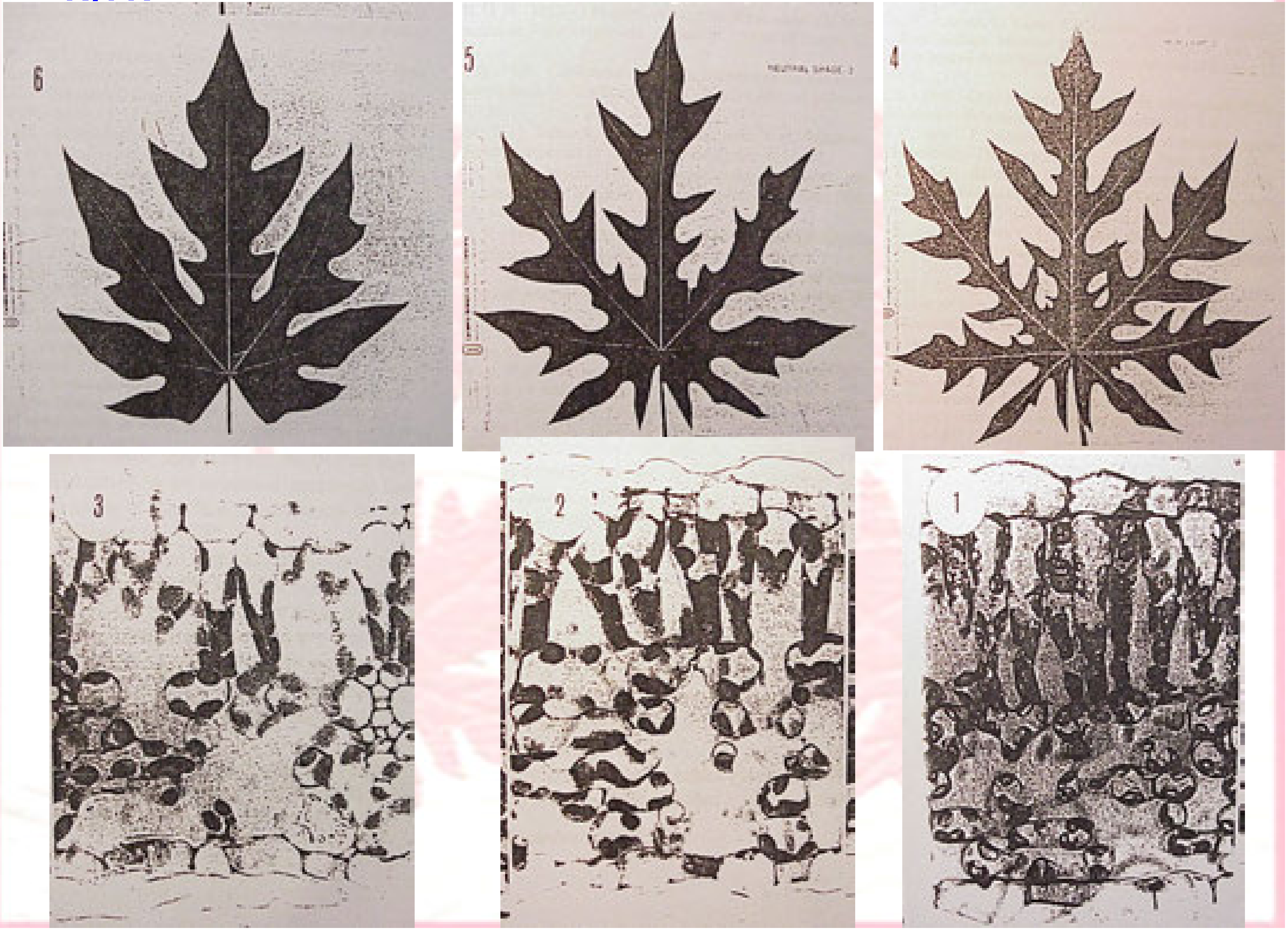


< R/FR

Shade 50%

Full sunlight

Buisson e Lee, 1993



Buisson e Lee, 1993

	Sun leaf	Shade leaf
Leaf thickness (µm)	137	**119**
Specific leaf mass (mg cm^{-2})	4,7	**2,8**
Leaf area (cm^{-2})	292	**162**
Chlorophyll content (µg cm^{-2})	3.57	**5.16**
Petiole lenght (mm)	207	**148**
Stomata density (mm^{-2})	465	**330**
Degree air space	0.29	**0.33**

Under conditions of low light intensity and low red:far red light , leaf lobing was dramatically reduced.

Change in spectral quality also resulted in a reduction in the ratio chlorophyll a to b

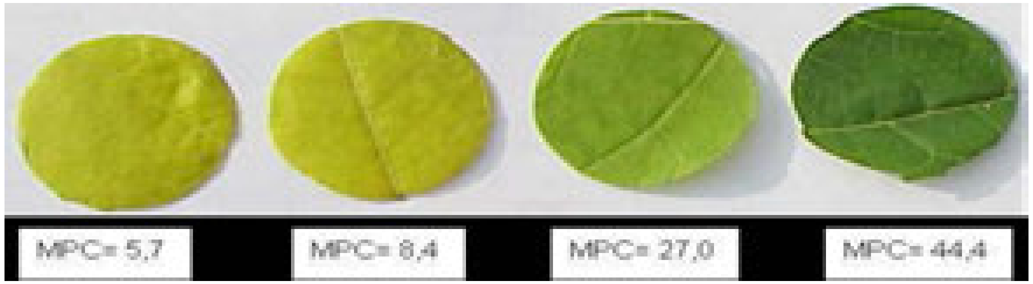
High Leaf lobing can reduce leaf temperature in sun leaf

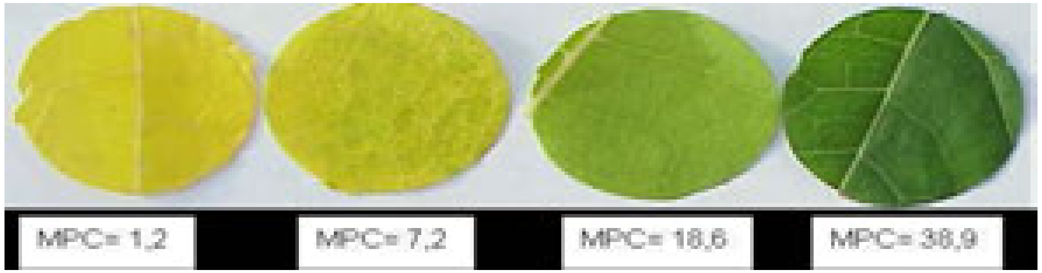
Motorcycle radiator

The papaya photosynthetic capacity can be linked to non stomatal limitation in soil field capacity condition.

As exemple:
-Nitrogen leaf concentration

15 g kg^{-1}DM **35 g kg^{-1}DM**





18 g kg^{-1}DM **37 g kg^{-1}DM**

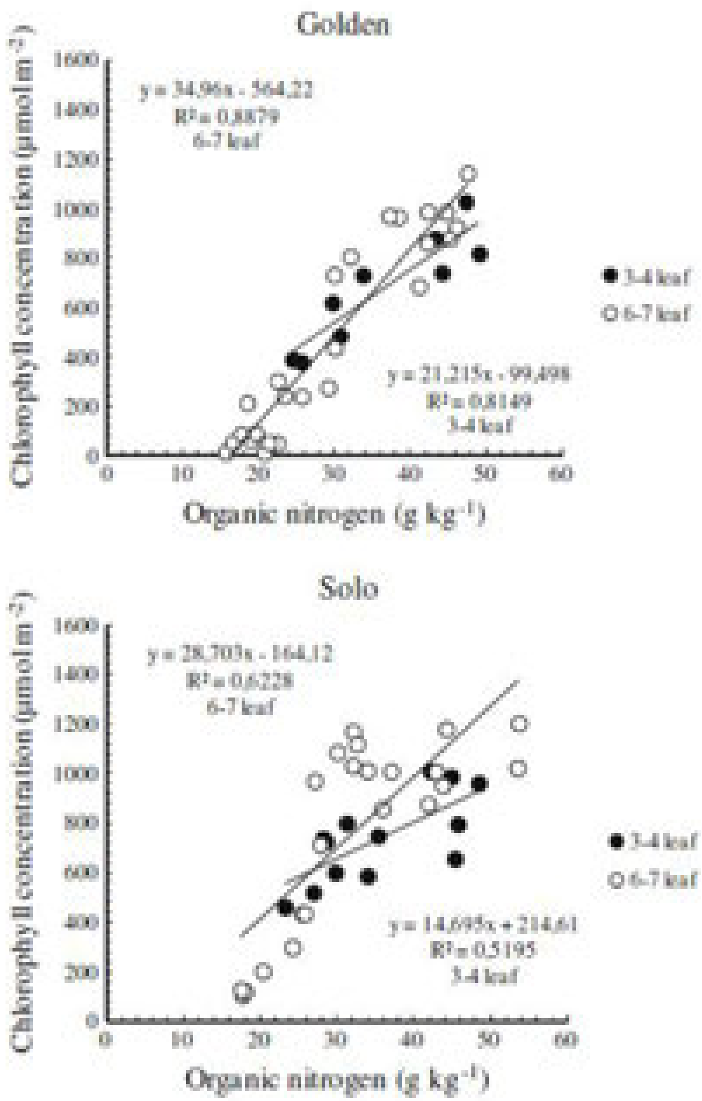
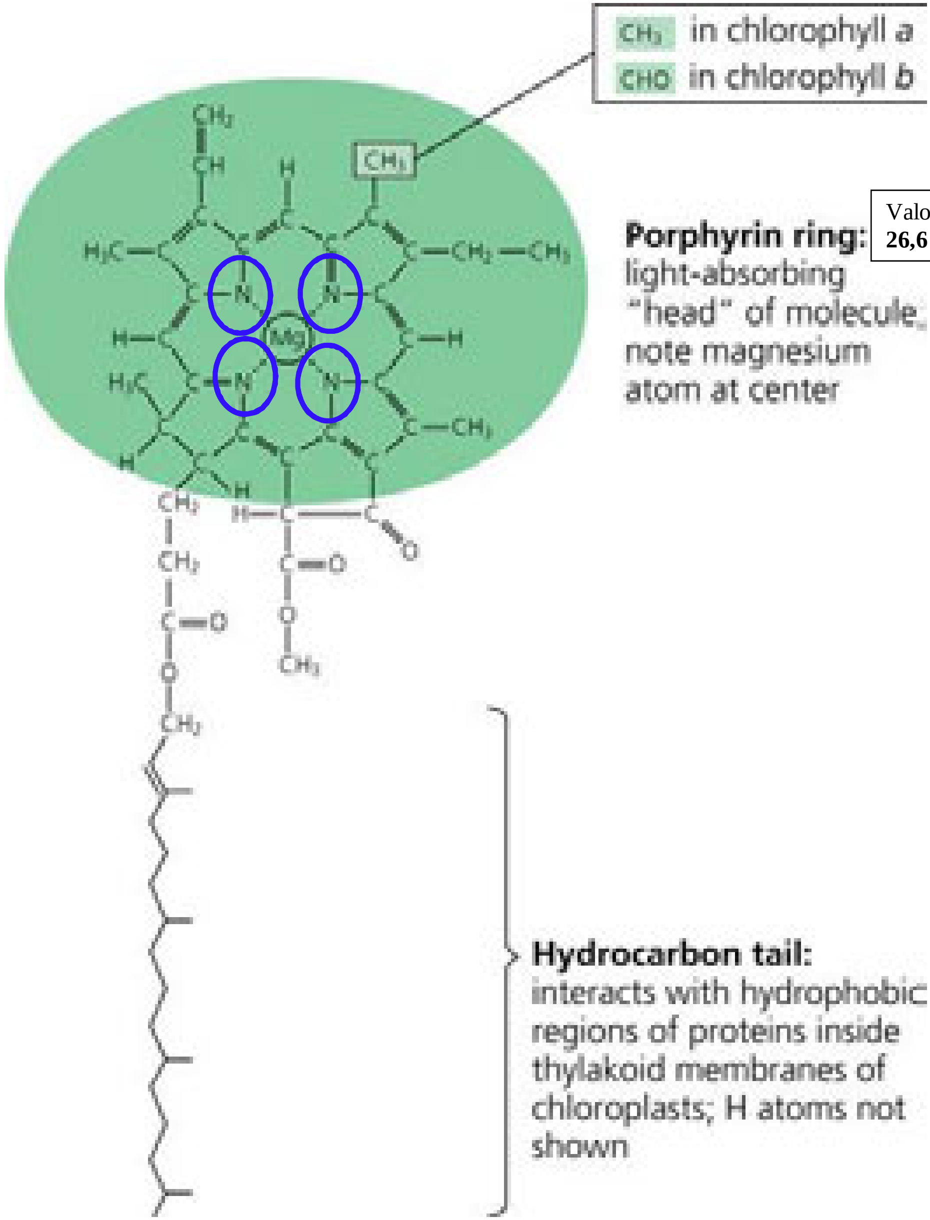
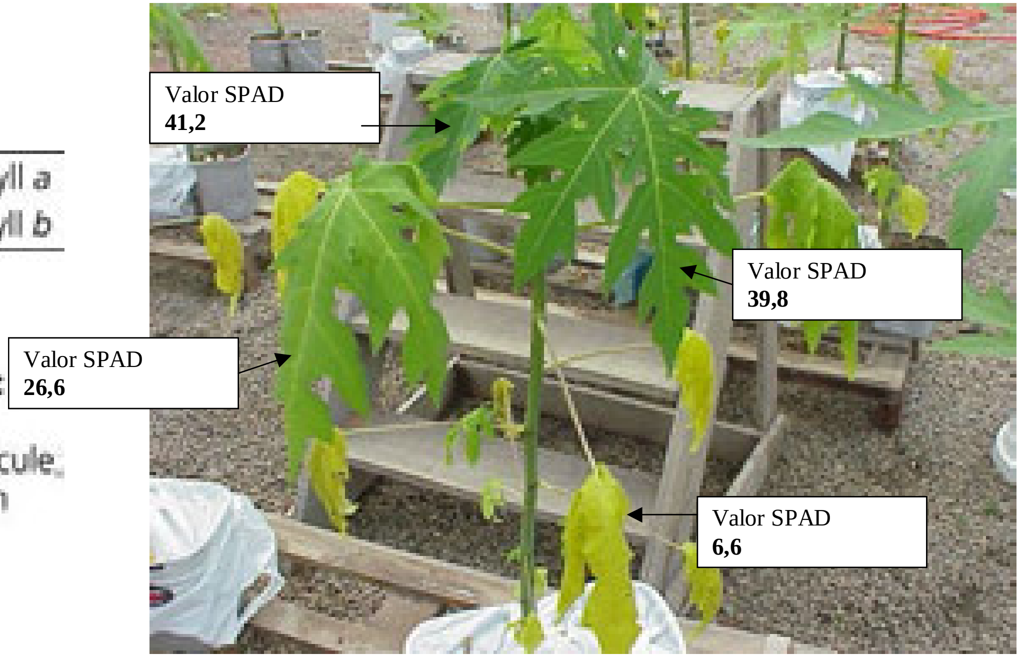


Fig. 2 Relationship between chlorophyll concentration (a+b) (µmol m^{-2}) and leaf N_{org} (g kg^{-1} DW) in 'Solo' and 'Golden' papaya plants cultivated in greenhouse conditions. The R^2 indicated significant correlation at the 0.1 % level


CH₃ in chlorophyll a
CHO in chlorophyll b
Porphyrin ring: light-absorbing "head" of molecule; note magnesium atom at center
Hydrocarbon tail: interacts with hydrophobic regions of proteins inside thylakoid membranes of chloroplasts; H atoms not shown


Valor SPAD 41,2
Valor SPAD 39,8
Valor SPAD 26,6
Valor SPAD 6,6

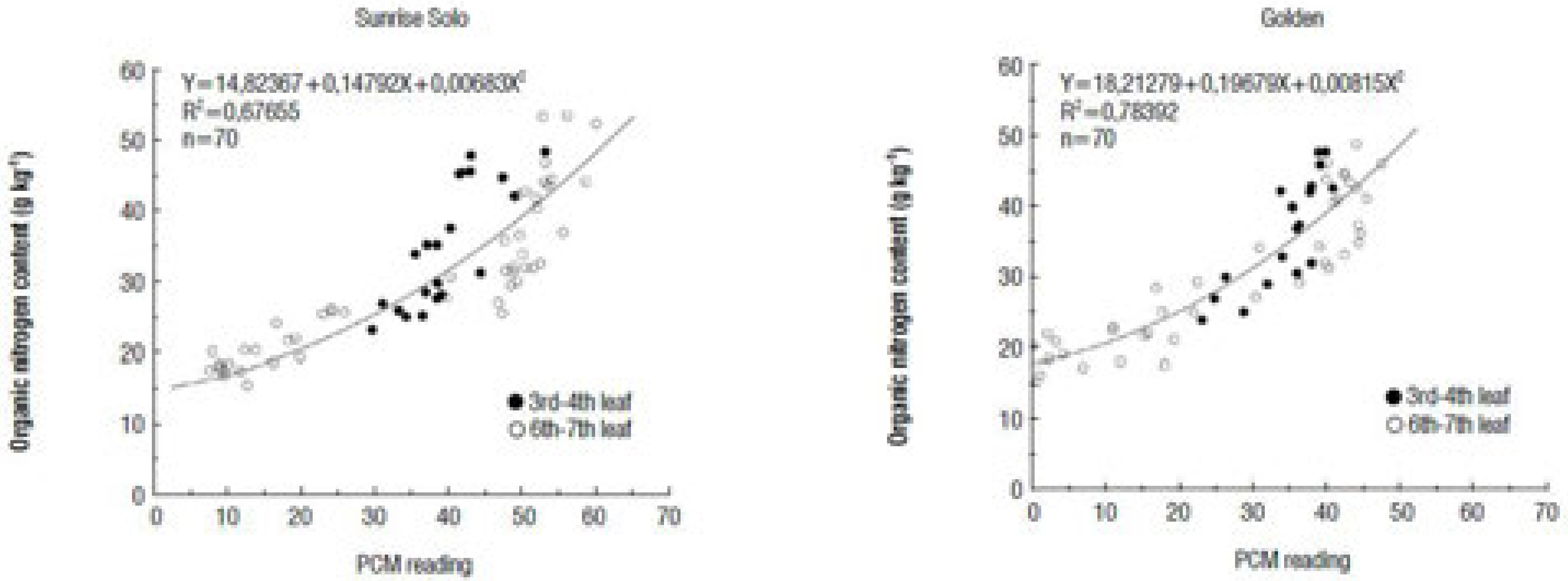
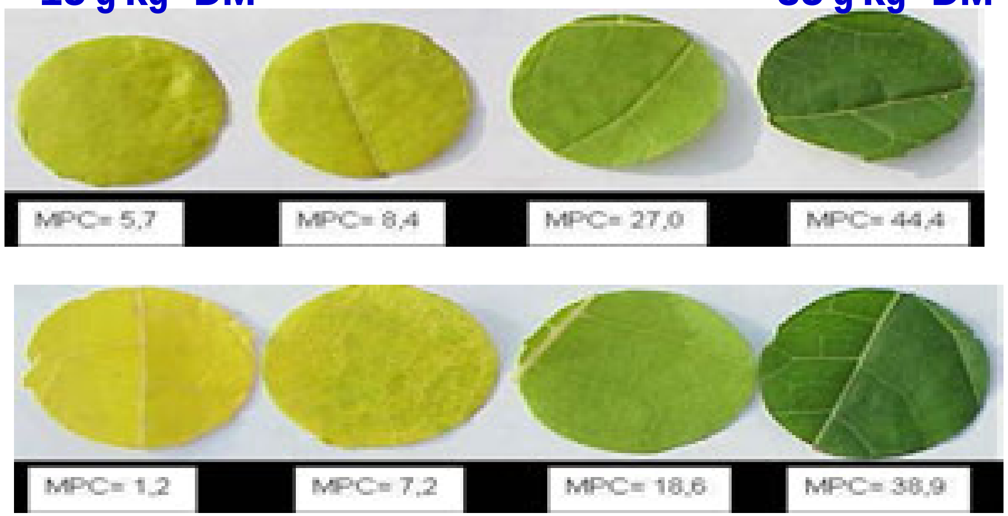


Figure 4. The relation between the organic nitrogen content and the PCM reading, in Sunrise Solo and Golden papaya plants, cultivated in a greenhouse. The open circles with reduced PCM readings (<30) refer the senescent 6th – 7th leaves.

15 g kg^{-1}DM **35 g kg^{-1}DM**



18 g kg^{-1}DM **37 g kg^{-1}DM**

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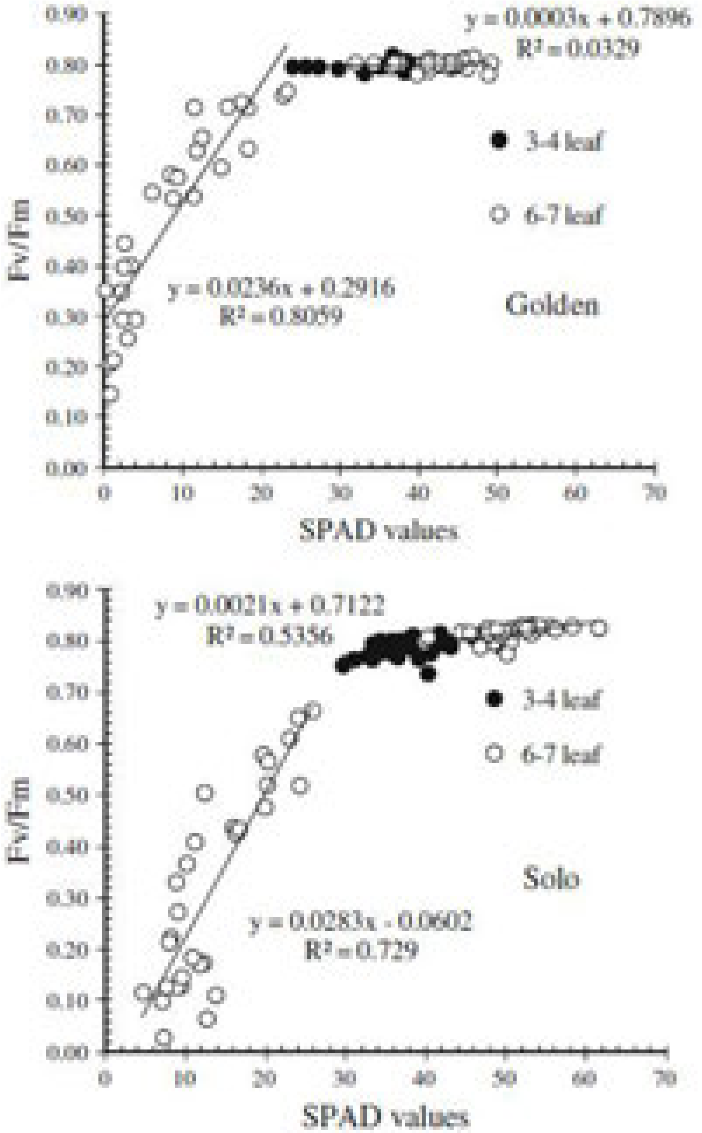


Fig. 6 Relationship between total maximum quantum efficiency (F_v/F_m) and SPAD values in 'Solo' and 'Golden' papaya plants cultivated in greenhouse conditions. R^2 indicate significant correlation at 0.1 % level

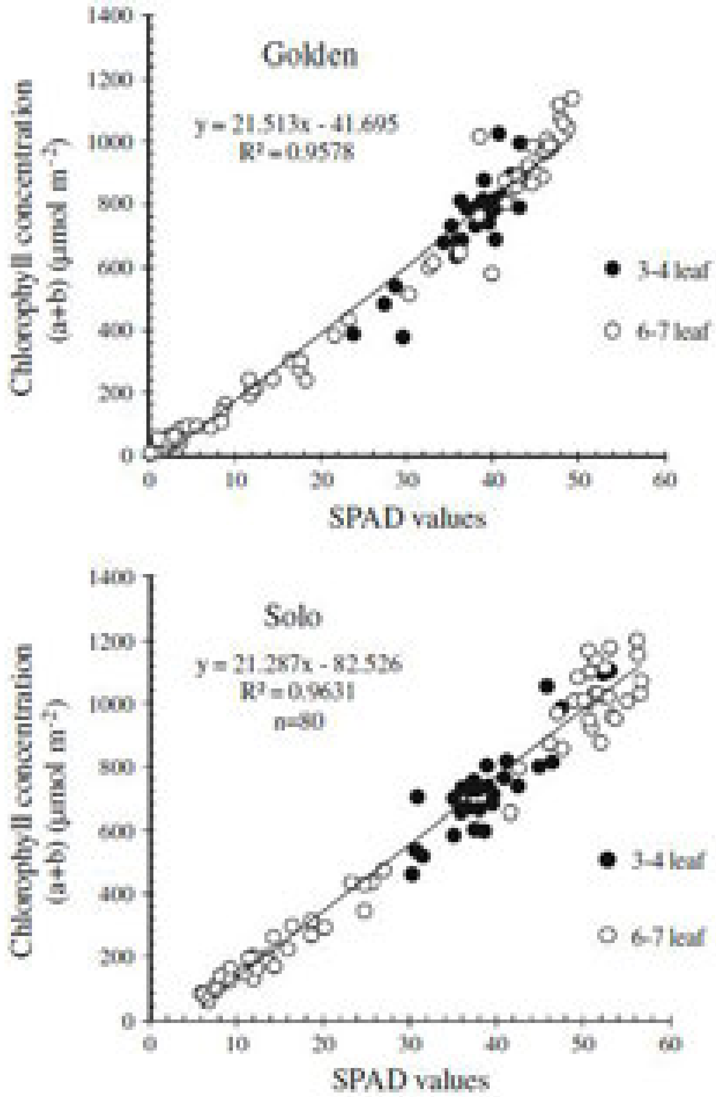


Fig. 4 Relationship between chlorophyll concentration (a + b) (μmol m^{-2}) and SPAD values in 'Solo' and 'Golden' papaya plants cultivated in greenhouse conditions. R^2 indicate significant correlation at the 0.1 % level

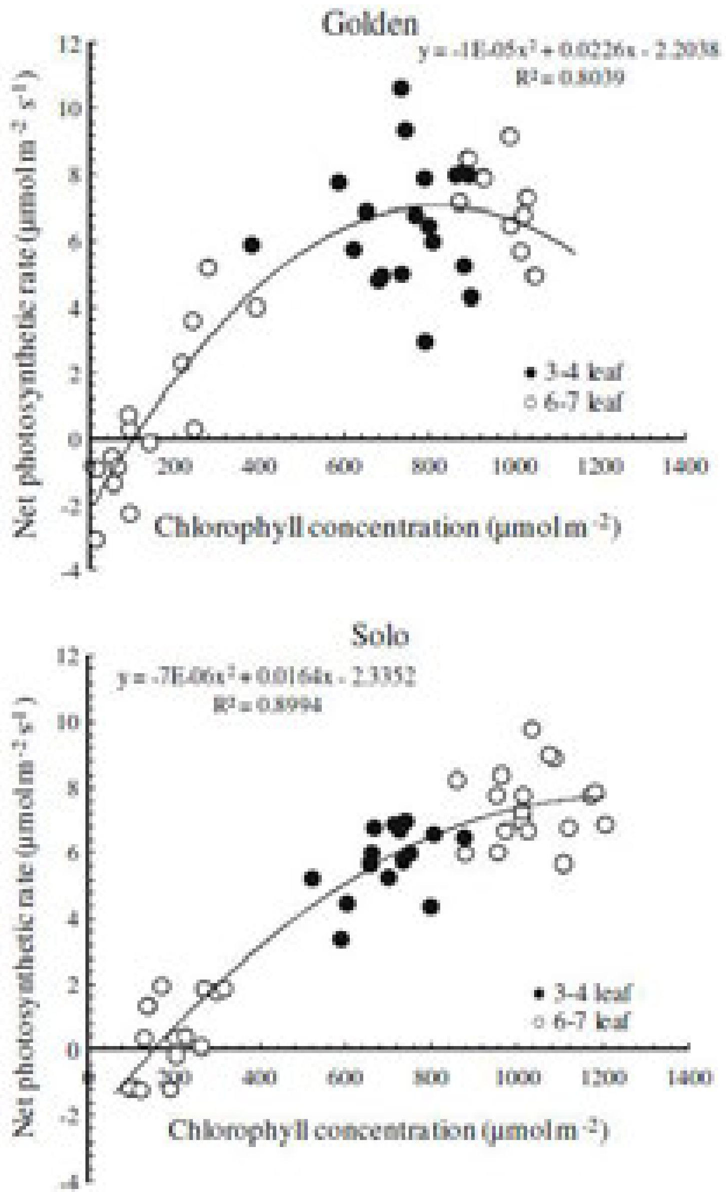


Fig. 3 Relationship between net photosynthetic rate (A) (μmol m^{-2} s^{-1}) and chlorophyll concentration (a + b) (μmol m^{-2}) in 'Solo' and 'Golden' papaya plants cultivated in greenhouse conditions. R^2 indicate significant correlation at the 0.1 % level

Theor. Exp. Plant Physiol.
DOI 10.1007/s40626-014-0018-y

Portable chlorophyll meter (PCM-502) values are related to total chlorophyll concentration and photosynthetic capacity in papaya (*Carica papaya* L.)

Fernanda Assumpção De Castro · Eliemar Campostrini · Alena Torres Netto · Mara De Menezes De Assis Gomes · Tiago Massi Ferraz · David Michael Glenn

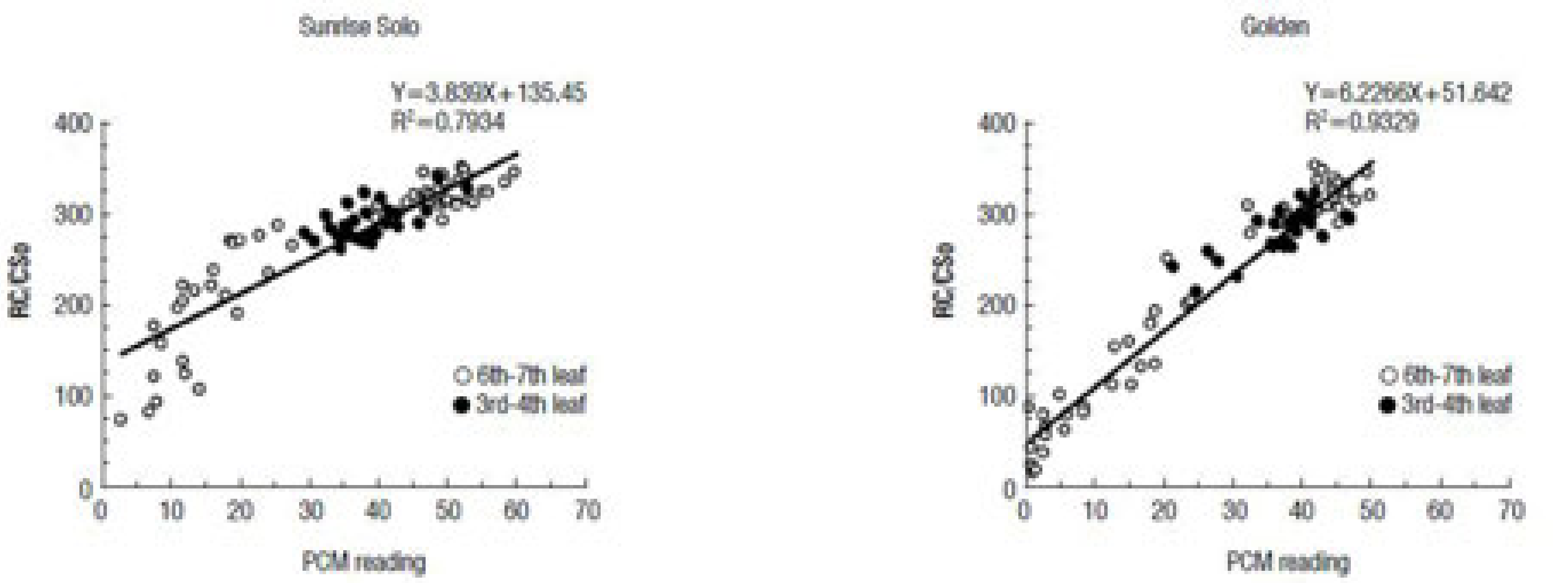
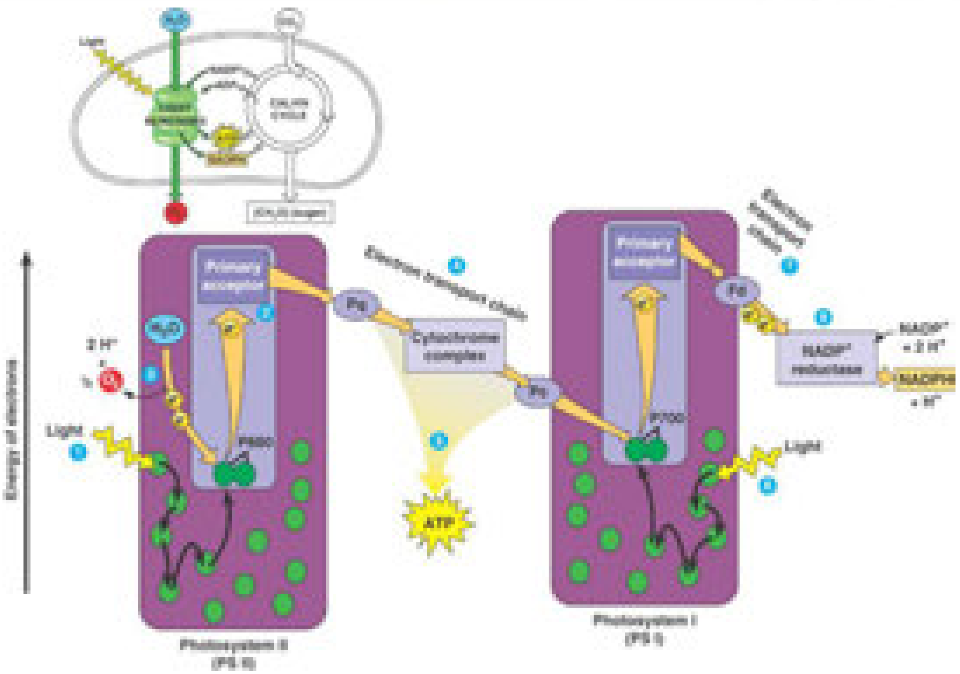


Figure 3. Relationship between the RC/CS_0 ratio (density of active reaction center related to reduction in Qa) and the PCM reading, in Sunrise Solo and Golden papaya plants cultivated in a greenhouse. The open circles with reduced PCM readings (<30) refer the senescent 6th – 7th leaves.



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RESEARCH ARTICLE

Relationship between photochemical efficiency (JIP-Test Parameters) and portable chlorophyll meter readings in papaya plants

Fernanda Assumpção Castro[1], Eliemar Campostrini[1]*, Alena Torres Netto[1], Leandro Hespanhol Viana[1]

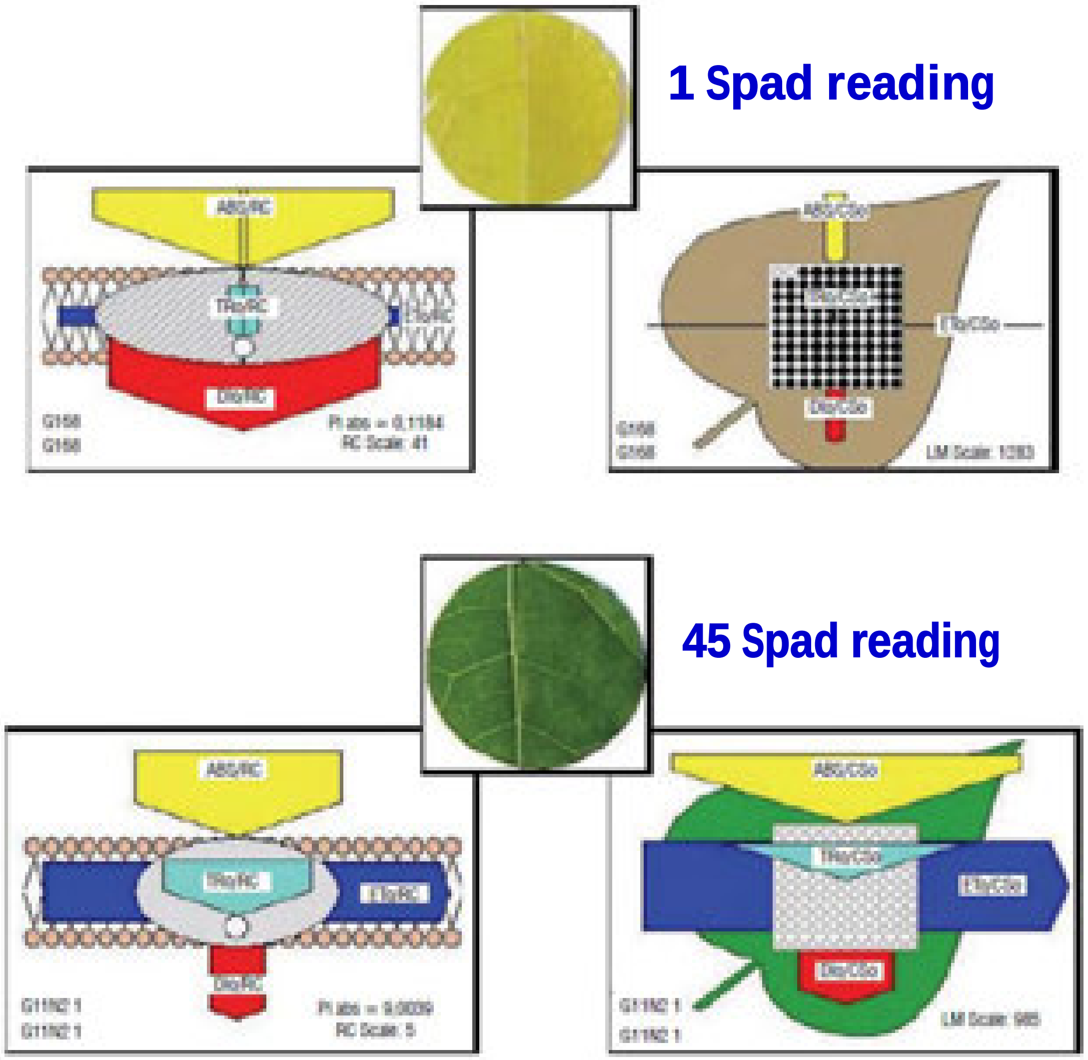
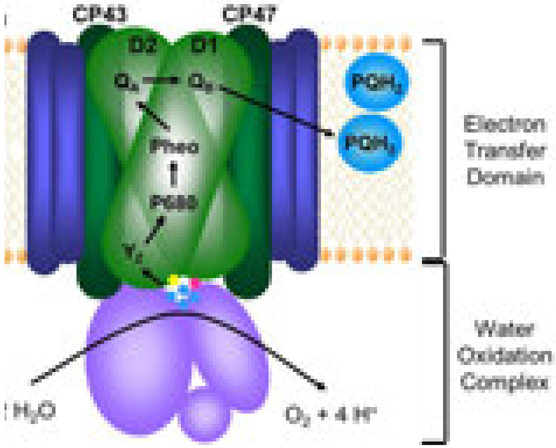
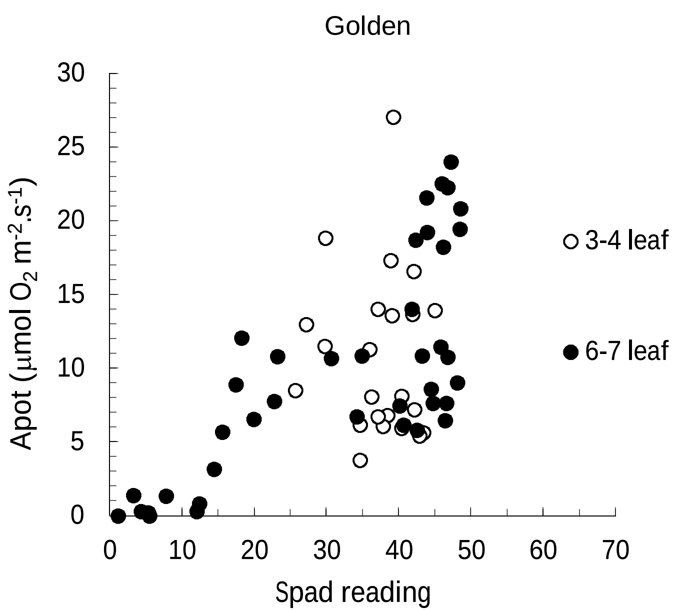
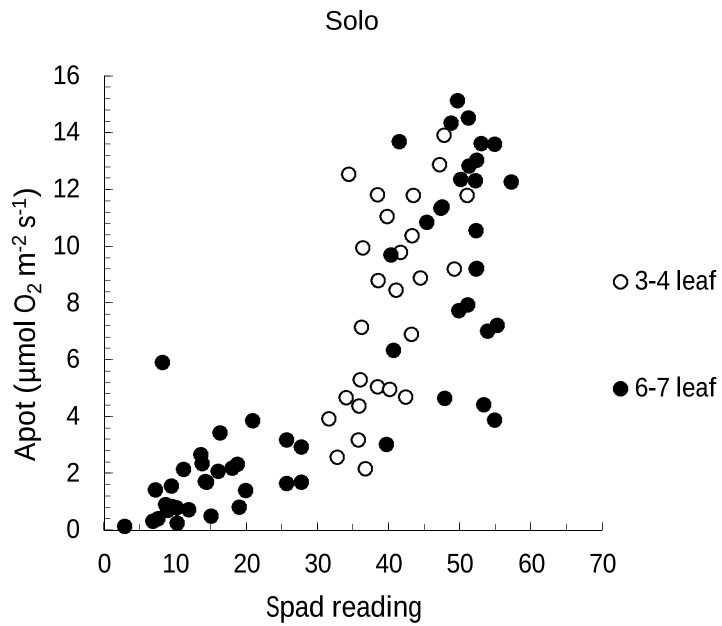
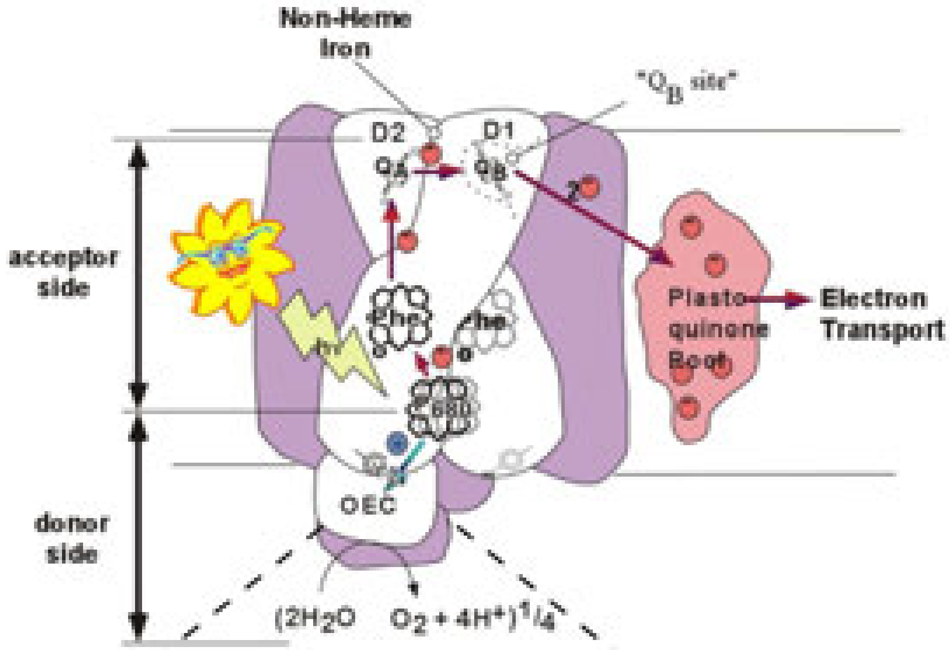


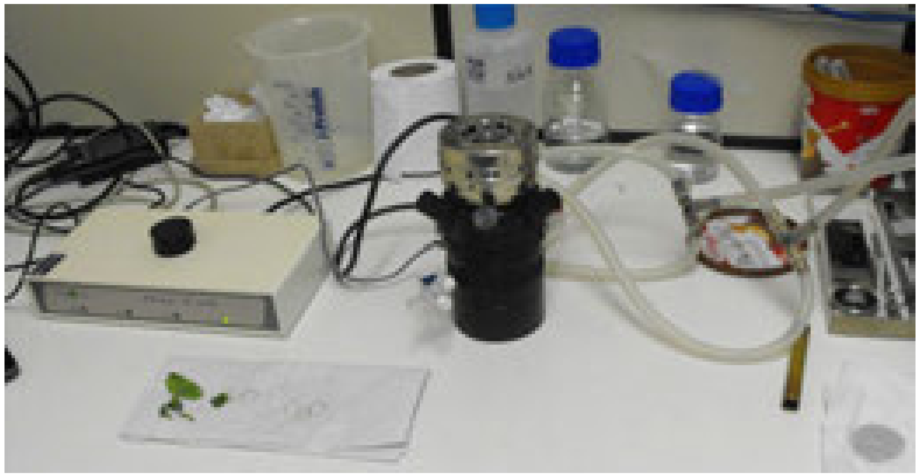
Figure 8. Energy pipeline models of the specific (membrane model, per RC) and phenomenological (leaf model, per CS) fluxes of leaf from a papaya plant of the Sunrise Solo genotype with PCM values of 6.0 (A) and 45 (B), and the Golden genotype with PCM values of 1.0 (C) and 39 (D). The solid and open circles show inactive and active RCs, respectively. The value of each of the parameters can be seen in the relative changes in the width of each arrow.




Golden
Apot (µmol O2 m-2.s-1)
Spad reading
3-4 leaf
6-7 leaf


Solo
Apot (µmol O2 m-2 s-1)
Spad reading
3-4 leaf
6-7 leaf


Non-Heme Iron
"QB site"
D2
D1
acceptor side
donor side
Plasto quinone Pool
Electron Transport
OEC
(2H2O O2 + 4H+)1/4



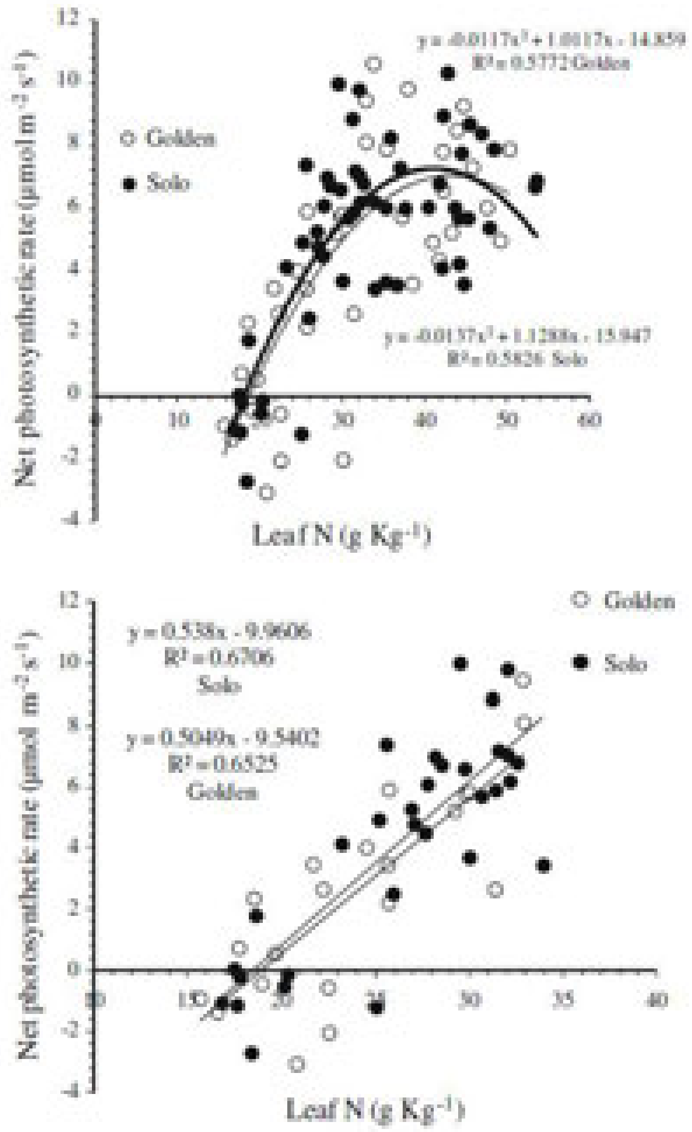


Fig. 1 Relationship between net photosynthetic rate (A) (µmol m^{-2} s^{-1}) and leaf N_{org} (g kg^{-1} DW) in 'Solo' and 'Golden' papaya plants cultivated in greenhouse conditions. The R^2 indicated significant correlation at the 0.1 % level. Fig. (b) is the linear part of the Fig. (a) and is related to the photosynthetic nitrogen use efficiency

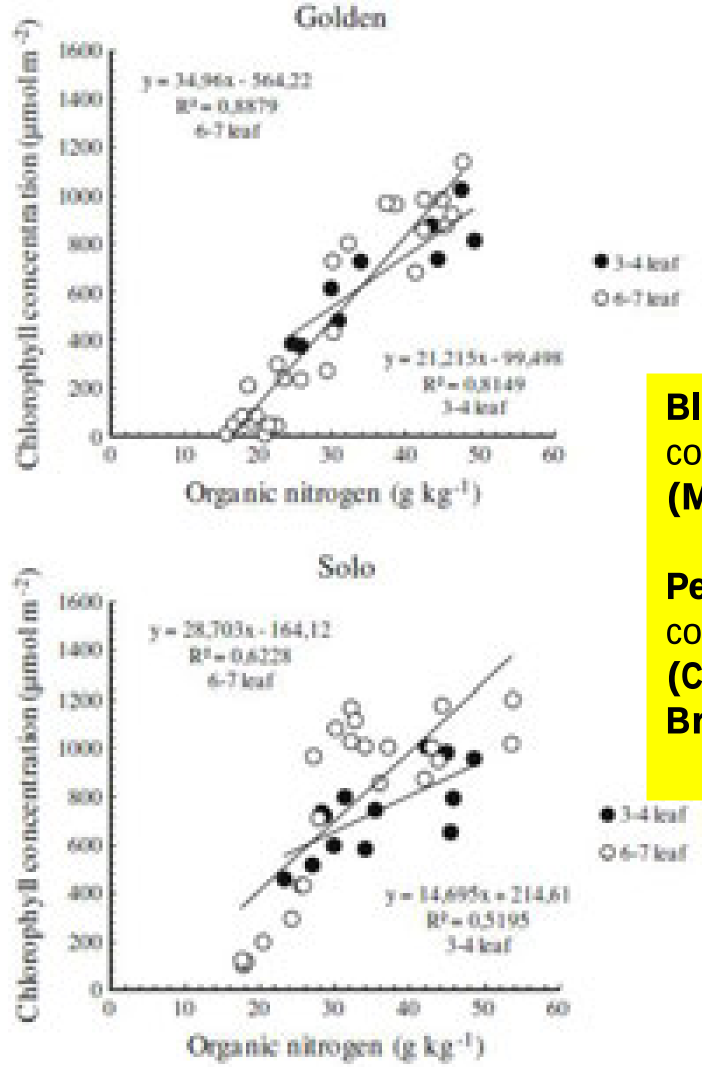


Fig. 2 Relationship between chlorophyll concentration (a+b) (µmol m^{-2}) and leaf N_{org} (g kg^{-1} DW) in 'Solo' and 'Golden' papaya plants cultivated in greenhouse conditions. The R^2 indicated significant correlation at the 0.1 % level

positively correlated with chlorophyll content (Fig. 2) although photosynthesis was curvilinearly related to

Blade Leaf: Optimal N concentration **50 g Kg^{-1}** **(Marinho 2002)**

Petiole: Optimal N concentration **11 g Kg^{-1}** **(Caliman Company, Brazil)**

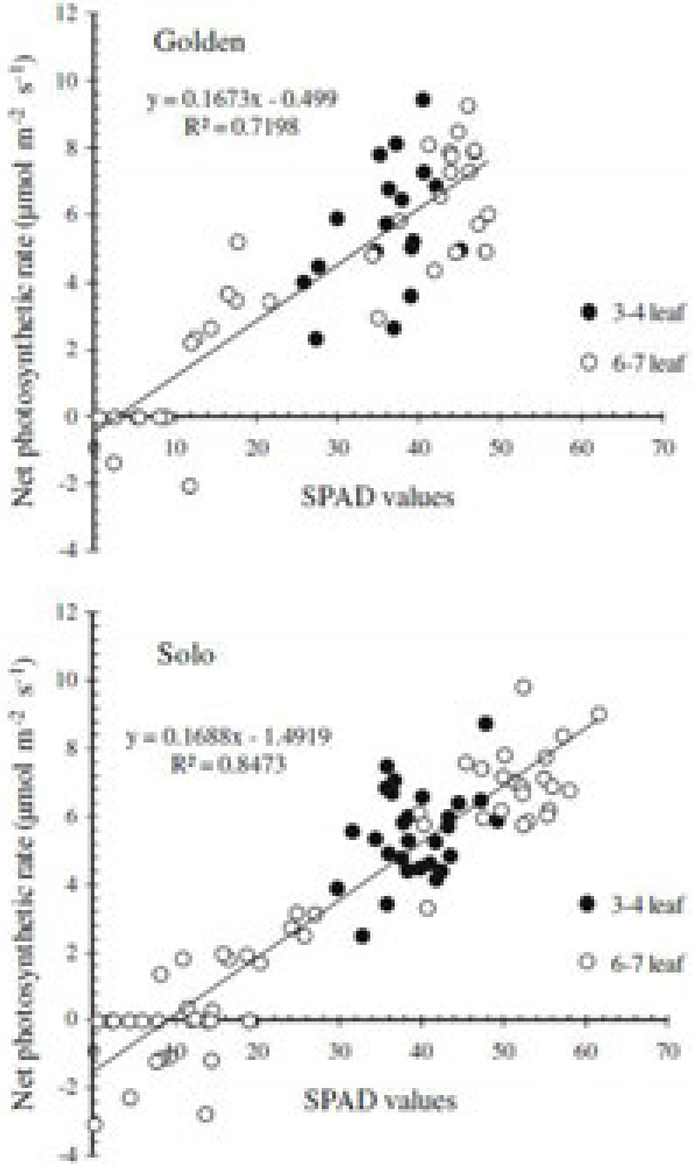
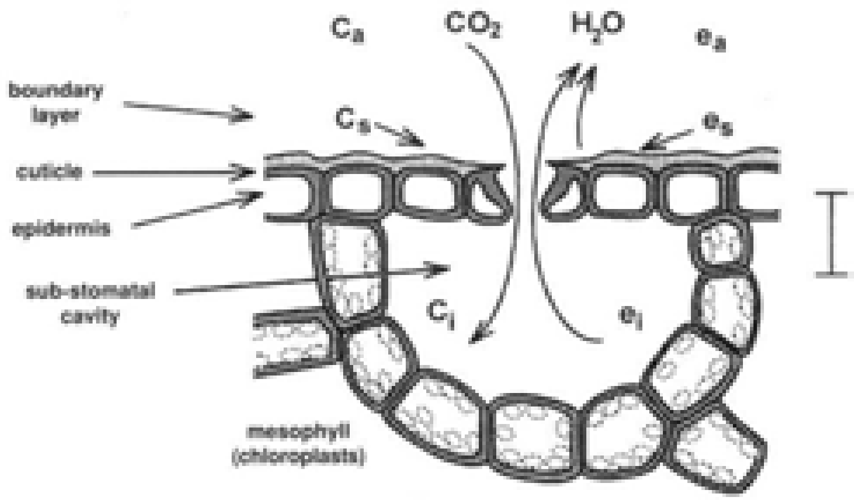


Fig. 5 Relationship between photosynthesis (A) (μmol m^{-2} s^{-1}) and SPAD values in 'Solo' and 'Golden' papaya plants cultivated in greenhouse conditions. R^2 indicate significant correlation at the 0.1 % level

Soil and air water

1) Air water:



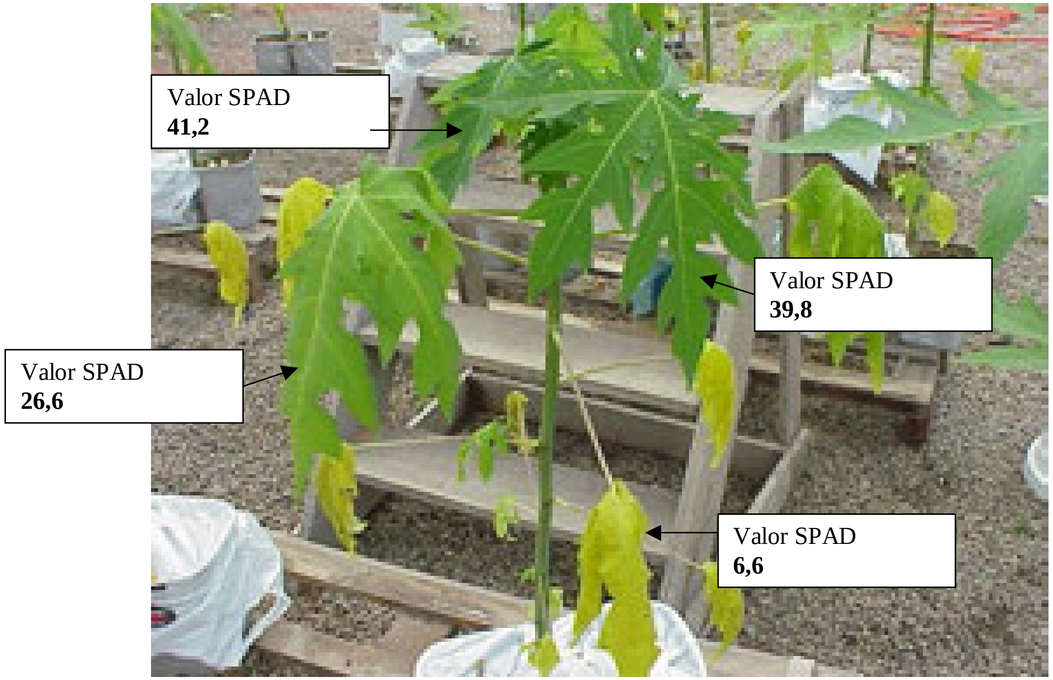
Threshold VPD values to papaya:

VPD_{air} = < 1kPa (e_{sair} – e_{air})

$VPD_{leaf\text{-}air}$= < 2kPa (e_{sleaf} –e_{air})

2) Soil water:

Papaya exhibits both stomatal and non stomatal response to soil water deficits and the source of the response signals are both hydraulic and non-hydraulic in nature



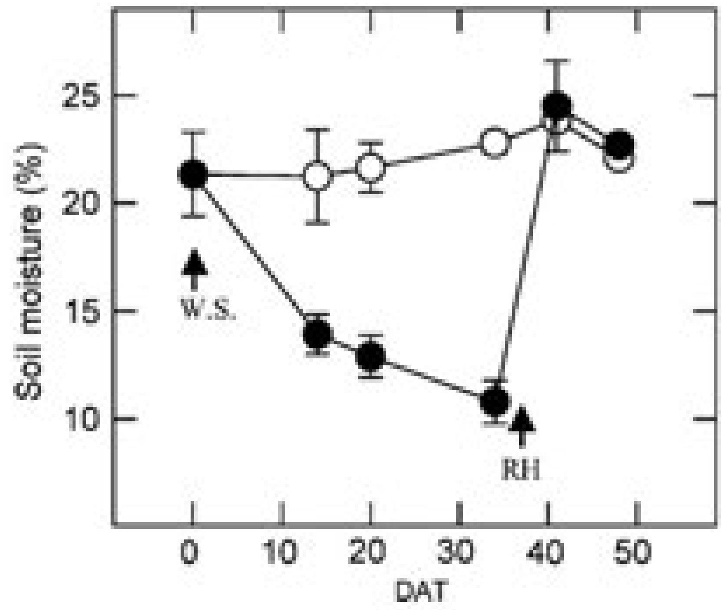


Figure 2. Moisture (%) in watered (○) and non-watered pot soils (●) of papaya seedlings. In non-watered soils, irrigation was suspended during 34 days and re-established thereafter until the end of experiment. Data are means ±SE and each value was determined by three TDR probes with three replicates per treatment ($n \geq 9$) (one probe per pot). DAT = days after treatment. WS: Water Stress. RH: Re-hydration.

Plant and Soil (2006) 281:137-146
DOI 10.1007/s11104-005-3935-3

Responses of papaya seedlings (*Carica papaya* L.) to water stress and re-hydration: growth, photosynthesis and mineral nutrient imbalance

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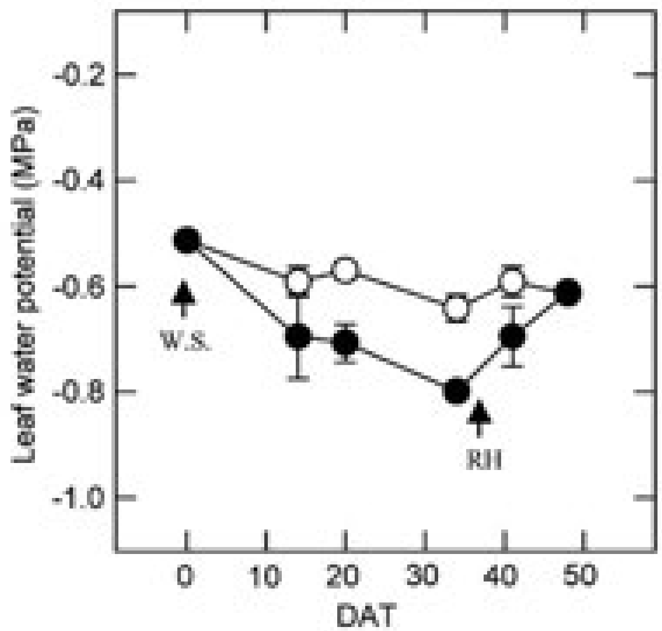


Figure 1. Leaf water potential in papaya seedlings. Treatments were: regular irrigated plants (○) and non-irrigated plants during 34 days followed by re-watering until the end of experiment (●). Data are means ±SE and each value was determined in at least three different plants with three replicates per treatment ($n \geq 9$). DAT = days after treatment. WS: Water Stress. RH: Re-hydration.

Baixinho de Santa Amália genotype
70L pots
Greenhouse
Maximum PAR 1200µmol m^{-2} s^{-1}
Severe water stress: ψ_{leaf} =-0,8MPa
Regular irrigated plants: ψ_{leaf} =-0,6MPa

Table 1. Plant height and stem circumference of papaya seedlings subjected to water stress and re-hydration. The treatment consisted of irrigation suppress during 34 days and re-watering establishment thereafter until 48 days (total experimental period). The data ($n \geq 9$) presented in each line followed by dissimilar letters differ significantly at ($P \leq 0.05$). *: $P \leq 0.01$. **: $P \leq 0.001$

Treatments	Plant height (cm)		Stem circumference (cm)	
	Control	Water stress	Control	Water stress
Water stress (Days)				
0	38.45 ± 0.67a	38.50 ± 0.56a	8.23 ± 0.09a	8.08 ± 0.15a
14	41.67 ± 0.80a	39.63 ± 0.58a	9.04 ± 0.10a	8.72 ± 0.13a
20	42.21 ± 1.06a	39.88 ± 0.60b	9.51 ± 0.11a	8.94 ± 0.15b*
34	43.83 ± 1.15a	40.13 ± 0.67b	9.79 ± 0.12a	8.98 ± 0.12b**
Rehydration (Days)				
41	46.13 ± 1.28a	41.20 ± 0.87b	10.10 ± 0.23a	8.98 ± 0.19b*
48	46.83 ± 1.86a	43.25 ± 1.75b	10.60 ± 0.32a	9.40 ± 0.35b

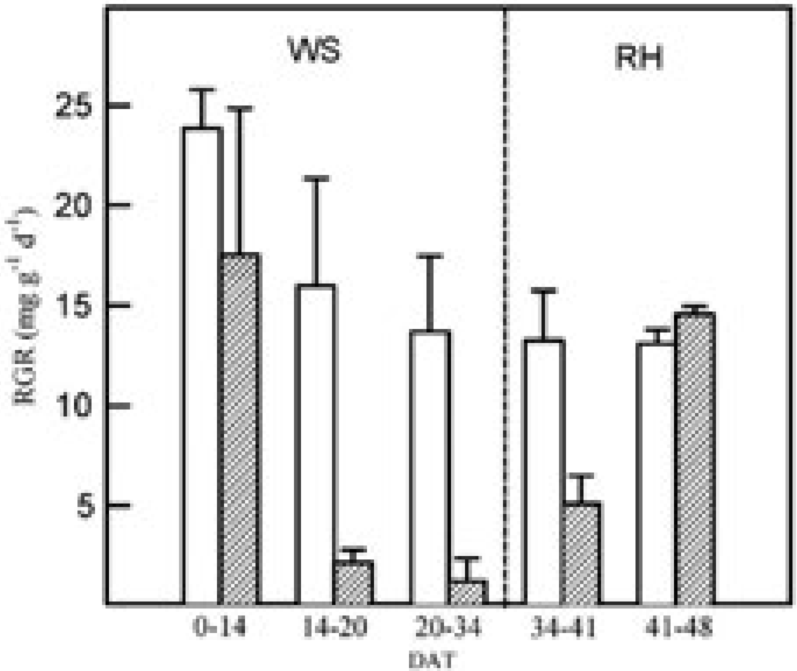


Figure 3. Relative growth rate using stem DW of papaya seedlings. Treatments were: regular irrigated plants (□) and non-irrigated plants during 34 days followed by re-watering until the end of experiment (▩). Data are means ± SE and each value was determined in at least three different plants with three replicates per treatment ($n \geq 9$). DAT = days after treatment. WS: Water Stress. RH: Re-hydration.

Table 2. Root fresh weight of papaya seedlings subjected to water stress and re-hydration. The treatment consisted of irrigation suppress during 34 days and re-watering establishment thereafter until 48 days (total experimental period). The data ($n \geq 9$) presented in each line followed by dissimilar letters differ significantly at ($P \leq 0.05$)

Treatments	Root fresh weight (g)	
	Control	Water stress
Water stress (Days)		
34	181.9 ± 16.5a	101.4 ± 18.7b
Rehydration (Days)		
48	183.0 ± 23.5a	119.7 ± 8.70b

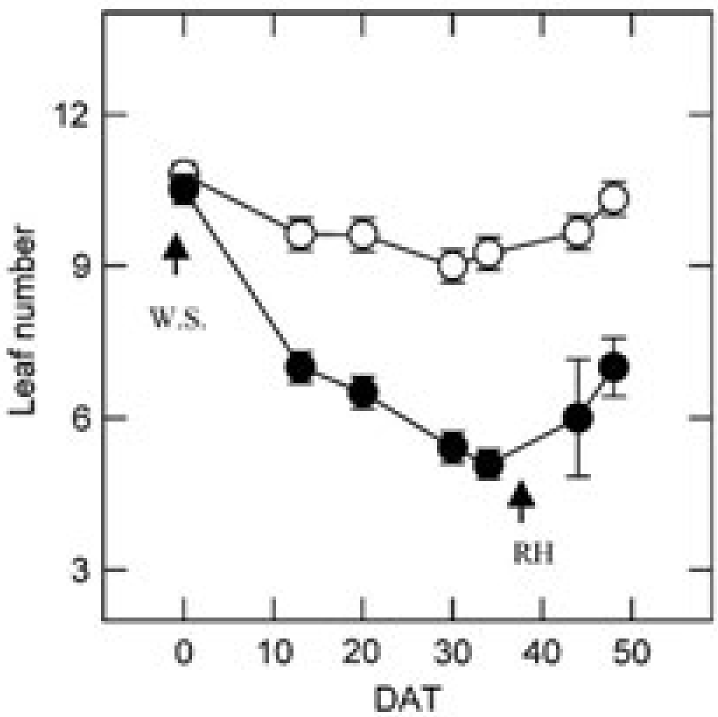


Figure 4. Number of remaining leaves in papaya seedlings. Treatments were: regular irrigated plants (○) and non-irrigated plants during 34 days followed by re-watering until the end of experiment (●). Data are means ± SE and each value was determined in at least three different plants with three replicates per treatment (*n* ≥ 9). DAT = days after treatment. WS: Water Stress. RH: Re-hydration.

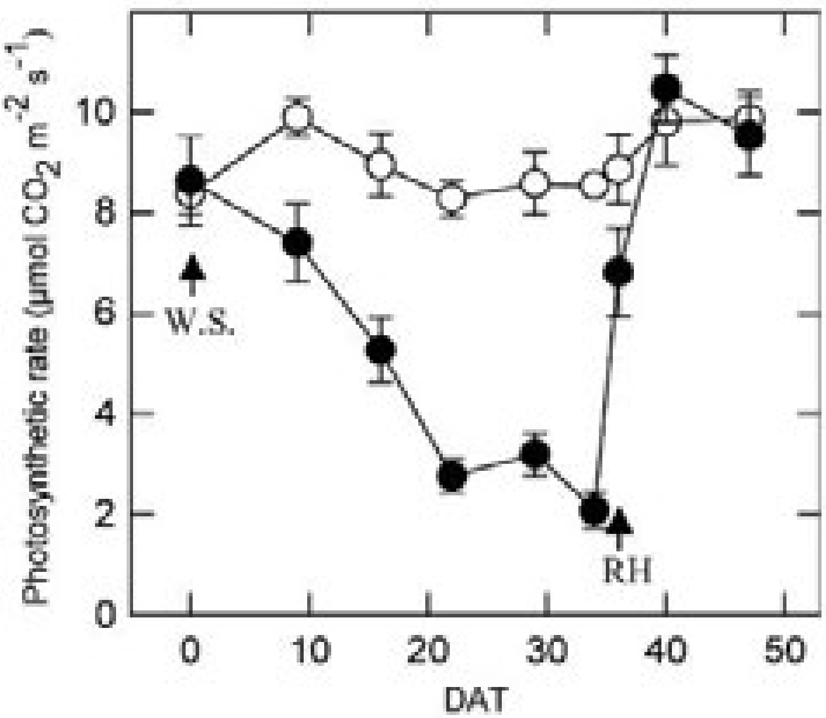


Figure 5. Photosynthetic rate (a) in fully expanded leaves in papaya seedlings. Treatments were: regular irrigated plants (○) and non-irrigated plants during 34 days followed by re-watering until the end of experiment (●). Data are means ± SE and each value was determined in at least three different plants with three replicates per treatment (*n* ≥ 9). DAT = days after treatment. WS: Water Stress. RH: Re-hydration.

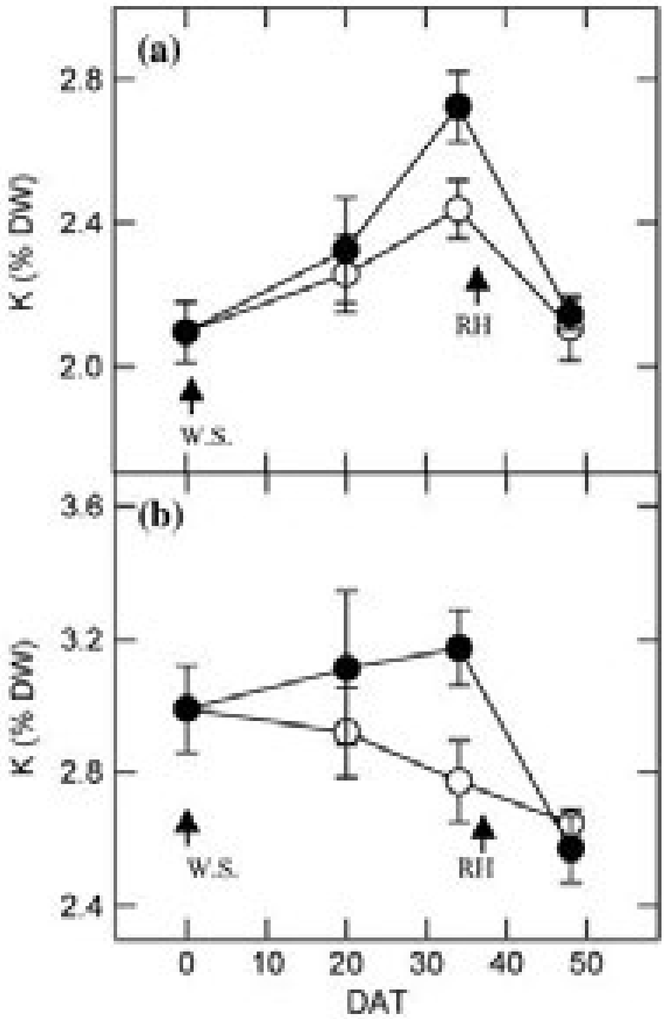


Figure 7. Potassium content in leaf (A) and root (B) tissues in papaya seedlings. Treatments were: regular irrigated plants (○) and non-irrigated plants during 34 days followed by re-watering until the end of experiment (●). Each value is the mean of at least three independent measurements ($n \geq 3$) ± SE. DAT = days after treatment. WS: Water Stress. RH: Re-hydration.

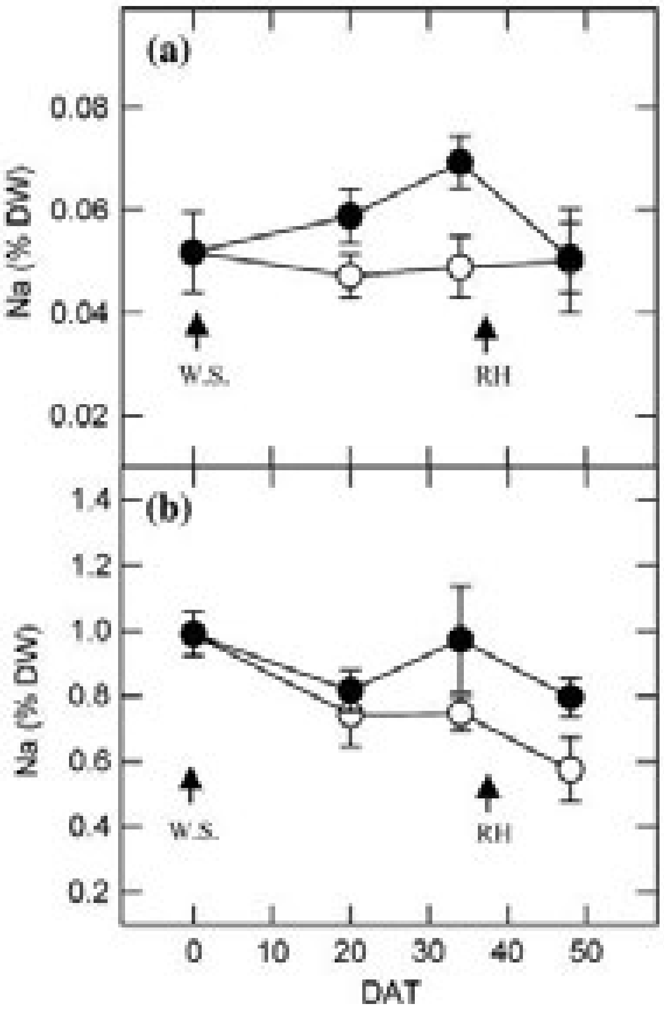


Figure 8. Sodium content in leaf (A) and root (B) tissues in papaya seedlings. Treatments were: regular irrigated plants (○) and non-irrigated plants during 34 days followed by re-watering until the end of experiment (●). Each value is the mean of at least three independent measurements ($n \geq 3$) ±SE. DAT = days after treatment. WS: Water Stress. RH: Re-hydration.

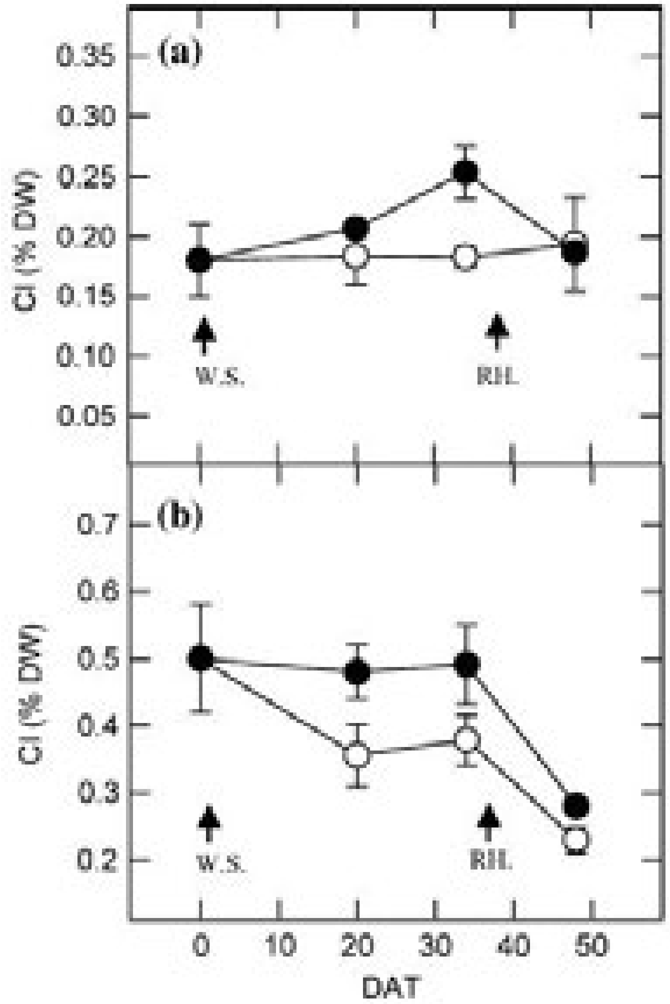


Figure 9. Chloride content in leaf (a) and root (b) tissues in papaya seedlings. Treatments were: regular irrigated plants (○) and non-irrigated plants during 34 days followed by re-watering until the end of experiment (●). Each value is the mean of at least three independent measurements ($n \geq 3$) ±SE. DAT = days after treatment. WS: Water Stress. RH: Re-hydration.

In conclusion, papaya plants subjected to water stress showed a tendency to accumulate ions such as K^+, Na^+ and Cl^-. The ion increases that were registered on per DW basis might apparently contribute for osmotic adjustment, enhancing water stress tolerance of these plants. The data also indicate that stress tolerance was not mediated through the reduction of leaf abscission, the detention of growth or decrease of net CO_2 assimilation. Re-irrigation induced plant morphological and physiological recovery without irreversible effects of water stress.

Plant Growth Regul (2007) 53:43–51
DOI 10.1007/s10725-007-9202-2

ORIGINAL PAPER

Hormonal changes in papaya seedlings subjected to progressive water stress and re-watering

Jalel Mahouachi · Vicent Arbona ·
Aurelio Gómez-Cadenas

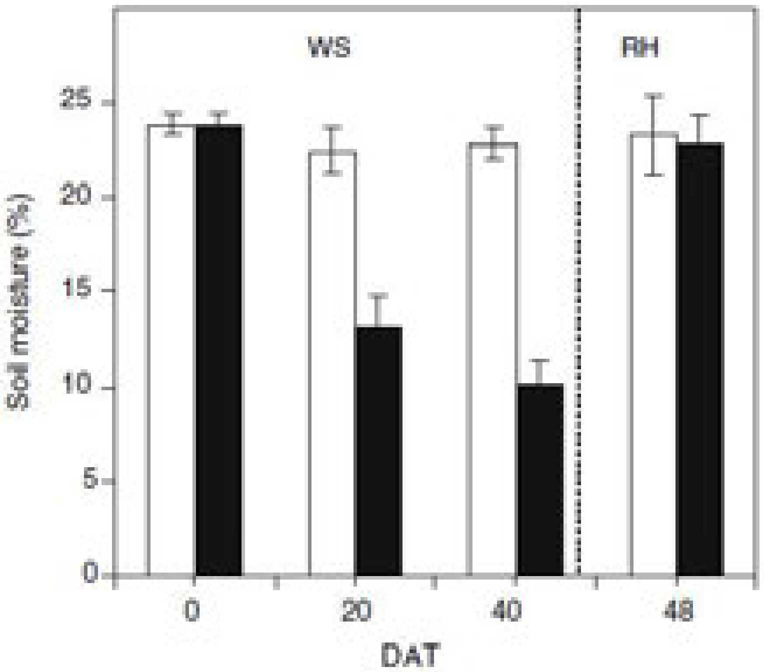


Fig. 1 Soil moisture (%) in irrigated (□) and non-irrigated pot soils (■) of papaya seedlings. In water-stressed soils, irrigation was released during 40 days and re-established thereafter until the end of experiment. Data are means ± SE and each value was determined by three TDR probes with three replicates per treatment ($n \geq 9$) (one probe per pot). DAT = days after treatment. WS: water stress. RH: rehydration

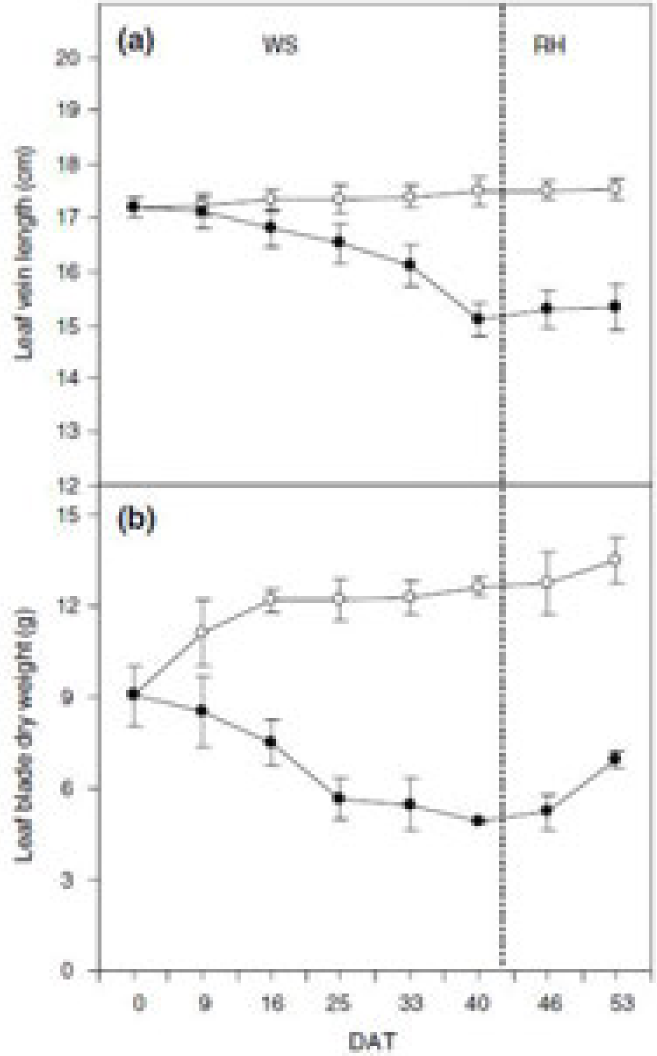


Fig. 2 Principal leaf vein length (a) and leaf blade dry weight (b) in papaya seedlings. Treatments were: regular irrigated plants (○) and water-stressed plants during 40 days followed by re-watering until the end of experiment (●). Data are means ± SE and each value was determined from at least three different plants with three replicates per treatment ($n \geq 9$). DAT = days after treatment. WS: water stress. RH: rehydration

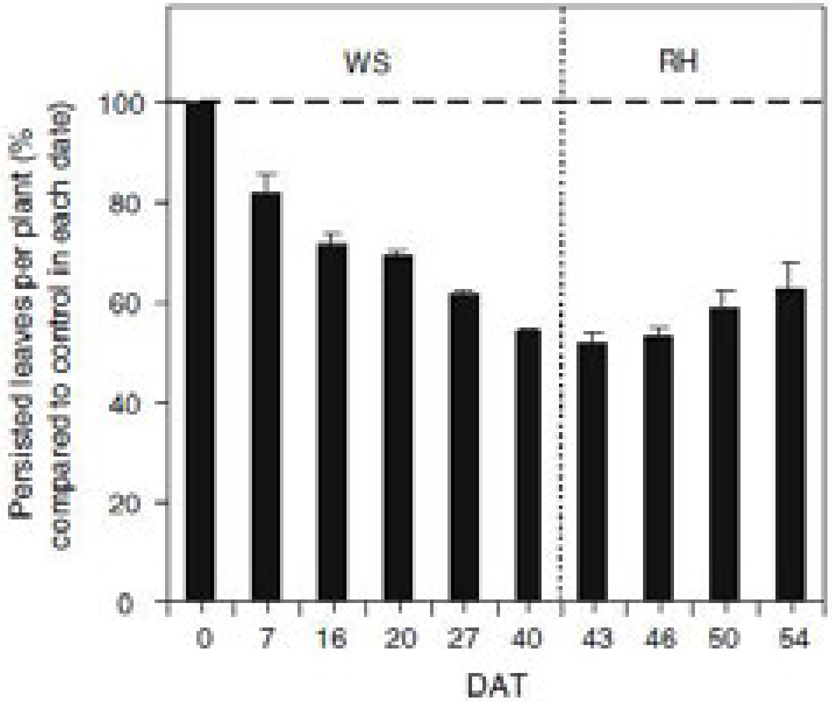


Fig. 3 Percentage of leaves present in papaya plants subjected to WS during 40 days and subsequent RH (■). Data are expressed as percentages with respect to control plants (– – – –) in each date. Data are means ± SE and each value was determined in at least three different plants with three replicates per treatment ($n \geq 9$). DAT = days after treatment. WS: water stress. RH: rehydration

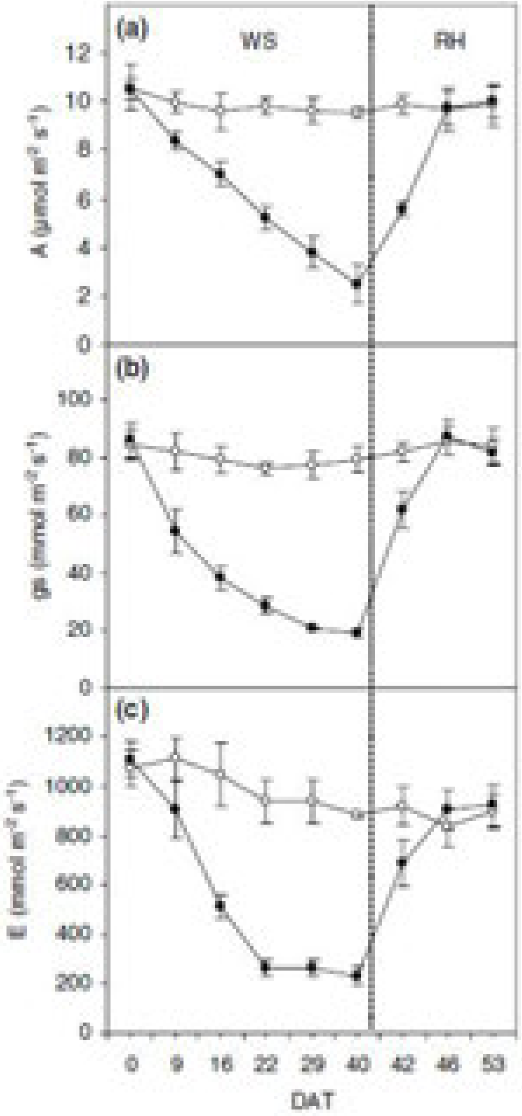


Fig. 4 Photosynthetic rate (A, (a)), stomatal conductance (gs, (b)) and transpiration rate (E, (c)) in fully expanded leaves in papaya seedlings. Treatments were: regular irrigated plants (○) and water-stressed plants during 40 days followed by re-watering until the end of experiment (●). Data are means ± SE and each value was determined in at least three different plants with three replicates per treatment ($n \geq 9$). DAT = days after treatment. WS: water stress. RH: rehydration

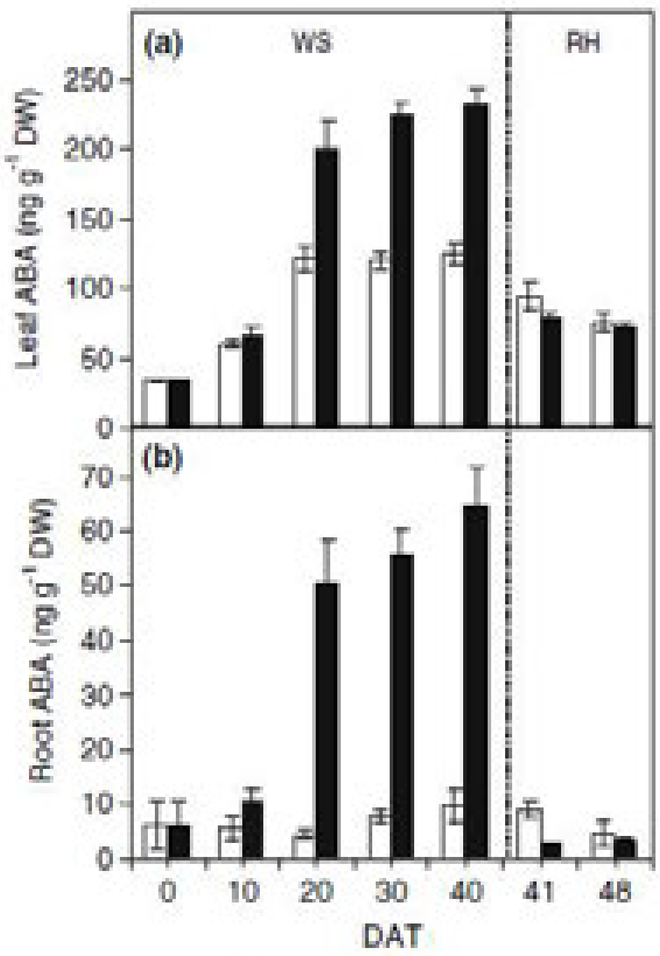
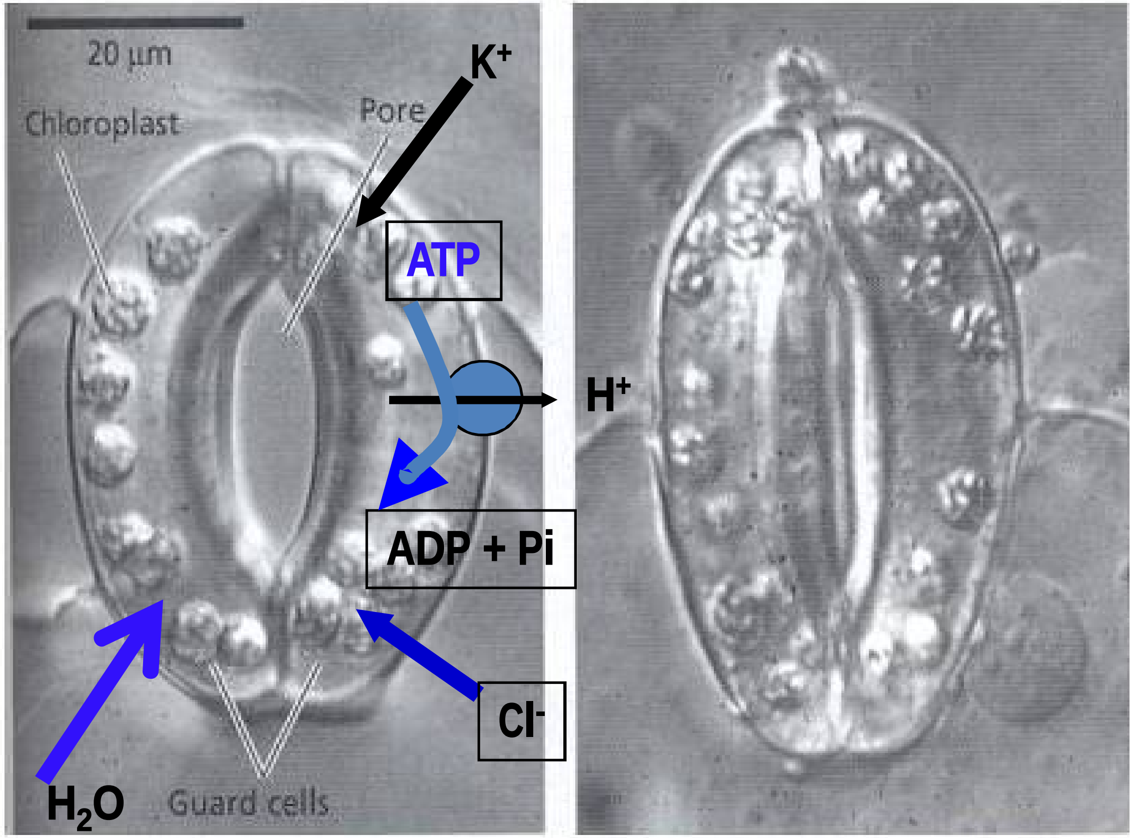
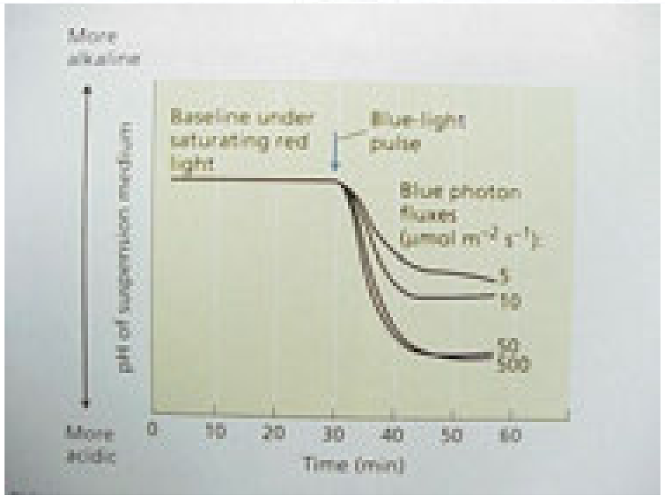
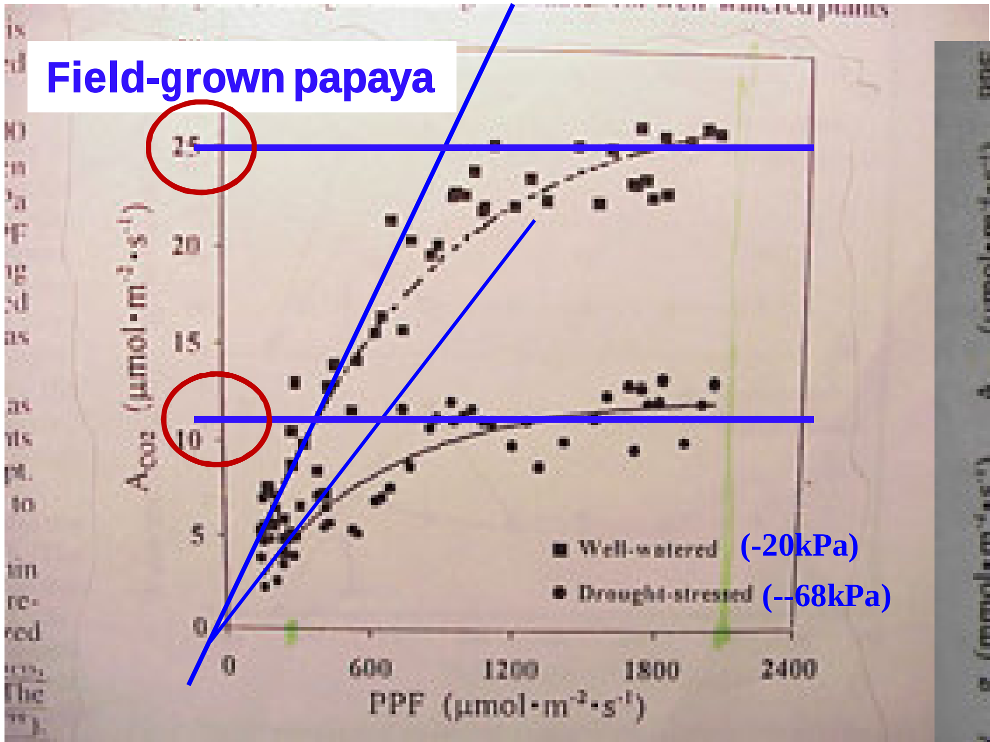
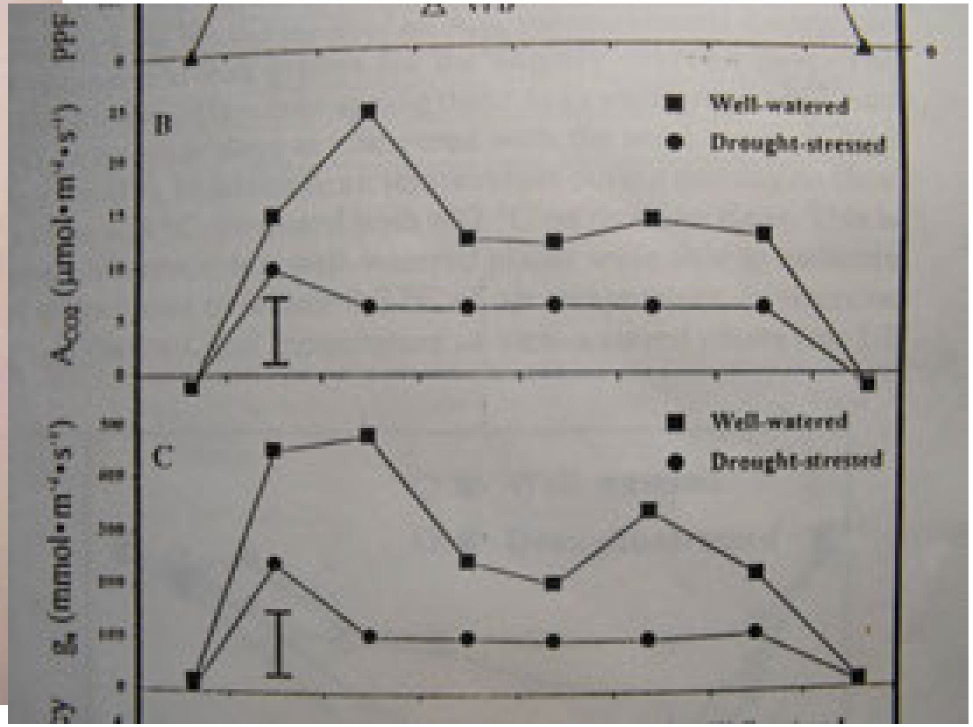


Fig. 5 Abscisic acid (ABA) levels in leaves (a) and roots (b) from well-watered plants (□) and from plants subjected to WS during 40 days and subsequent RH (■) in papaya seedlings. Each value is the mean of at least three independent measurements ($n \geq 3$) ±SE. DAT = days after treatment. WS: water stress. RH: rehydration









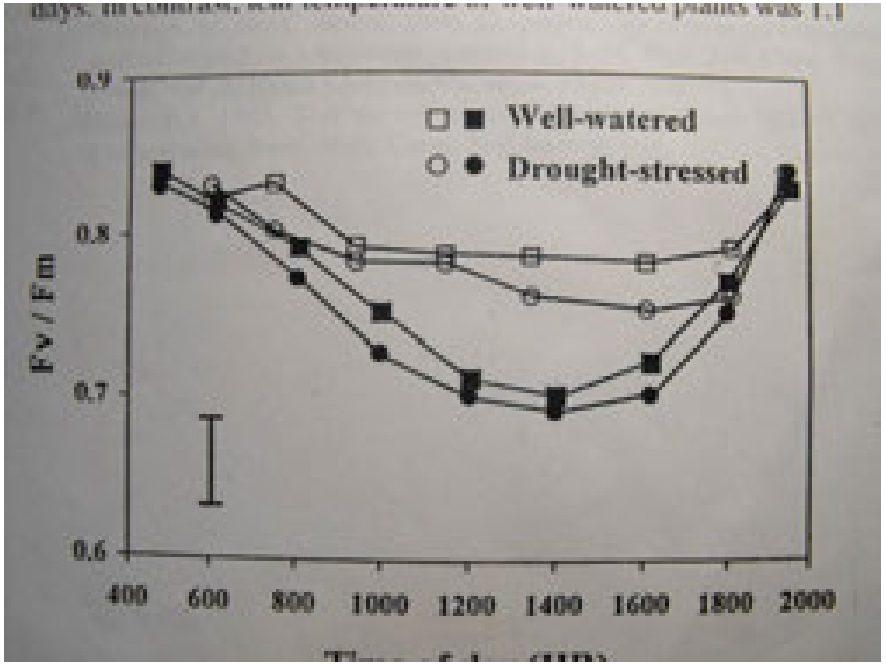
21 Mar. 1996, when ψ_m was −62 kPa for the drought-stressed ... obtained on 29 Mar., when ψ_m was −68 kPa for the drought

Treatment		ϕ_i (mol CO_2/mol incident quanta)
Control	Tainung	0.039 ± 0.001
Drought		0.025 ± 0.001**
Control	Red Lady	0.044 ± 0.001
Drought		0.024 ± 0.001**
Control	Sunrise	0.040 ± 0.001
Drought		0.024 ± 0.001**

**Significant at P = 0.01.

...apidly increased to an early or mid...

Marler e Mickelbart, 1998



Strategies to increase effective use of water in papaya

-Regulated deficit irrigation (RDI)
-Partial rootzone drying (PRD)

Scientia Horticulturae 183 (2015) 13–22

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Partial rootzone drying (PRD) and regulated deficit irrigation (RDI) effects on stomatal conductance, growth, photosynthetic capacity, and water-use efficiency of papaya[☆]

CrossMark

Roberta Samara Nunes de Lima[a], Fábio Afonso Mazzei Moura de Assis Figueiredo[a], Amanda Oliveira Martins[a], Bruna Corrêa da Silva de Deus[a], Tiago Massi Ferraz[a], Mara de Menezes de Assis Gomes[a], Elias Fernandes de Sousa[b], David Michael Glenn[c], Eliemar Campostrini[a,*]

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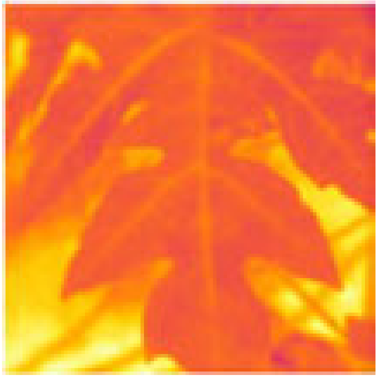
Strategies to increase effective use of water in papaya

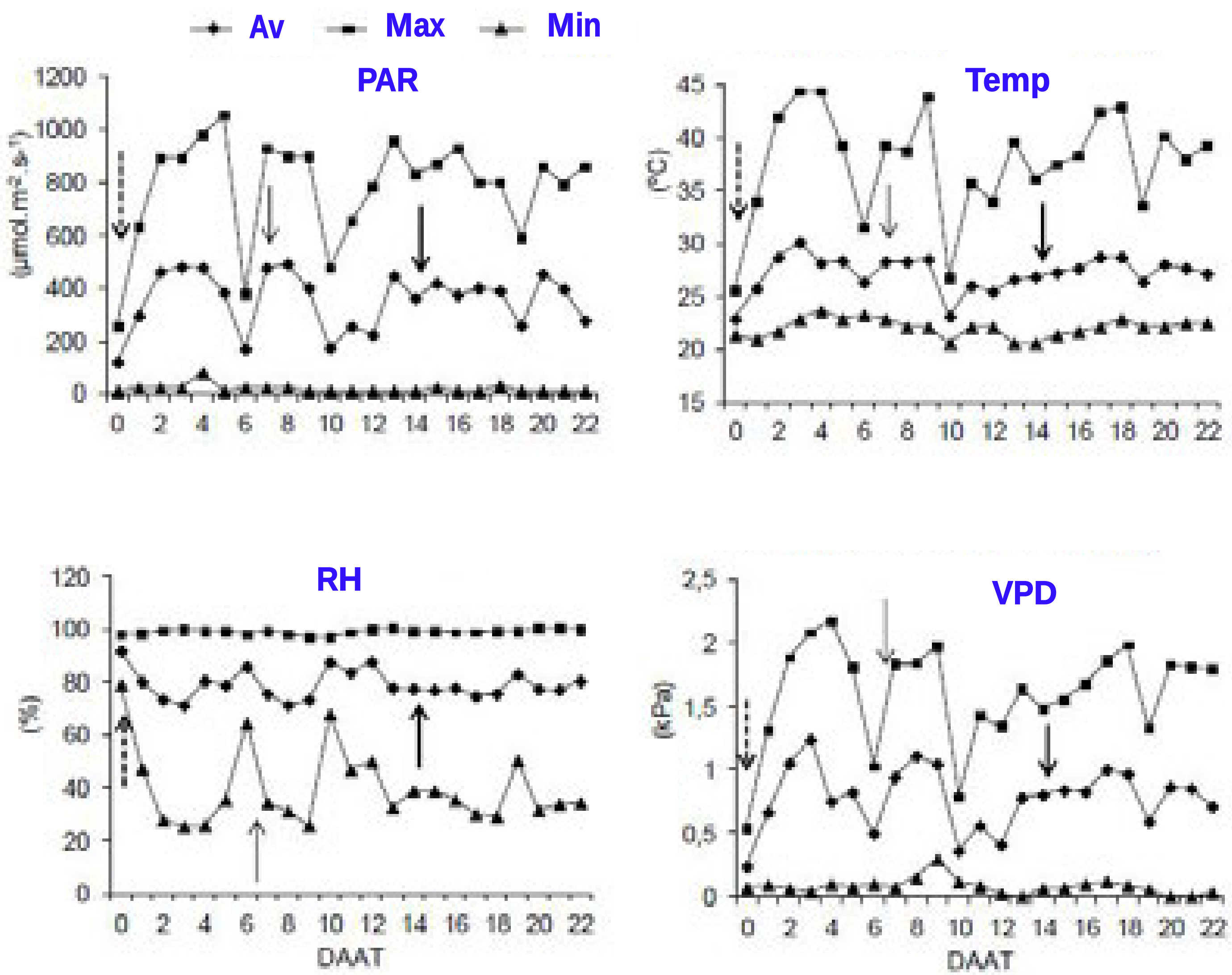
-Regulated deficit irrigation (RDI)
-Partial rootzone drying (PRD)

15L pots
Substrate soil, sand and cattle manure (2:1:2)
The plants were kept at field capacity (FC) until they were 96 days old.





-Gas exchange
-Chlorophyll fluorescence
-Growth (central vein lenght, root dry biomass, stem dry biomass, leaf dry biomass, total dry biomass, root volume)
-Proline
-Carbon isotope discrimination
-Agronomic water use efficiency
-Thermal imaging


Av
Max
Min
PAR
(µmol.m-2.s-1)
Temp
(°C)
RH
(%)
VPD
(kPa)
DAAT
DAAT

The plants were kept at field capacity (FC) until they were 96 days old.

Table 1
Timeline of irrigation treatments.

		Days after irrigation treatment application																					
Treatment	Pot	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
FI	1												100% FC										
	2												100% FC										
PRD	1					100% FC														100% FC			
	2												100% FC										
RDI	1												50% FC										
	2												50% FC										
NI	1																			100% FC			
	2																			100% FC			

Full irrigated (FI); partial-root-zone drying (PRD); regulated deficit irrigation (RDI); non-irrigated (NI). Dark-grey represents the period of days in which irrigation was applied at 100% of field capacity (FC). The light grey represents the days with irrigation at 50% of field capacity. The white color represents the period of time with no irrigation.

Table 1
Total volume of water applied, and volume applied per day of greenhouse-grown papaya (*Carica papaya* L.) in splitroot pots with four different irrigation treatments: full irrigated (FI), Partial Rootzone Drying (PRD), Regulated Deficit Irrigation (RDI), and non-irrigated followed by 6 days of FI (NI-gh).

Treatment	Total volume of water applied (L)	Volume of water applied per day (L)
FI	47.50	2.3
PRD	23.8	1.1
RDI	23.8	1.1
NI-gh	21.3	1.0

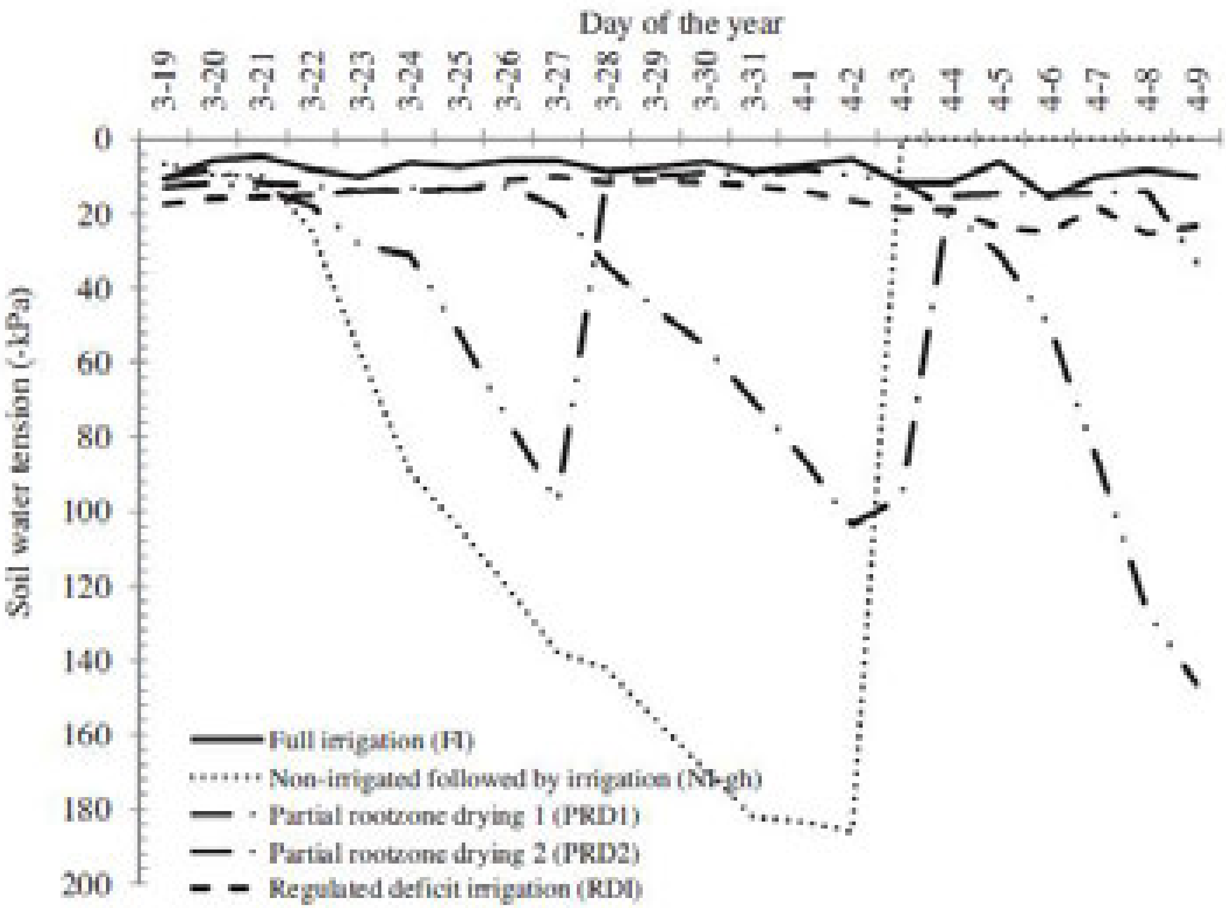


Fig. 1. Daily soil water potential (−kPa) planted with 'Grand Golden' papaya with four irrigation treatments. PRD-1 and PRD-2 indicate the two sides of the PRD pots.

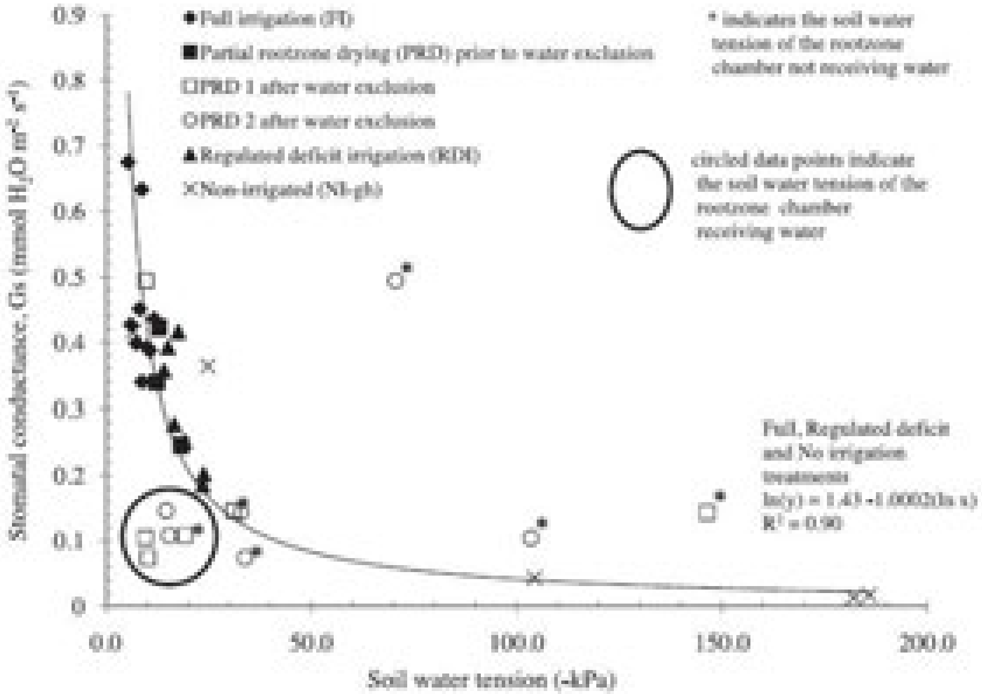
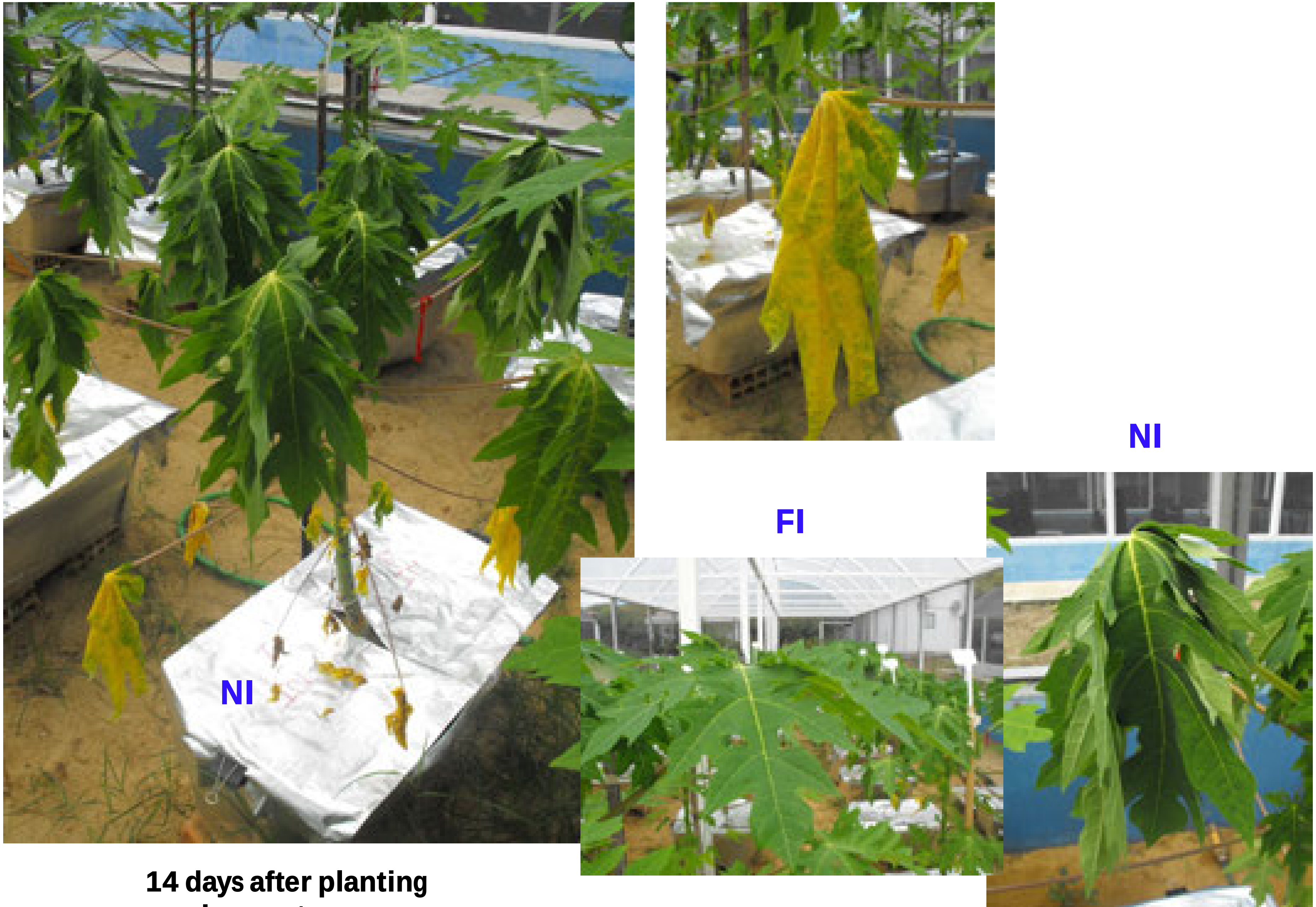


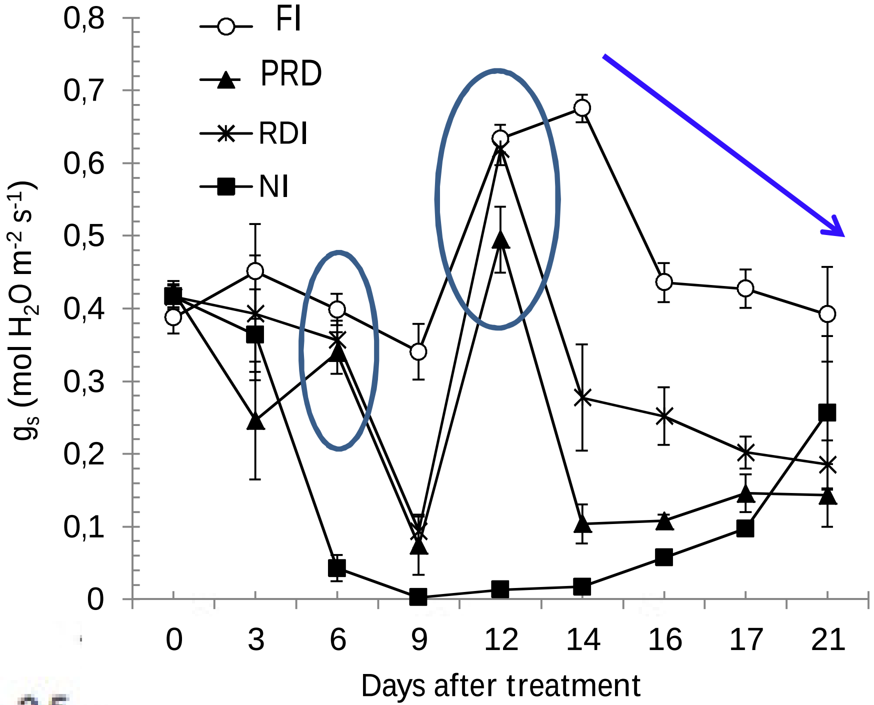
Fig. 10. Relationship between stomatal conductance and soil water potential in papaya in four irrigation treatments in the greenhouse.

NI **PRD**

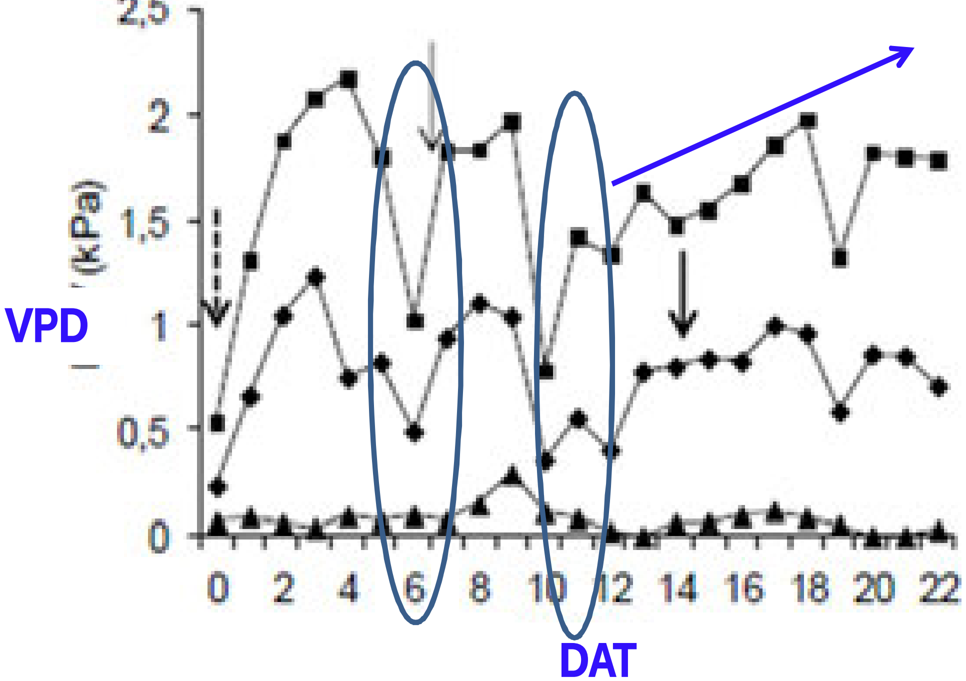
14 days after planting maximum stress



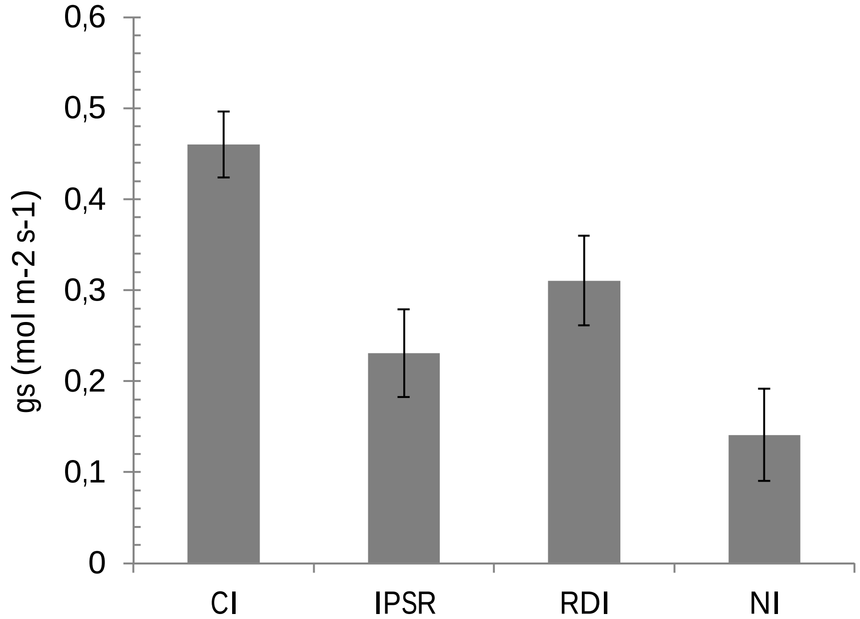
14 days after planting
maximum stress



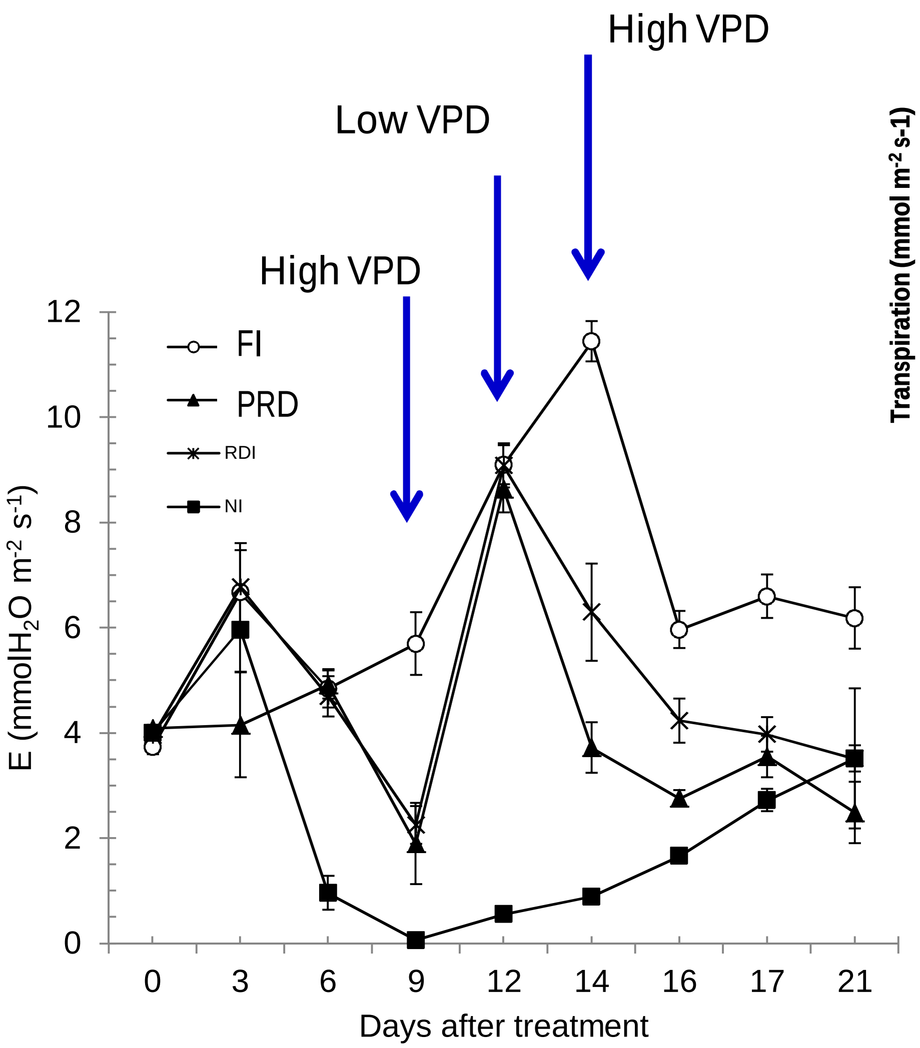
FI
PRD
RDI
NI
g_s (mol H_2O m^{-2} s^{-1})
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0 3 6 9 12 14 16 17 21
Days after treatment

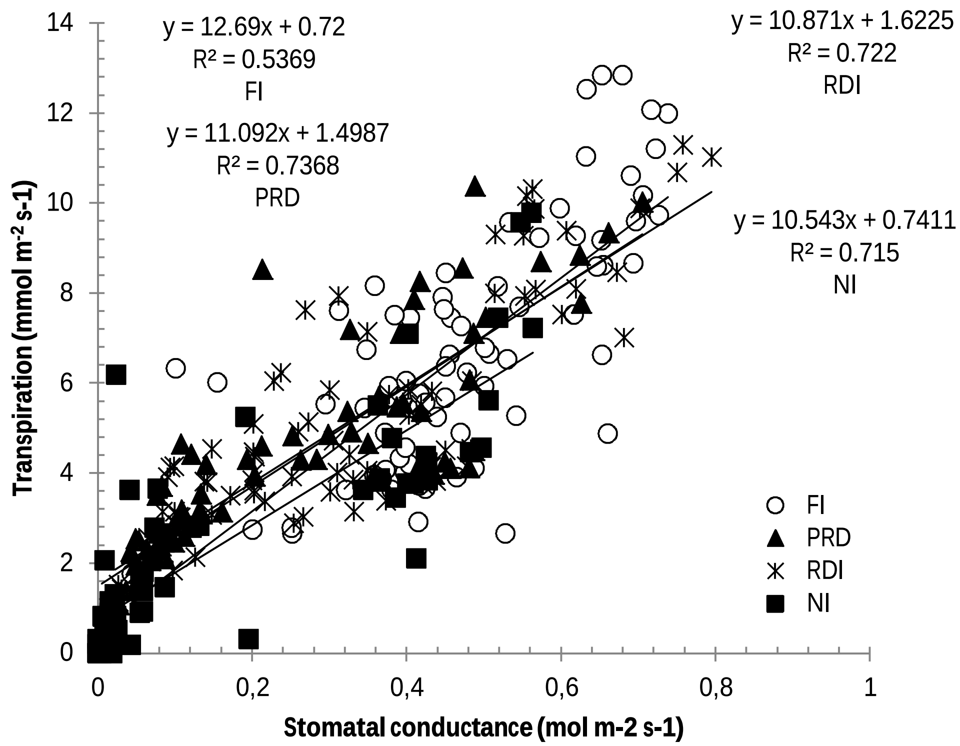


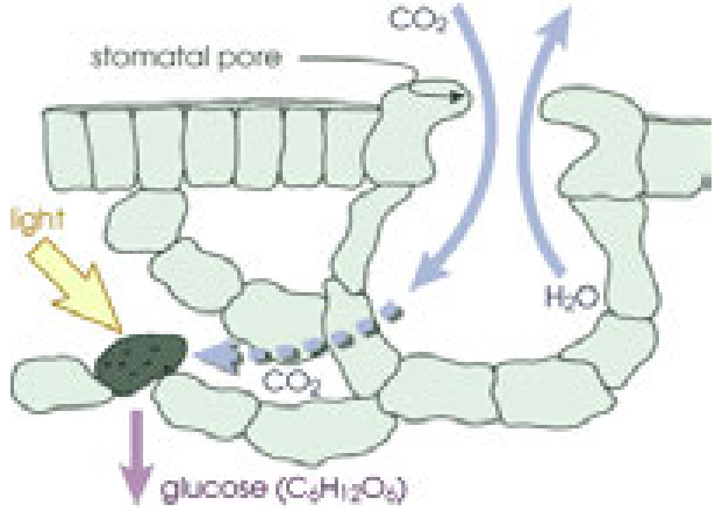
VPD
(kPa)
2,5
2
1,5
1
0,5
0
0 2 4 6 8 10 12 14 16 18 20 22
DAT



gs (mol m-2 s-1)
0,6
0,5
0,4
0,3
0,2
0,1
0
CI
IPSR
RDI
NI


High VPD
Low VPD
High VPD
FI
PRD
RDI
NI
E (mmolH2O m-2 s-1)
Days after treatment
0 3 6 9 12 14 16 17 21


y = 12.69x + 0.72
R² = 0.5369
FI
y = 11.092x + 1.4987
R² = 0.7368
PRD
y = 10.871x + 1.6225
R² = 0.722
RDI
y = 10.543x + 0.7411
R² = 0.715
NI
Transpiration (mmol m-2 s-1)
Stomatal conductance (mol m-2 s-1)
FI
PRD
RDI
NI


stomatal pore
CO2
H2O
light
CO2
glucose (C6H12O6)

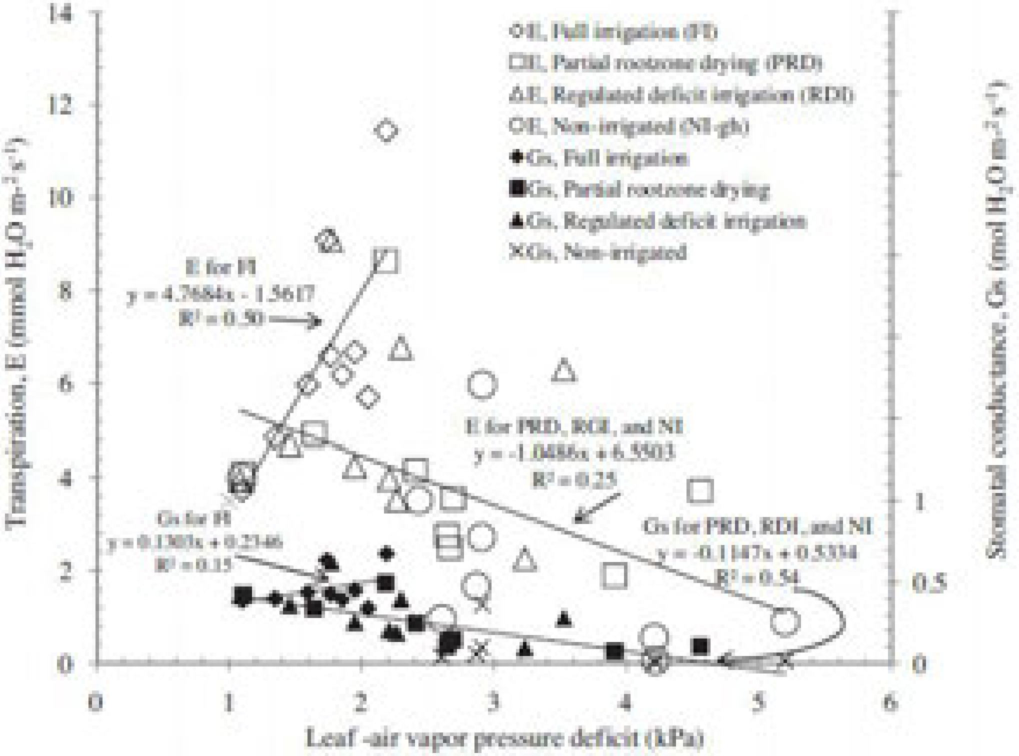
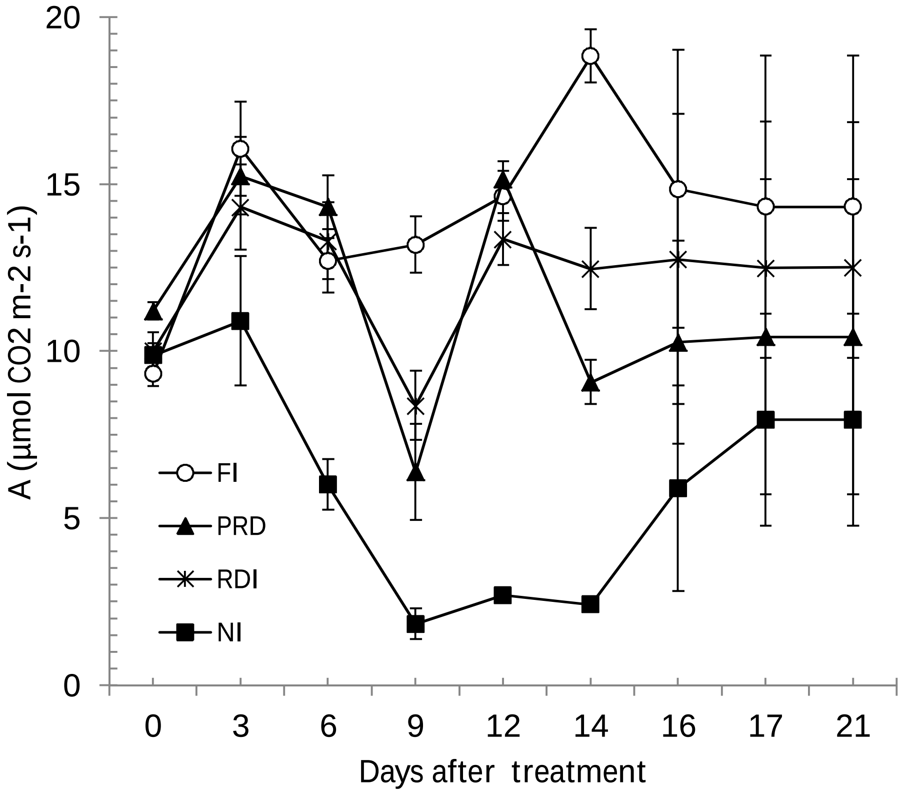
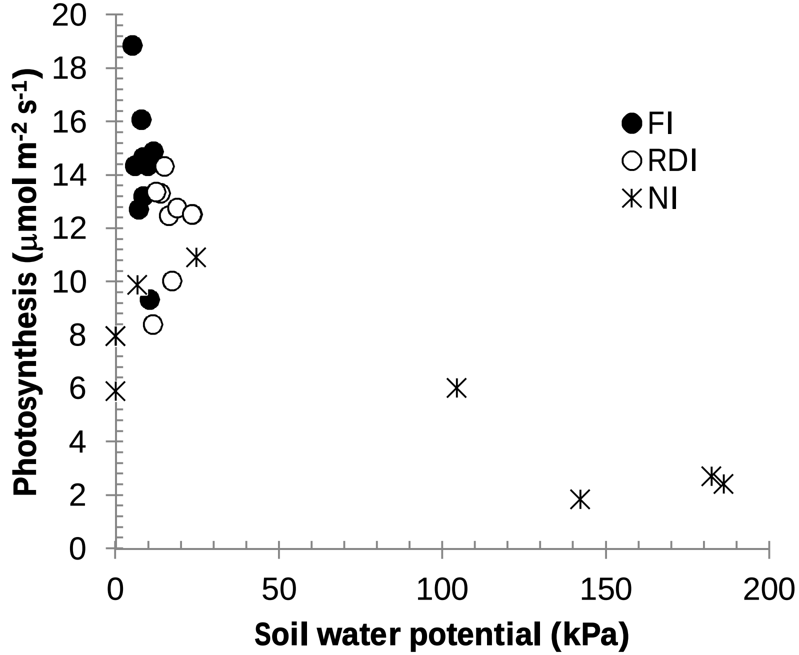
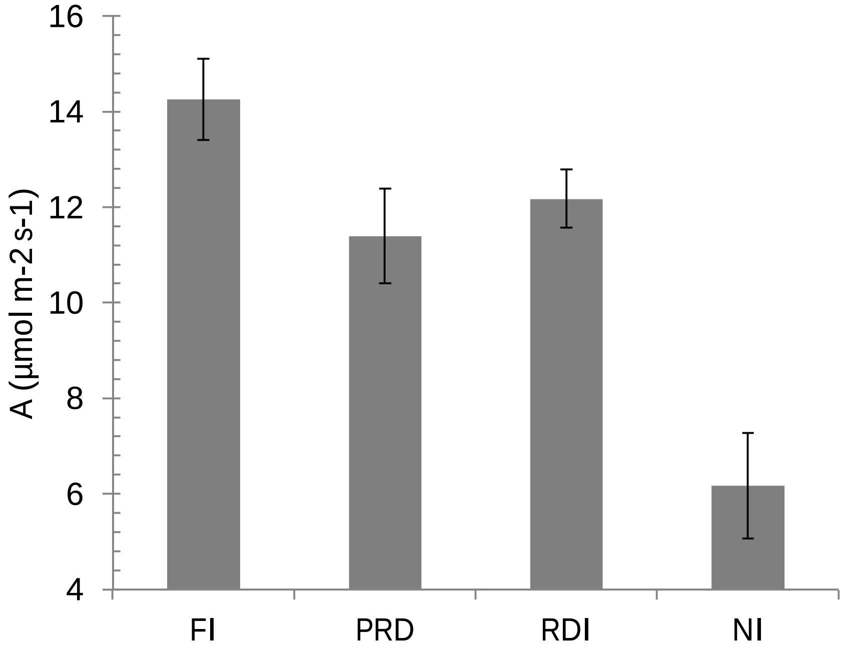


Fig. 6. Relationship of leaf–air vapor pressure deficit to transpiration and stomatal conductance in papaya in four irrigation treatments in a greenhouse.


A (µmol CO2 m-2 s-1)
Days after treatment
0
3
6
9
12
14
16
17
21
FI
PRD
RDI
NI


Photosynthesis (µmol m-2 s-1)
Soil water potential (kPa)
FI
RDI
NI


A (µmol m-2 s-1)
FI
PRD
RDI
NI

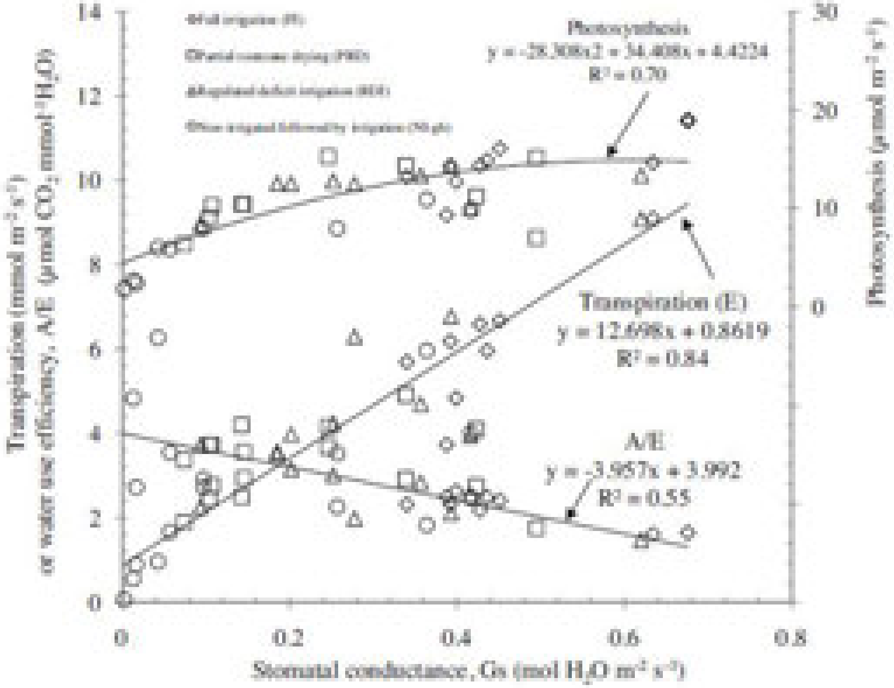


Fig. 3. Relationship of stomatal conductance (G_s) to transpiration (E), photosynthesis (A) and water use efficiency (A/E) for papaya treated with four irrigation regimes.

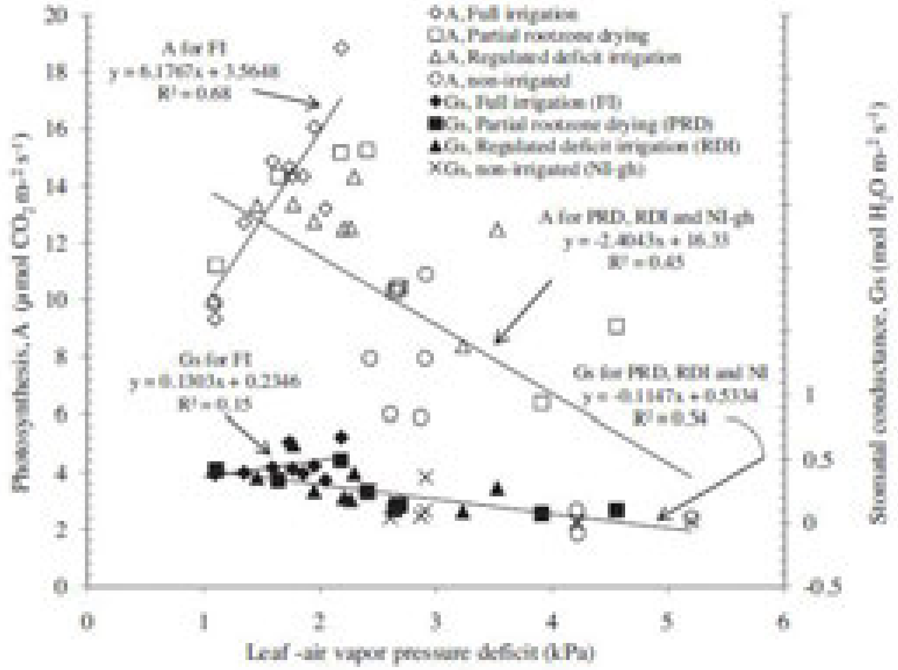


Fig. 5. Relationship of photosynthesis to stomatal conductance with the leaf-air vapor pressure deficit in papaya treated with four irrigation treatments in the greenhouse.

Photochemical efficiency of PSII

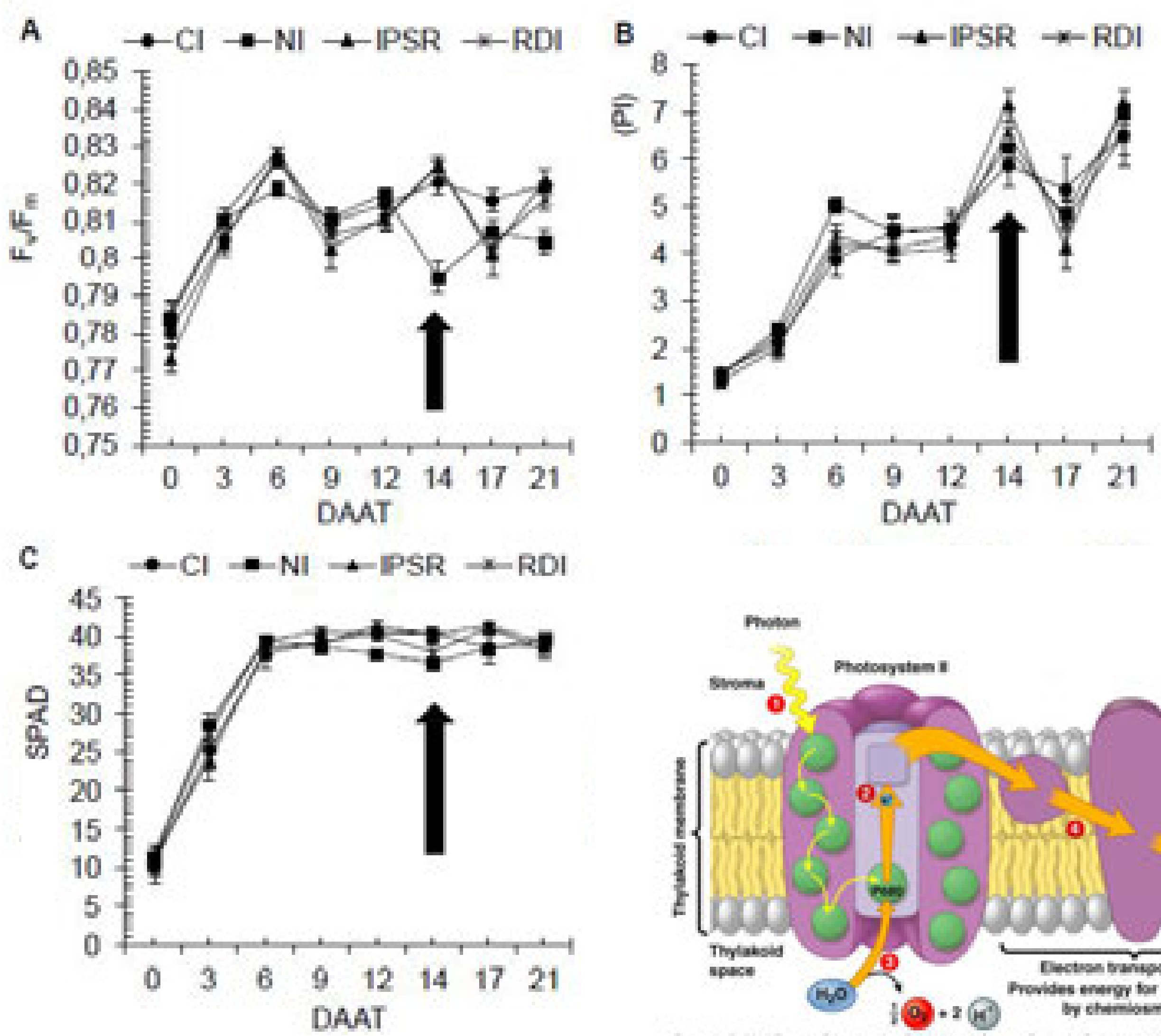
PI=(RC/ABS) x (TR/DI) x (ET/(TR-ET))

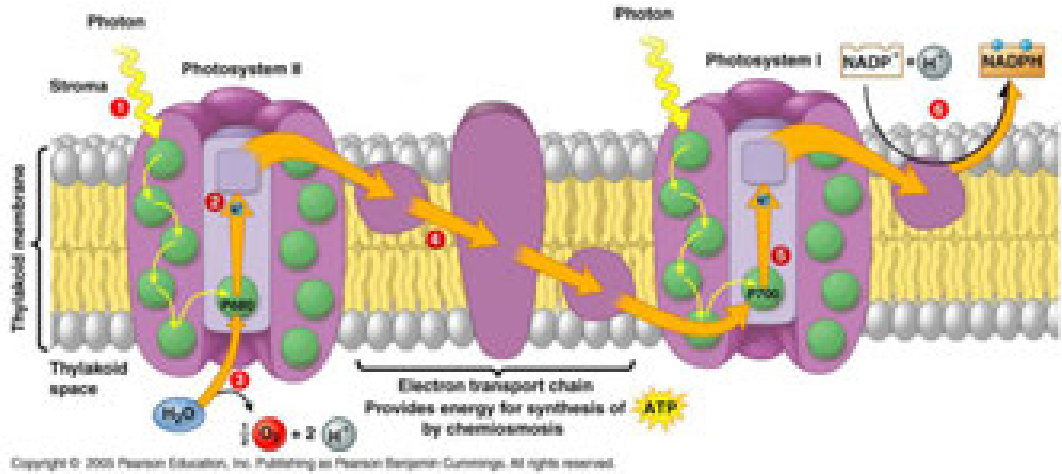
(RC/ABS): Active RC density on a Chl basis

(F_V/F_0): Performance due to trapping probability $F_v/F_0=TR/DI$

(ET/(TR-ET): Performance due to electron-transport probability

$F_v/F_m= TR/ABS$





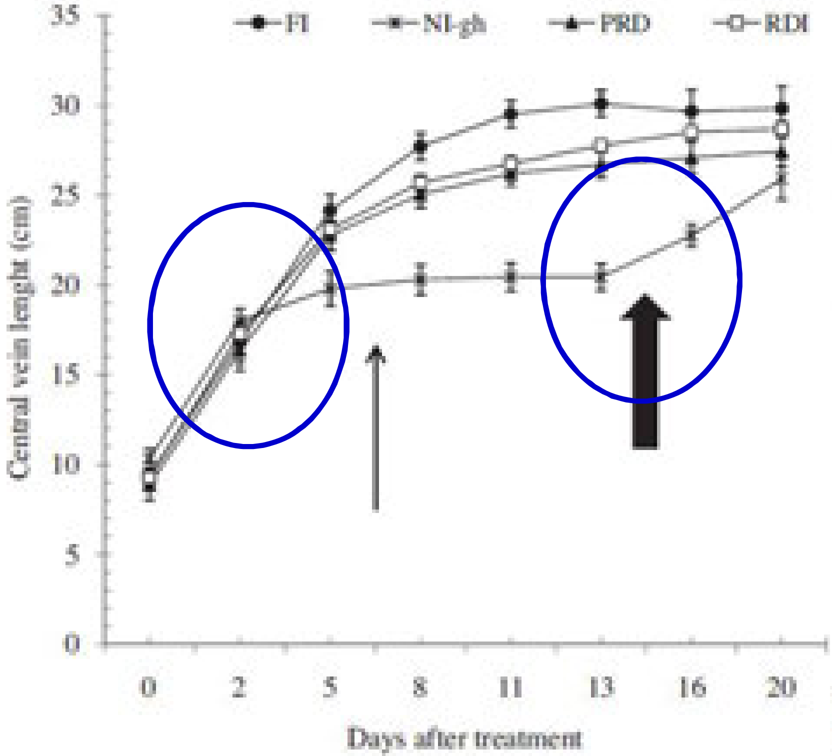


Fig. 7. Central vein length during the ontogeny of the youngest leaf of each plant ('Grand Golden' papaya) in splitroot pots under four different irrigation regimes: FI, NI-gh, PRD, RDI. The narrow and broad arrows indicate the first alternating between the two root sides of the PRD pots and rehydration of NI treatment, respectively ($n = 10$).

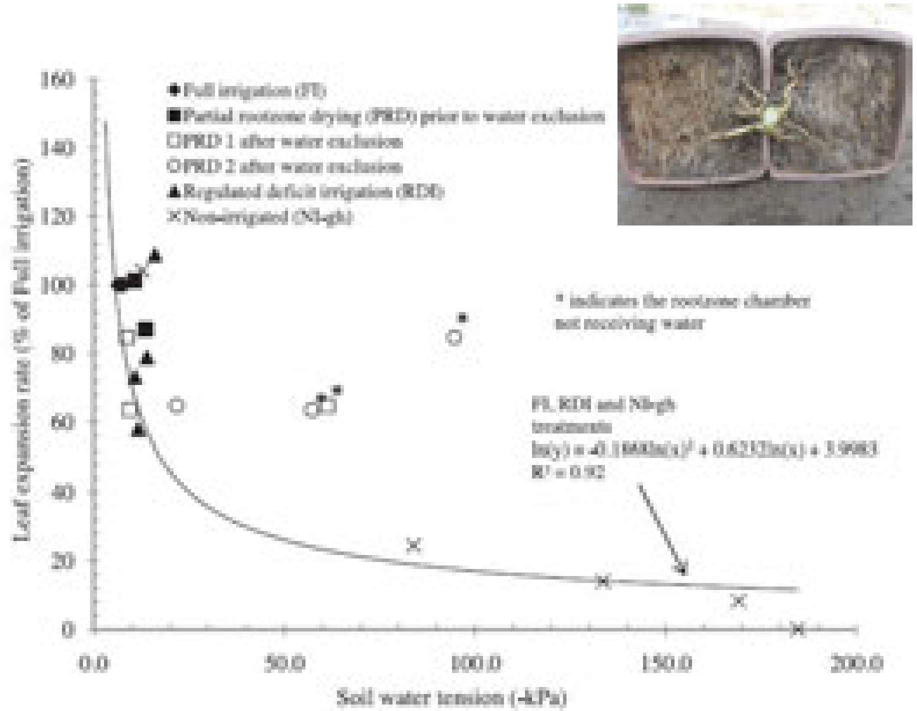
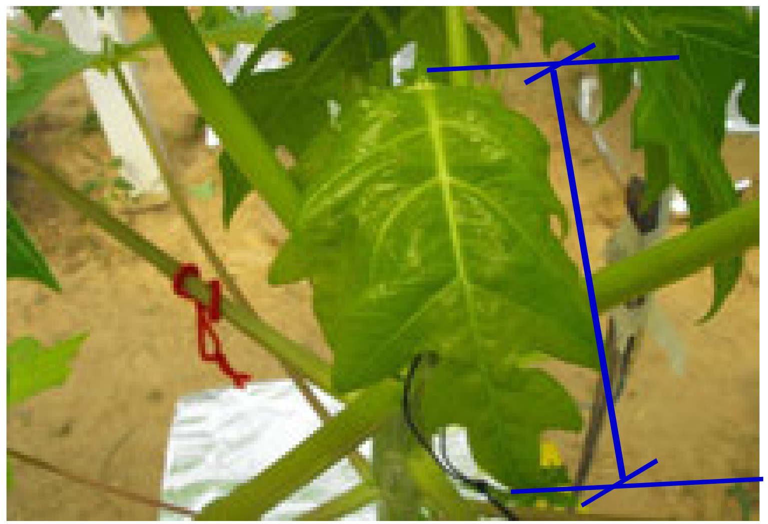
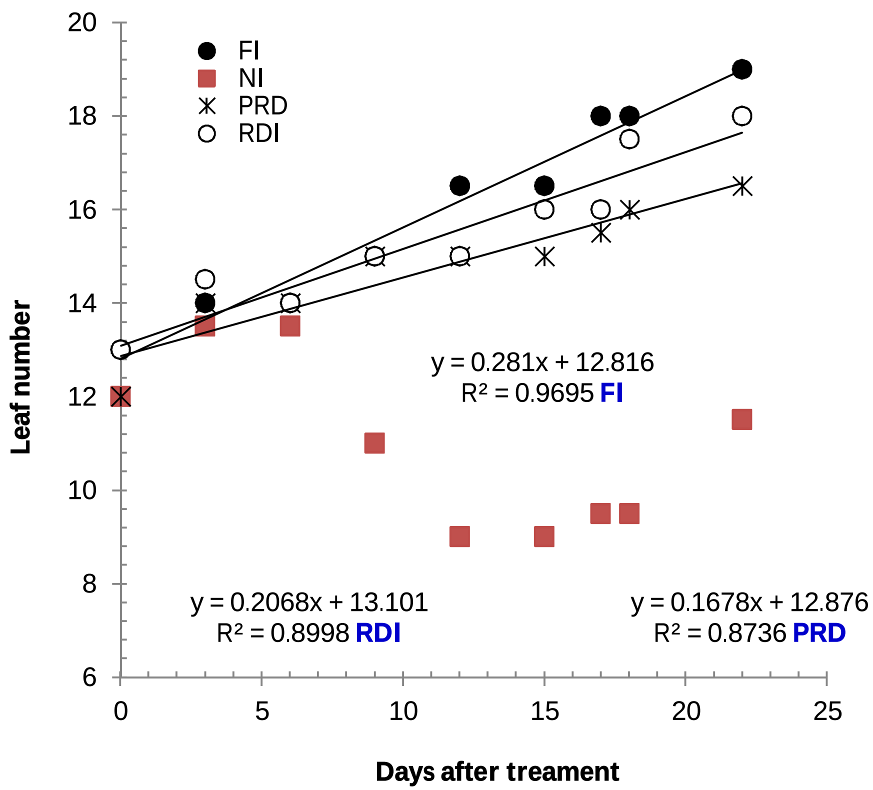
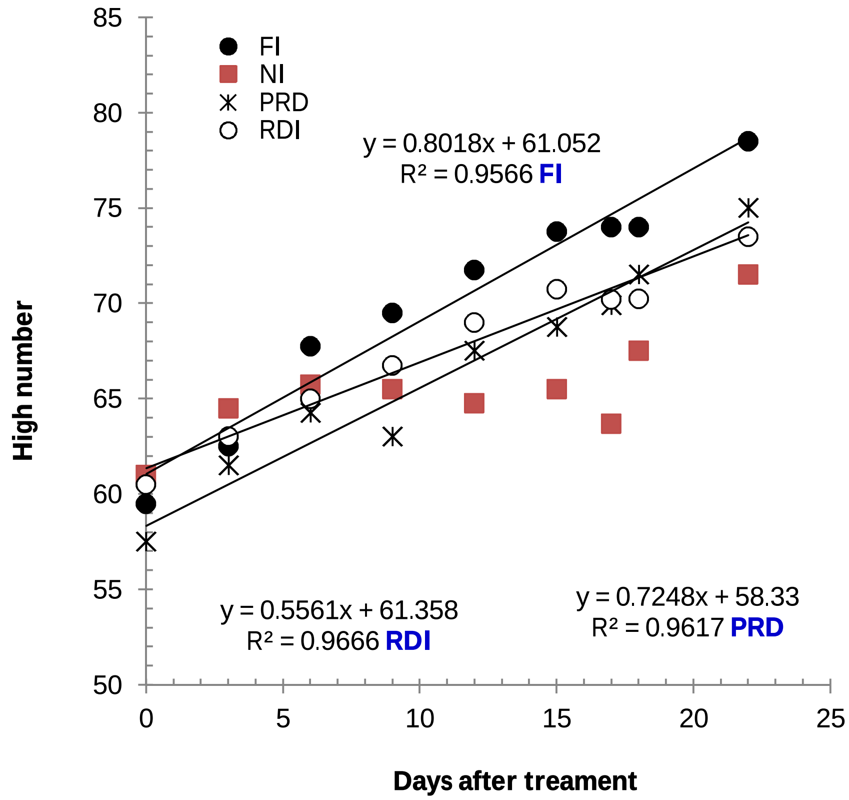


Fig. 11. Relationship between incremental leaf growth (% of full irrigation) and soil water potential in papaya in four irrigation treatments in the greenhouse.





Leaf number
Days after treament
FI
NI
PRD
RDI
y = 0.281x + 12.816
R² = 0.9695 FI
y = 0.2068x + 13.101
R² = 0.8998 RDI
y = 0.1678x + 12.876
R² = 0.8736 PRD



High number
Days after treament
FI
NI
PRD
RDI
y = 0.8018x + 61.052
R² = 0.9566 FI
y = 0.5561x + 61.358
R² = 0.9666 RDI
y = 0.7248x + 58.33
R² = 0.9617 PRD

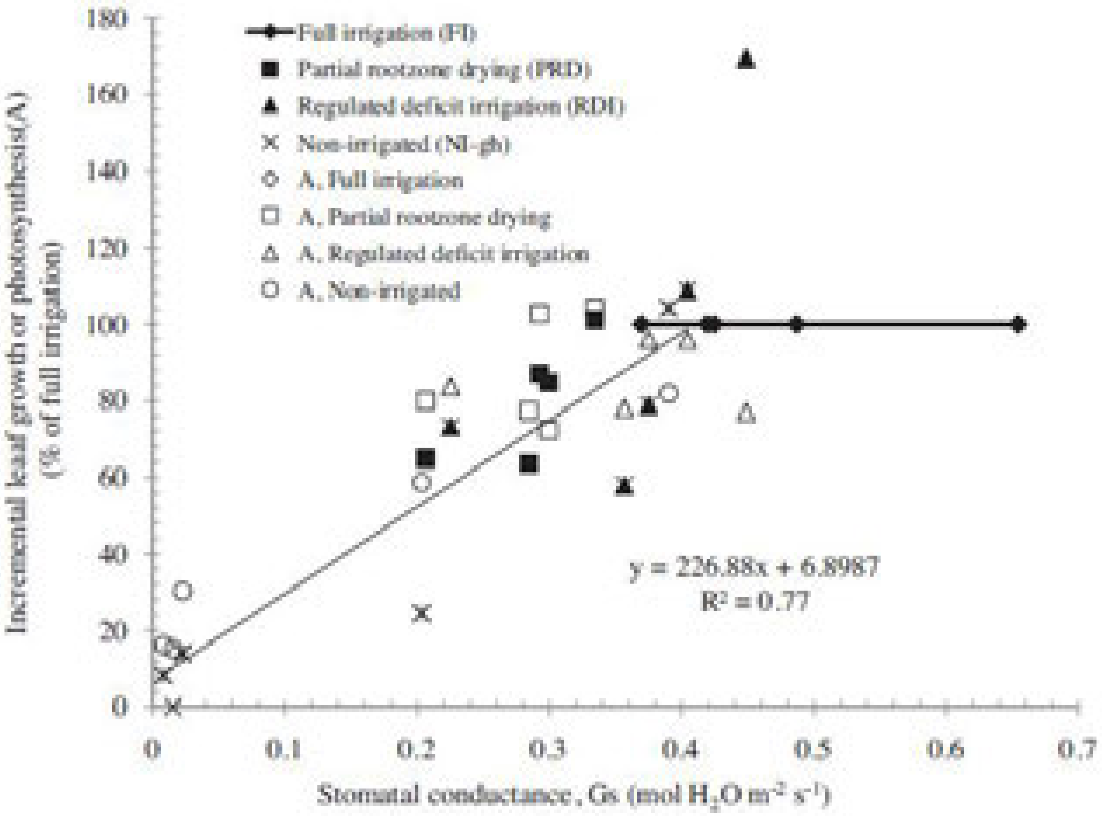


Fig. 12. Relationship of stomatal conductance (G_s) to incremental leaf growth and photosynthesis (A) in papaya in four irrigation treatments in a greenhouse.

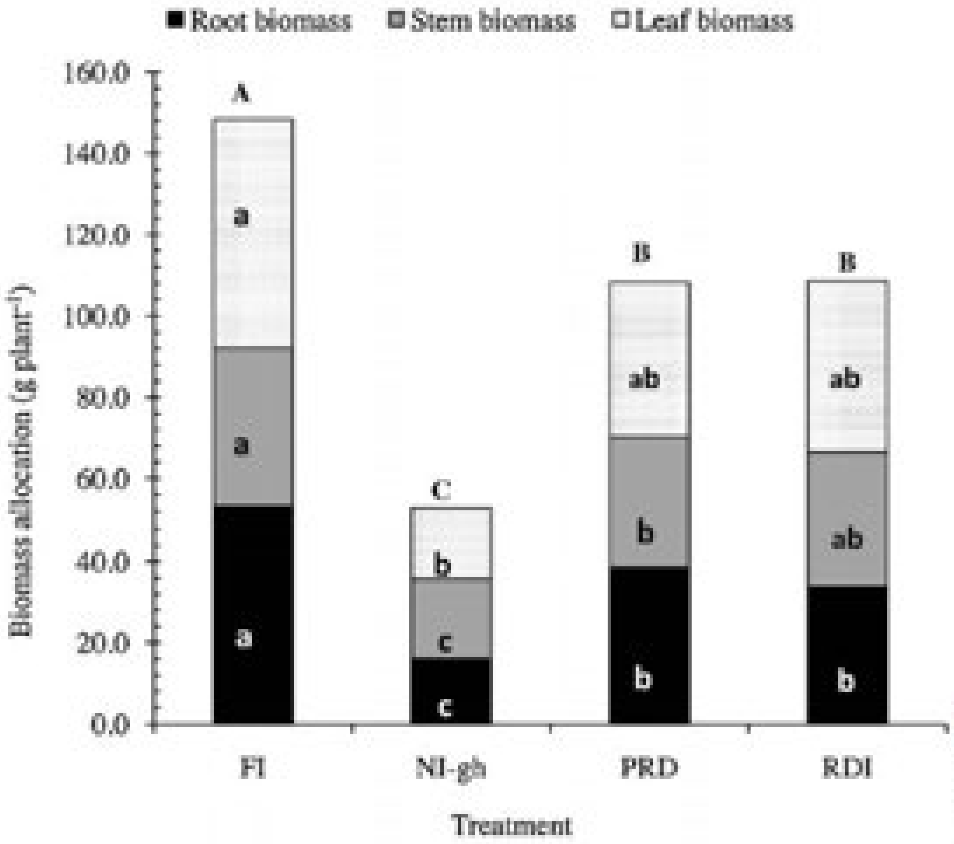


Fig. 8. Biomass allocation of leaf, trunk and root (g dry weight plant^{-1}) tissues in papaya treated with four irrigation regimes in the greenhouse. FI, NI-gh, PRD, RDI. Capital letters refer to mean separation between treatments. Lower case letters refer to mean separation within the three tissue components (*P* = *0.05*).

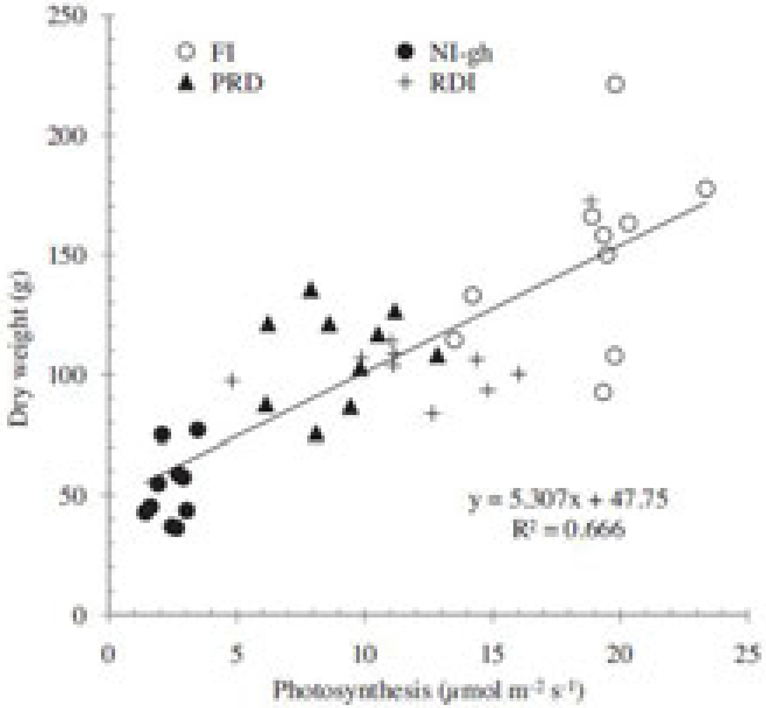
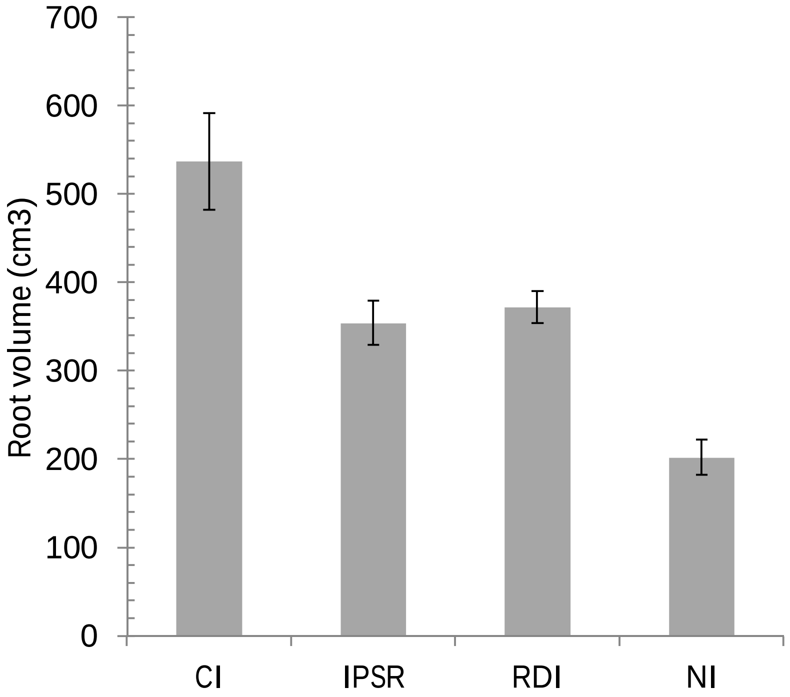
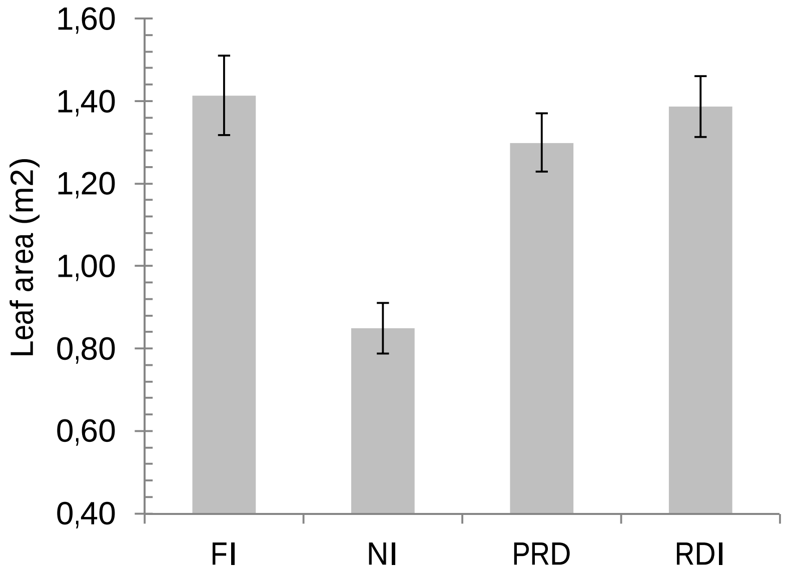


Fig. 9. Relationship of photosynthesis to dry weight 14 days after initiating treatments (the day of most intense water stress for the plants in NI-gh) in 110-days-old 'Grand Golden' papaya plants grown in splitroot pots under four different irrigation regimes (FI, NI-gh, PRD, RDI) in a greenhouse. Values represent means of 10 replicates.


Root volume (cm3)
700
600
500
400
300
200
100
0
CI
IPSR
RDI
NI


Leaf area (m2)
1,60
1,40
1,20
1,00
0,80
0,60
0,40
FI
NI
PRD
RDI

FI

NI

RDI

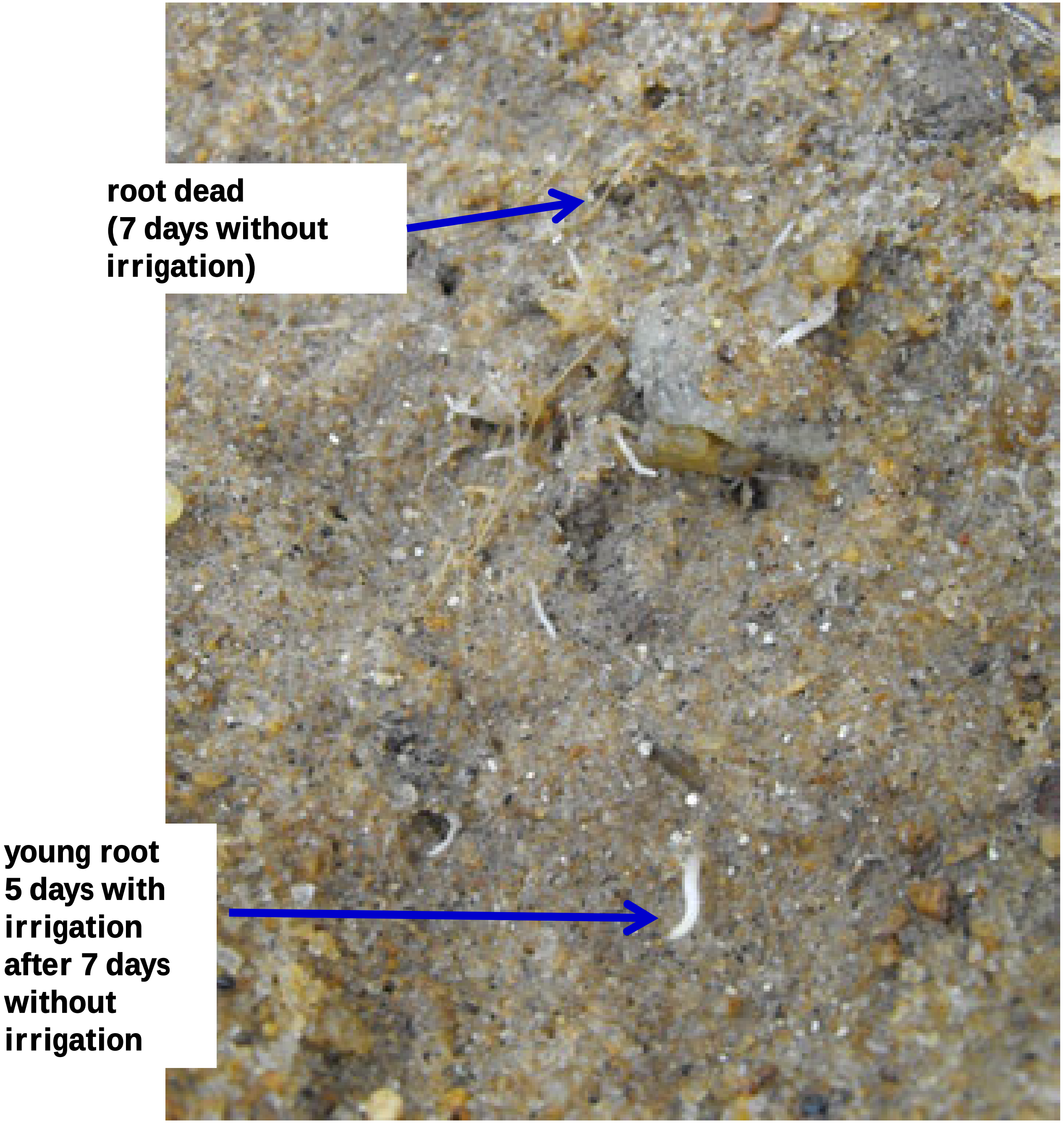
PRD

FI

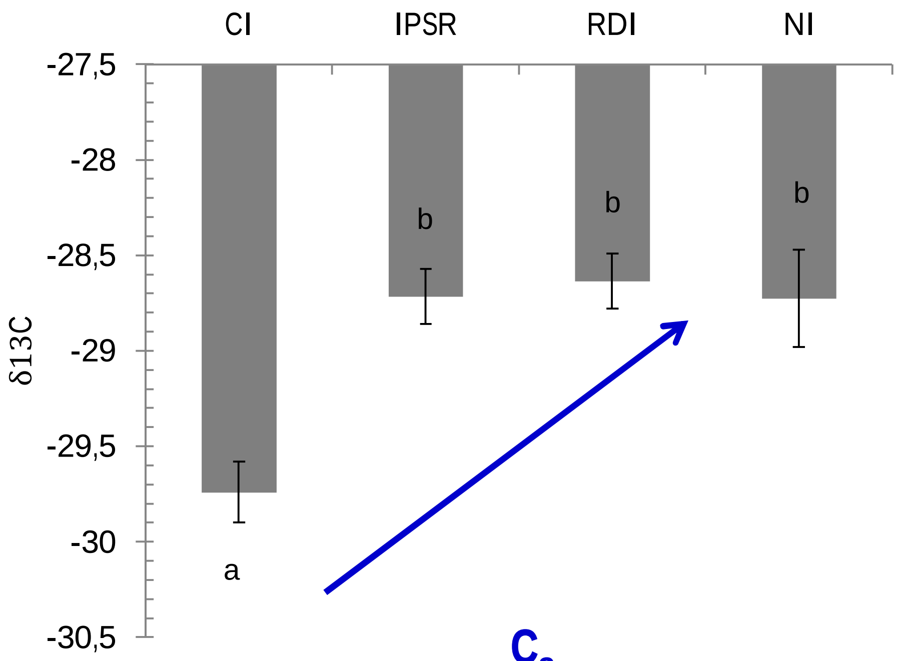
FI

NI

Dry side of PRD

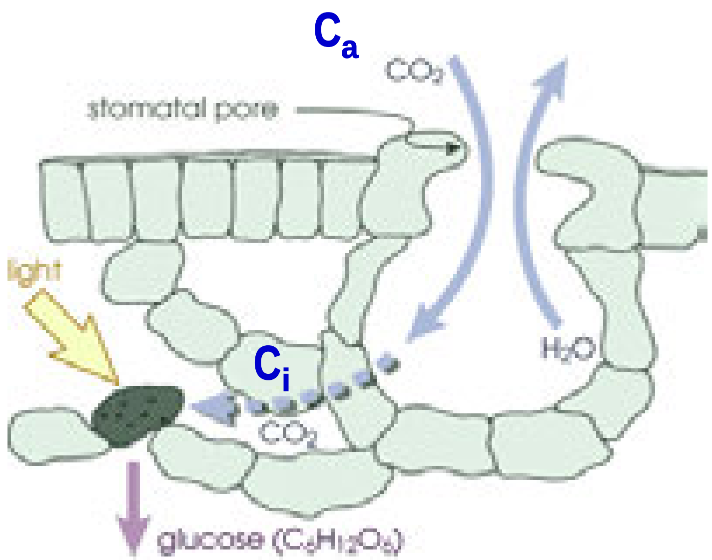

root dead
(7 days without
irrigation)
young root
5 days with
irrigation
after 7 days
without
irrigation

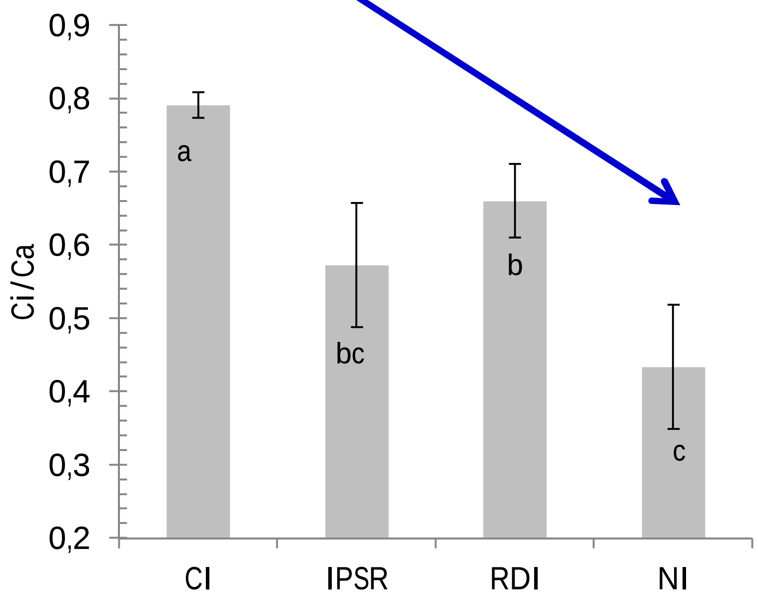
Carbon isotope discrimination



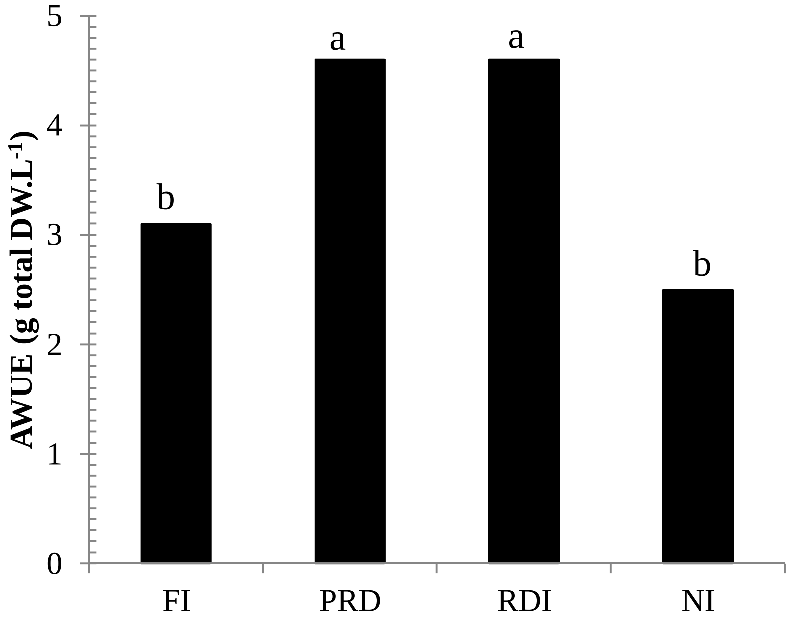
$>C_i/C_a\ (\approx 0{,}7) = \mathbf{<\delta\ ‰}$

$<C_i/C_a\ (\approx 0{,}3) = \mathbf{>\delta\ ‰}$





Agronomic water use efficiency



Treatment	Water economy in relation FI (%)	AWUE (g DM L^{-1})	Transpiration rate (L H_2O g DM^{-1})
FI	-	3.12	0.322
PRD	**50%**	4.55	0.217
RDI	**50%**	4.57	0.217
NI	55.14%	2.46	0.400

C3 crops
1 to 6 g DM L^{-1} H_2O

C4 grasses
10 to 30 g DM L^{-1} H_2O

Arkley (1982)

Table 1
Total volume of water applied, and volume applied per day of greenhouse-grown papaya (*Carica papaya* L.) in splitroot pots with four different irrigation treatments: full irrigated (FI), Partial Rootzone Drying (PRD), Regulated Deficit Irrigation (RDI), and non-irrigated followed by 6 days of FI (NI-gh).

Treatment	Total volume of water applied (L)	Volume of water applied per day (L)
FI	47.50	2.3
PRD	23.8	1.1
RDI	23.8	1.1
NI-gh	21.3	1.0

Treatment	L H_2O m^{-2} day^{-1}
FI	1.63
PRD	0.84
RDI	0.78
NI	1.17

Treatment	Volume water applied per plant per day	Transpiration L H2O per m² leaf per day per plant	Transpiration L H20 per plant per day	Leaf area m2	age
Whole canopy summer	16.0	2.5	10	4.0	5 months
Whole canopy winter	10.0	4.2	15	3.5	5 months
FI	2.3	1.63	2.3	1.41	3 months
PRD	1.1	0.84	1.1	1.30	3 months
RDI	1.1	0.78	1.1	1.40	3 months
NI	1.0	1.17	1.0	0.85	3 months

Thermal imaging

G Model
AGWAT-4235; No. of Pages 10

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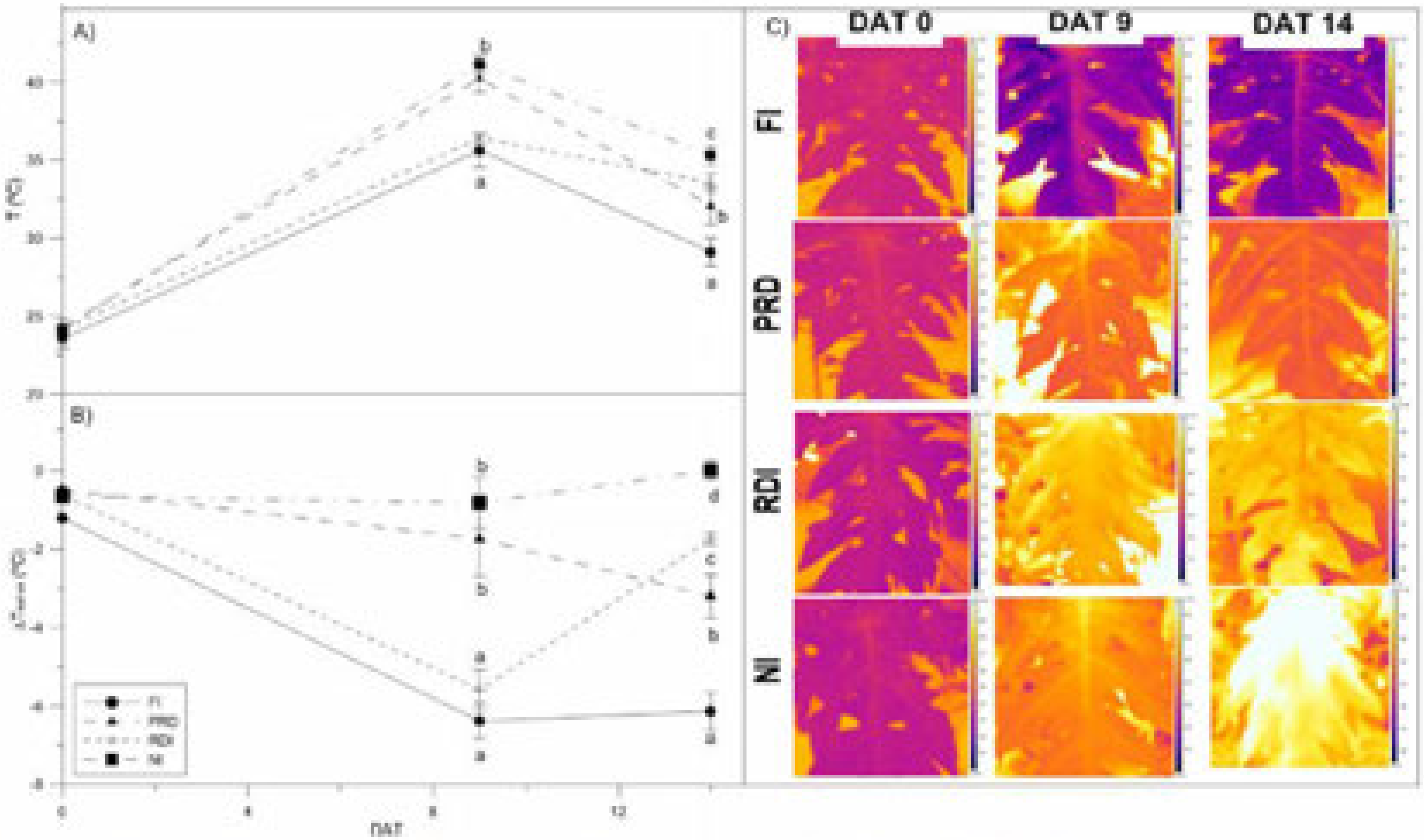
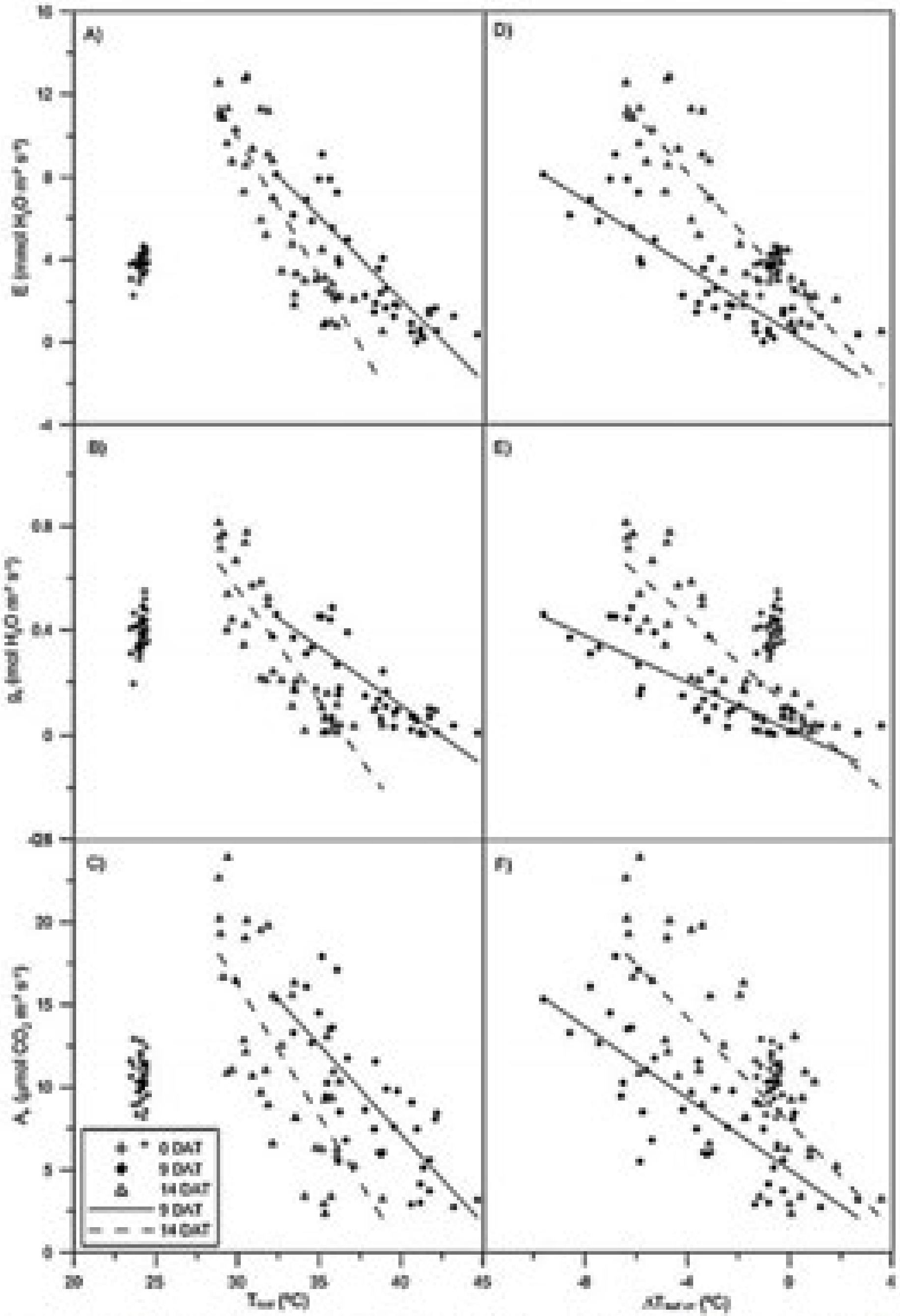


Fig. 3. (A) Leaf temperature (T_{leaf}) derived from IR measurements during the study (DAT); (B) difference of leaf to air temperature ($\Delta T_{leaf-air}$), and (C) false-colored IR thermal images showing a selected fully expanded leaf, along the experiment for the different treatments: fully irrigated (FI); partial root drying (PRD); regulated-deficit irrigation (RDI); non-irrigated (NI). Climate conditions at 0 DAT (T_{air} max: 25 °C, RH_{min}: 80%, ϕ_{soil} = −10 kPa, PAR_{max} = 257 μmol m^{-2} s^{-1}); 9 DAT (T_{air} max: 44 °C, RH_{min}: 26%, PAR_{max} = 900 μmol m^{-2} s^{-1}) and 14 DAT (T_{air} max: 36 °C, RH_{min}: 39%, PAR_{max} = 830 μmol m^{-2} s^{-1}). Leaf temperature scale is identical for four treatments in the same day of observation. Different letters indicate significant differences at $P < 0.05$ by the Tukey's test ($n = 10$).



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Linking thermal imaging to physiological indicators in *Carica papaya* L. under different watering regimes

R.S.N Lima, I. García-Tejero, T.S. Lopes, J.M. Costa, M. Vaz, V.H. Durán-Zuazo, M. Chaves, D.M. Glenn, E. Campostrini

Fig. 4. Relationship between transpiration (E), stomatal conductance to water vapor (g_s) and net assimilation (A_N) vs. the leaf temperature (T_{leaf}) and the difference between T_{leaf} and air temperature ($\Delta T_{leaf-air}$). Each linear function was determined with 80 pair of data (n = 80).

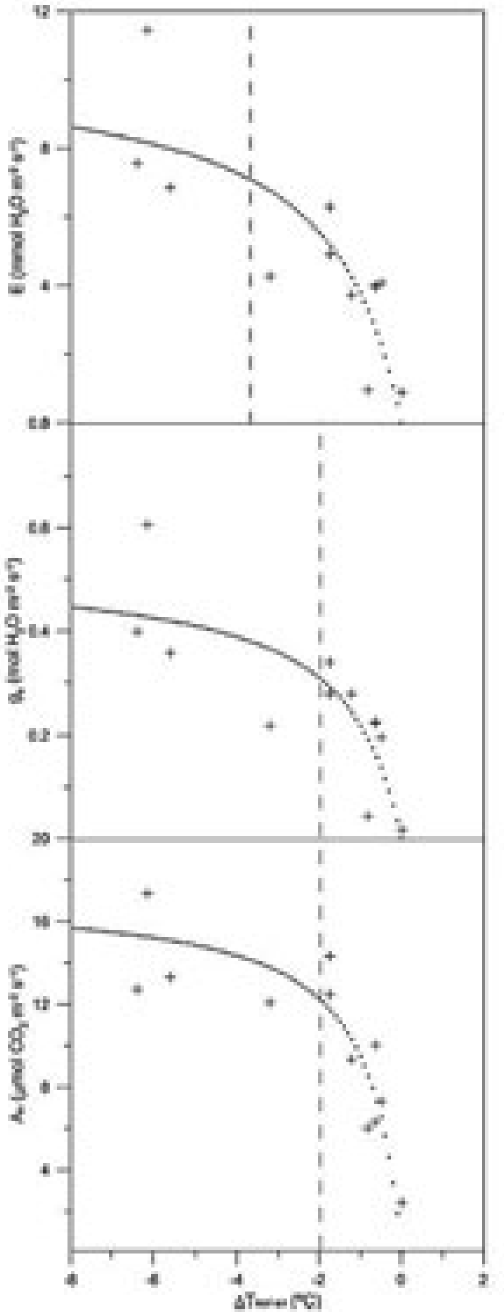

Fig. 5. Relationship between air temperature ($\Delta T_{leaf-air}$), stomatal conductance (g_s) and net photosynthesis (A).

Scientia Horticulturae 183 (2015) 13–22

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Partial rootzone drying (PRD) and regulated deficit irrigation (RDI) effects on stomatal conductance, growth, photosynthetic capacity, and water-use efficiency of papaya☆

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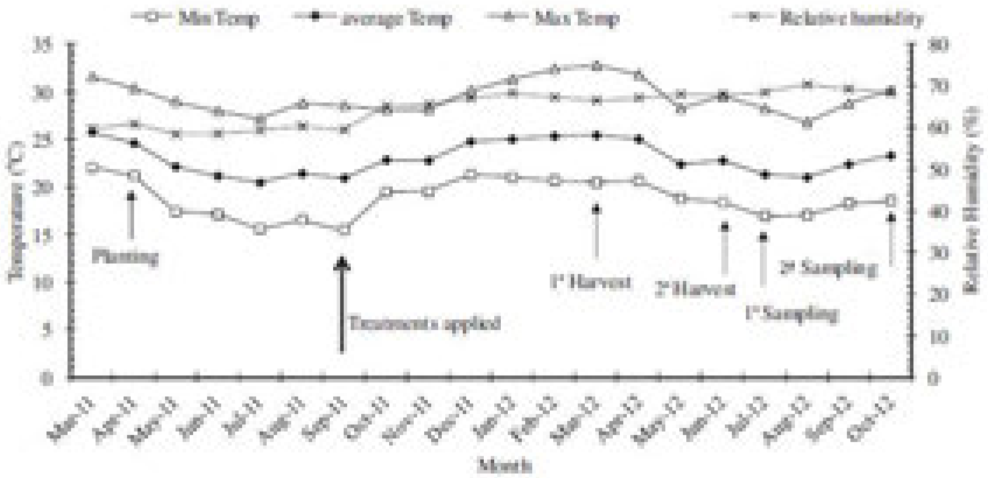
[c] USDA-ARS, Appalachian Fruit Research Station, 2217 Wiltshire Road, Kearneysville, WV 25430, USA

20 months
Caliman company
Brazil
http://www.caliman.com.br/pt/

Field condition

Field condition



Treatment	Irrigation + precipitation (L)
FI	2698
NI-field	1025
PRD100	2698
PRD70	2189
RDI	2189
FI	3755
NI-field	1107
PRD100	3755
PRD70	2949
RDI	2949

ET_0

measurement period (Jones, 1992). The meteorological station was installed 300 m the experiment, and the data were used to calculate the reference evapotranspiration (ET_0) using the Penman equation parameterized by the United Nations Food and Agriculture Organization (FAO) (Pereira et al., 1997) (Eq. (1)). We considered that the daily balance heat flow in soil was zero ($G = 0$).

$$ET_0 = \frac{s}{(s+\gamma^*)}(Rn - G)\frac{1}{\lambda} + \frac{\gamma}{(s+\gamma^*)(T+275)}U_2(e_s - e_a) \quad (1)$$

where: s is the slope of the vapor pressure curve (kPa °C^{-1}); γ^* is the modified psychrometric constant (kPa °C^{-1}); Rn is the net radiation (MJ m^{-2} d^{-1}); G is the heat flow in soil (MJ m^{-2} d^{-1}); λ is the latent heat of evaporation (MJ kg^{-1}); γ = psychrometric coefficient (kPa °C^{-1}); T is the average temperature (°C); U_2 is the wind speed at 2 m (m s^{-1}); e_s is the saturation vapor pressure (kPa); e_a is the partial pressure of vapor (kPa).

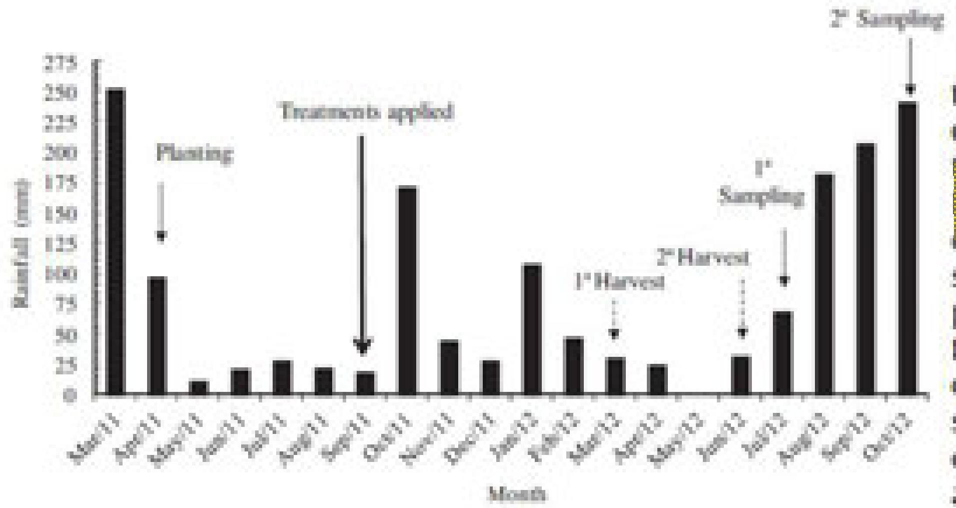


Fig. 2. Meteorological variables in a field study.

to 5-month-old plants: [illegible] was applied on both sides of the root with 1 drip line and 2 emitters per plant (0.75 m emit- [illegible] ow was 2.3 L h^{-1} (total flow: 4.6 L plant^{-1}); [illegible] applied to one side only of the root, and [illegible] as applied to the alternate side of the root system. Water was applied with 2 drip lines and 2 emitters per plant (0.75 m emitter [illegible] mitter flow was 2.3 L h^{-1} (total flow: 4.6 L plant^{-1}); [illegible] was applied to one side only of the root, and eve [illegible] was applied to the alternate side of the root system to allow always a part of the root system experience a mild water stress. Water was applied with 2 drip lines and 2 emitters per plant (0.50 m emitter spacing). Emitter flow was 1.6 L h^{-1} (total flow: 3.2 L plant^{-1}); [illegible] was applied to both sides of the root system. Water was applied with 1 drip line and 2 emitters per plant (0.50 m e [illegible] Emitter flow was 1.6 L h^{-1} (total flow: 3.2 L plant^{-1} [illegible] non irrigated received only natural rainfall. There was only one soil column in the field study with PRD treatments achieved by applying different amounts of irrigation water to opposite sides of the plant. Air tem-

Field condition

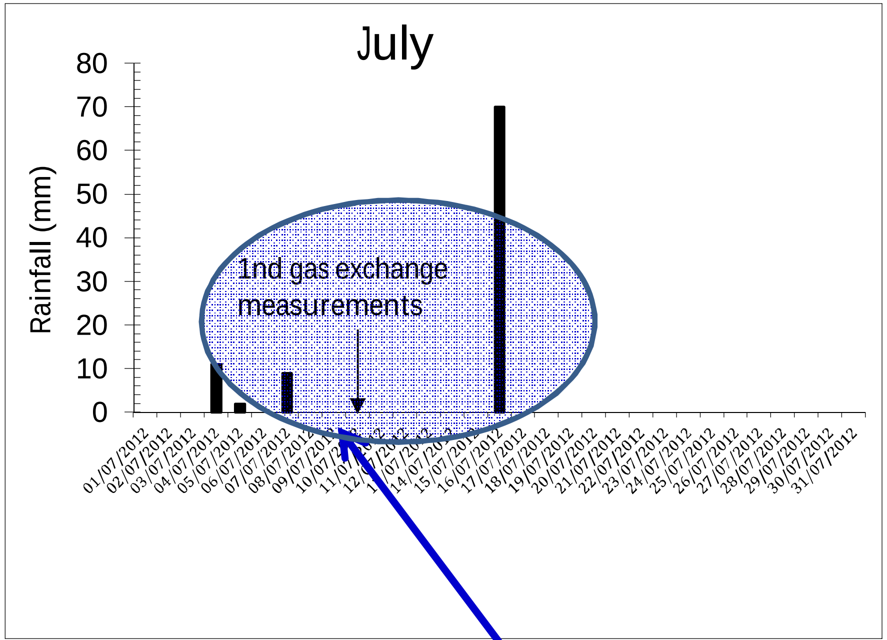
Table 2
Effect of five irrigation treatments on stem diameter and height of papaya in a field study. July (2012) and October (2012).

Treatment[a]	Sampling Time			
	July		October	
	Diameter (mm)	Height (m)	Diameter (mm)	Height (m)
RDI	115.91	3.48ab[z]	114.32	3.61
FI	110.52	3.31ab	115.35	3.41
NI-field	113.76	3.08c	113.87	3.65
PRD100	112.80	3.37ab	121.35	3.67
PRD70	117.85	3.57a	116.88	3.79
	ns[y]		ns	ns

[a] FI = full irrigation; NI-field = no irrigation after treatment initiation; PRD100 = partial root zone drying with 100% water replacement; PRD70 = partial root zone drying with 70% water replacement; RDI = regulated deficit irrigation with 70% water replacement.

[z] Mean values within a column followed by the same letter are not significantly different (P = 0.05) based on Tukey's multiple range test.

[y] Non-significant difference.



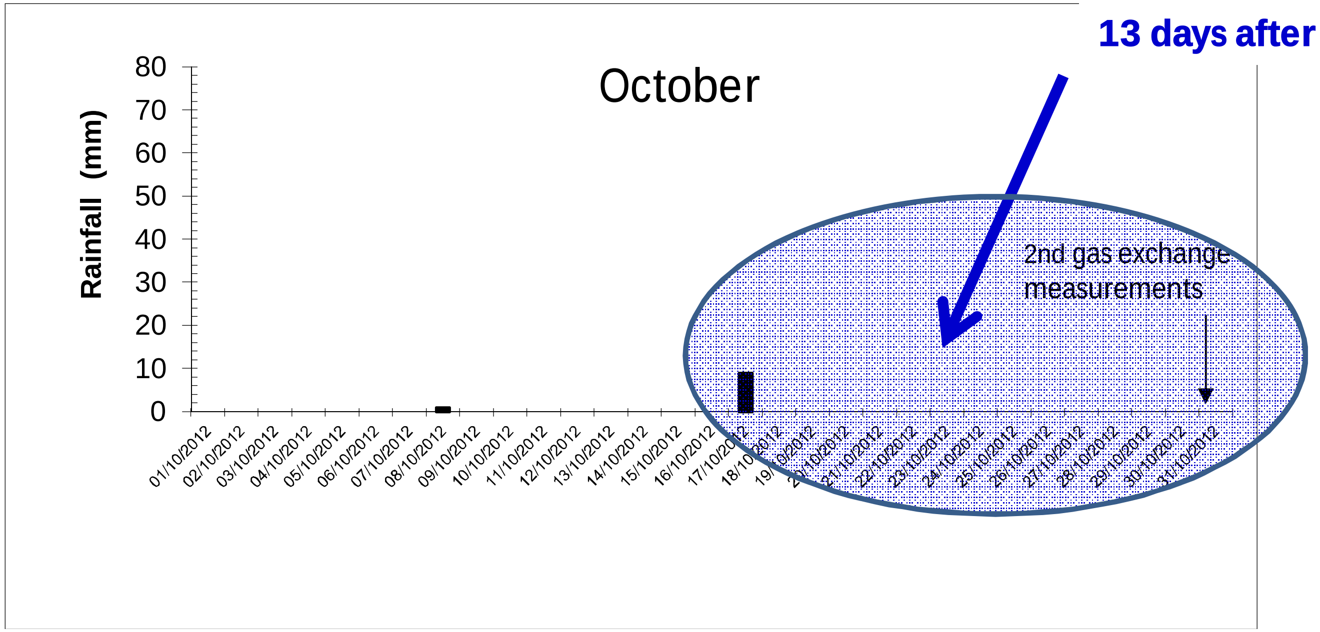
3 days after rainfall

Table 4
Effect of 5 irrigation treatments on photosynthesis (*A*), stomatal conductance (G_s) and transpiration (*E*) of papaya in a field study, July (2012) and October (2012).

Treatment[a]	Sampling	*A* (μmol m^{-2} s^{-1})	G_s (mol m^{-2} s^{-1})	*E* (mmol m^{-2} s^{-1})
RDI **70%**	July	14.8	0.19	4.3
FI	July	12.1	0.15	3.5
NI-field	July	13.2	0.21	4.4
PRD100	July	12.5	0.15	3.3
PRD70	July	12.7	0.18	4.0
		ns[y]	ns	Ns
RDI **70%**	October	9.5ab[z] ←	0.12ab ←	4.4ab ←
FI	October	10.8a ←	0.13a ←	5.5a ←
NI-field	October	6.5b	0.06c	3.2b
PRD100	October	9.3ab	0.11abc	4.6ab ←
PRD70	October	7.2b	0.08bc	3.4b

[a] FI = full irrigation; NI-field = no irrigation after treatment initiation; PRD100 = partial root zone drying with 100% water replacement; PRD70 = partial root zone drying with 70% water replacement; RDI = regulated deficit irrigation with 70% water replacement.
[z] Mean values within a column followed by the same letter are not significantly different ($P = 0.05$) based on Tukey's multiple range test.
[y] Non-significant difference.

13 days after rainfall



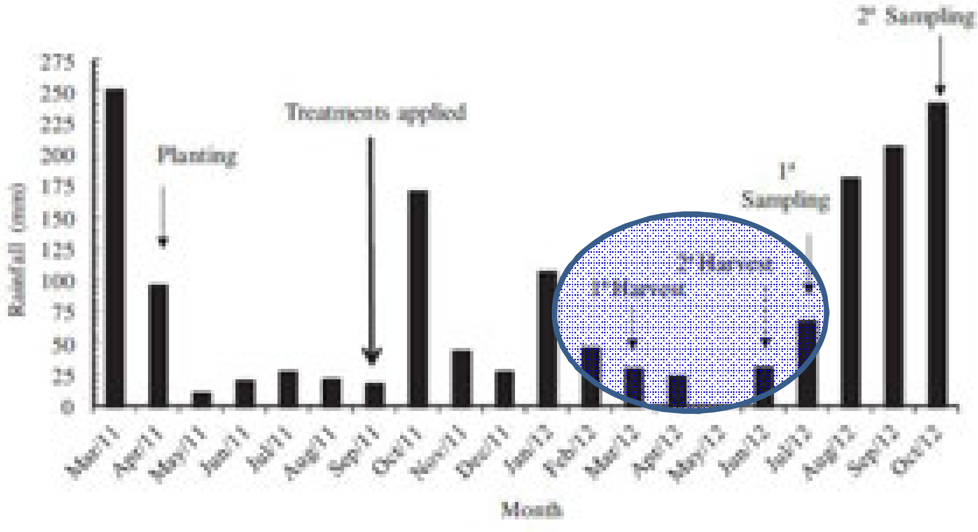


Fig. 2. Meteorological variables in a field study.

Table 3
Effect of 5 irrigation treatments on yield components and agronomic water use efficiency (AWUE) of papaya in a field study. March (2012) and June (2012).

Harvest	Treatment[a]	Number fruit plant^{-1}	Average weight (g FW fruit^{-1})	Yield (kg FW ha^{-1})	kg FW plant^{-1}	Irrigation + precipitation (L)	AWUE (kg FW fruit L^{-1})	AWUE (number fruit L^{-1})
March	FI	30b[z]	409ab	22,065ab	11.9b	2698	0.0044c	0.011c
March	NI-field	33ab	391b	23,991b	13.0ab	1025	0.0126a	0.032a
March	PRD100	38ab	436ab	31,290ab	16.9ab	2698	0.0063bc	0.014bc
March	PRD70	41a	437a	33,827a	18.3a	2189	0.0084b	0.019b
March	RDI	39ab	430ab	31,117ab	16.8ab	2189	0.0077b	0.018b
			$P = 0.10$					
June	FI	21a	244ab	9620ab	5.2ab	3755	0.0014	0.006
June	NI-field	6b	191b	2651b	1.4b	1107	0.0013	0.006
June	PRD100	26a	309a	14,881	8.0a	3755	0.0021	0.007
June	PRD70	19a	286a	10,390a	5.6ab	2949	0.0019	0.006
June	RDI	20a	282a	11,145a	6.0ab	2949	0.0020	0.007
							ns[y]	ns

[a] FI = full irrigation; NI-field = no irrigation after treatment initiation; PRD100 = partial root zone drying with 100% water replacement; PRD70 = partial root zone drying with 70% water replacement; RDI = regulated deficit irrigation with 70% water replacement.

[z] Mean values within a column followed by the same letter are not significantly different ($P = 0.05$) based on Tukey's multiple range test.

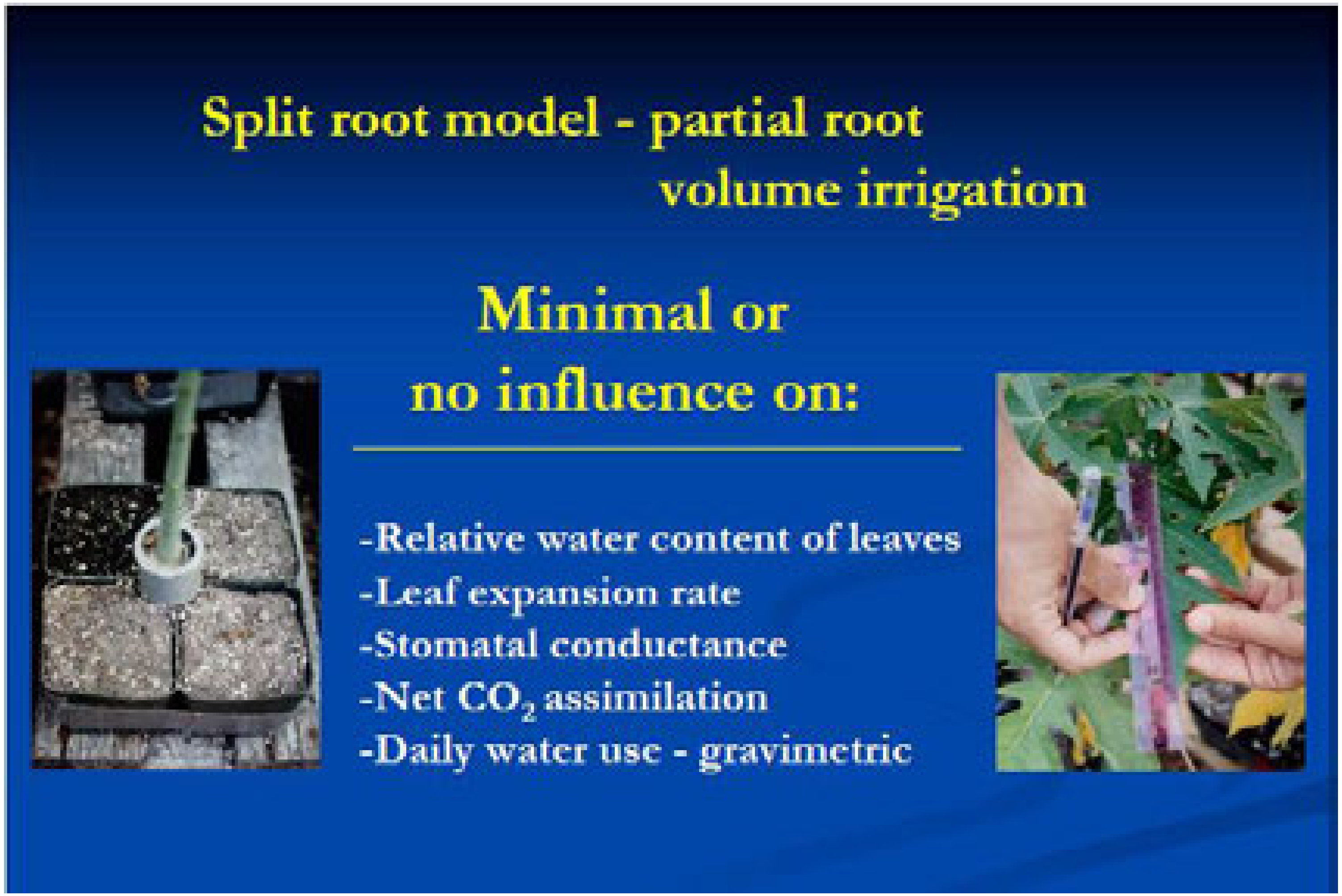
[y] Non-significant difference.

5. Conclusion

While there was evidence of non-hydraulic signals inducing stomatal closure in the PRD treatments compared to RDI in greenhouse studies, these effects were insufficient to alter dry matter partitioning, biomass, or yield components since there were no significant differences between PRD and RDI at either a 30% or 50% water deficit. A 50% water deficit in the greenhouse study for the PRD and RDI treatments was sufficient to significantly reduce biomass and dry matter partitioning compared to the FI treatment. In the field study, a 30% water deficit in both PRD70 and RDI treatments did not significantly reduce vegetative growth or yield components, compared to FI. It appears that papaya can tolerate moderate water deficits without a significant reduction in yield components indicating that <100% ET irrigation replacement may be scheduled but there is little or no difference between PRD and RDI. Further research will be needed to verify that moderate soil water deficits do not reduce quality.

Dr. Thomas Marler
University of Guam
Guam

Western Pacific Tropical Research Center
Research for Guam's Future
University of Guam



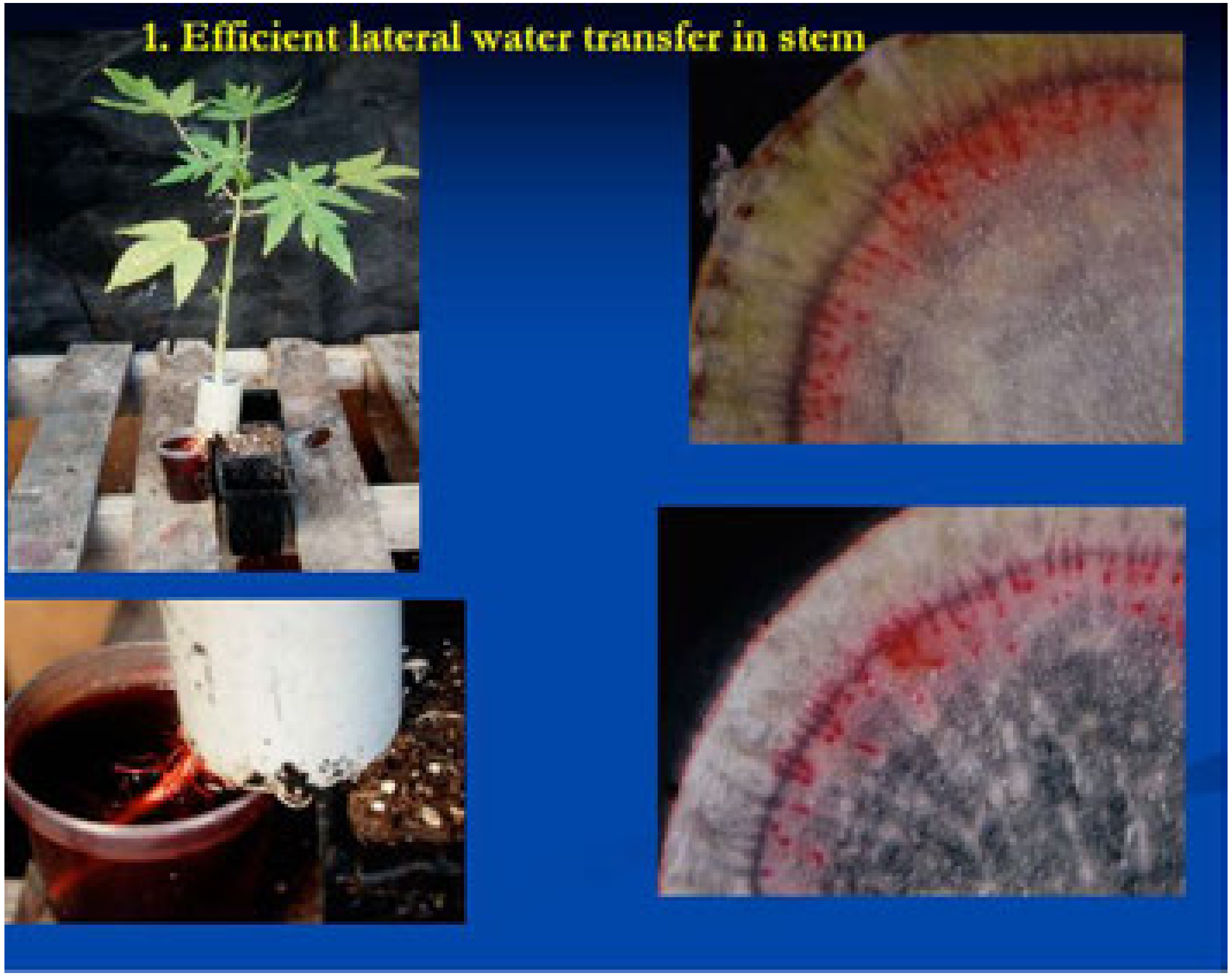
Microsprinkler : 90°, 180°, or 360° application coverage

No influence on:

- Growth - height or stem diameter
- Date of first flowers
- Height of first fruit
- Yield

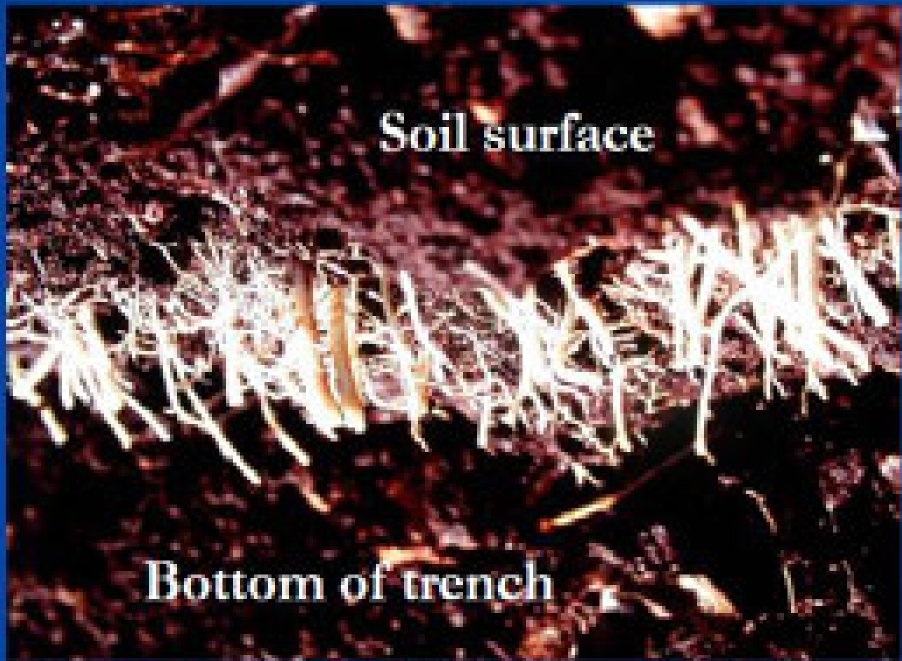
Papaya attributes that allow for this:

1. Efficient lateral transfer of water in stem
2. Rapid root proliferation in wet zones
3. Hydraulic redistribution into dry zones



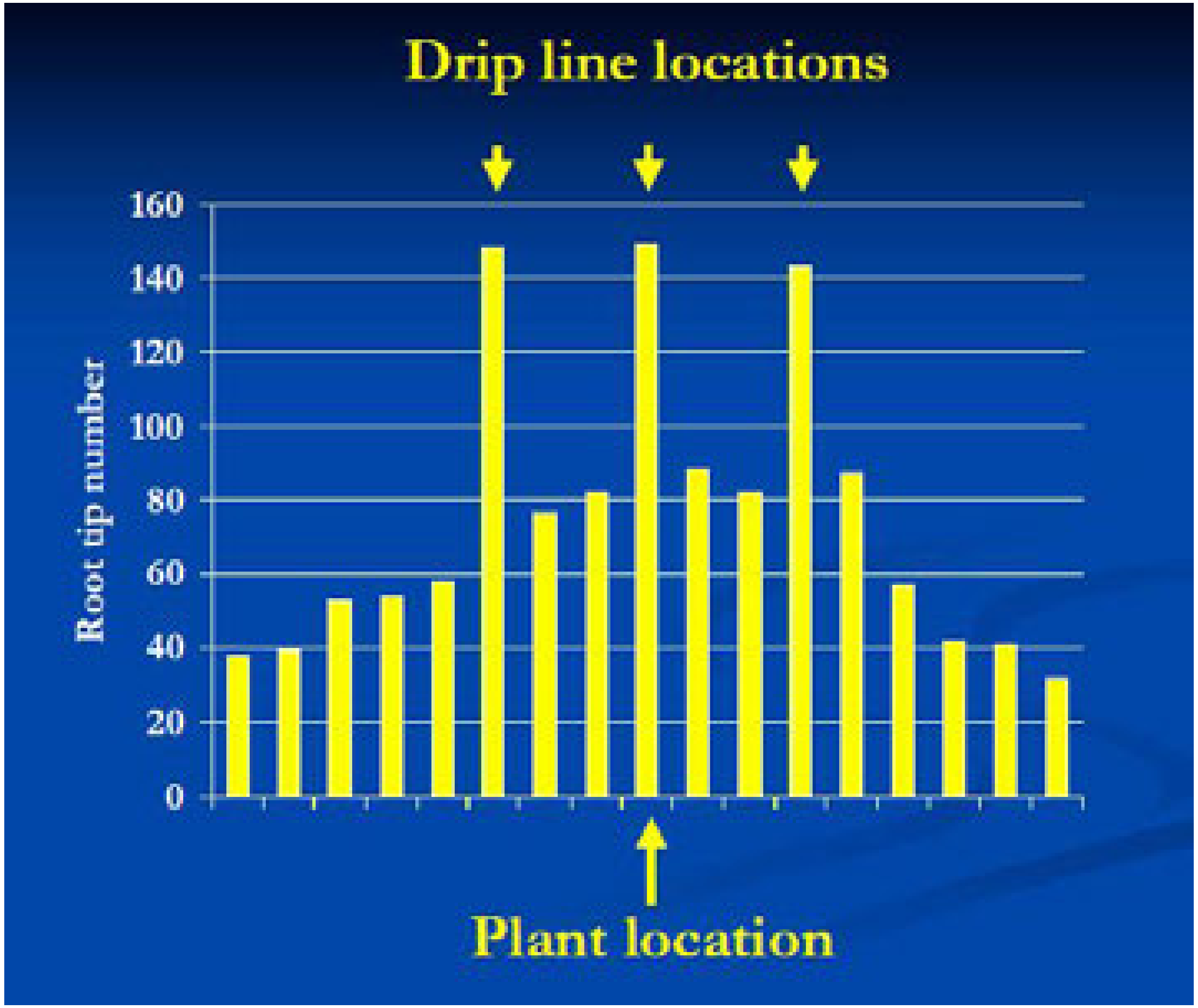

20 cm above-
100%
10 cm above-
80%
6 cm above-
50%

Papaya attributes that allow for this:
2. Rapid root proliferation in wet zones



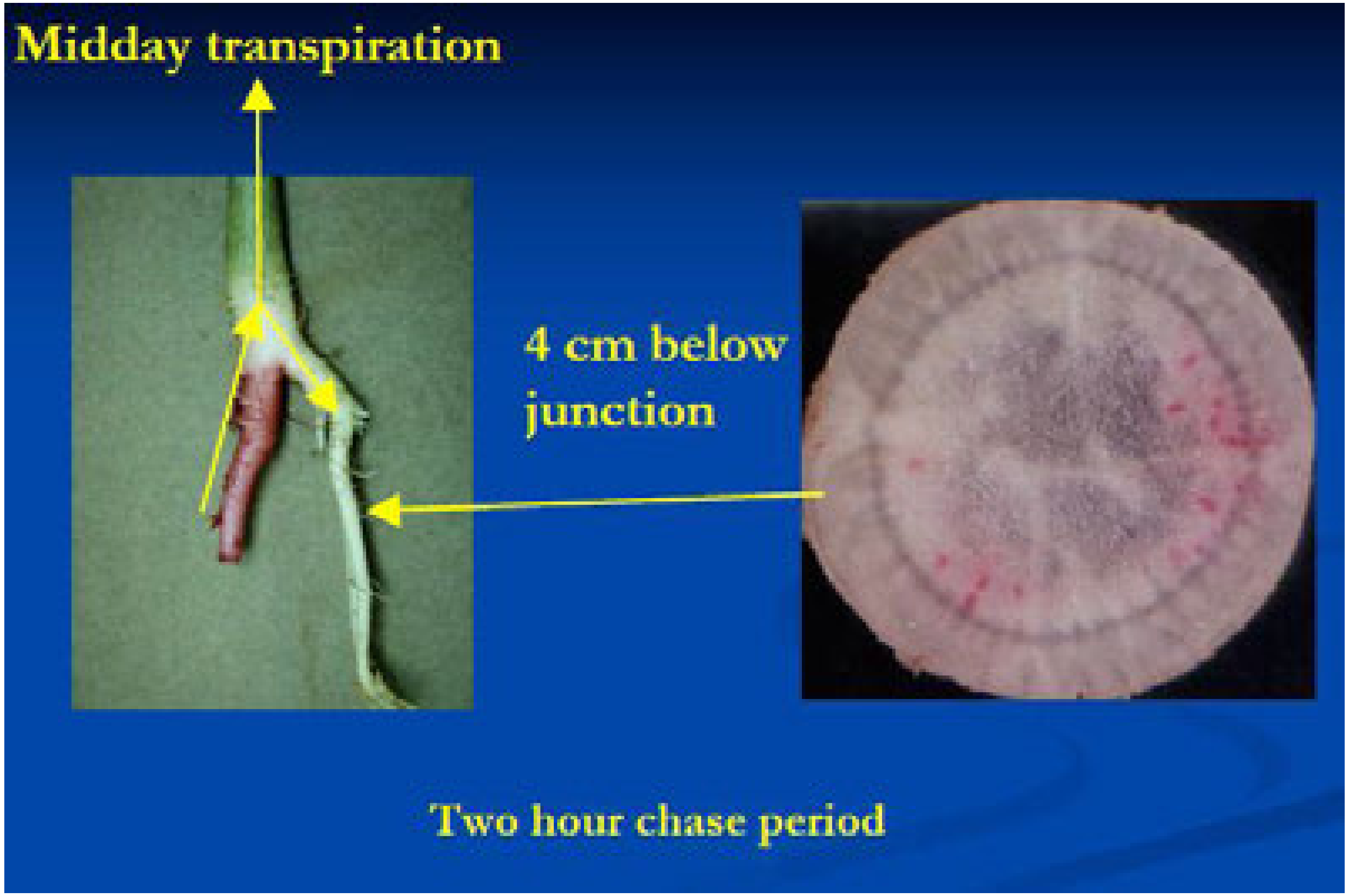
-Trench profile

-Cores



Drip line locations
160
140
120
100
80
60
40
20
0
Root tip number
Plant location

3. Hydraulic redistribution into dry zones



Water Transfer in a Papaya-Corn Culture System

Proc. Third IS on Papaya
Eds.: N. Chomchalow et al.
Acta Hort. 1022, ISHS 2014

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USA

Abstract

'Tainung 2' and 'Sunrise' papaya seedlings were grown in split-root containers. 'Honey Jean 3' sweet corn seeds were planted in one of the two containers that comprised each split-root papaya system. Following establishment of the corn seedlings, the papaya-corn systems were subjected to one of three treatments: 1) both halves of the papaya roots were well-watered (control); 2) both halves of the papaya roots received no water; (3) the papaya root half without the corn seedling was watered but the half with the corn seedling received no water. Pre-dawn leaf relative water content (RWC) and mid-morning stomatal conductance of corn leaves were the response variables used to quantify drought stress. Stomatal conductance reached zero by day 10, when RWC of treatment 2 plants was less than 50% and that of treatment 3 plants was 80%. At this stage, half of the remaining replications in treatment 3 were treated by cutting the connection between the roots in the dry compartment and the base of the papaya stem. This procedure relieved competition between the two species, but also eliminated the watered half of the papaya roots as a possible source of water for the corn plants. Leaf RWC of the corn plants relieved of papaya root competition declined to below that of corn plants within intact treatment 3 papaya split root systems. These results indicate hydraulic redistribution occurred from papaya roots in the watered pots to the corn plants. Water redistribution within papaya plants may have impacts on hydrologic processes, and should be considered when scaling fluxes to the orchard level.

FI. We hypothesized that the difference observed in physiological response to PRD and RDI treatments between the papaya grown in the greenhouse and field may be related to the different volumes of soil explored by the root system. The physiological response of papaya to PRD and RDI was more affected in greenhouse-grown than field-grown papaya because in the greenhouse study, the roots are limited to the volume of the pot. In addition, in field conditions rainfall can increase water availability in the soil and the roots have a greater volume of soil to explore. Thus, environmental variables such as VPD and PAR can more severely affect the gas exchange and growth of plants grown in the greenhouse than plants grown under field condition. In addition, PRD and RDI can increase stomatal sensitivity to VPD (Collins et al., 2010).

Collins, M.J., Fuentes, S., Barlow, W.R., 2010. Partial rootzone drying and deficit irrigation increase stomatal sensitivity to vapour pressure deficit in anisohydric grapevines. Funct. Plant Biol. 37, 128–138.

Flooding

Papaya is considered a species sensitive to low oxygen availability in the soil (hypoxia), which is commonly caused by waterlogging (Ogden et al., 1981; Malo and Campbell, 1986)

Reduced oxygen can occur as a result of tropical storms that saturate the soil for several days, flood irrigation, as well as micro-irrigation practices that create microenvironments of reduced soil oxygen

A completely flooded soil can cause **death to papaya plants in 2 d** (Wolf and Lynch, 1940; Khondaker and Ozawa, 2007) **or 3 to 4 d** (Samson, 1980)

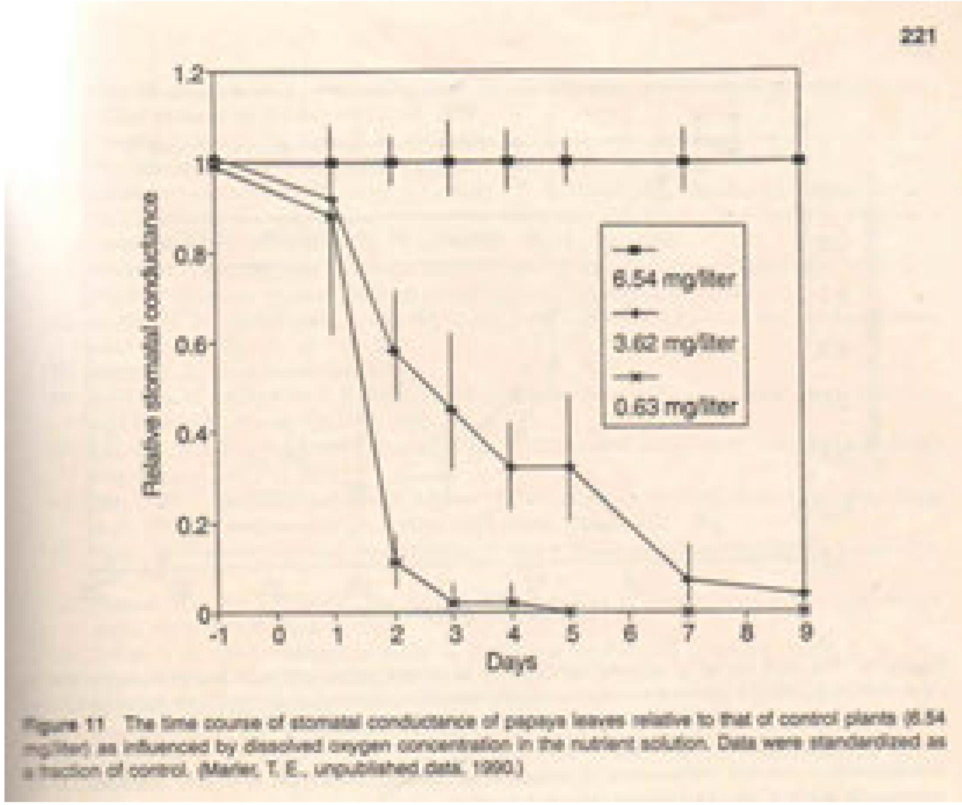

Figure 11 The time course of stomatal conductance of papaya leaves relative to that of control plants (6.54 mg/liter) as influenced by dissolved oxygen concentration in the nutrient solution. Data were standardized as a fraction of control. (Marler, T. E., unpublished data, 1990.)

Khondaker and Ozawa (2007) constructed chambers that controlled soil gas composition at ambient (20%), 18% and 11% oxygen; under soil oxygen at and below 18%, *A*, chlorophyll content, large and small roots, and shoot dry matter were all decreased

Papaya Plant Growth as Affected by Soil Air Oxygen Deficiency

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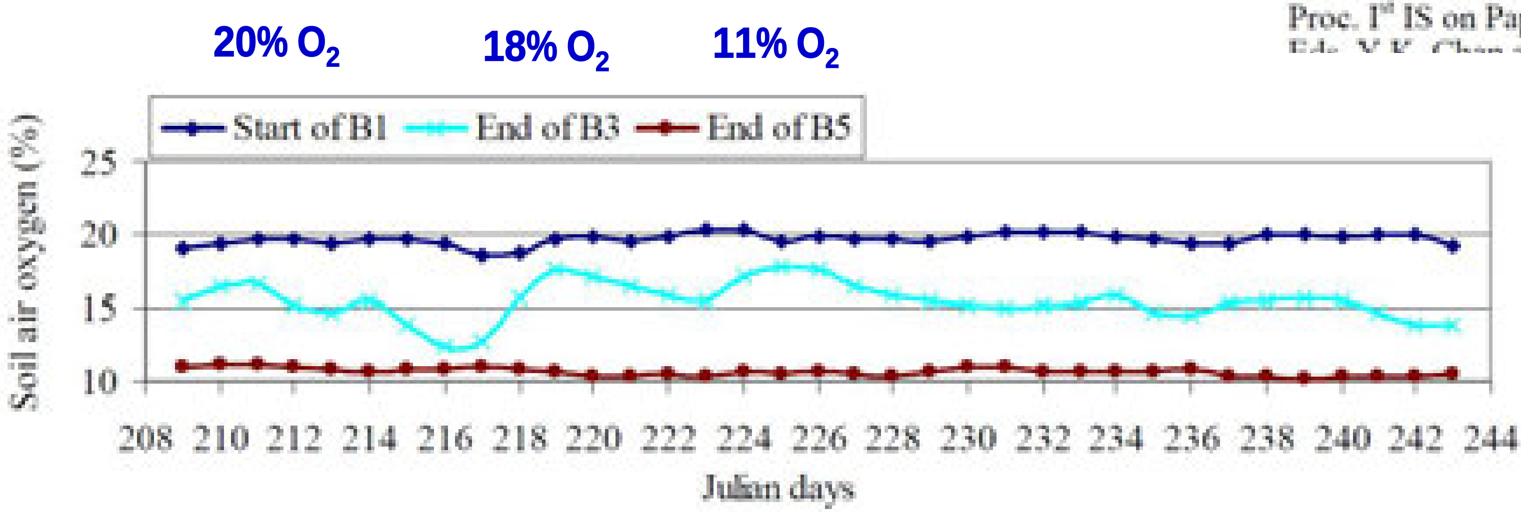
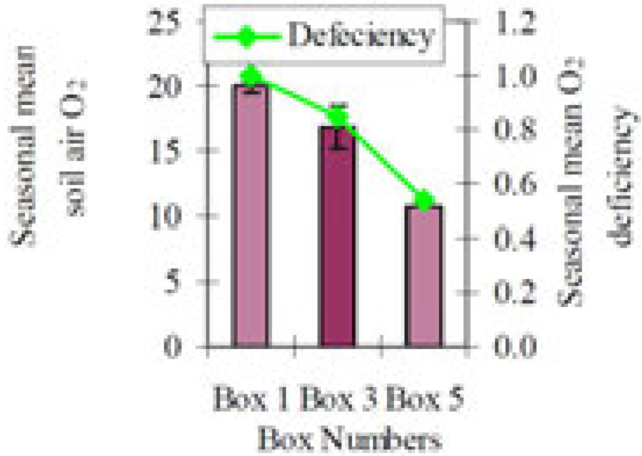
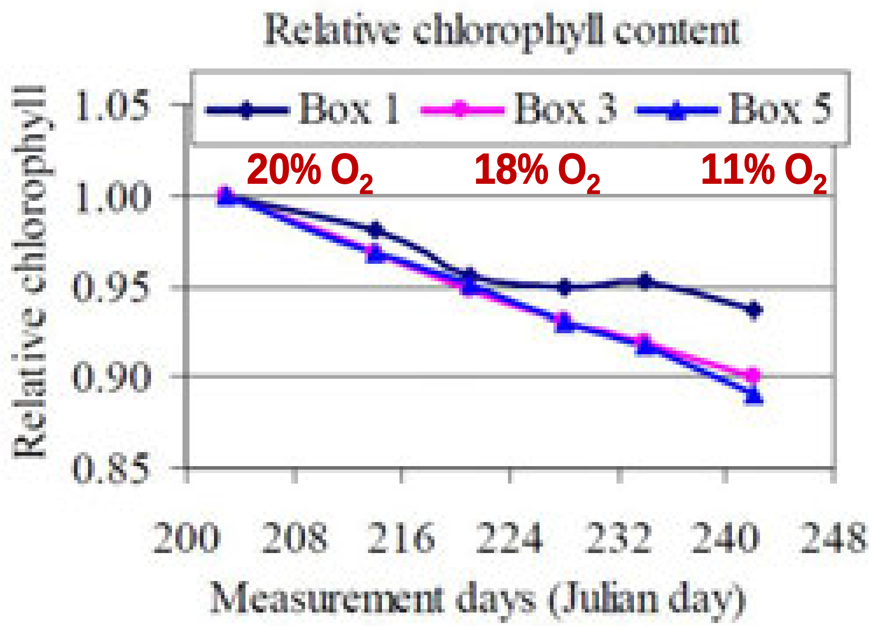
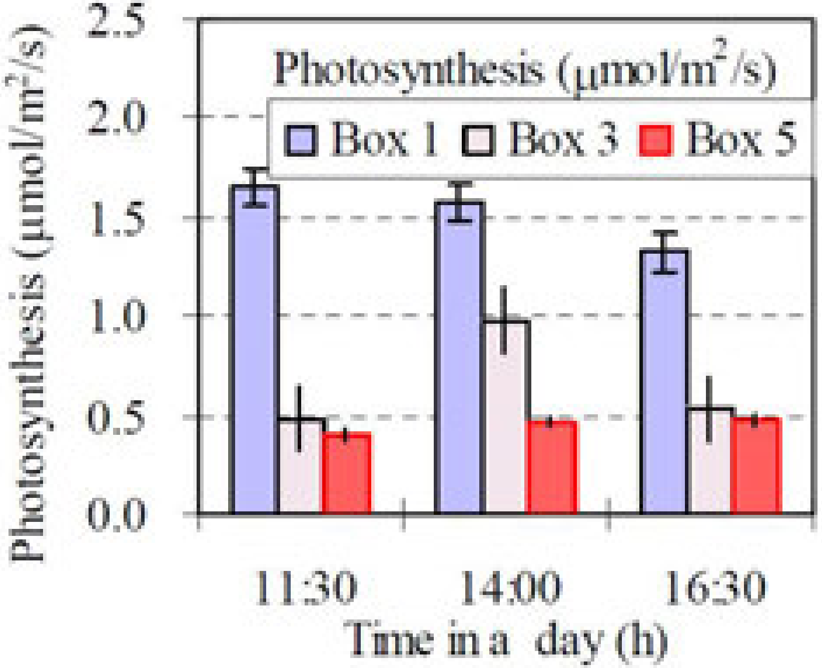
IS 2007

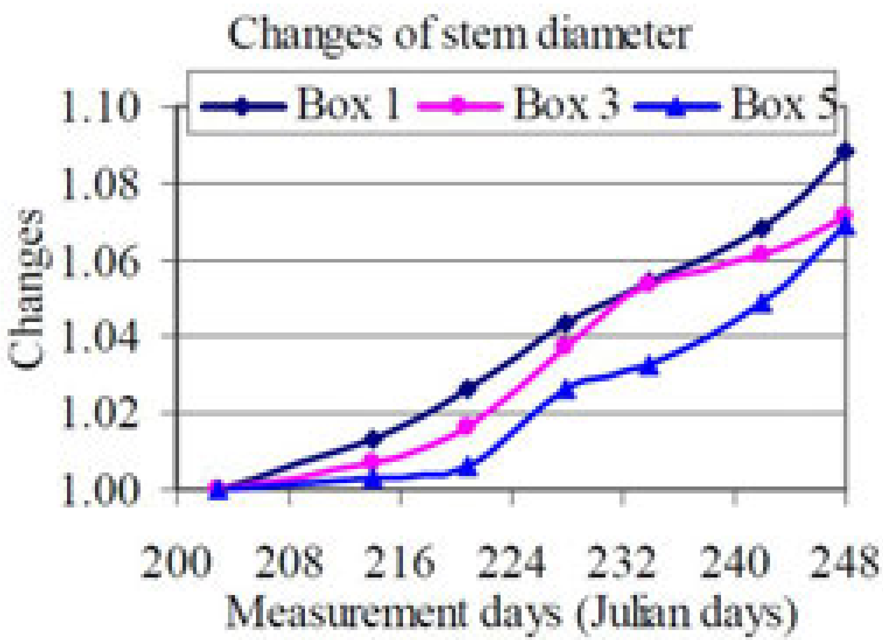


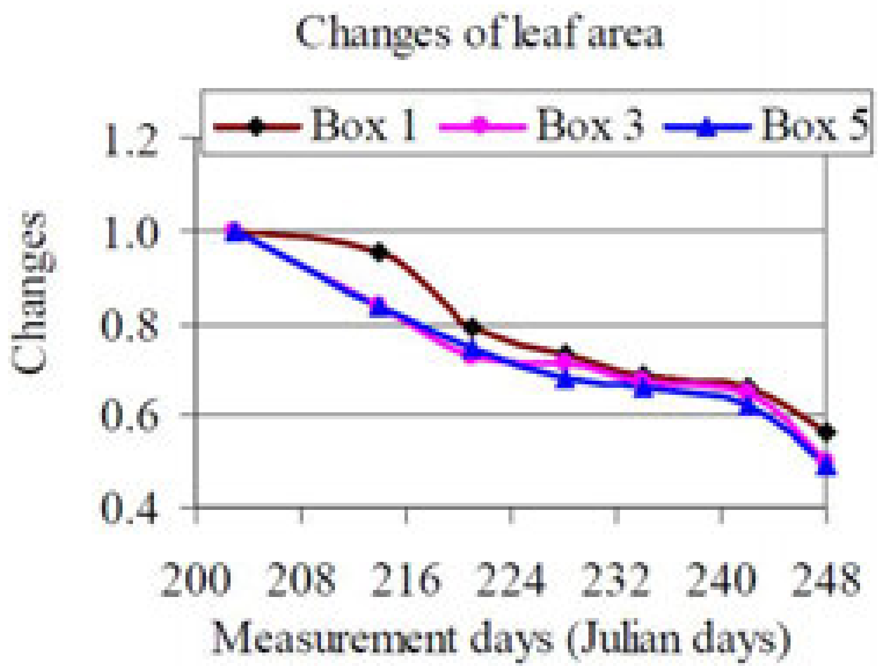


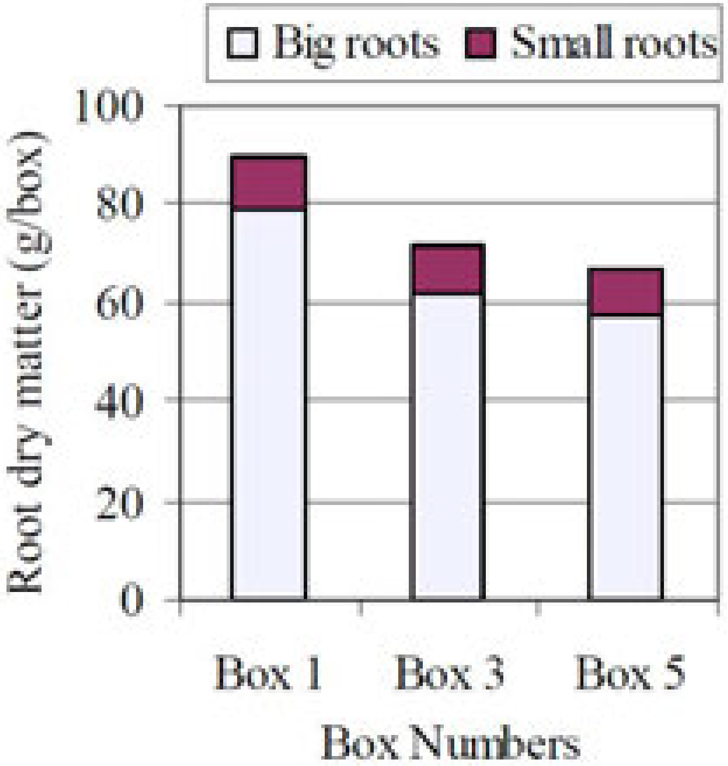

Relative chlorophyll content
Box 1
Box 3
Box 5
20% O2
18% O2
11% O2
Relative chlorophyll
1.05
1.00
0.95
0.90
0.85
200
208
216
224
232
240
248
Measurement days (Julian day)

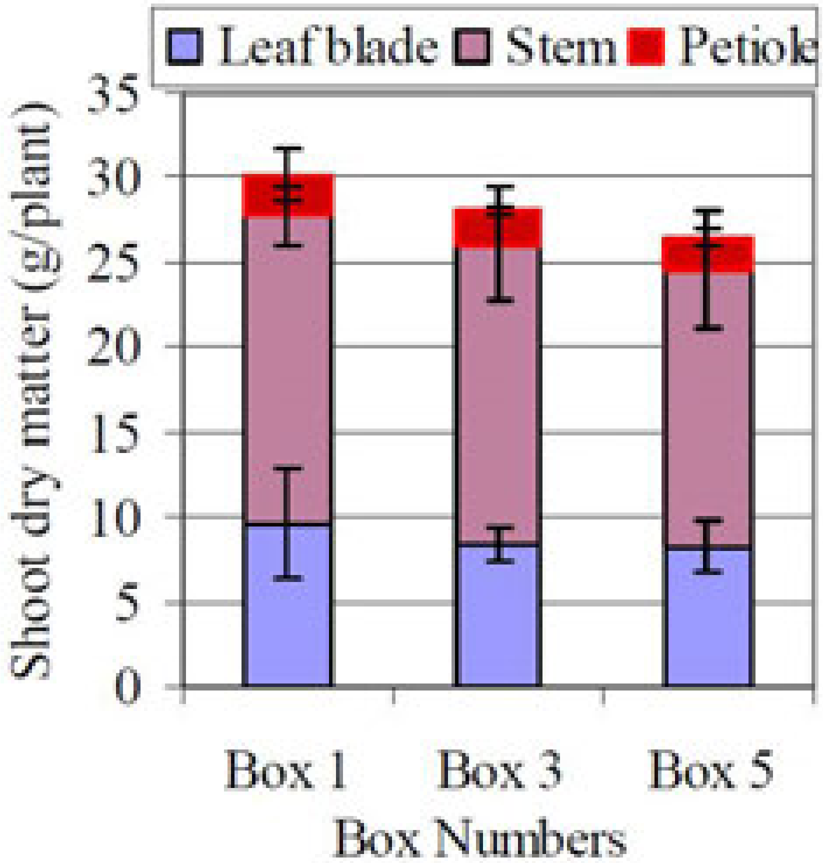

Photosynthesis (μmol/m2/s)
Box 1
Box 3
Box 5
Photosynthesis (μmol/m2/s)
2.5
2.0
1.5
1.0
0.5
0.0
11:30
14:00
16:30
Time in a day (h)

Box 1: 20% O_2
Box 2: 18% O_2
Box 3: 11% O_2






Big roots
Small roots
Root dry matter (g/box)
100
80
60
40
20
0
Box 1
Box 3
Box 5
Box Numbers


Leaf blade
Stem
Petiole
Shoot dry matter (g/plant)
35
30
25
20
15
10
5
0
Box 1
Box 3
Box 5
Box Numbers

Papaya, considered sensitive to hypoxia, responds with accentuated senescence (chlorotic leaves), leaf fall and does not recover after hypoxic conditions are removed (Marler et al., 1994).

These studies indicate that papaya is sensitive to small reductions in soil oxygen content and it is likely that micro-irrigation saturation of a small portion of the soil is having some negative effects. Consequently, a welldrained soil is essential for high productivity.

Treatment	100% of roots submerged	
	Dissolved O_2 concentration ($mg\,l^{-1}$)	
	Day 1	Day 2
0 g CaO_2	3.63 ± 0.92b	4.38 ± 0.89b
2.28 g CaO_2	7.00 ± 0.76a	5.38 ± 1.70ba
4.57 g CaO_2	8.03 ± 1.09a	7.19 ± 1.50a

et al., 2009a). Hydrogen peroxide decomposes in the soil, releasing O_2 which is needed for aerobic metabolism in the roots (Gil et al., 2009a,b). When H_2O_2 comes in contact with water, it reacts to give off 0.5 mol of O_2 per mole H_2O_2 as shown in the equation $H_2O_2 + H_2O \rightarrow 0.5O_2 + 2H_2O$ (Gil et al., 2009a). In soil, solid oxygen compounds (i.e., CaO_2, MgO_2) breakdown to H_2O_2 which then provides oxygen to the rhizosphere (Liu and Porterfield, 2014).