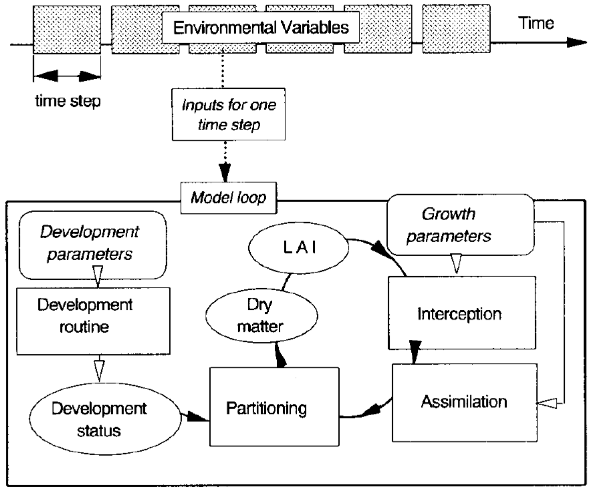
# The needs for data: can remote sensing be used for crop models' inputs?


## Davide Cammarano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# Outline

- Definition of crop simulation models
- Data needed by crop models
- Remote sensing of crop models’ parameters
- Future prospective
- Conclusions

# Introduction: Definition of crop simulation models

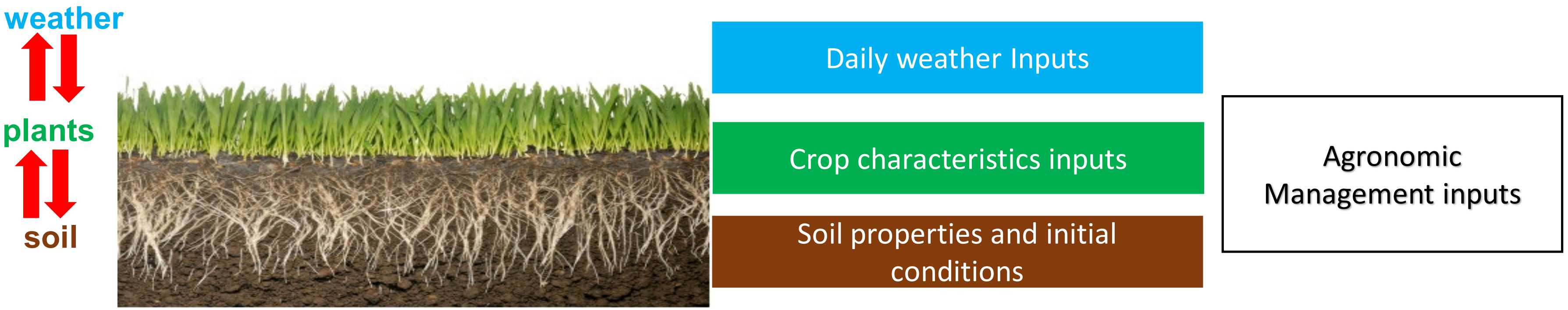
**System models (CSM) consist of a set of equations describing underlying processes, which are then coupled together to create a model that describes a system**

- transferability of field-based research;
- High costs of field experimentation (“complement field experimentation”);
- Climate related risks;
- Crop models are only an approximation of the real world;
- Nevertheless, they have played important roles in the interpretation of agronomic results, and their application as decision support systems for farmers is increasing.

*Wallach et al., 2020; Hoogenboom et al., 2019*

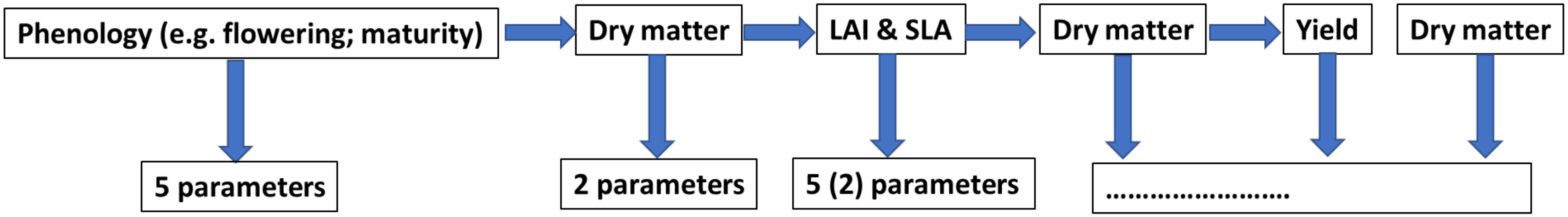
# Crop Simulation Models (CMS): Input

- Based on the understanding of the interactions between **plants**, **soil**, **weather**, **management** interactions
- Require information (Inputs), such as:
  - Soil
  - Weather (daily/hourly)
  - Cultivar characteristics
  - Management
- Predict growth, yield, timing (and depending on models many other outputs)



# Model calibration and response

- **Commonly, on crop models, the parameters are estimated by studying the system and estimate the parameters (or a subset) by fitting the overall system model to the system data.**
  - **Usually, the parameters to calibrate are the ones that define a cultivar. Often, some soil inputs need to be quantified if not measured (e.g. hydraulic properties).**
  - **The parameters to calibrate vary by model (e.g. for defining a cultivar some models have 4 and some have 20+ parameters to calibrate).**




*Boote, 1994; Wallach et al., 2020*

# Data for models’ calibration and evaluation

*https://bigdata.cgiar.org/blog-post/webinar-minimum-data-requirements-for-crop-modeling/*

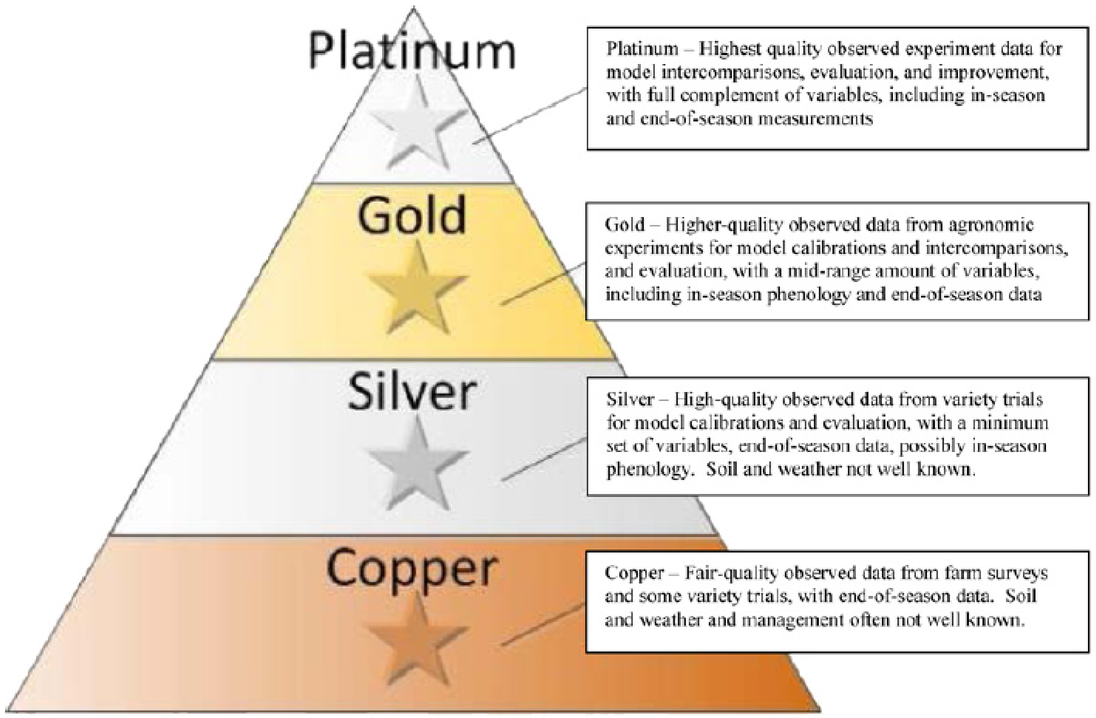
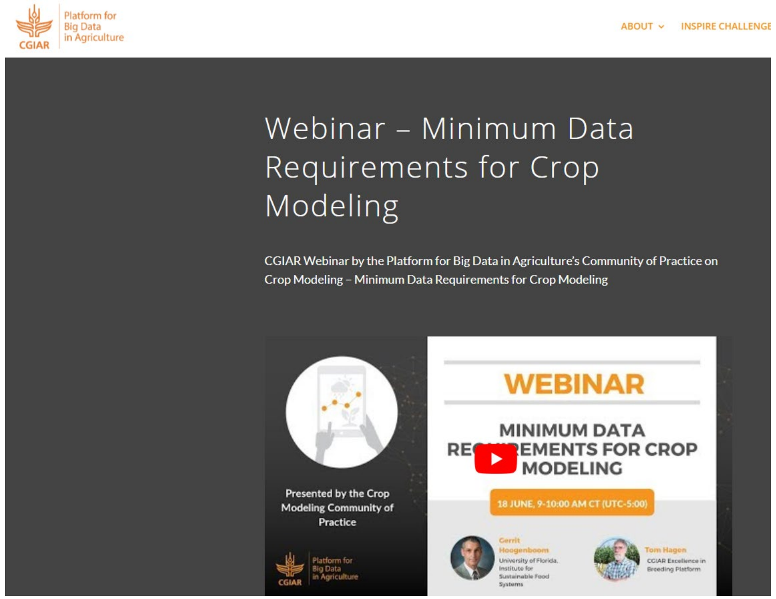


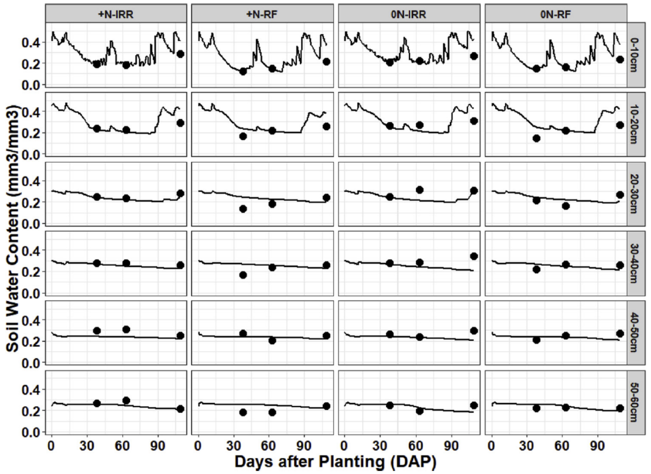

Fig. 1. Sentinel site rating criteria as developed by the Agricultural Model Intercomparison and Improvement Project (Rosenzweig et al., 2013; Kersebaum et al., 2015).

*Boote et al., 2016*



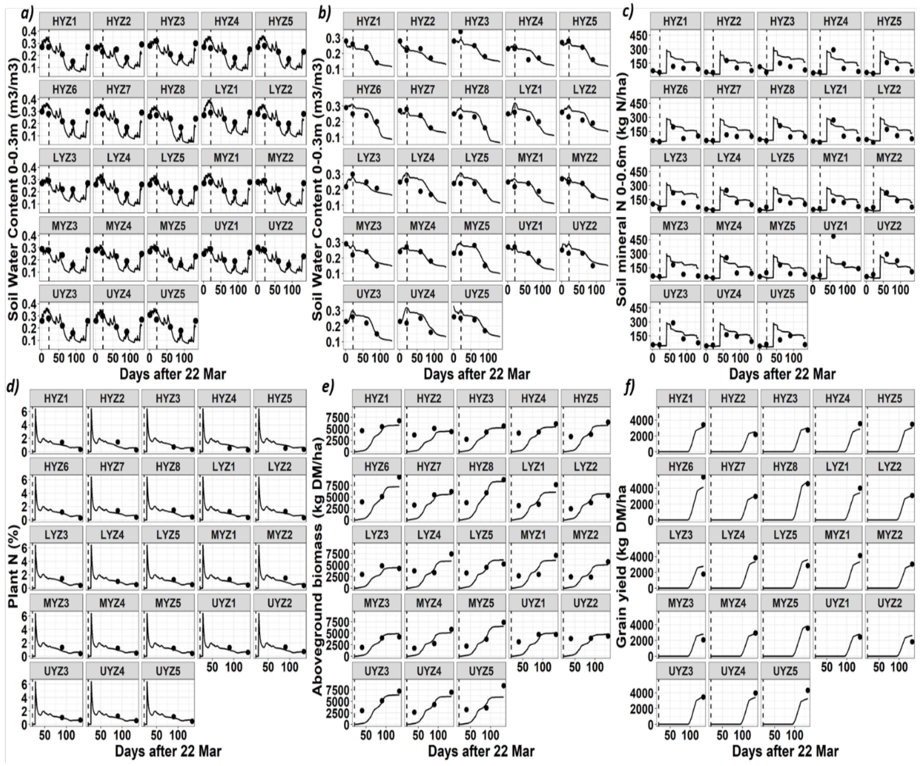
# Model calibration & evaluation

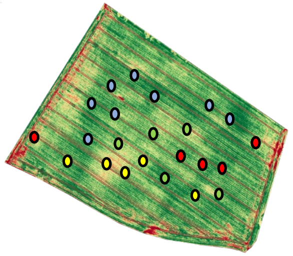
A spring barley cultivar calibrated and evaluated on a field experiment (Water and Nitrogen)




The same cultivar was grown in a farmer's field.

<u>IF initial soil conditions and all the input needed are available the model performs well in simulating observed data</u>



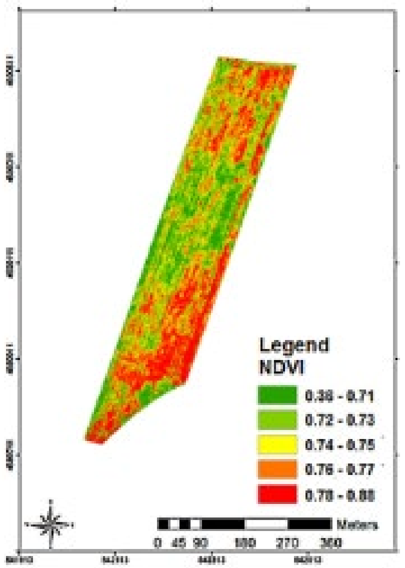



It was a lot of work!!

*Cammarano et al., 2019; Cammarano et al., 2020 submitted*

# Remote Sensing

- **Attractive because it has a spatial and temporal component**
- **Offers potential to obtain data for:**
  - **Crop models parameters**
    - **FPAR, canopy cover, biomass, canopy N, LAI**
  - **Input data**
    - **soil properties (e.g. through inverse modeling to calibrate for others)**

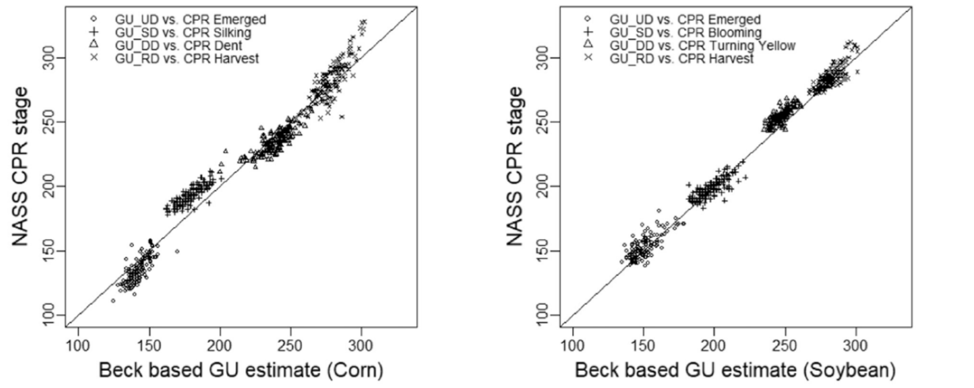



*Basso et al., 2011*

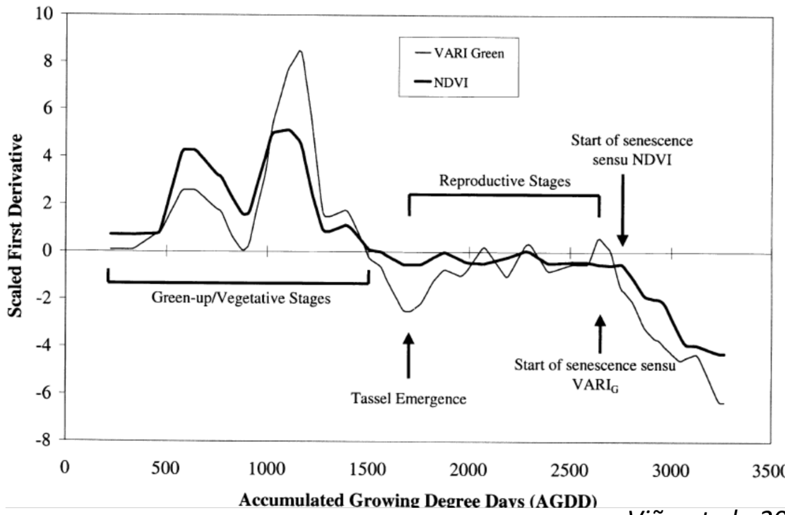
# Example of crop parameters

- ➢ **Phenology-derived RS data are more challenging if real-time information are needed**

- ➢ **Temporal patterns of Vegetation Indices might be able to provide some phenology information.**



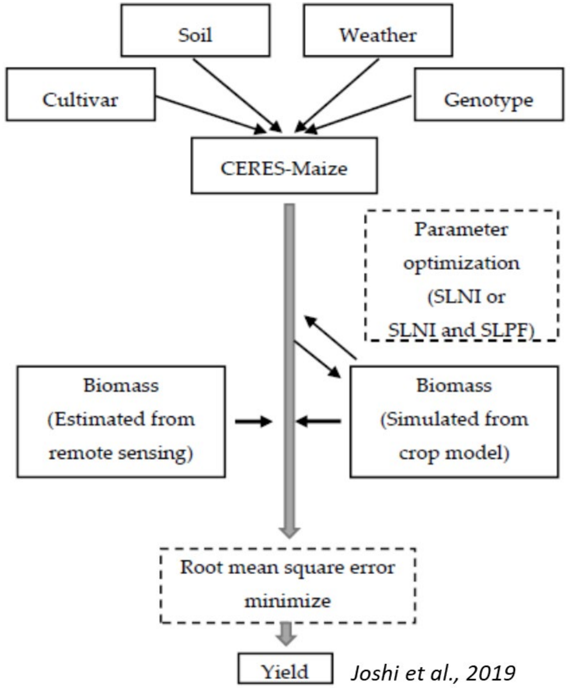

*Diao, 2020*



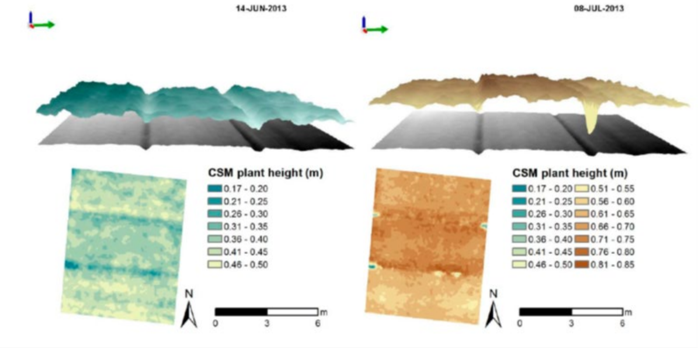

*Viña et al., 2004*

# Example of crop parameters

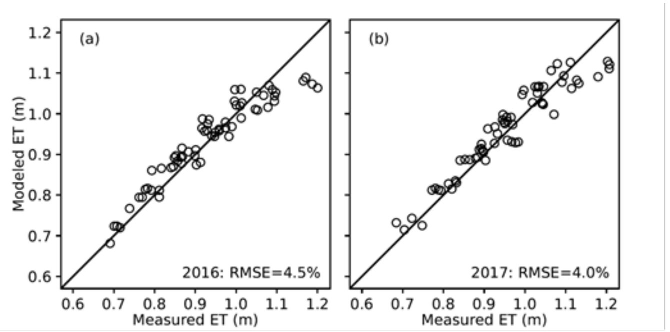
- ➢ **Crop height**
- ➢ **Crop aboveground biomass**
- ➢ **FPAR**
- ➢ **Canopy ET (e.g. multispectral cameras + fcover)**



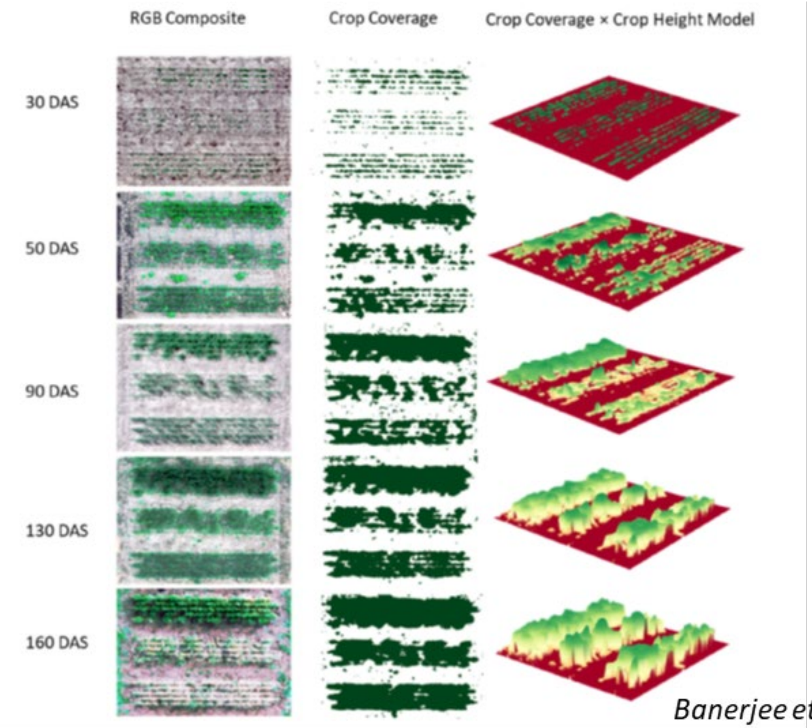

*Joshi et al., 2019*



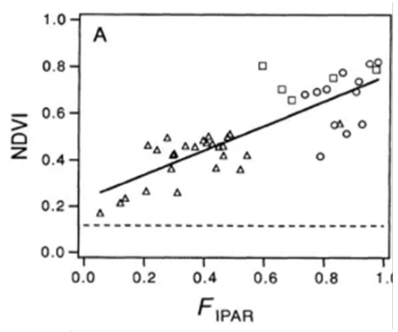

*Bending et al., 2014*




*Thorp et al., 2018*



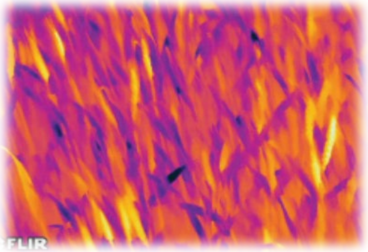

*Banerjee et al., 2020*




*Gamon et al. (1995)*

# Example of crop parameters

- Thermal cameras, combined with optical/multispectral cameras, can provide information on water-stress resistant genotypes;
  - Useful indirect information to water balance and onset of pest/diseases;
- Information on Canopy Temperature (CT)
  - CT + water index for estimation of water uptake

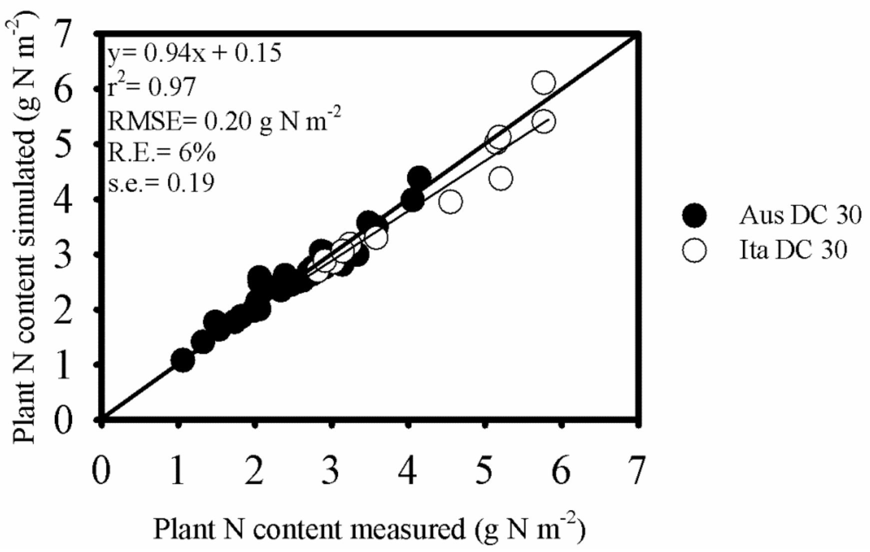


*Jin et al., 2020*

# Example of crop parameters: nitrogen content

**Contemporary presence of water and N stress**

**Canopy N% at different growth stages**




$$N\ [g\ N\ m^{-2}] = [(\%N_{max} - \%N_{min})*(1.86*CCCI - 0.346) + \%\ N_{min}]*(\text{dry biomass}/100)$$

**Linkage to CSM is through Biomass or N**

*Cammarano 2010; Cammarano et al., 2011*

# Example of soil input

**Great potentiality to link proximal soil sensors' information to soil input (e.g. texture, organic matter, bulk density):**

- **Ground-truth needed**

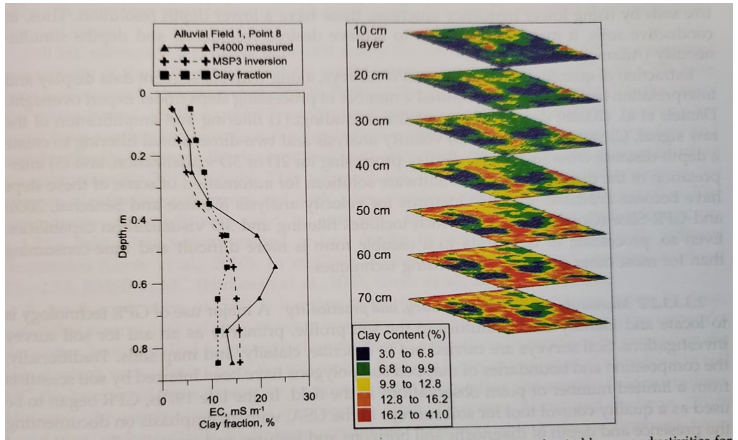
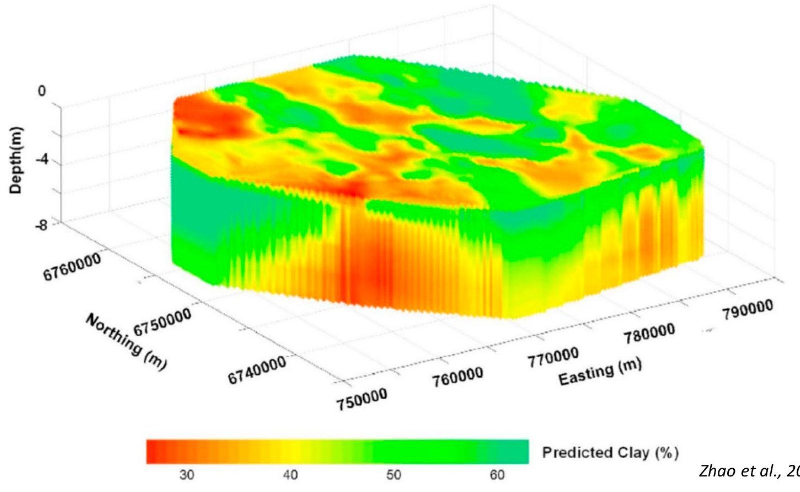



FIGURE 2.11 Comparison of profile clay variation to measured and inversion-estimated layer conductivities for one alluvial field calibration point (left), and inversion-estimated CC maps for the same field (right).

*Mouazen et al., 2020*



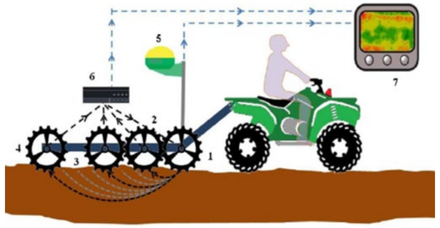

*Zhao et al., 2019*

Fig. 6. Areal distribution of predicted clay content in 3D view.

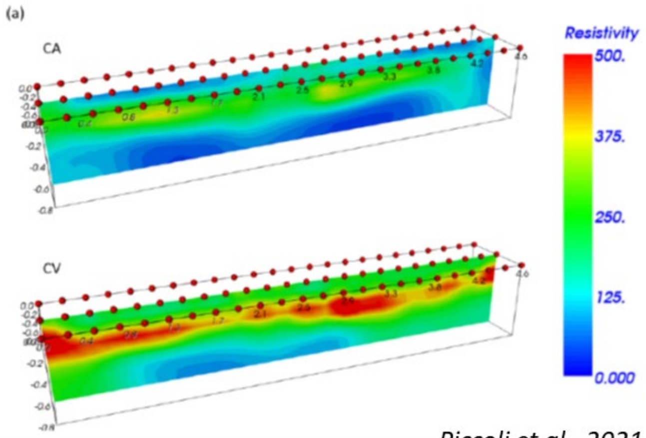
# Example of soil input

**Soil resistivity is also a proxy for variability of soil properties:**

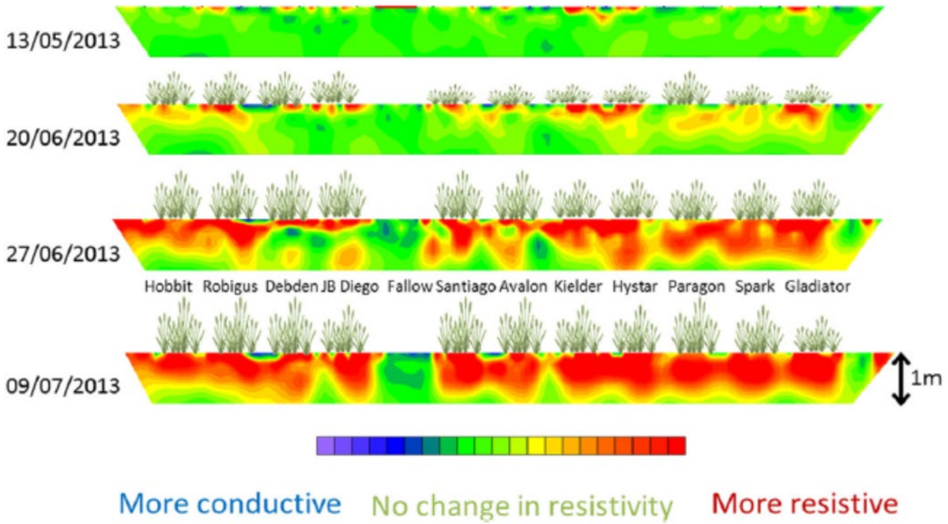
- **Great potential for the information of rooting depth;**
- **Subsoil constrains;**
- **Texture;**
- **Moisture.**



*Cillis et al., 2018*




*Piccoli et al., 2021*




*Whalley et al., 2016*

# Example of crop parameters: LAI

- **Key parameter in photosynthesis and evapotranspiration;**

- **Often at the center of remote sensing assimilation in crop models;**
  - **Above LAI >3 remotely sensed indices tend to saturate (most of them).**

**Studies that used a given Target Variable to parameterize crop models with the objective to simulate:**

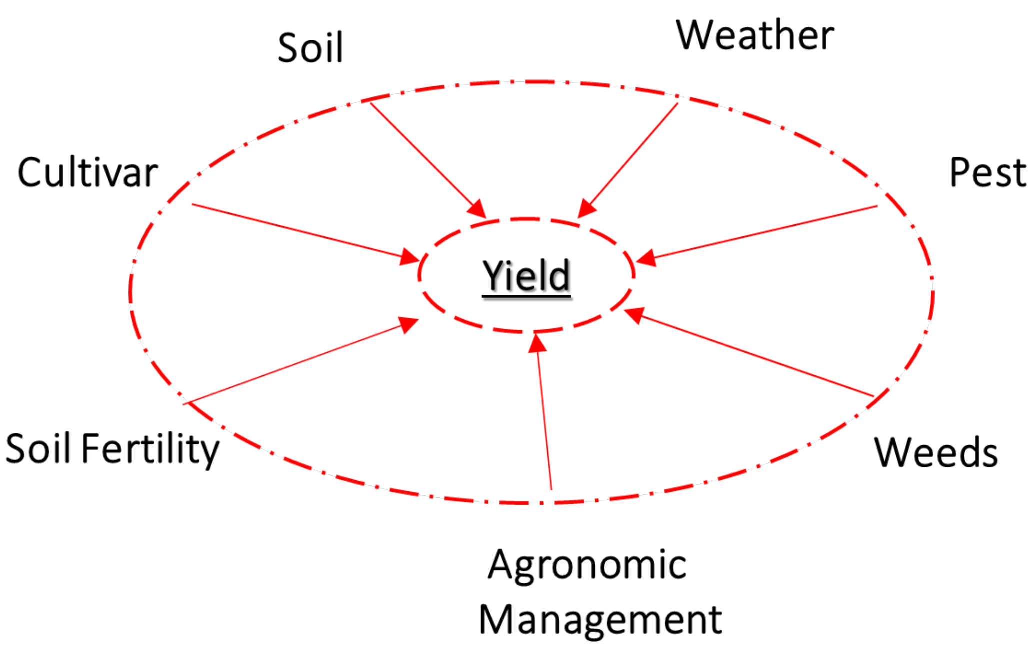
| Target variable | # |
|---|---|
| LAI | 41 |
| FAPAR | 3 |
| ET | 1 |
| N | 3 |
| Flowering | 1 |
| RUE | 1 |
| Soil moisture | 5 |

| Objective | # |
|---|---|
| Yield | 34 |
| LAI | 10 |
| ET | 1 |
| Biomass | 4 |
| Soil Moisture | 2 |

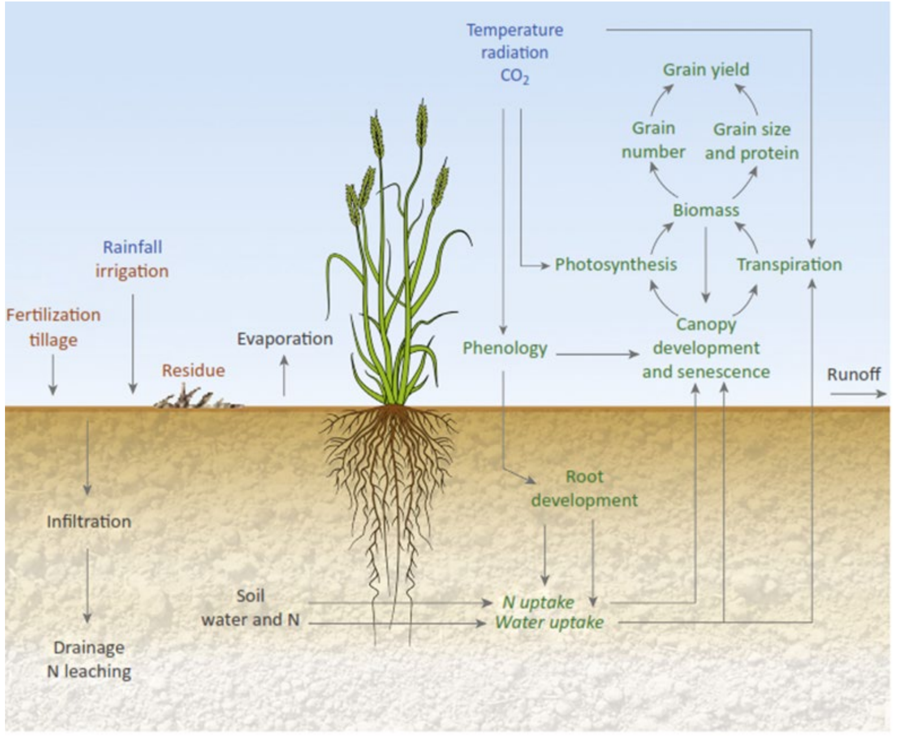
# Is yield only affected by LAI?

**Yield is the resultant of many dynamic (spatial and temporal) factors:**

***Agronomy***



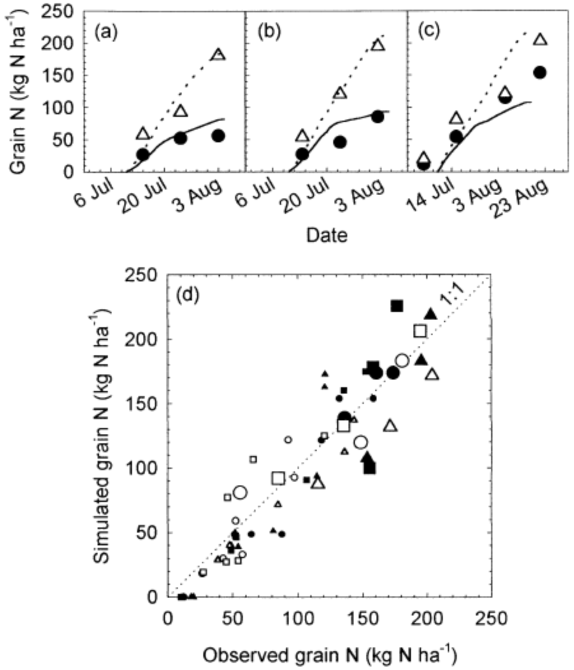

***Crop Modelling***

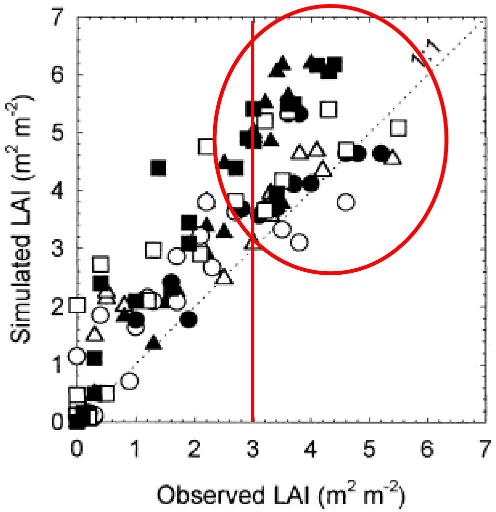


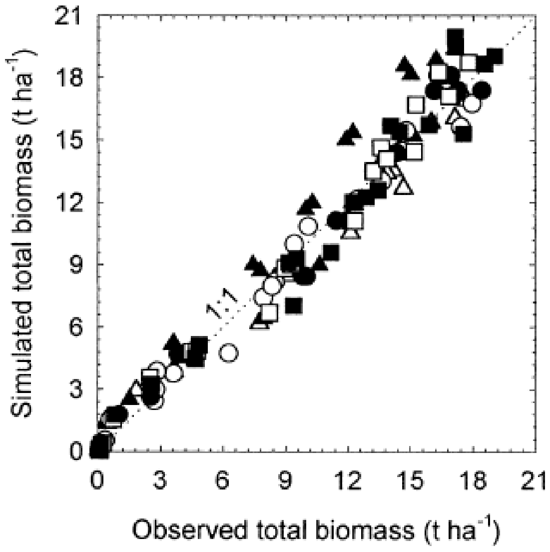

*Chenu et al., 2017*　　**Trends in Plant Science**

# Example of crop parameters: LAI

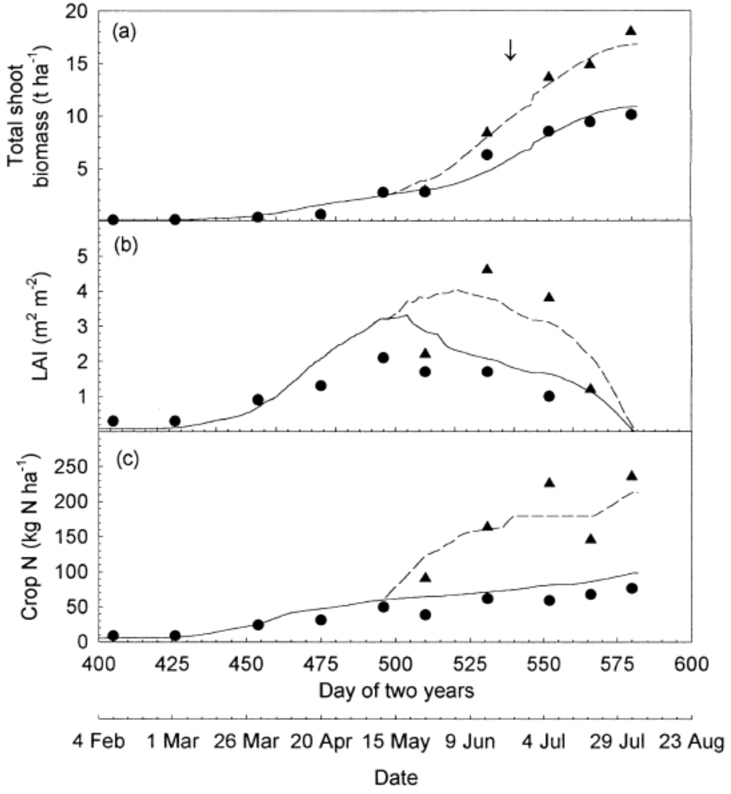
**A crop model can simulate with a given accuracy crop biomass, N uptake and yield and still over-estimate LAI**




**One cause is LAI values above 3 and at senescence**



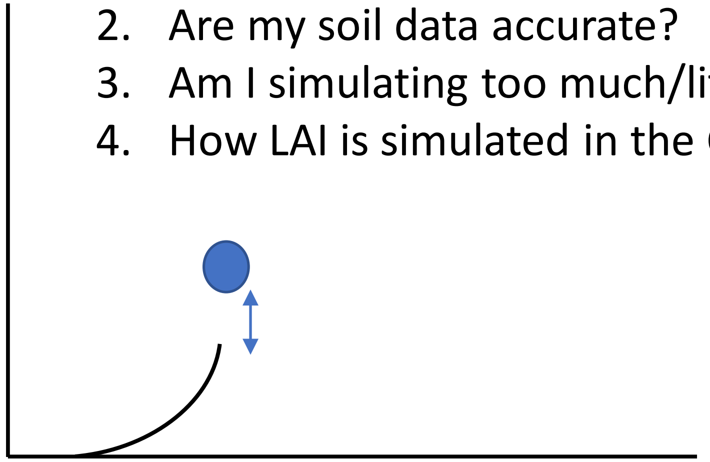

*Asseng et al., 2000*

# Example of crop parameters: LAI

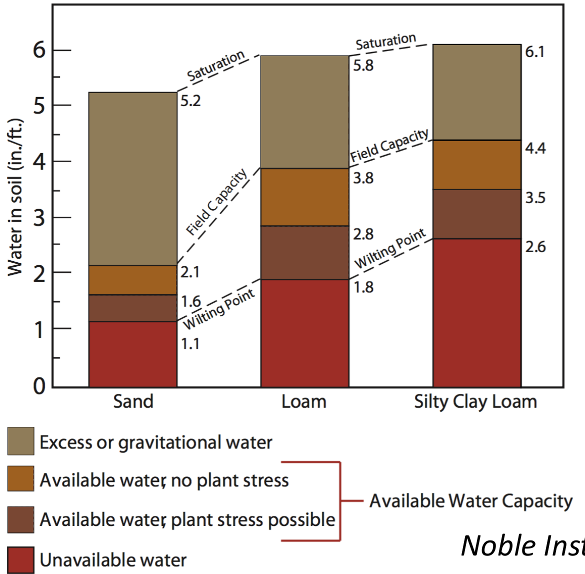
1. **“Initial conditions” like soil water and soil mineral N are very important boundary conditions**
2. **LAI being modelled as an expansive growth process is very sensitive to water stress**
3. **IF the users do not pay attention to either initial condition or the quality of their soil they might parameterize LAI wrongly**
4. **In crop models LAI is only one of the expansive growth processes**

Why this gap?

1. Are my initial conditions wrong?
2. Are my soil data accurate?
3. Am I simulating too much/little water stress?
4. How LAI is simulated in the CSM?



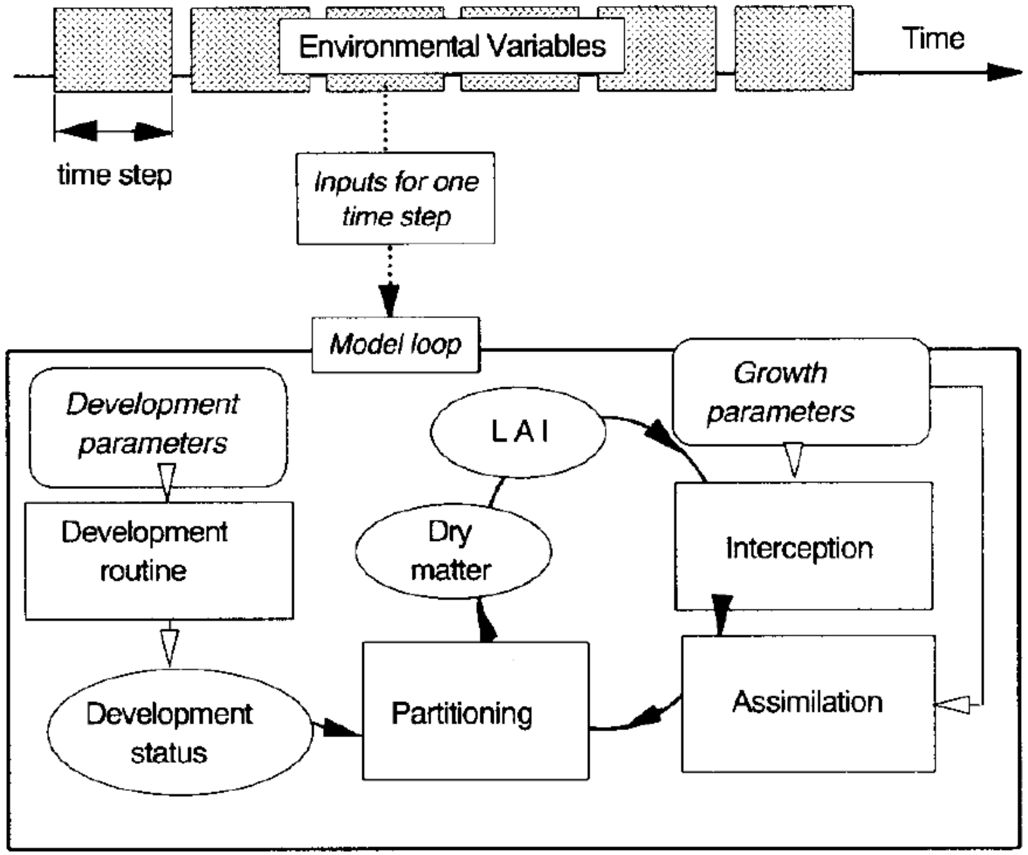
| Available Water Capacity by Soil Texture | |
|---|---|
| Textural Class | Available Water Capacity (Inches/Foot of Depth) |
| Coarse sand | 0.25–0.75 |
| Fine sand | 0.75–1.00 |
| Loamy sand | 1.10–1.20 |
| Sandy loam | 1.25–1.40 |
| Fine sandy loam | 1.50–2.00 |
| Silt loam | 2.00–2.50 |
| Silty clay loam | 1.80–2.00 |
| Silty clay | 1.50–1.70 |
| Clay | 1.20–1.50 |




*Noble Institute*

# Methods of integration between RS and CSM

**They were idealized for landscape modelling and with a simplified version of a CSM**




*Delecolle et al., 1992*

**There are many successful examples of data assimilation between CSM and RS at landscape level (e.g. de Wit et al…; Donohue et al., 2018)**

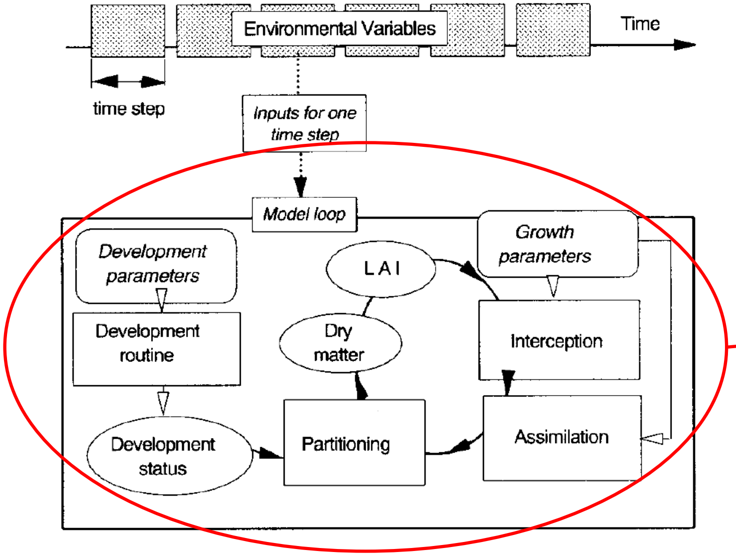
# Example of crop parameter: LAI

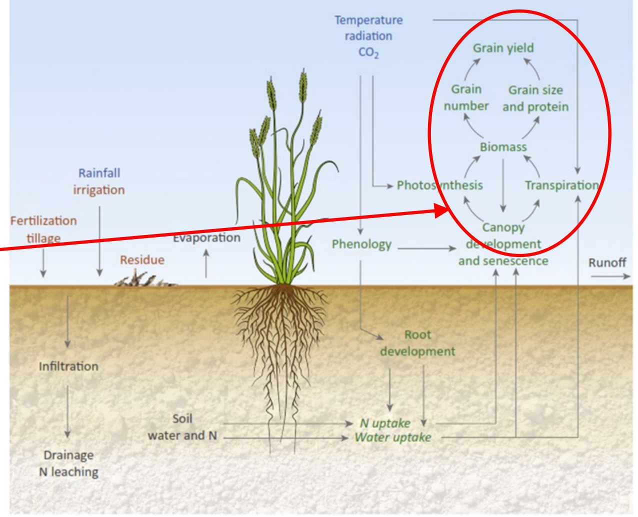
## Simplified representation of the calibration (from Boote, 1994; CROPGRO):

***LAI is one of the multi-parameters to calibrate***

**Phenology (e.g. flowering; maturity)** → **Dry matter** → **LAI & SLA** → **Dry matter** → **Yield** | **Dry matter**

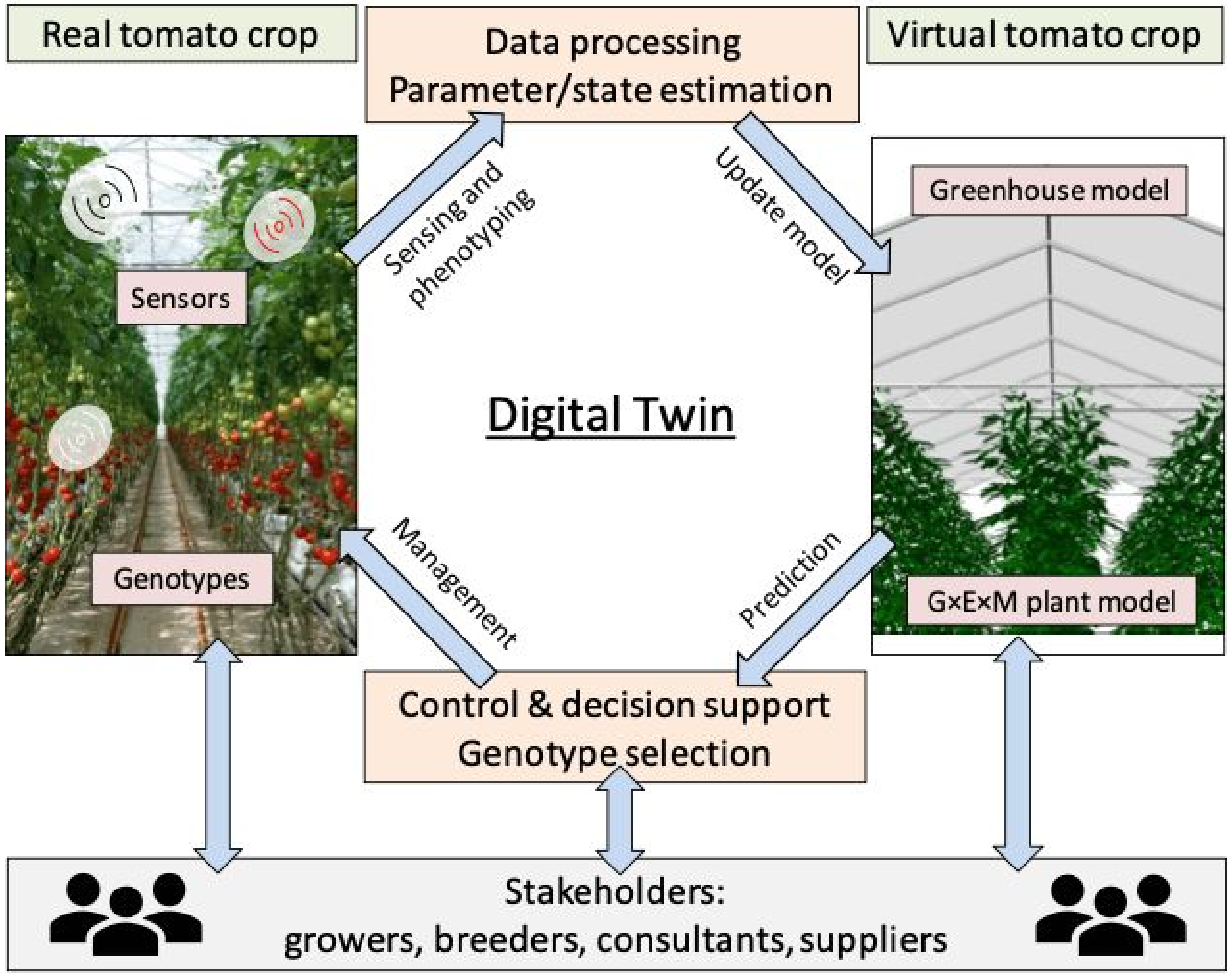
- Phenology (e.g. flowering; maturity) → **5 parameters**
- Dry matter → **2 parameters**
- LAI & SLA → **5 (2) parameters**
- Dry matter, Yield, Dry matter → **……………………**




*Chenu et al., 2017*  Trends in Plant Science

# Digital twinning



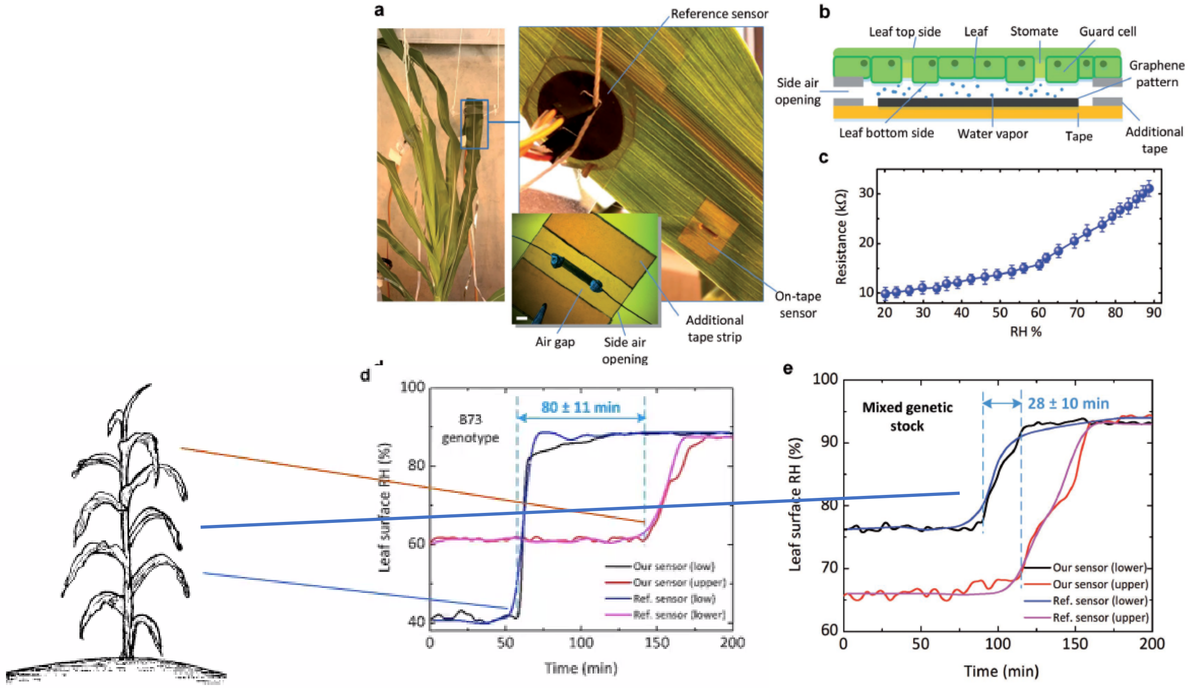

*https://www.wur.nl/en/Persons/Jochem-dr.-JB-Jochem-Evers.htm*

# Future outlook

- **Nanosensors will be able to provide useful information regarding crop status/stress**
    - **Dong et al. (2017) developed a nanosensor that can detect relative humidity at leaf level**

- **Models' based on machine learning (can replace CSM?)**

- **Link with concepts of Precision Agriculture**
    - **GxExMxSpatial**

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*Dong et al., 2017*

# Conclusion

- Digital twinning will become an important tool for integrating crop models' and sensing;
- Each crop model is different, therefore understand assumptions and main processes simulated;
- When using a crop model "system-based" approach thinking is important;
- Ground truthing is important.