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## Producing food and electricity in the same system. Experimental evidence of agrivoltaic systems potential

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# Producing food and electricity in the same system

Experimental evidence of  
**AGRIVOLTAIC SYSTEMS** potential

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INRA – UMR SYSTEM (France, Montpellier)



Helsinki, 21<sup>st</sup> August 2012





# Agrivoltaic systems (AVS) : what and what for?

An AVS is a production system that associates on the same land unit at the same time solar panels and food crops

- Key assets :
  - Intensify land productivity (food + energy)
  - Keep arable land available for food production
  - Increase food security
  
- A wide range of possibilities



# Agrivoltaic system under study

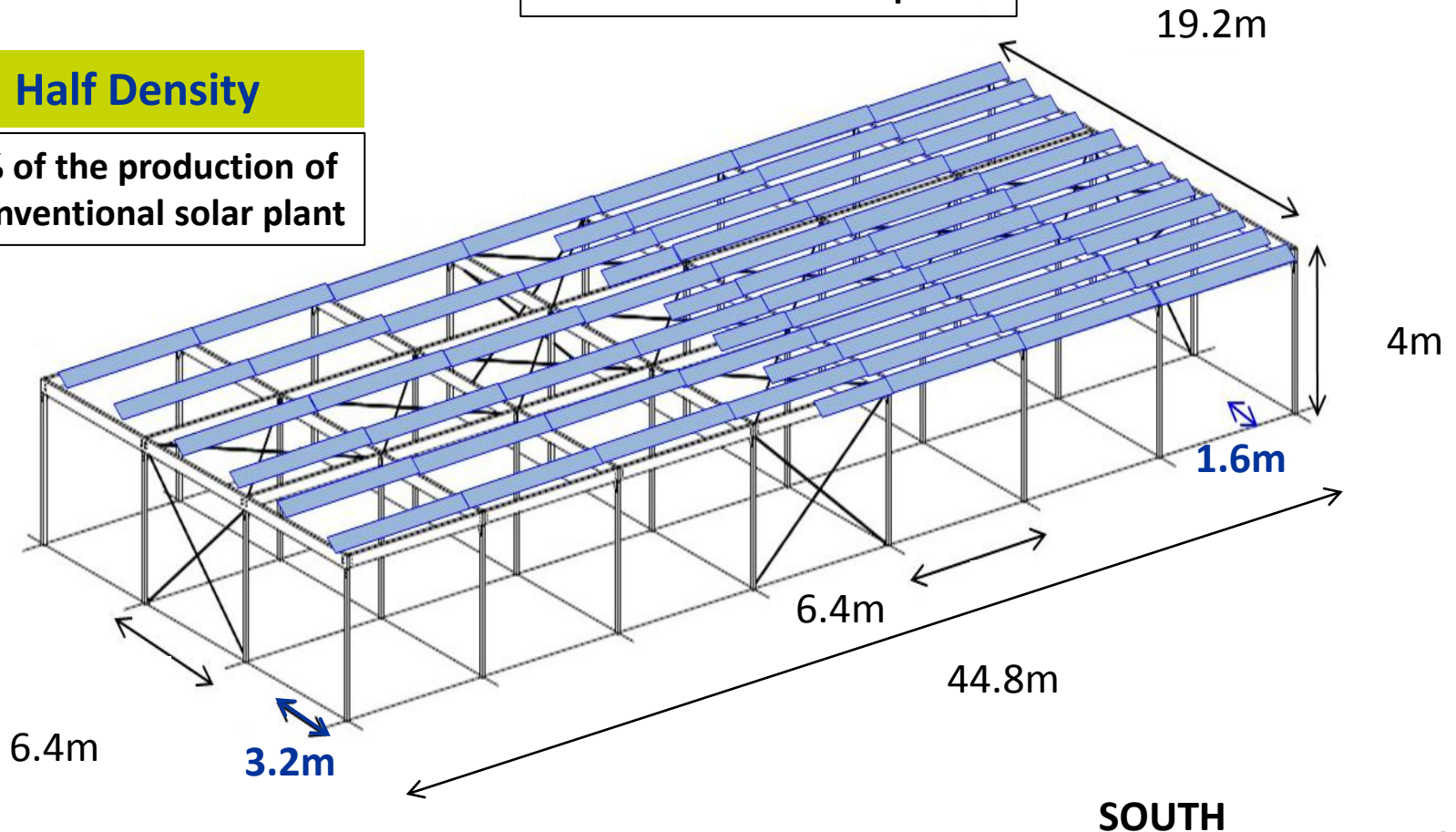
NORTH

## Full Density

Same energy production as a conventional solar plant

## Half Density

50% of the production of a conventional solar plant

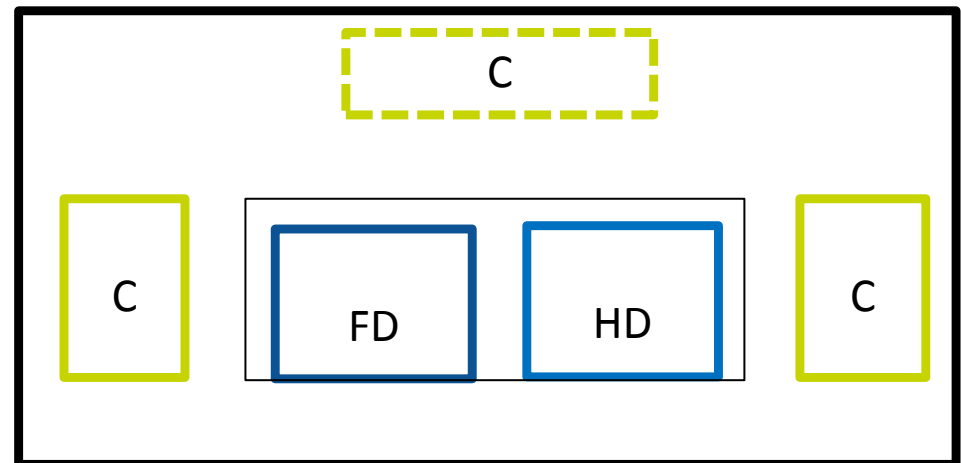


# Agrivoltaic system under study

- 3 radiative treatments:
  - FD= Full Density of panels
  - HD = Half Density of panels
  - C = Full sun Control
  
- No H<sub>2</sub>O stress, no N stress
  
- Different species
  - Lettuces (2 seasons, 5 varieties)
  - French beans
  - Cucumbers
  - Wheat



SOUTH



NORTH

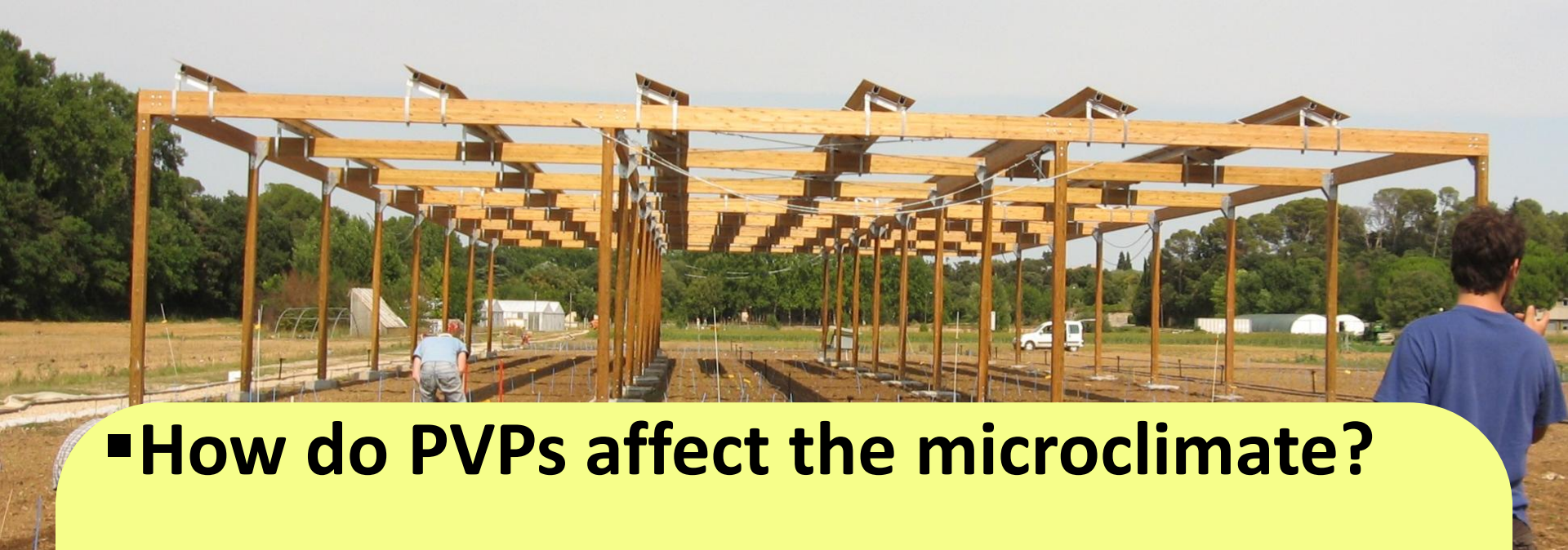












- How do PVPs affect the microclimate?
- What is the impact on crop productivity?





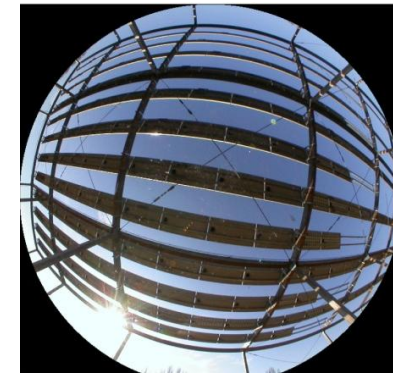


How dark is it, there?

# Assessment of the available radiation

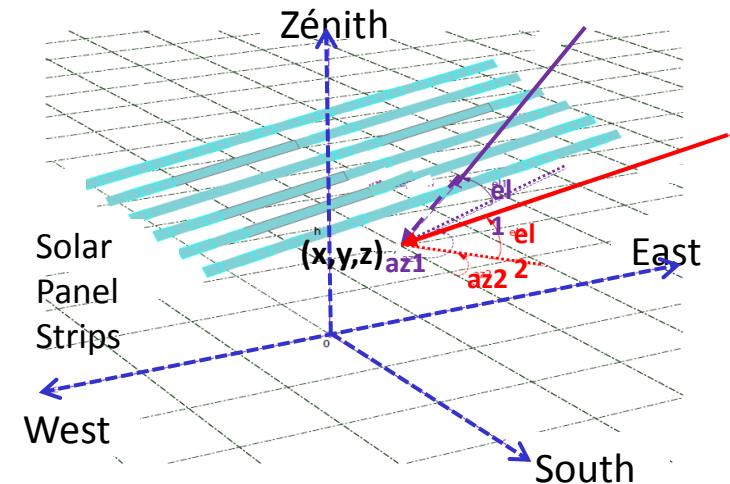
Light distribution is **HETEROGENOUS** in FD and HD

- Measurements on the field :



- Development of a radiation model

- Validation with field data (2010)
- RMSE : 9-11%

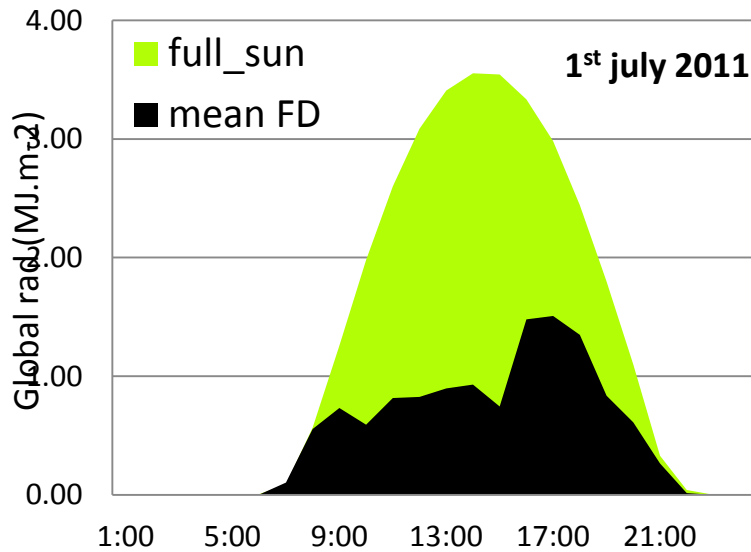




# Available radiation at ground level

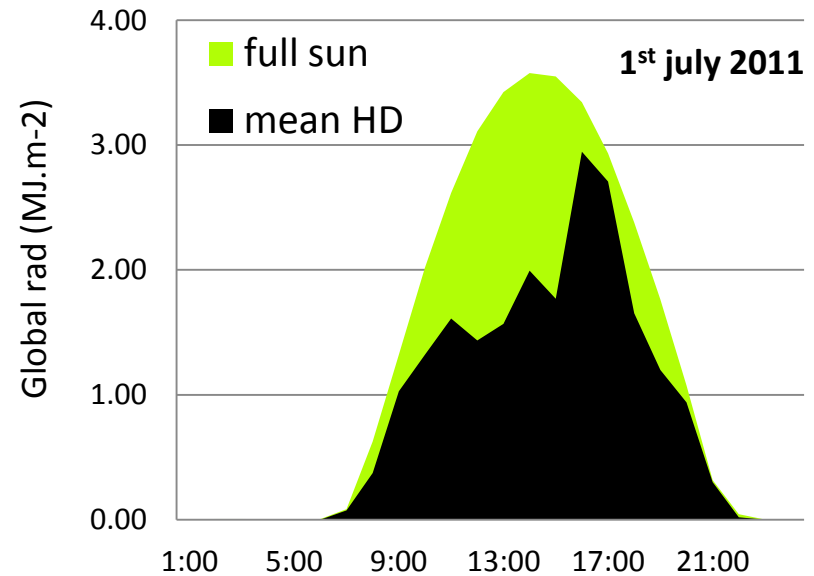
## Full Density : 50% GR

Summer 2010 : 51%  
Spring 2011 : 49%



## Half Density : 70% GR

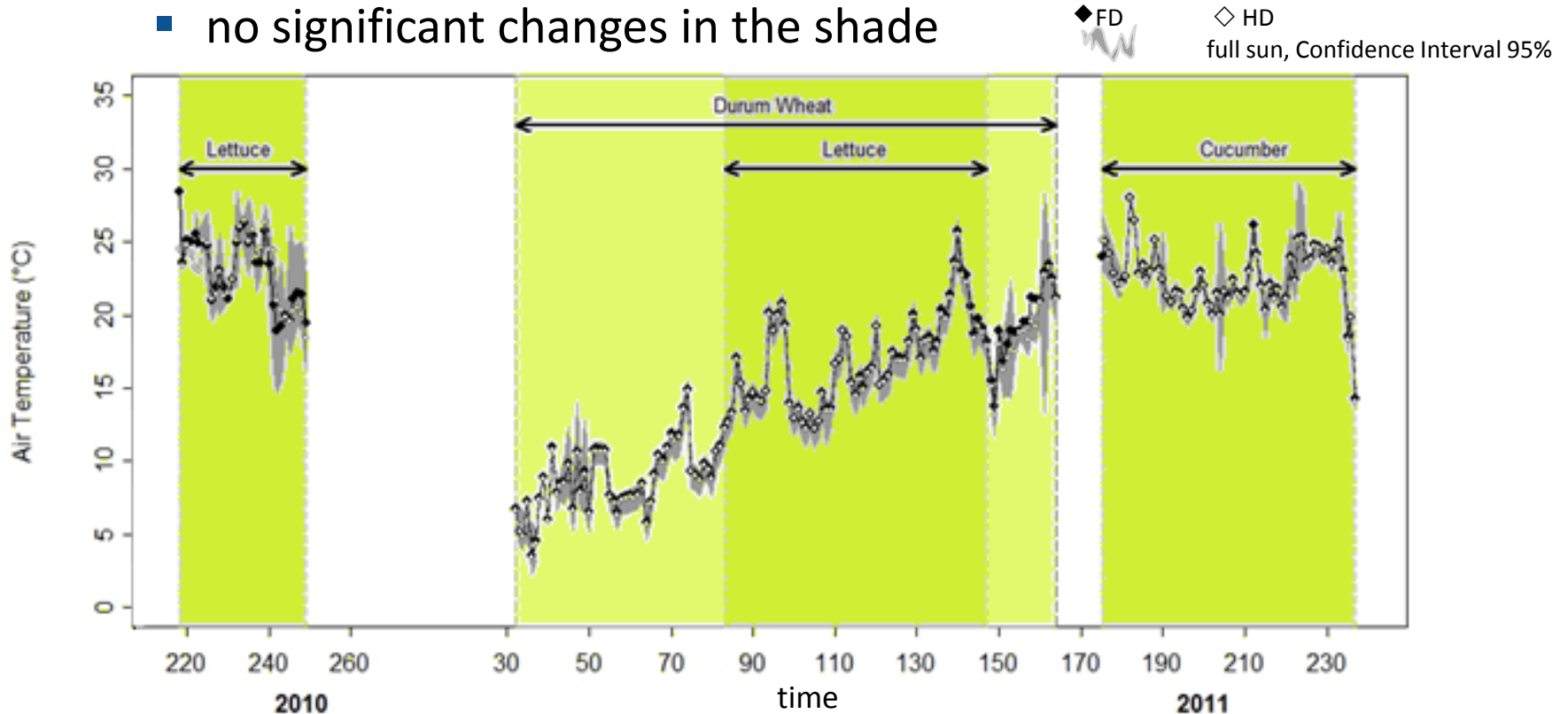
Summer 2010 : 76%  
Spring 2011 : 67%



# Control point : Temperature and humidity

- Mean daily Air T° :

- no significant changes in the shade



- Hourly Air T°, Air VPD, and Wind Speed

- Non significant changes either



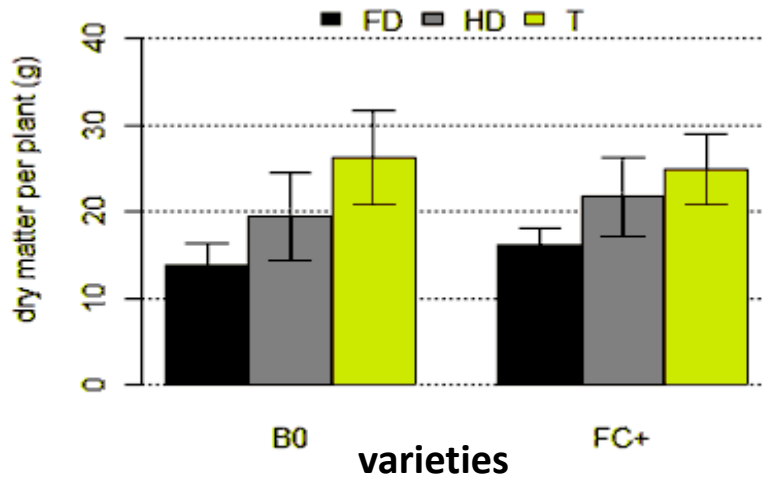
Does it grow?



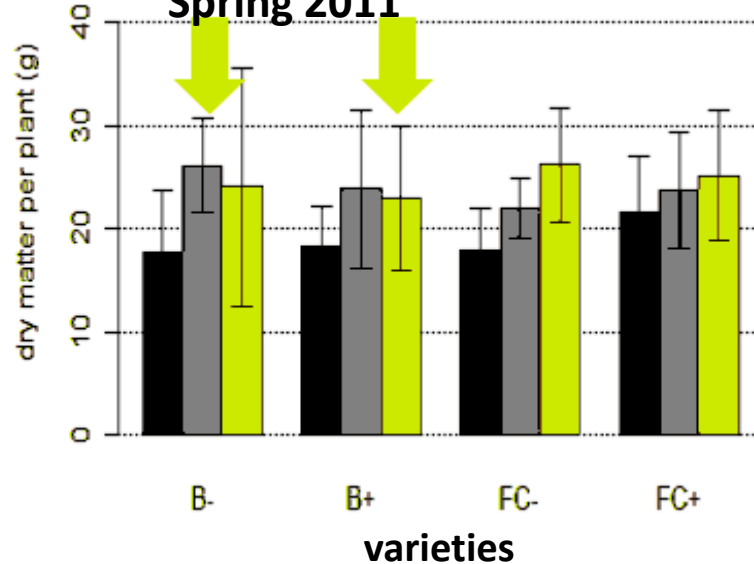


# Lettuces

Summer 2010



Spring 2011



*Marrou, H., Wery, J., Dufour, L., Dupraz, C., 2013. Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels. European Journal of Agronomy 44 (0), 54-66.*

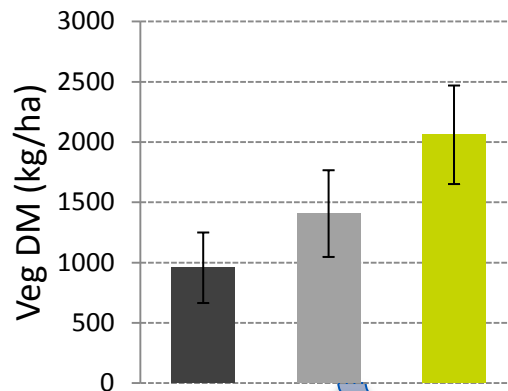


# Fruit crops

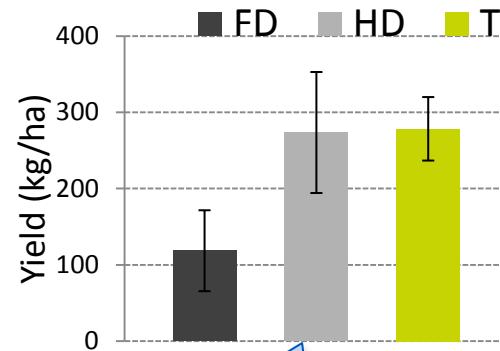


Dwarf French beans

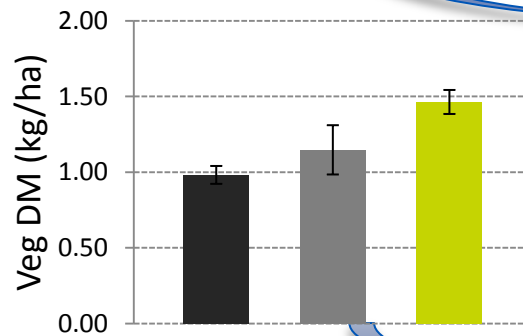
## LEAVES and STEMS



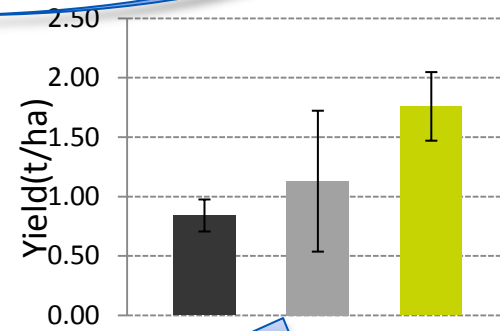
## FRUITS or GRAIN



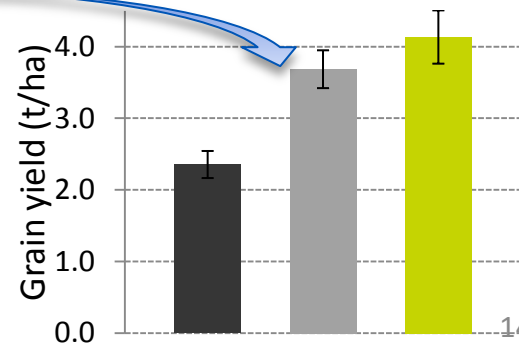
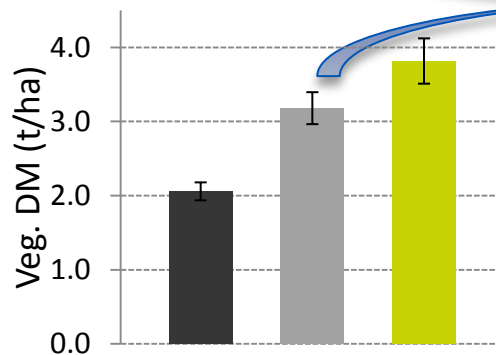
Cucumbers



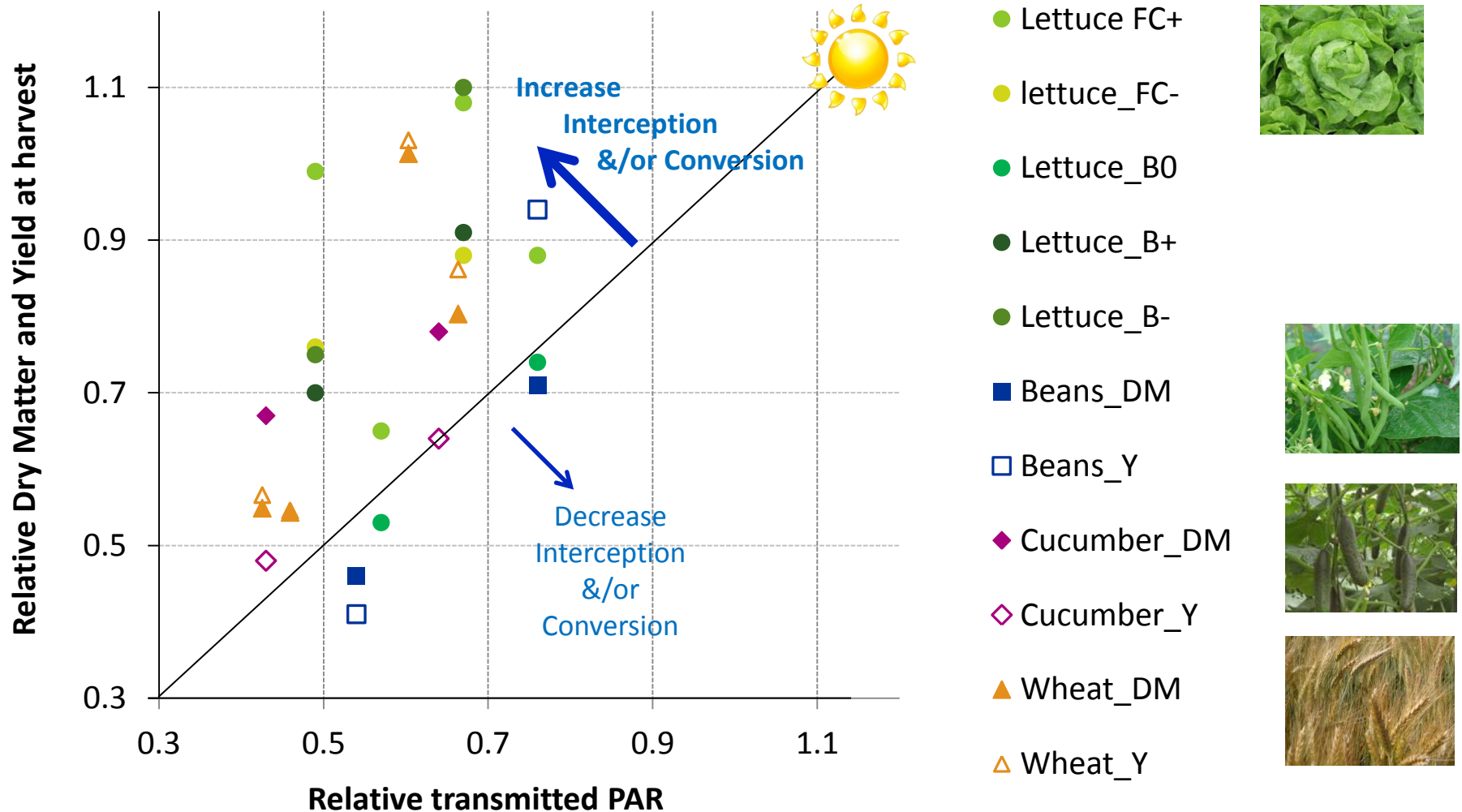
Different allocation of DM



Durum wheat



# Crops use light more efficiently in the shade





# Decomposing : from light to biomass

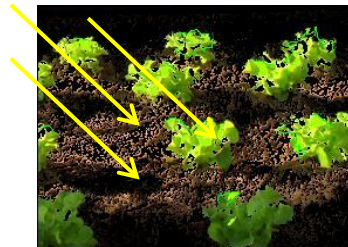
$$\text{PAR}_{\text{ini}} \times \text{RTE} \times \text{RIE} \times \text{RCE} = \text{DM}$$



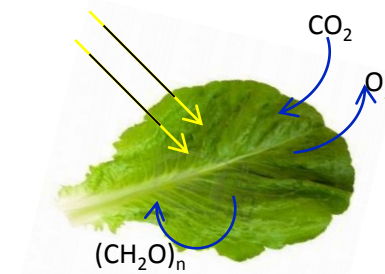
*Climatic  
resource*



*Solar Panels  
Transmittance*



*Physical  
Interception*

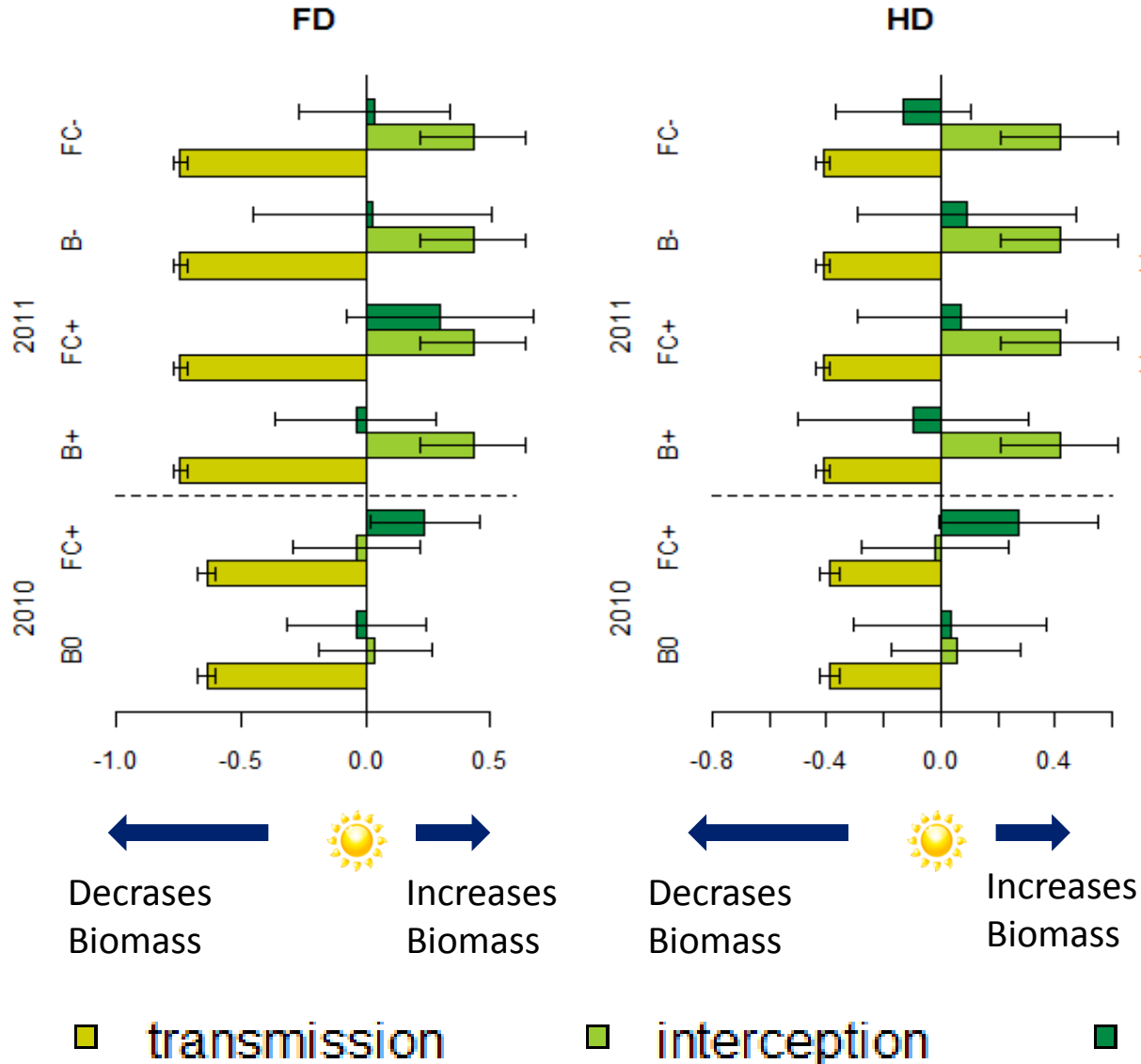


*Biological  
conversion*



*Biomass*

# Assessing RIE and RCE in the shade



- Main shade compensation relies in increased RIE
- Ability to increase RCE depends on variety
- Different varieties have different tolerance to shade

*Marrou, et al., 2013. European Journal of Agronomy 44 (0), 54-66.*



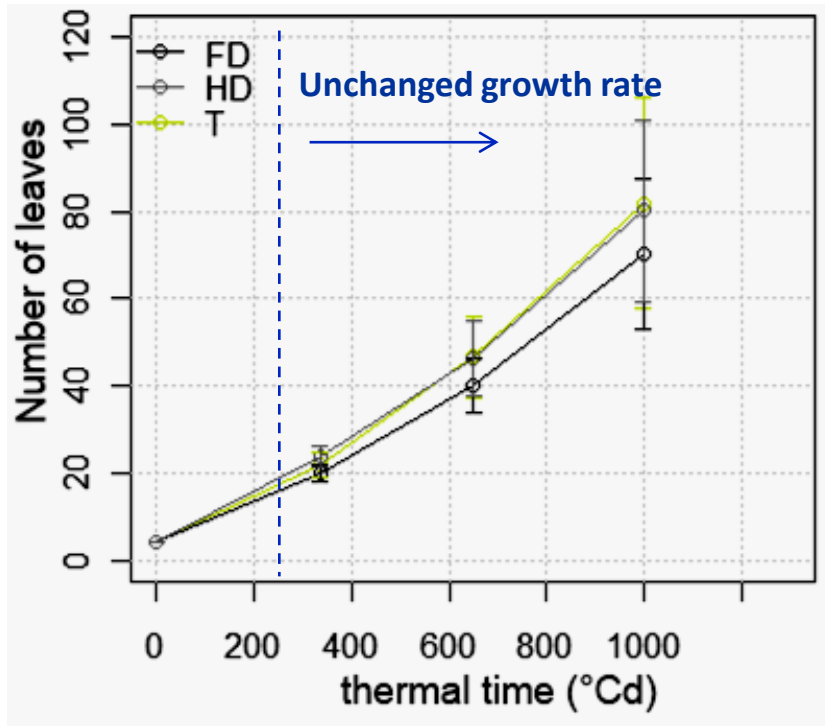


How can they intercept  
more light?

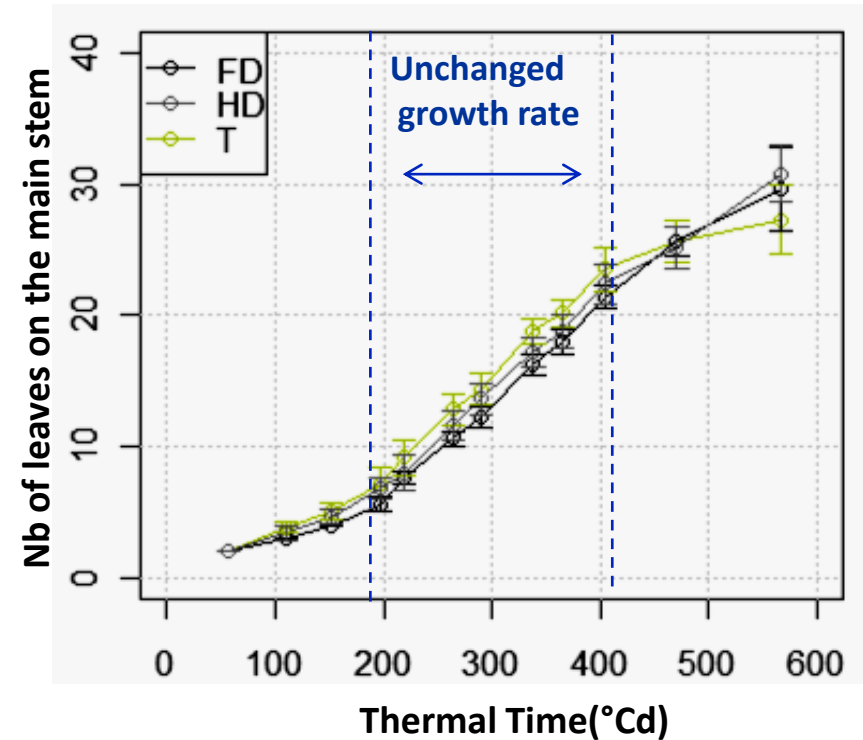


# 1/ Increased growth rate?

## Lettuces (summer 2011)



## Cucumbers

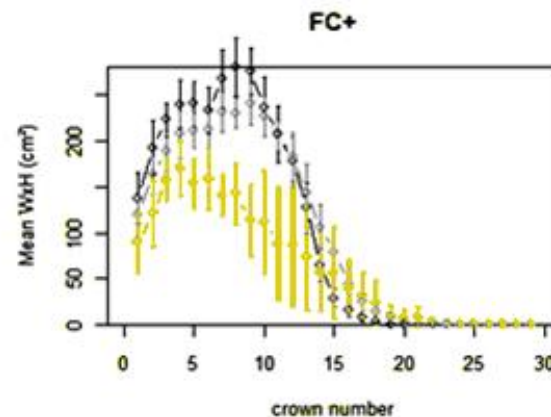
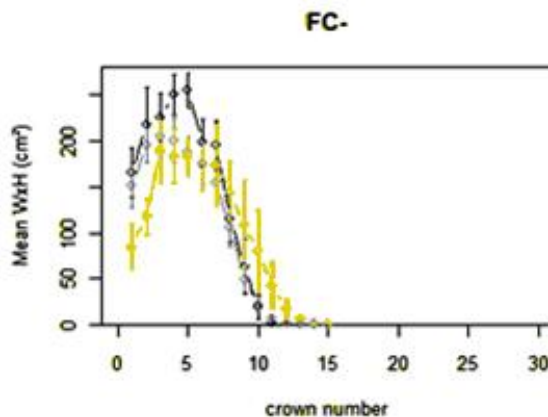
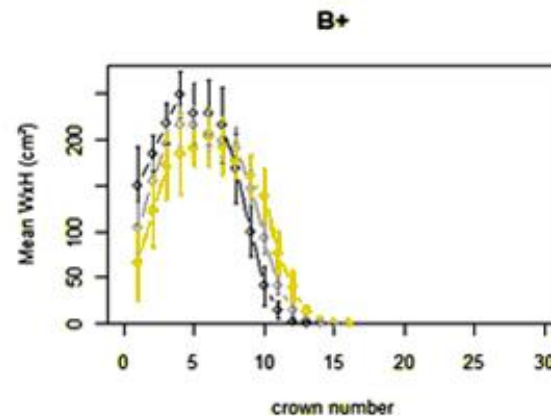
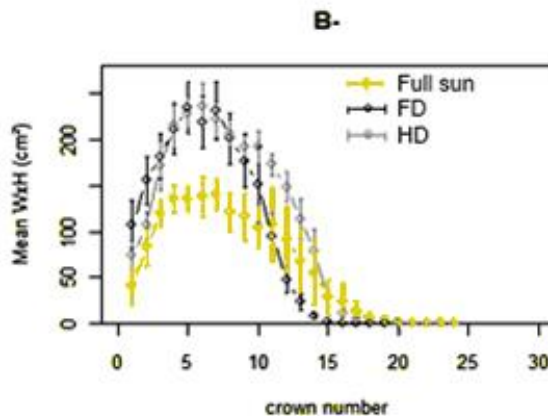


- Growth rate is not affected by shading except in the 3 first weeks of development



## 2/ Morphological adaptations?

- Total leaf area significantly increases in the shade
- leaf area is distributed differently in the leaf pool



- Bigger leaves are larger and wider
- ➔ Lettuce head diameter increases

*Marrou, et al., 2013. European Journal of Agronomy 44 (0), 54-66.*



## In conclusion

- **High productivity is maintained under solar panels**
  - Energy + food production = promising systems
  - At least 70% of radiation at canopy level (HD)
- **High yield is achieved through increased RIE**
- **High RIE efficiencies relies on morphological changes**





# Perspectives for agrivoltaic systems design

- **Further research on plant adaptation to partial/ intermittent shade**
  - Identification of specific traits for plant breeding
- **Optimize solar panels strips**
  - Solar panels on mobile structure
- **Integrated assessment**
  - Assessment of productivity at crop rotation level
  - Economic assessment
  - Environmental assessment





**THANK YOU  
FOR YOUR  
ATTENTION**

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