Crop-wheather modeling

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Global climate change

- Atmospheric [CO_2] concentration is definitely going up, therefore
- Climate is changing
  - Warmer (probably)
  - Changes in rainfall patterns
    - spatial
    - seasonal
- Effects on natural and agricultural ecosystems

Sensitivity to global change

- Direct responses to changes in [CO_2], temperature and water supply

  [CO_2] increase → growth rate increase

  Temperature increase → growth duration decrease

  Temperature increase → harvest index change (?)

  Combined [CO_2] & T increase → Increased WUE

  Changes in water supply → ???

  Combined [CO_2] & T increase & Water shortage → ???

Strategy making

- Climate scenarios for the future (General Circulation Models)
- Experimental work to determine responses to changes in temperature, water supply, [CO_2] and agrotechnics (new varieties, nutrient supply, sowing date)
  - Experiments take long time, high costs, difficult to study interactions
- Simulation modells that incorporates known responses
  - low cost investigation of studying the effects of many factors
  - independently of each other and also applying their interaction
- Advices on new agrotechnics, new varieties

Definition

- System analysis and simulation has been used by engineers for more than a half century.
- Their successes inspire biologists and agronomists to apply similar techniques in their disciplines.
- The approach is characterized by the terms: systems, models and simulation.
- A system is a limited part of reality that contains interrelated elements. It has definite boundaries.
- A model is a simplified representation of a system.
- A simulation is the building models using mathematical, logical or experiential relationships to predict the status of an organism or system in response to changing conditions.

Types of models

- Descriptive models uses data sets for making statistical analysis to show the existence of relations between elements without any explanation.

- Explanatory models - have the purpose of explaining interrelations.
  - Objective of explaining the bridges between levels of organization.
  - Understanding of larger systems on the basis of the knowledge on smaller systems.
  - Properties of membranes may be understood better by studying molecules and the properties of ecosystems by studying species.

- Dynamic models are obtained if the time dimension is introduced during the collection and treatment of the data.

- Simulation models are dynamic explanatory models building from mathematical expressions.

Variables

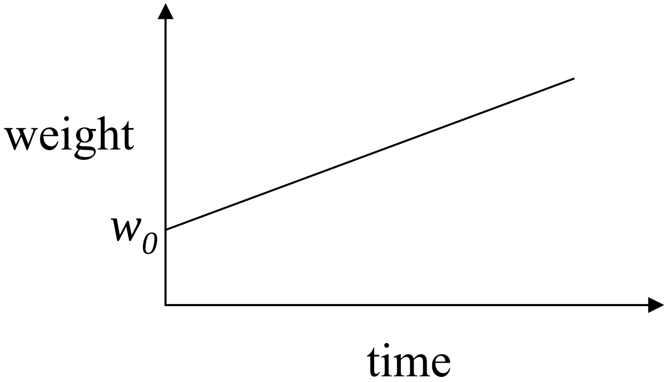
- Dynamic models are based on the assumption that the state of each system at any moment can be quantified, and that changes in the state can be describe by mathematical equations. In these models state, rate and driving variables are distinquished.
- State variables are quantities like biomass, number for a species, the amount of nitrogen in soil, plant or animal, the water content of the soil - variables that can be measured when time stands.
- Driving variables, or forcing functions characterize the effect of the environment on the system at its boundaries, and their value must be monitored continuously. Examples are macrometeorological variables like rain, wind, temperature and irradiation – over the boundaries of the system.
- Each state variable is associated with rate variables that characterize their rate of change in time as a result of specific processes. These variables represent flows of material or energy between state variables. Their values depend on the state and driving variables according to rules that are based on knowledge of the physical, chemical and biological processes that take place, and not on a statisctical analysis of the behaviour of the system that is being studied. This is the most important distinction between models that describe and models that attempt to explain.
- The number of variables of a model describing a living organism can be very large.

- State variable (t+Δt) = state variable(t) + rate variable(t) * Δt
- This procedure called integration.
- It gives the new values of the state variables

- For example linear growth is:

$$\frac{dw}{dt} = c_m$$

$$w = w_0 + c_m \cdot (t - t_0)$$



- w is the biomass (gm^{-2}) – state variable
- w_0 is the biomass (gm^{-2}) at t_0
- c_m is the maximum growth rate ($gm^{-2}d^{-1}$) – rate variable – depends on driving and state variable
- t is the time (d)
- t_0 is the start moment (d)

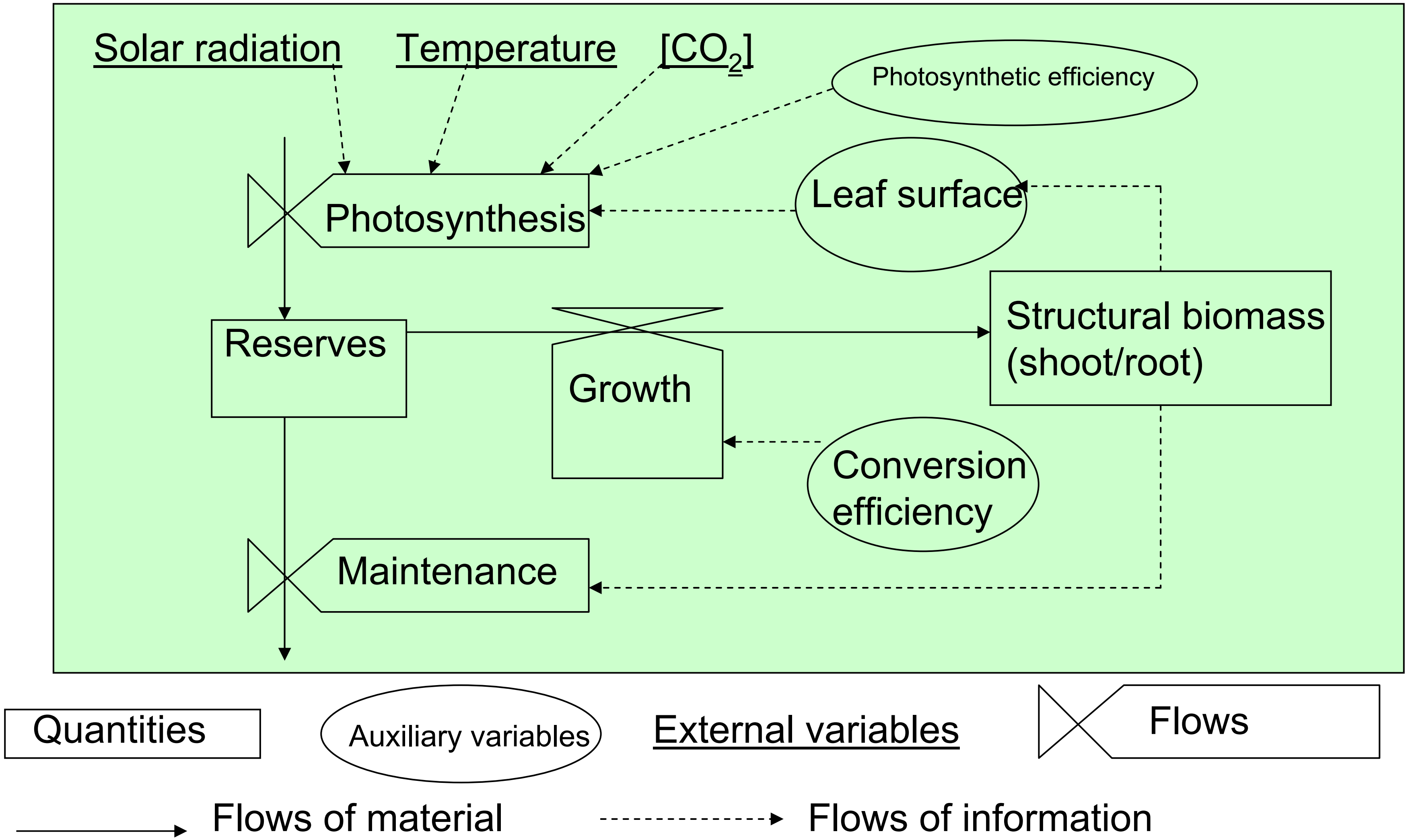
- Crop models can be used to understand interactions between crop parameters.
- Crop modelling has progressed significantly, extending the considered factors
  - water- and N-limitations,
  - biotic and abiotic stresses,
  - competition with other plants
- Crop models can describe plant properties
  - product quantity and quality,
  - morphological characteristics
- And the scales of application is broadening
  - from the detailed levels of systems biology
  - to the coarse levels for climate impact assessment.

- In simulation of crop growth, we have to find the balance between emphasis on different disciplines, in view of the objective of the model such as between physiology (research purpose) and agronomy (decision making).

- We have to determine the boundaries of the system between which the integration process will be done. The boundary can not be the leaf surface, but at a few centimeters away from the leaf surface away – because of micrometerological effects.

- The time scale of the processes is another important feature.
  - It is not always clear how long the simulation will last.
  - The environment of the system (the driving force) may change during the simulation run.
  - For example crop growth models's time step is usually one day, but the driving forces temperature and radiation changes within a day, so time step of submodel photosynthesis is 1 hour.

Relational diagramm of the essence of growth at potential production (without nutrient and water limitation)



Process of modeling

- Experimental data
- Building mathematical representation of relationships → simulation model
- Parameterization
  - Usually parameterization of a simulation model is not an easy work.
  - Most of the plant varieties respond to their environment in different way and degree, so the parameter values are also different for varieties and very often for cultivars, too.
- Validation of models using experimental data

Minimum Data

- The minimum data set refers to a minimum set of data required to run the crop models and validate the outputs.

- Validation requires:

  – Site weather data for the duration of the growing season,
  – Site soil data, and
  – Management and observed data from an experiment

Weather Data

- The required minimum weather data includes:
- latitude and longitude of the weather station,
- daily values of incoming solar radiation (MJ/m^2-day),
- maximum and minimum air temperature (ºC), and
- rainfall (mm).
- The period of weather records for validation must, at a minimum, cover the duration of the experiment and preferably should begin a few weeks before planting and continue a few weeks after harvest so that "what-if" type analyses may be performed as desirable.

Soil Data

- Desired soil data includes soil classification, surface slope, soil color, permeability, and drainage class.

- Soil profile data by soil horizons include:

  - upper and lower horizon depths (cm),
  - percentage sand, silt, and clay centent,
  - 1/3 bar bulk density,
  - organic carbon,
  - pH in water,
  - aluminum saturation, and
  - information on abundance of roots

Management and Experiment/Observed Data

- Management data includes information on planting date, dates when soil conditions were measured prior to planting, planting density, row spacing, planting depth, crop variety, irrigation, and fertilizer practices. This data are needed for both model validation and strategy evaluation.

- In addition to site soil and weather data, experimental data includes crop growth data, soil water and fertility measurements. This data are needed for model validation.

Some of the available wheat simulation models

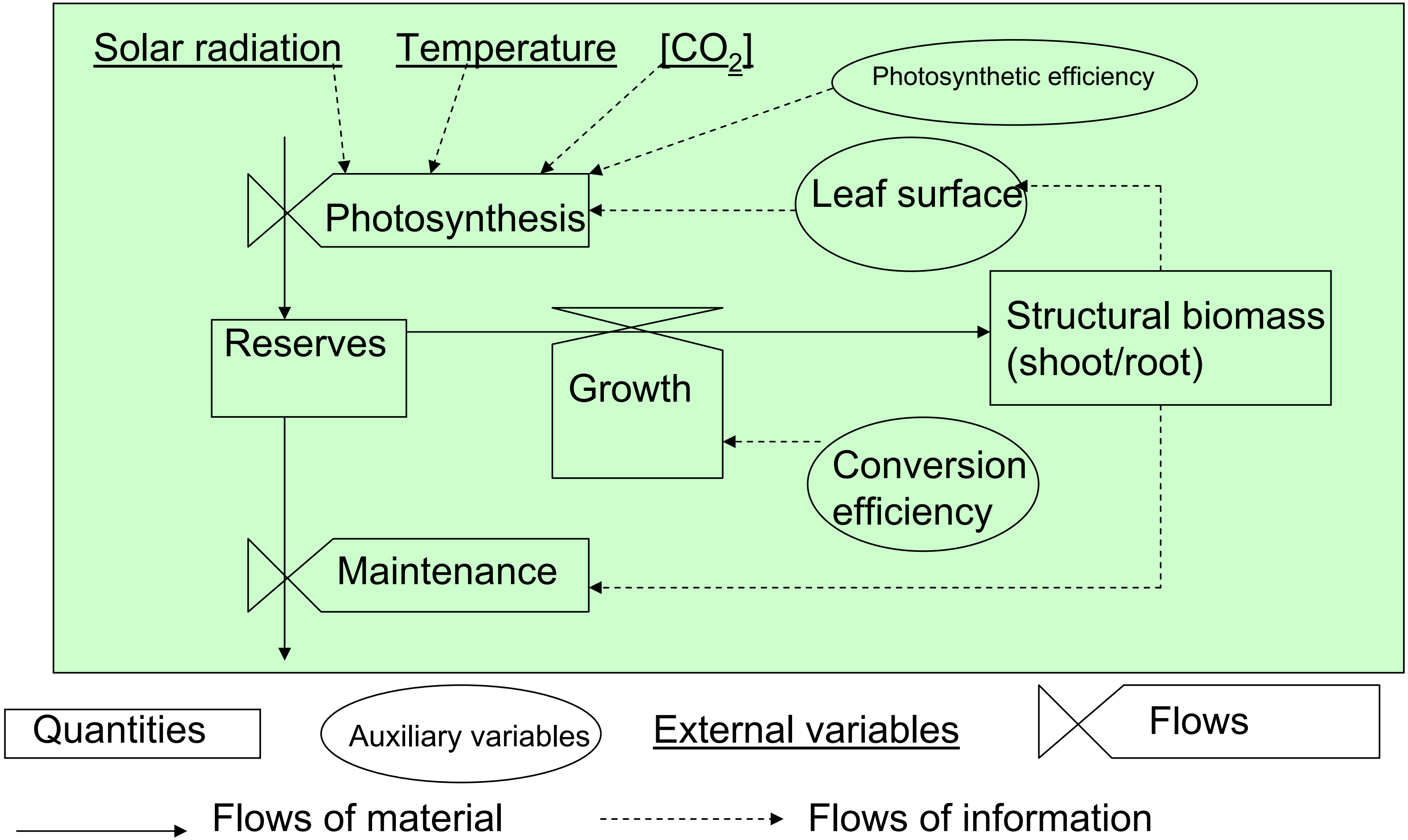
- Research:
  - AFRCWHEAT2
  - SWHEAT
  - SUCROS
  - CropSim
  - Sirius

- Decision support models:
  - DSSAT - CERES-Wheat
  - 4M → Friday

Two simple examples for modeling

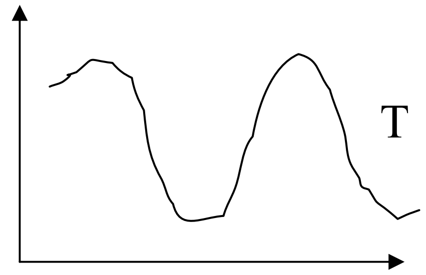
- A biochemical model describing net CO_2 assimilation in C_3 plants
  - A very known model is the biochemical model of Farquhar et al. (1980) and Farquhar and von Caemmerer (1982) and modified by Sharkey (1985) and Harley and Sharkey (1991).
- Validation of crop growth simulation models
  - Ceres-Wheat,
  - AFRCWHEAT2

Relational diagramm of the essence of growth at potential production



A simplified algorithm

Repeat *hour*=0 to 24



Calculate PAR for *hour*

Calculate Temperature for *hour*

Calculate photosynthesis (PAR, TEMP, CO2, Leaf area, photosynthetic efficiency) for four leaf levels

Calculate growth (reserves, developing rate)

Calculate maintenance (reserves, structural biomass)

END

An example for modeling net CO_2 assimilation

- Experiment on winter wheat in OTC
  - Ambient and doubled [CO_2]
  - Potential water and nutrient supply
  - Dataset:
    - Net CO_2 assimilation rate on
      - flag leaf on changing [CO_2] and temperature
      - at four vertical leaf levels
- Model of net CO_2 assimilation
- Validation

Model of net CO_2 assimilation (A) by Farquhar et al. (1980), Sharkey (1985) and Harley & Sharkey (1991) (Farquhar model):

$$A = V_c - 0{,}5V_o - R_{day} = V_c \left(1 - \frac{0{,}5O_i}{\tau \quad C_i}\right) - R_{day}$$

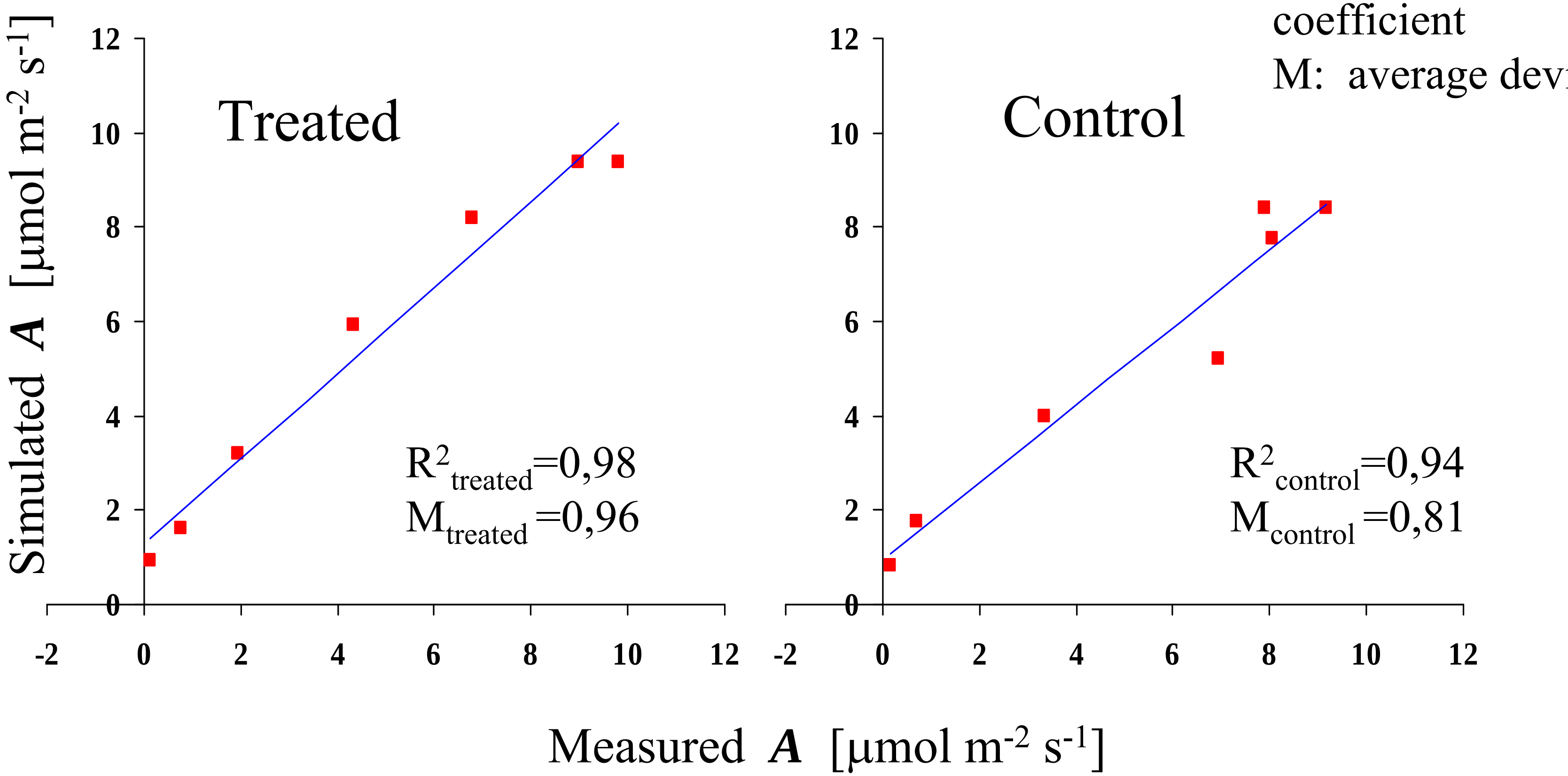
V_c and V_o rate of carboxilation and oxigenation,
R_{day} day respiration rate (excluding photorespiration),
τ specifity factor for Rubisco,
O_i and C_i intercellular O_2 and CO_2 concentration.

Vc=min{Wc, Wj, Wp} carboxilation rate is limited by the quantity, activity and kinetics of Rubisco (Wc), the light limiting rate (Wj) and the rate of TPU use (at high PAR and high Ci).

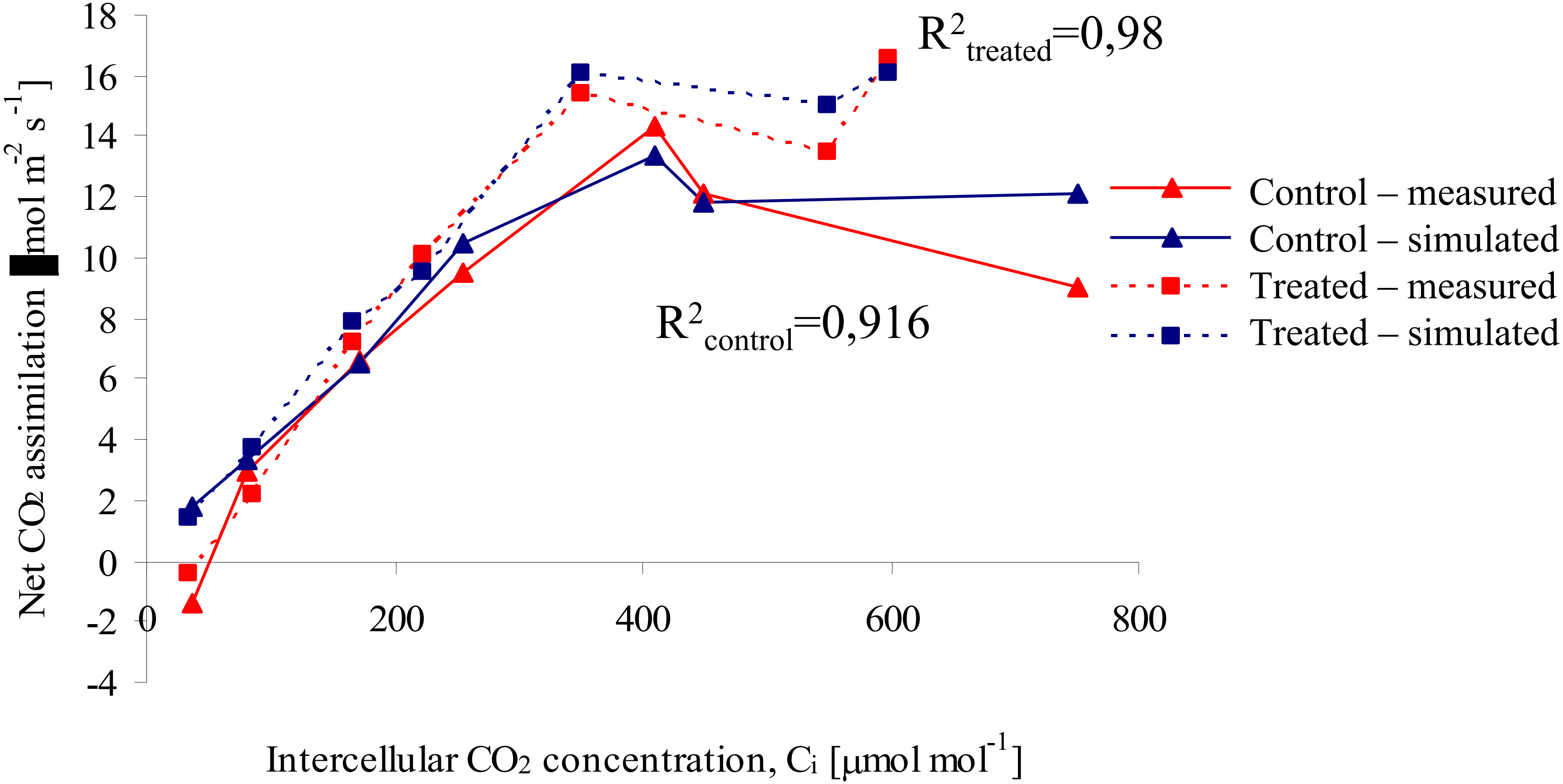
It is not yet a dynamic model, it does not change with time.

Measured and simulated net CO_2 assimilation (*A*) of flag leaf of winter wheat (Mv-16) grown at PC and EC

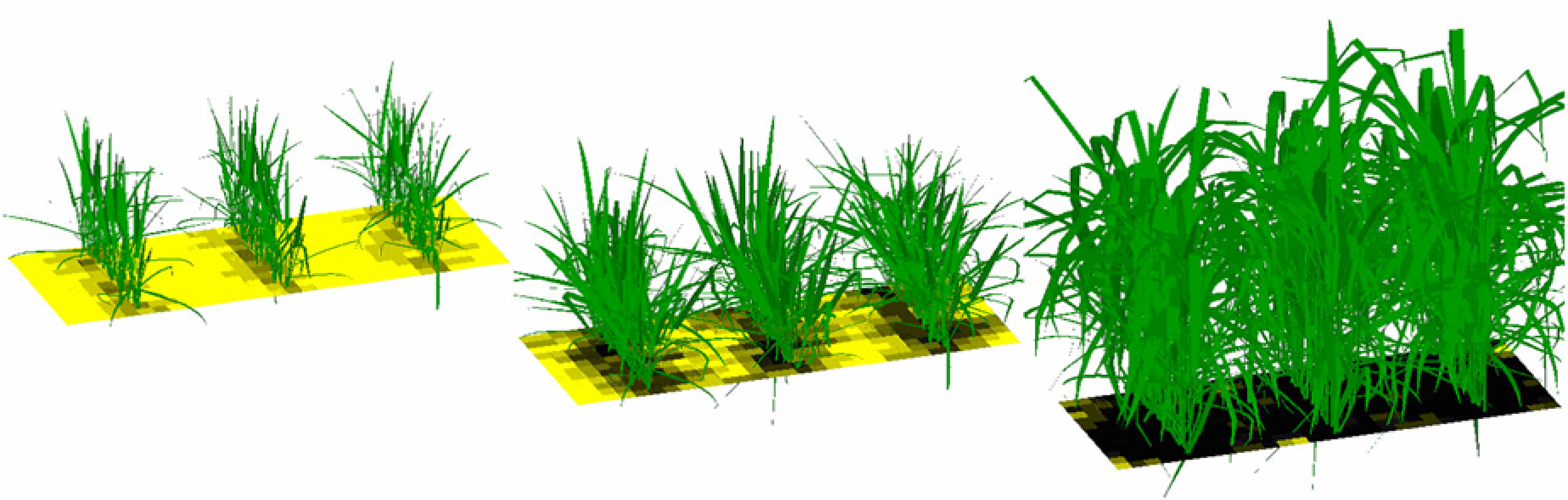
R^2: determination coefficient
M: average deviation



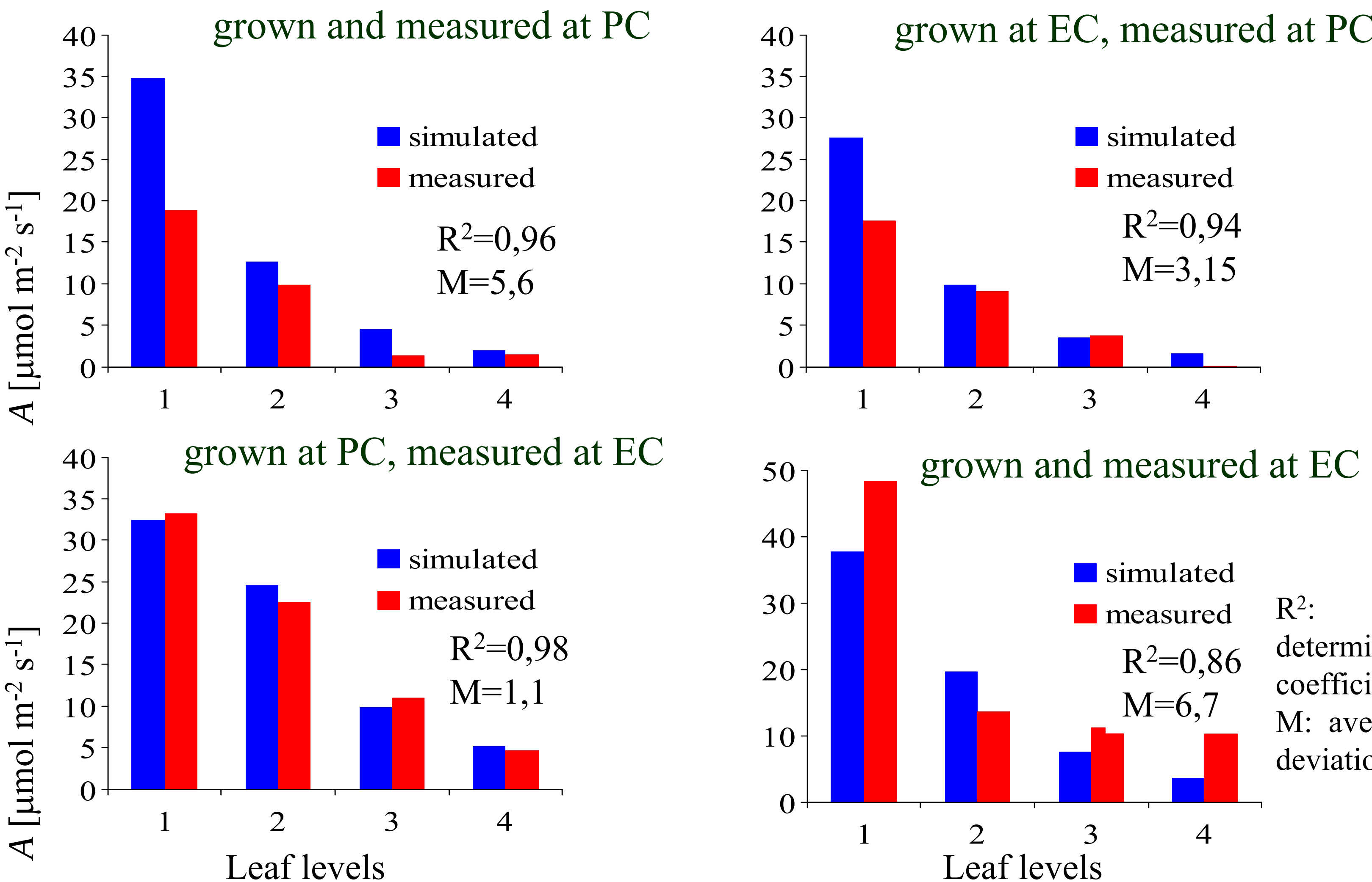
Measured and simulated net CO_2 assimilation (*A*) of flag leaf of winter wheat grown at PC and EC



Visualization of three stages in vegetative wheat development. The colour of the soil elements represents the percentage of light that penetrated the canopy onto the soil element [ranging from black (0%) to bright yellow (100%)].

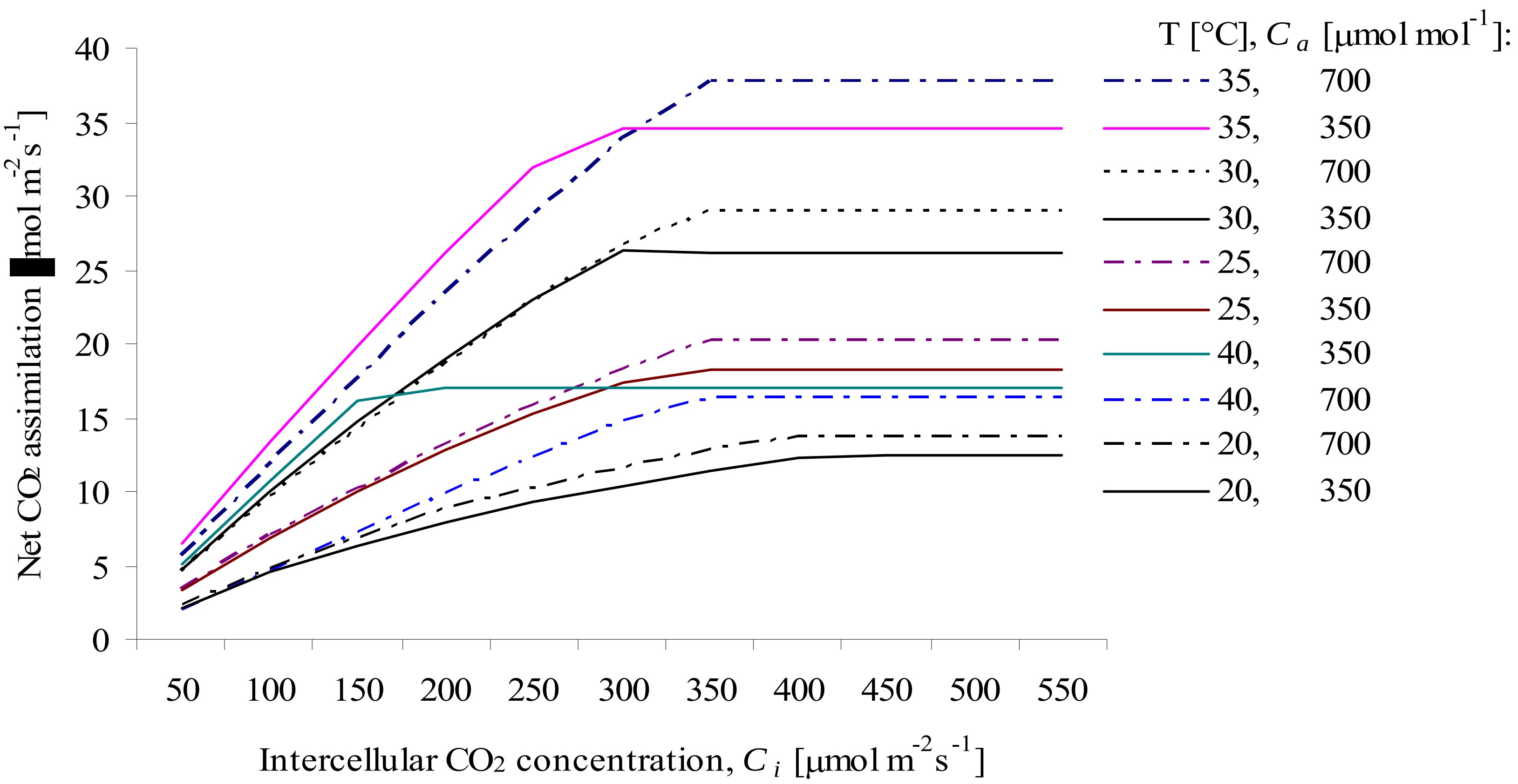


Measured and simulated net CO_2 assimilation (*A*) of winter wheat at four vertical leaf levels grown a PC and EC



R^2: determination coefficient
M: average deviation

Net CO_2 assimilation of winter wheat grown at ambient or doubled CO_2 measured on different CO_2 levels and temperatures (20-40°C) calculated by Farquhar model



Applied crop growth

AFRCWHEAT2 (for research purposes)
Ceres-Wheat (part of DSSAT)

•Complex models of development and production of wheat.

•Description of phenological development, dry matter production and partitioning in daily steps sensitive to weather.

•Description of soil water balance and water use by crop, soil nitrogen transformation and uptake by crop.

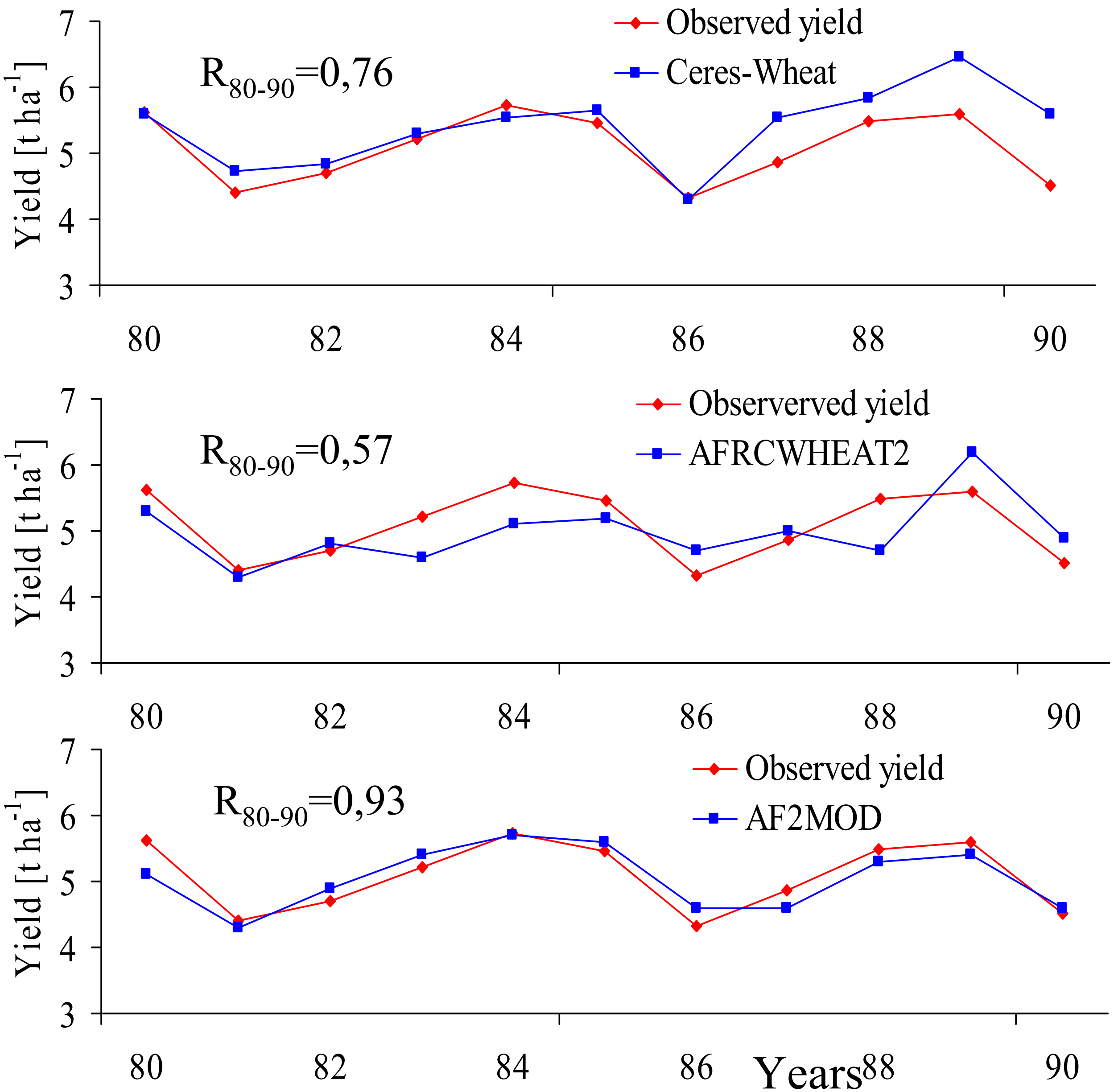
Producing AF2MOD model

The module of discription of photosynthesis in AFRCWHEAT2 was changed with Farquhar model.

Effects of elevated CO_2 concentration are effected by temperature, solar radiation.

Dataset for testing the models

Observed meteorological and grain yield data in
Győr-Moson-Sopron county situated in west Hungary
for the period 1980 and 1990.

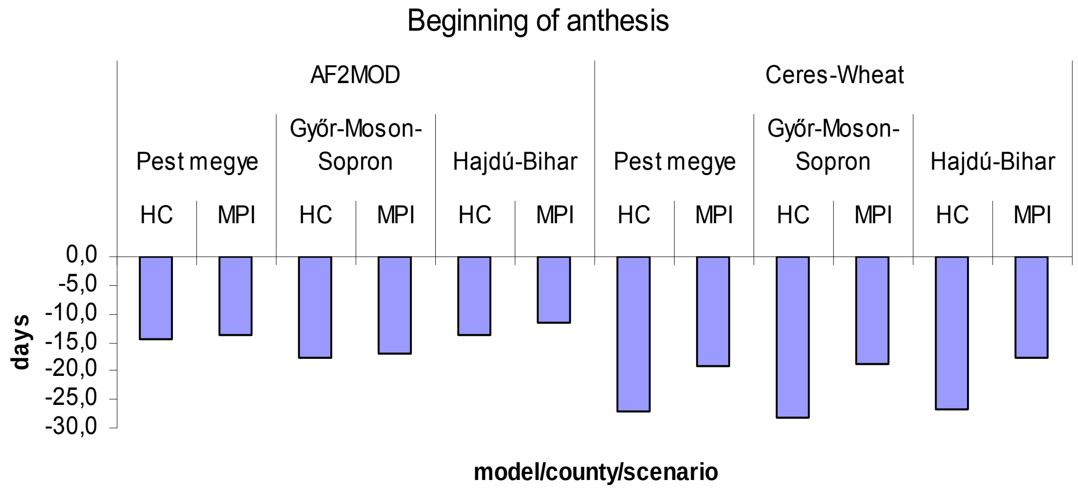


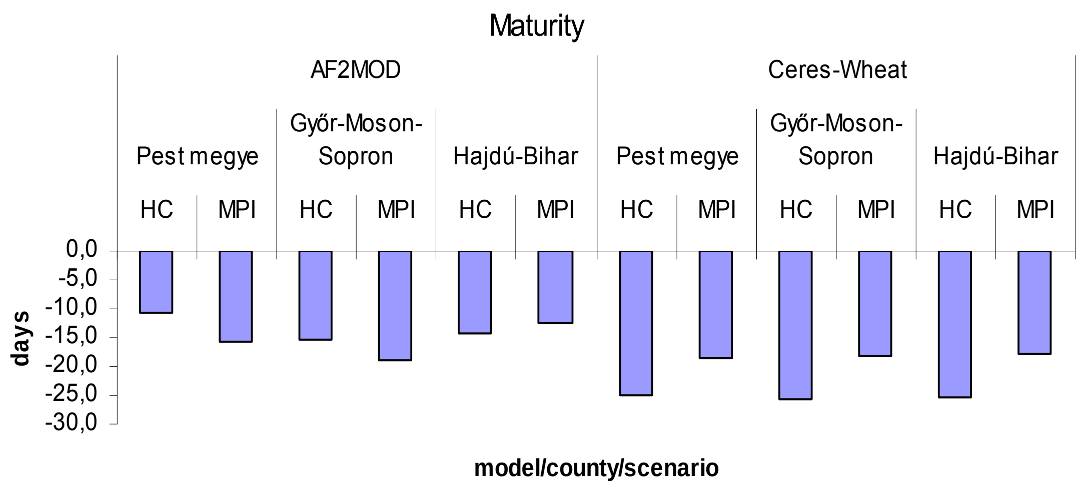
Observed yield
Ceres-Wheat
R80-90=0,76
Yield [t ha-1]
Observerved yield
AFRCWHEAT2
R80-90=0,57
Yield [t ha-1]
Observed yield
AF2MOD
R80-90=0,93
Yield [t ha-1]
Years

Temperature and precipitation changes in Hungary in 2070-2100 (Bartholy et al. 2007). GCM scenarios from Hadley Centre (HC) and Max Planck Institute (MPI).

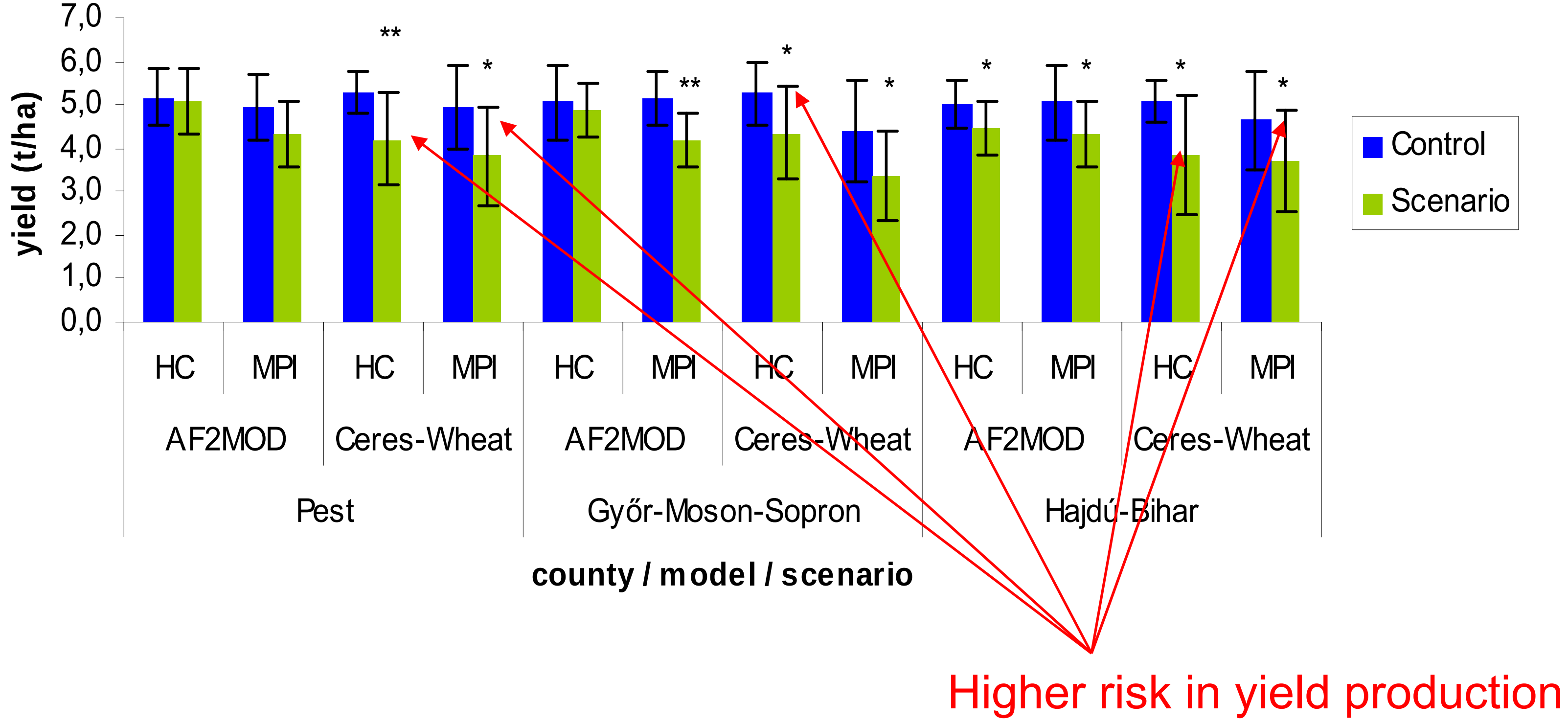
A2 scenario	Spring	Summer	Autumn	Winter
Average temperature	2.9-3.2 °C	4.5-5.1 °C	4.1-4.3 °C	3.7-4.3 °C
Maximum	2.8-3.3 °C	4.9-5.3 °C	4.3-4.6 °C	3.7-4.2 °C
Minimum	3.0-3.2 °C	4.2-4.8 °C	4.0-4.2 °C	3.8-4.6 °C
Precipitation	0 – (+10) %	(-24) – (-33) %	(-3) – (-10) %	(+23) – (+37) %

Simulated phenological phases of winter wheat on climate change scenarios made by Hadley Centre (HC) and Max Planck Institute (MPI). Every date has changed significantly from simulated dates in present climate.





Changes of simulated winter wheat yield on several climate change scenarios made by HC és MPI compared to that on present climate in average of 30 years simulation.
'**' and '*' denotes signifacant changes on 1% or 5% probability levels.



Simulation models have not yet reached the level that we could neglect experiments, but

experiments have to be planed and carried out to be able to use result to develop and validate simulation models.

Thank you for your attention