Challenges in modelling climate change effects on the productivity of vegetable crops

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Background

Crop production in a future climate

- elevated CO_2 & temperature, altered precipitation pattern[1,4]
- main results from FACE, OTC experiments → photosynthesis, yield…[5,6]

Crop models (CM) are useful tools in climate change impact studies

- deal with multiple climate factors and how they interact with various crop growth and yield formation processes that are sensitive to climate
- applied in many studies (e.g. Asseng et al. 2014; 2015)
- focus on main agricultural crops; food security and rising population[1,3]

Field vegetable crops

- provide healthy food & important economic sector [2]
- studies with CC-experiments under natural, often limiting environmental conditions and/or the corresponding simulation studies are lacking

(IPCC, 2013[1]; Welbaum, 2015[2]; Myers *et al.*, 2014[3]; Zachos *et al.*, 2001 & 2008[4]; Ainsworth and Long, 2005[5]; Leakey *et al.*, 2009[6])

I. Vegetable crops: growth & production

Harvest at different phenological stages

- many different edible plant parts (harvest organs): e.g. leaves, bulb, pseudo-stem, rhizome, inflorescence, immature flower stalk
- phenological stage: immature vegetative or reproductive development stage
- biomass allocation:
  - biomass present in organ (leaves, stem, flowers...)
  - environment & genotype affect source-sink relationship

Harvest several times within a growth season

- short growth cycle, several cycles within a year (season)
- season: different environmental conditions:
  - spring, summer, autumn, through winter
  - varying light & temperature conditions
- intensive water & nutrient demand

I. Vegetable crops: future climate

Responses to elevated CO_2 (eCO_2)

perennial ryegrass
- no down-regulation of photosynthesis shortly after cutting and in spring at eCO2

(Ainsworth *et al.*, 2003)

potato
- higher yield under eCO_2 primarily due to a higher number of tubers
- increase of photosynthetic rates and carbon assimilation under eCO_2

(Miglietta et al., 1998)

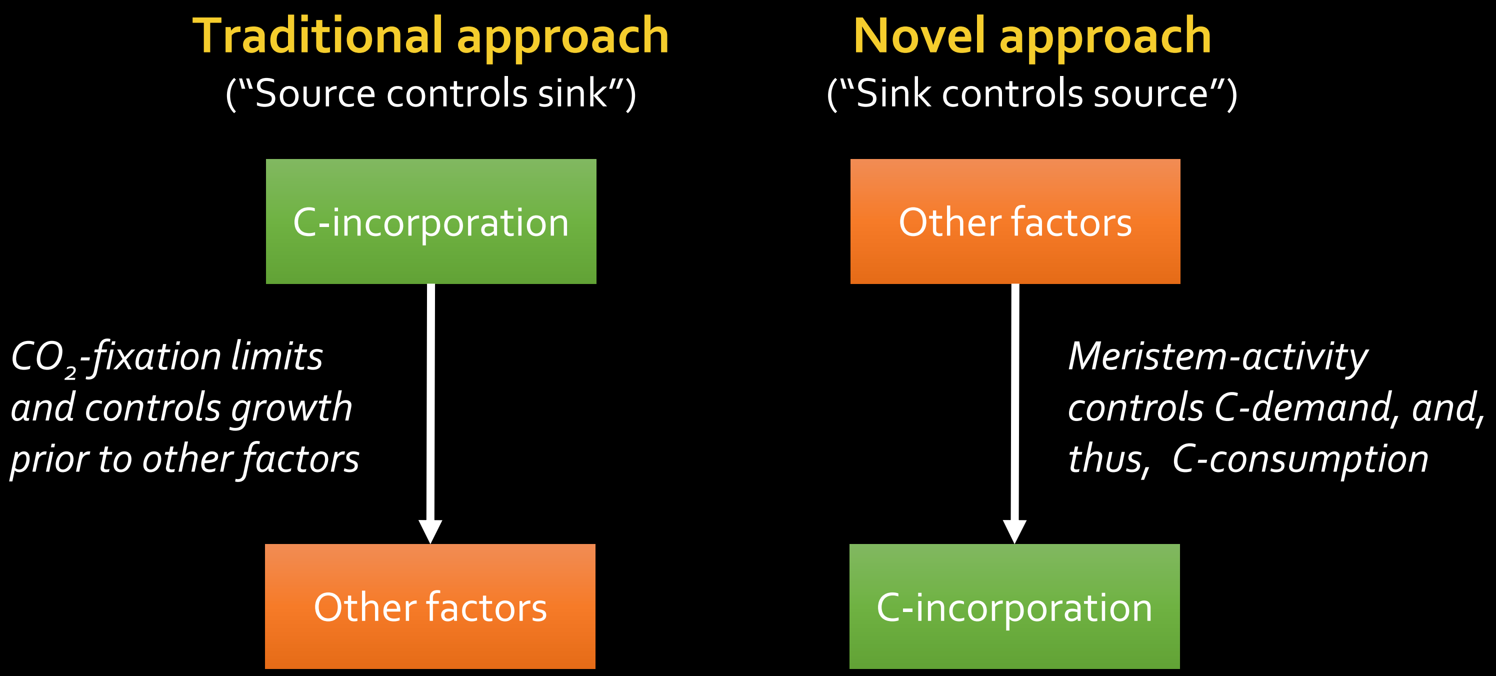
leafy vegetable
spinach (Proietti *et al.*, 2013)

fruit vegetable
cucumber (Kimball, 1983)

soybean
- stimulation of seed yield diminished to zero as drought intensified
- stimulation of leaf-level photosynthesis eliminated during periods of rapid drying

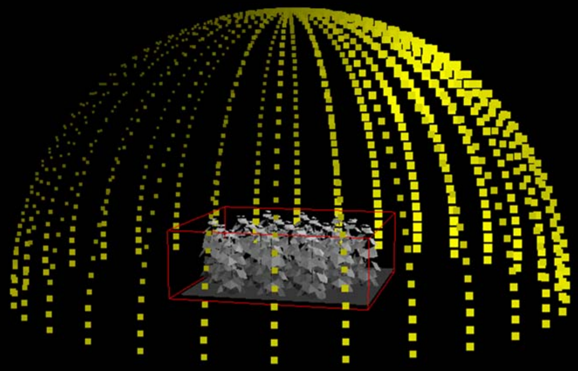
(Gray et al. 2016)

I. Vegetable crops: future climate

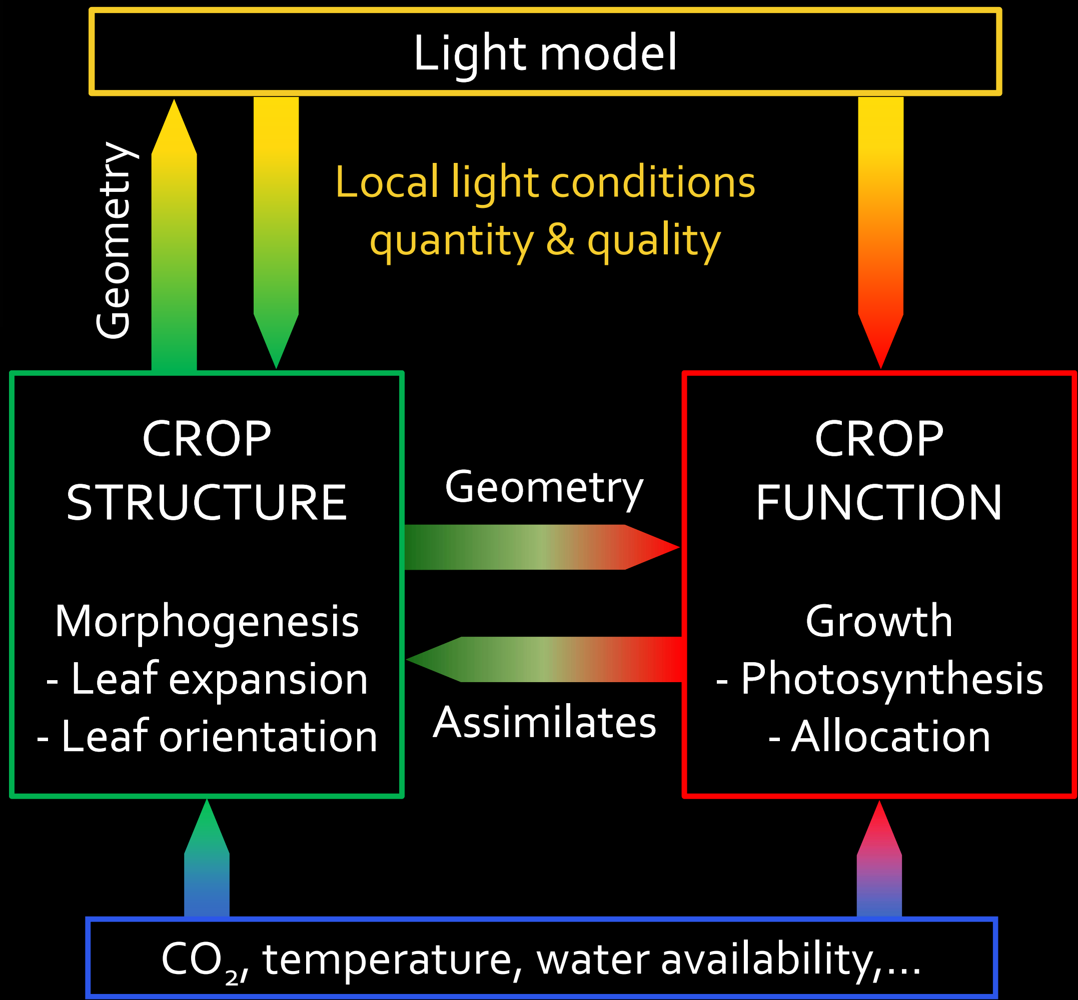


Priorities in plant growth control when nutrients, temperature or water availability (other factors) constrain plant growth or productivity (adapted from Körner, 2015), who stated: "Growth restrictions under eCO_2 are assumed to be mainly caused by sink-limitations"

II. Plant architecture: Virtual plants



Dynamic 3d plant growth model



II. Plant architecture: photosynthesis

Extended approaches for quantitative limitation analysis of photosynthesis

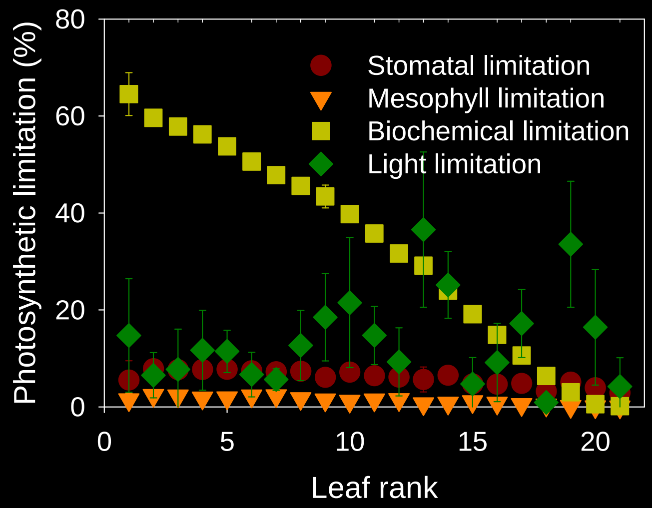
- non-saturated light

  What is the most prominent factor limiting photosynthesis in a cucumber canopy?

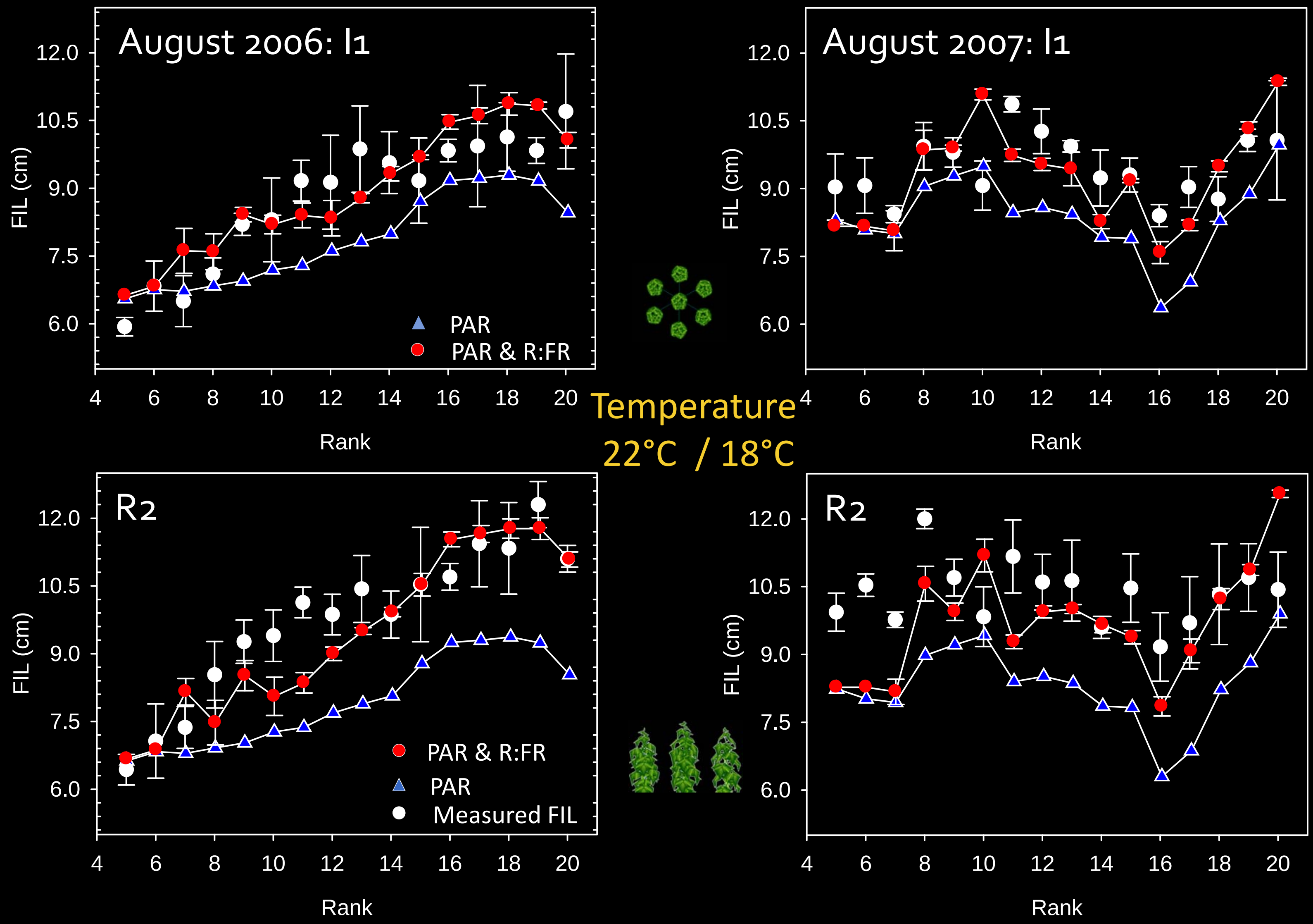
  (Chen et al. 2014 AoB)

- salt stress

  (Chen et al. 2015 PCE)

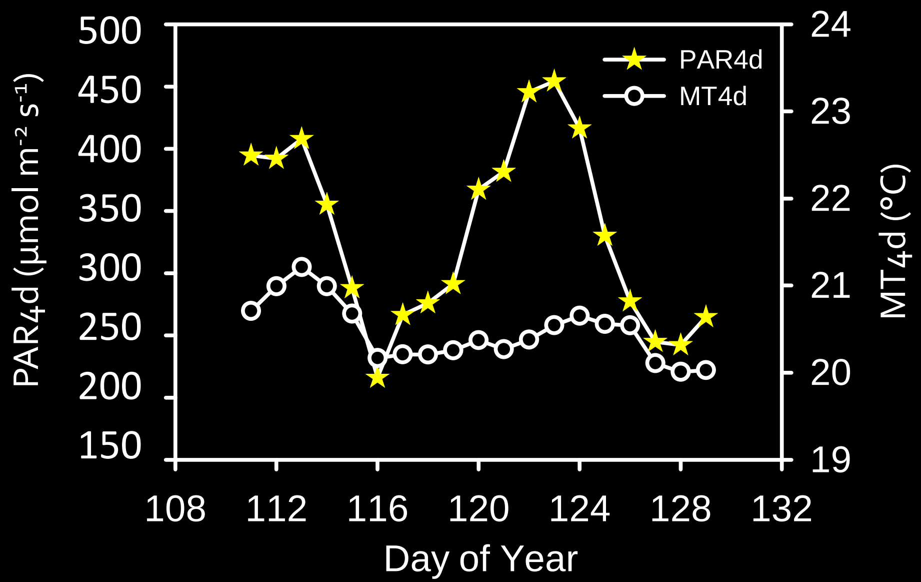


II. Plant architecture: light

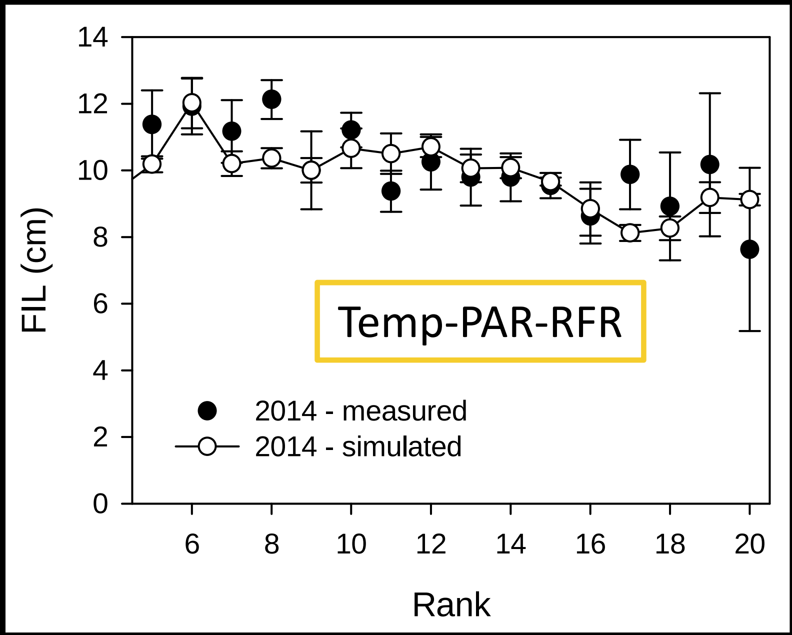


(Kahlen and Stützel, 2011)

II. Plant architecture: light & temperature



Measured climatic data with
MT4d = mean temperature of 4 days (°C)
PAR4d = mean PAR of 4 days (µmol m^{-2} s^{-1}).

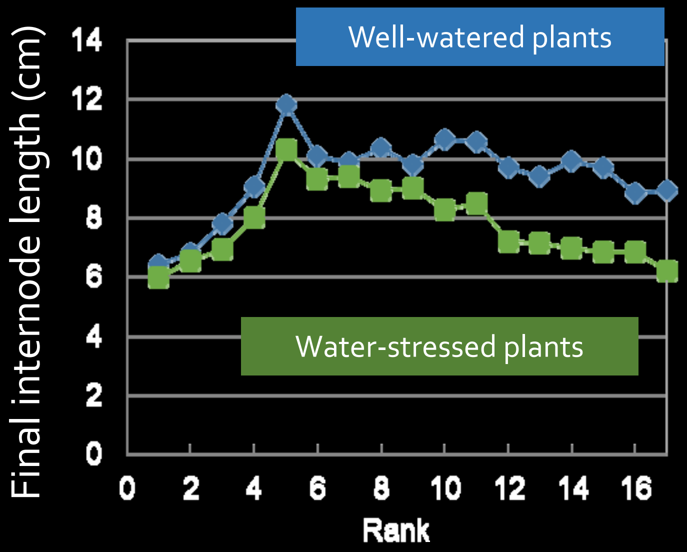


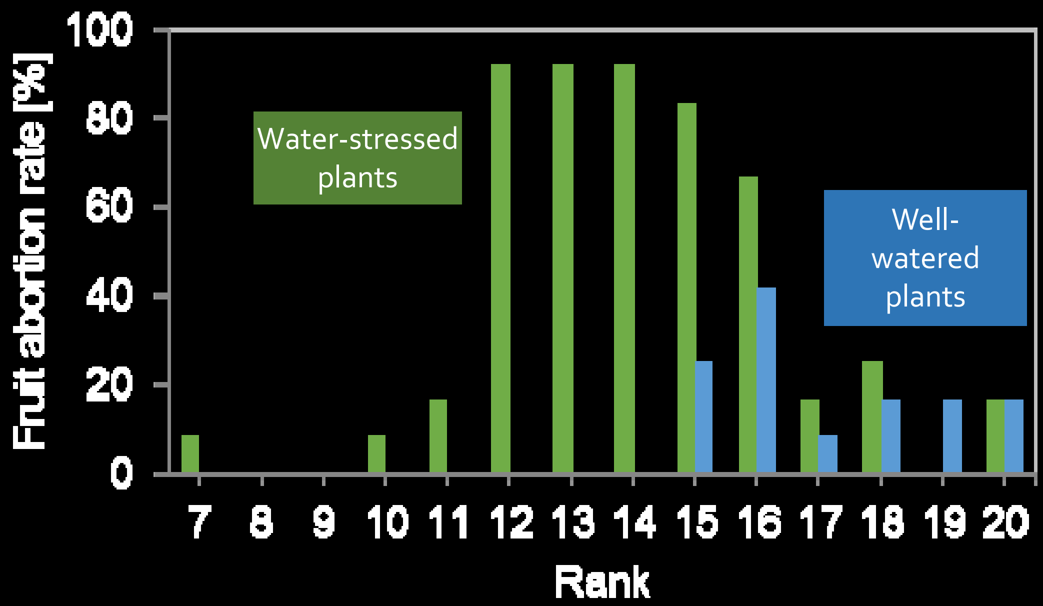
Observed and simulated lengths of internodes (FIL) cucumber plants at 4 weeks after transplanting

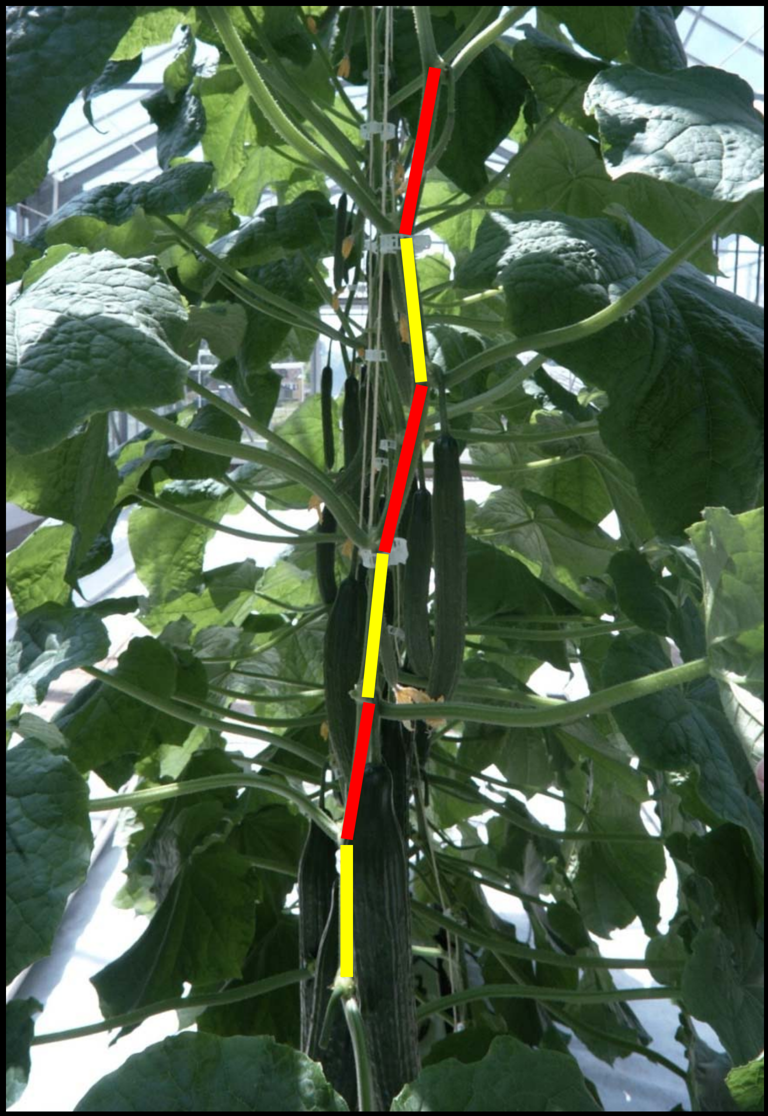
	PAR	PAR-RFR	Temp-PAR-RFR
RMSD	1,8	1,4	1,0
Rel. RMSD	18%	14%	10%
Bias	1,7	0,9	0,1
SPE	89%	41%	2%

(Kahlen and Chen, 2015)

II. Plant architecture: drought stress







(Fruit model: Wiechers et al. 2011)

III. Virtual plant modelling: changing / future climate

Recent studies of

Pallas and Christophe (2015, grapevine)
Moriondo et al. (2015, olive trees and grapevine)

summarize

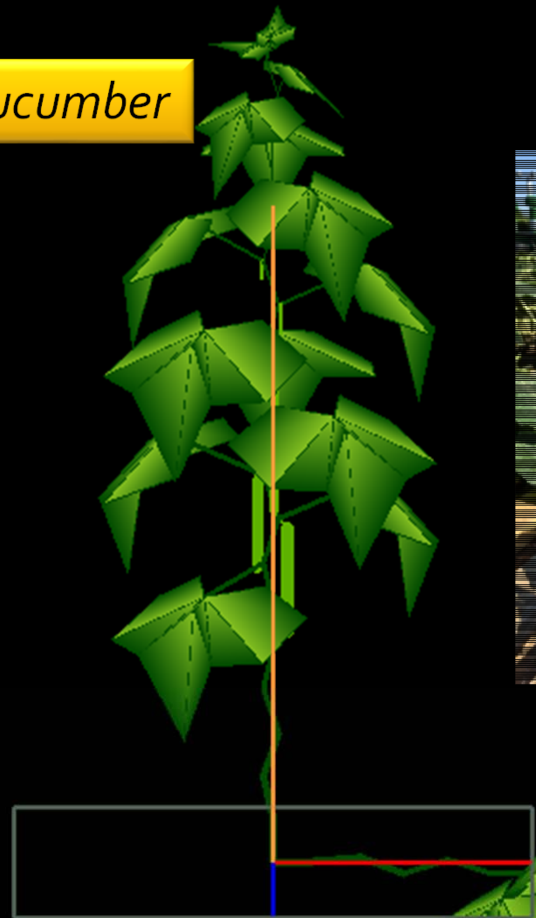
- usefulness of models combining the responses of individual organs to environmental conditions with processes taking the effect of multiple constraints into account

- need to take into account the variability in sink strength under abiotic constraints
  e.g. intrinsic leaf sink strength depends on abiotic stress(es)

- need large range of experimental conditions for parameter estimation

III. Virtual plant modelling: future climate

L-*Cucumber*



I. conceptualize virtual plant model for field-grown pickling cucumber based on *L-Cucumber*

II. integrate plant responses to changes in water availability, integrate concepts for branching and adapt the model for fruit growth via sink activity

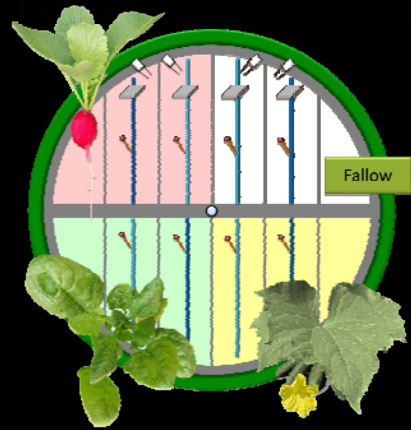
III. parameterization: data from growth chambers, greenhouses

eL-PicklingCucumber

III. Virtual plant modelling: future climate

FACE2FACE

IV. Model evaluation: use data from face facility, e.g. at Geisenheim University (Germany)



Face2Face-Project with work packages for three vegetable crops and modelling

V. Simulation scenarios: conduct *in silico* experiments

Summary - challenges

I. Vegetable crops versus major agricultural crops

- growth characteristics & harvest organs, functional groups
- learning from agricultural crops
- role of sinks/other control pathways in responses to elevated CO_2 under limiting conditions

II. Role of plant architecture

- resource use efficiency
- plant growth and development
- interplay with productivity under changing environmental conditions

III. Virtual plants - suggestions

- start with greenhouse crop model
- learn from grapevine studies
- use sound experiments for model evaluation