University of Natural Resources
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Department of Crop Sciences

# Crop modelling as a phenotying tool for enhancing wheat adaptation to abiotic stresses

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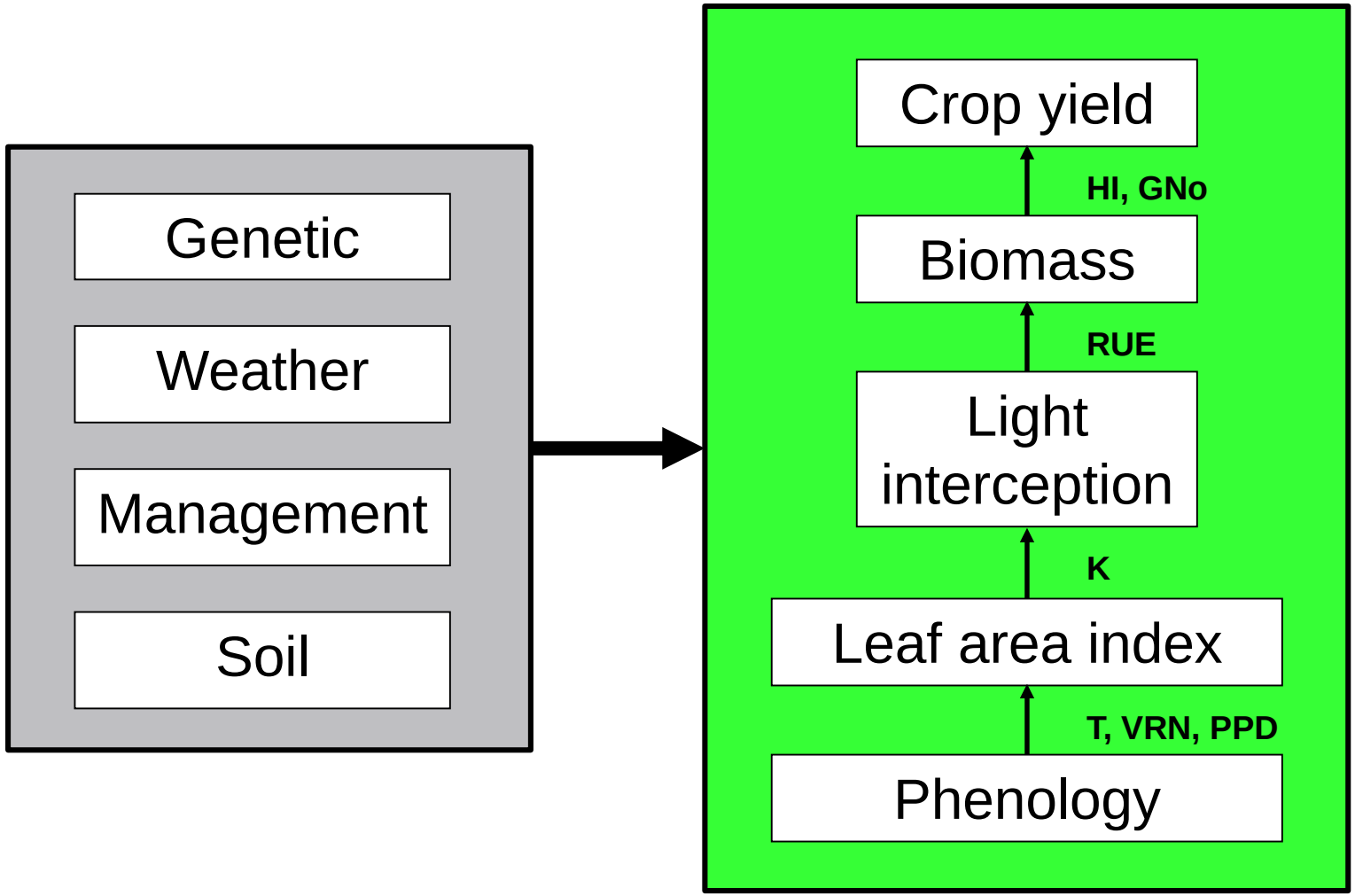
# Outline

- Whole-Plant (Crop) Growth & Development Models
- APSIM (**A**gricultural **P**roduction **S**ystems s**IM**ulatar)
- Application of crop models for genotype-to-phenotype (G-to-P) prediction (Model-assisted phenotyping)
  - Crop phenology – Pre-anthesis phases
  - Root architecture – Drought adaptation
- Conclusions

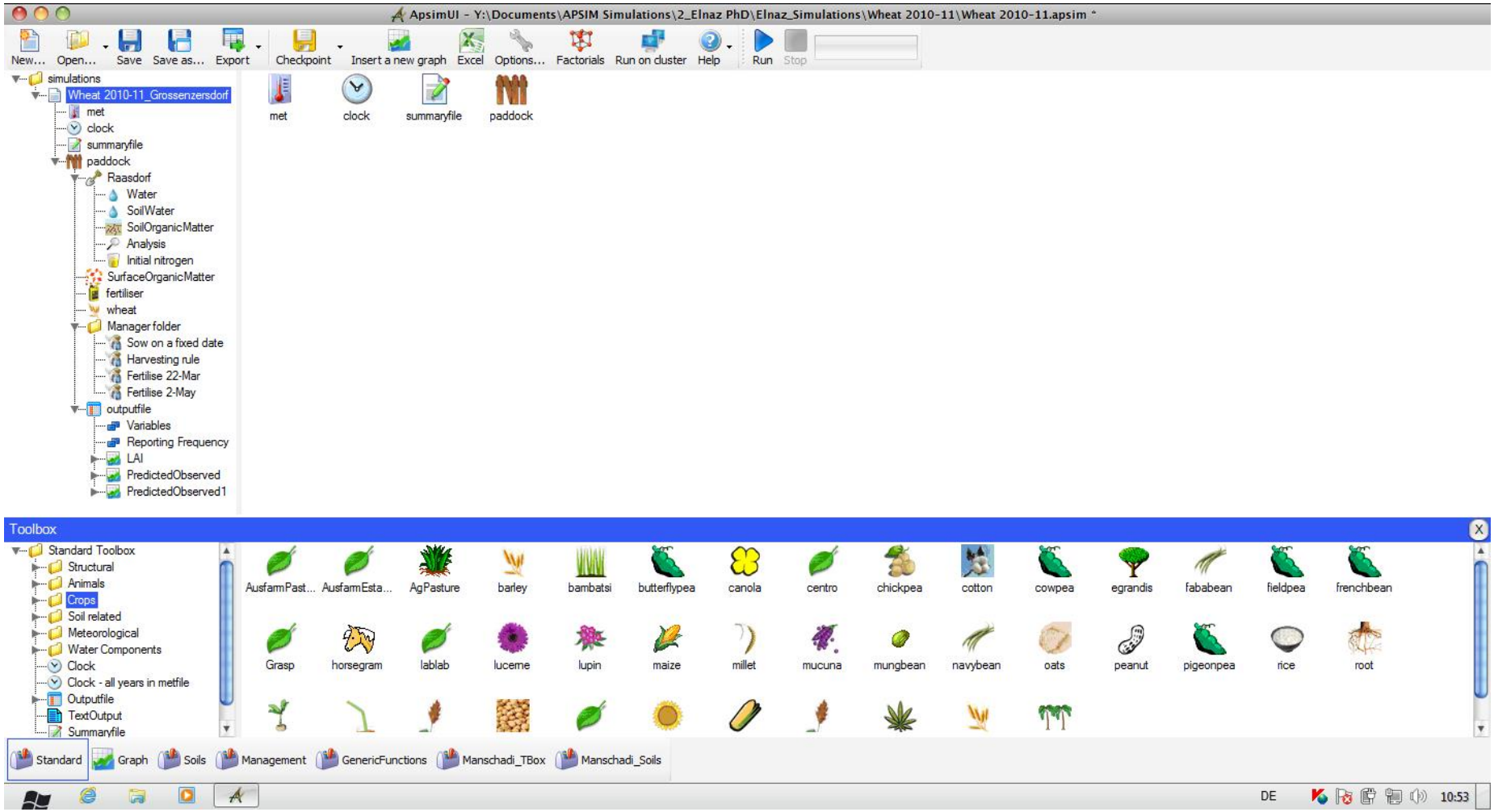
# Whole-Plant (Crop) Growth & Development Models

- Integrate physiological understanding within a mathematical framework



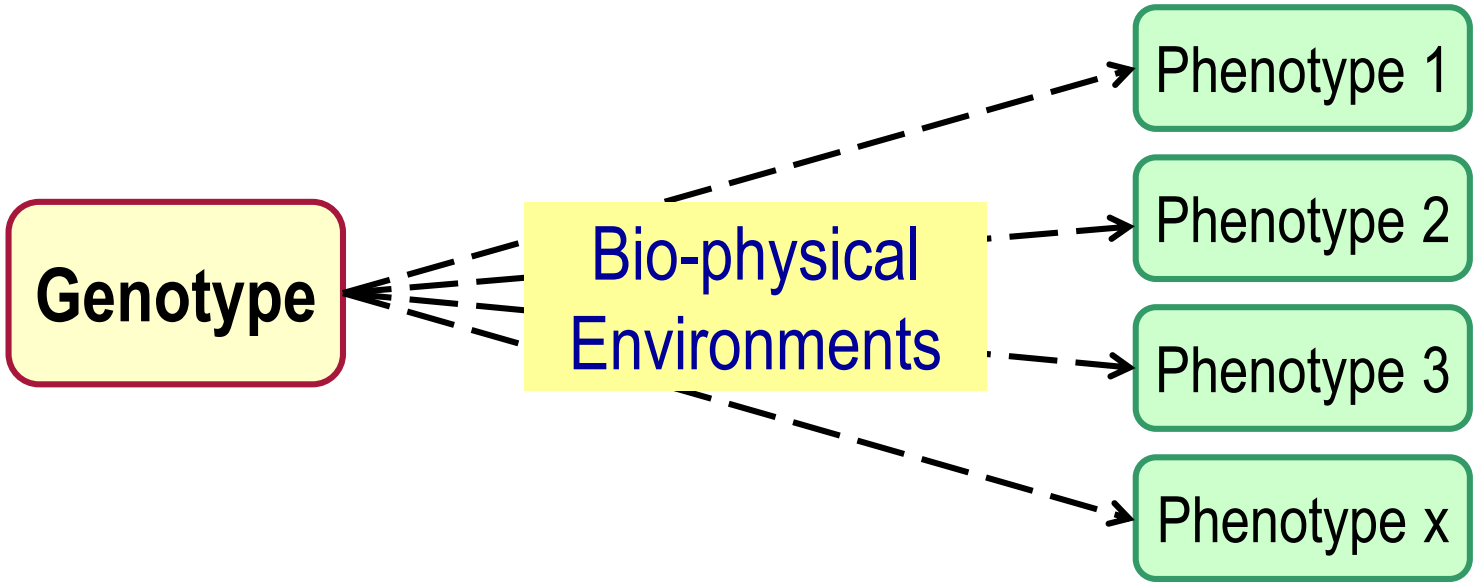
# Whole-Plant (Crop) Growth & Development Models

- APSIM (**A**gricultural **P**roduction **S**ystems s**IM**ulator) (***www.apsim.info***)



# Genotype-to-Phenotype Prediction

- Genetic variation not consistent among environments (G x E interaction)

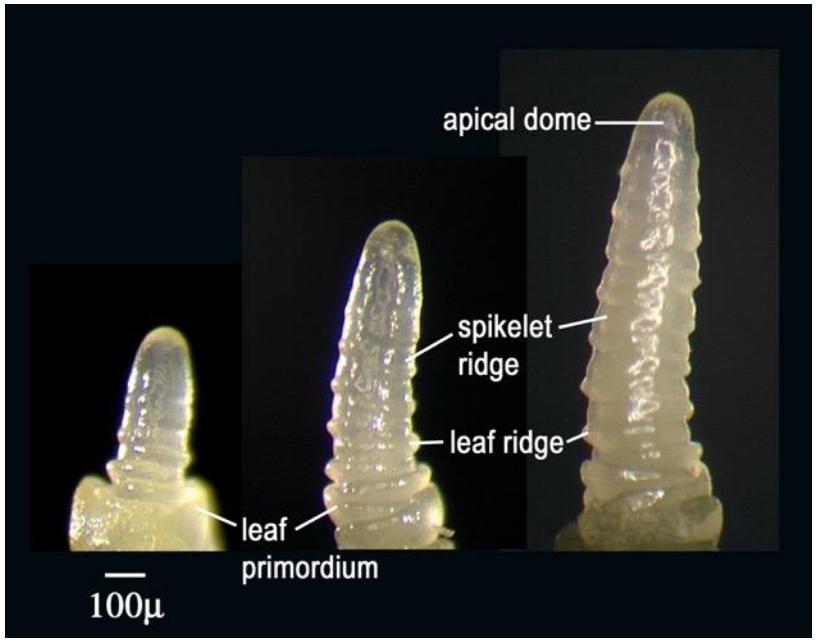



- Water- and nutrient-use efficiency: multi-genic traits (G x G, G x E, G x E x M)
- **G-to-P predictability gap – Major constraint to crop improvement (breeding)**

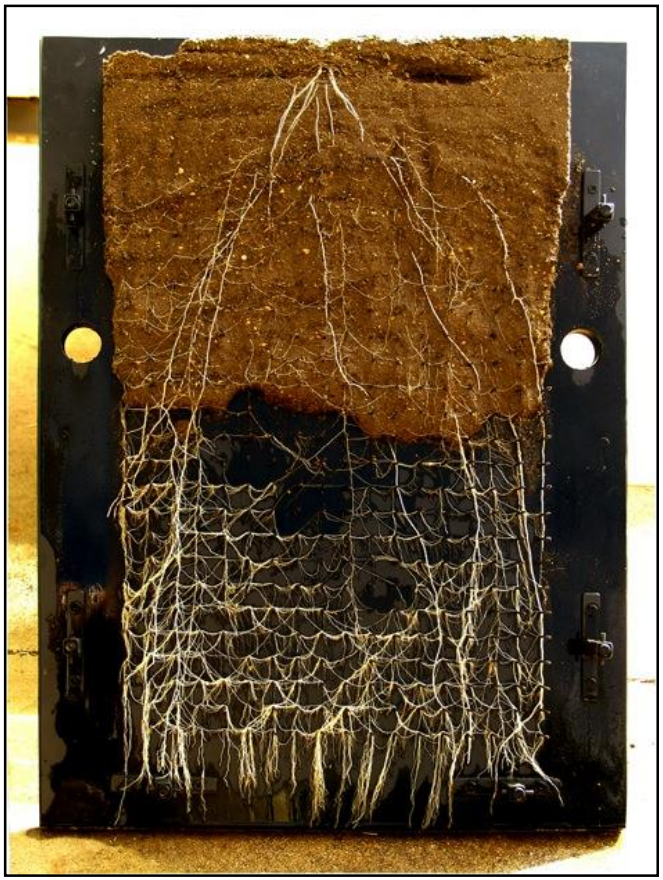
# Model-assisted Phenotyping: Case Studies

- Simulating emergent consequences of genotypic variation in:

**Phenology**
(wheat)

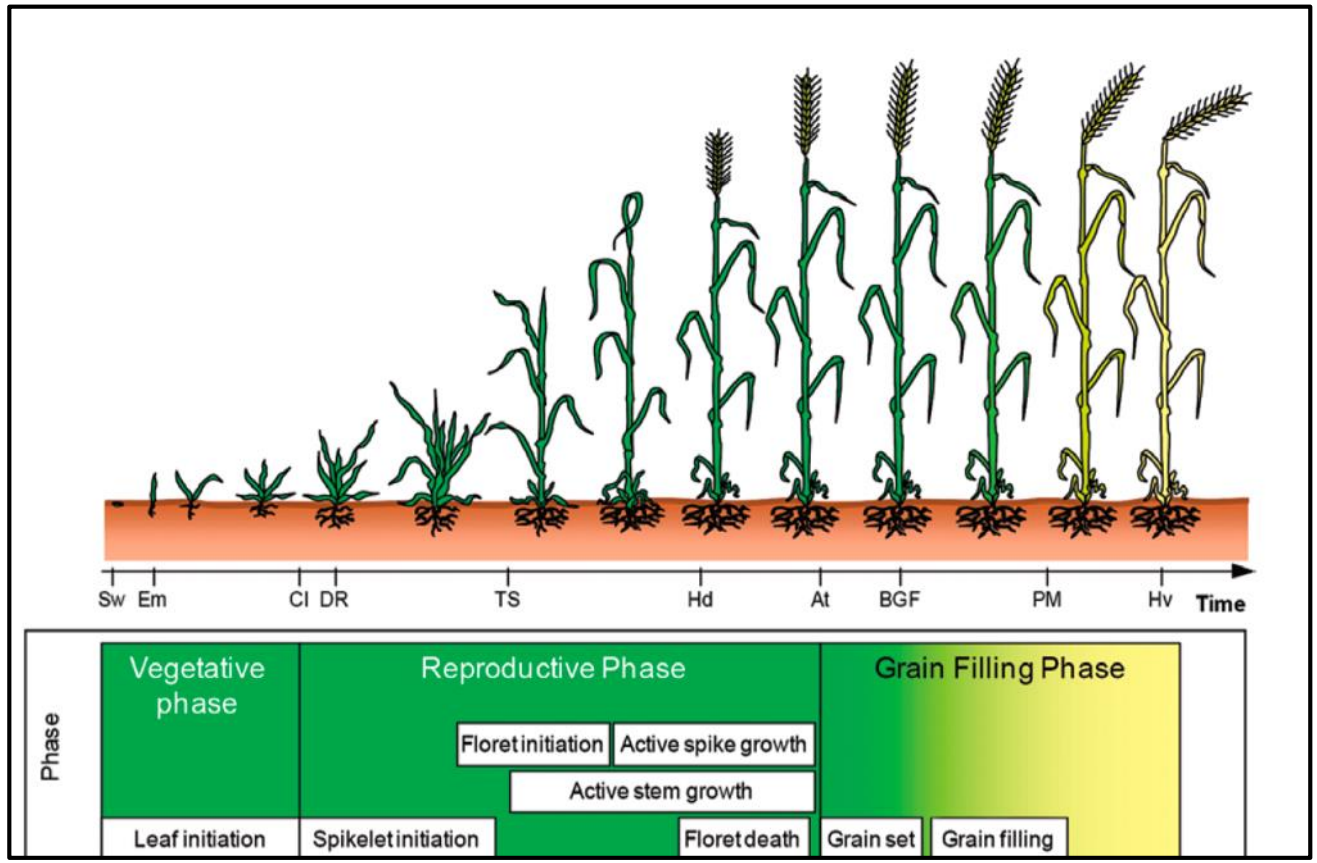



**Root Architecture**
(wheat)



# Wheat Phenology

- Flowering behaviour: Breeding wheat genotypes for a wide range of environments
  - **VRN1 (VERNALISATION1)**
  - **PPD1 (PHOTOPERIOD1)**
  - Allelic variation: Winter and spring genotypes



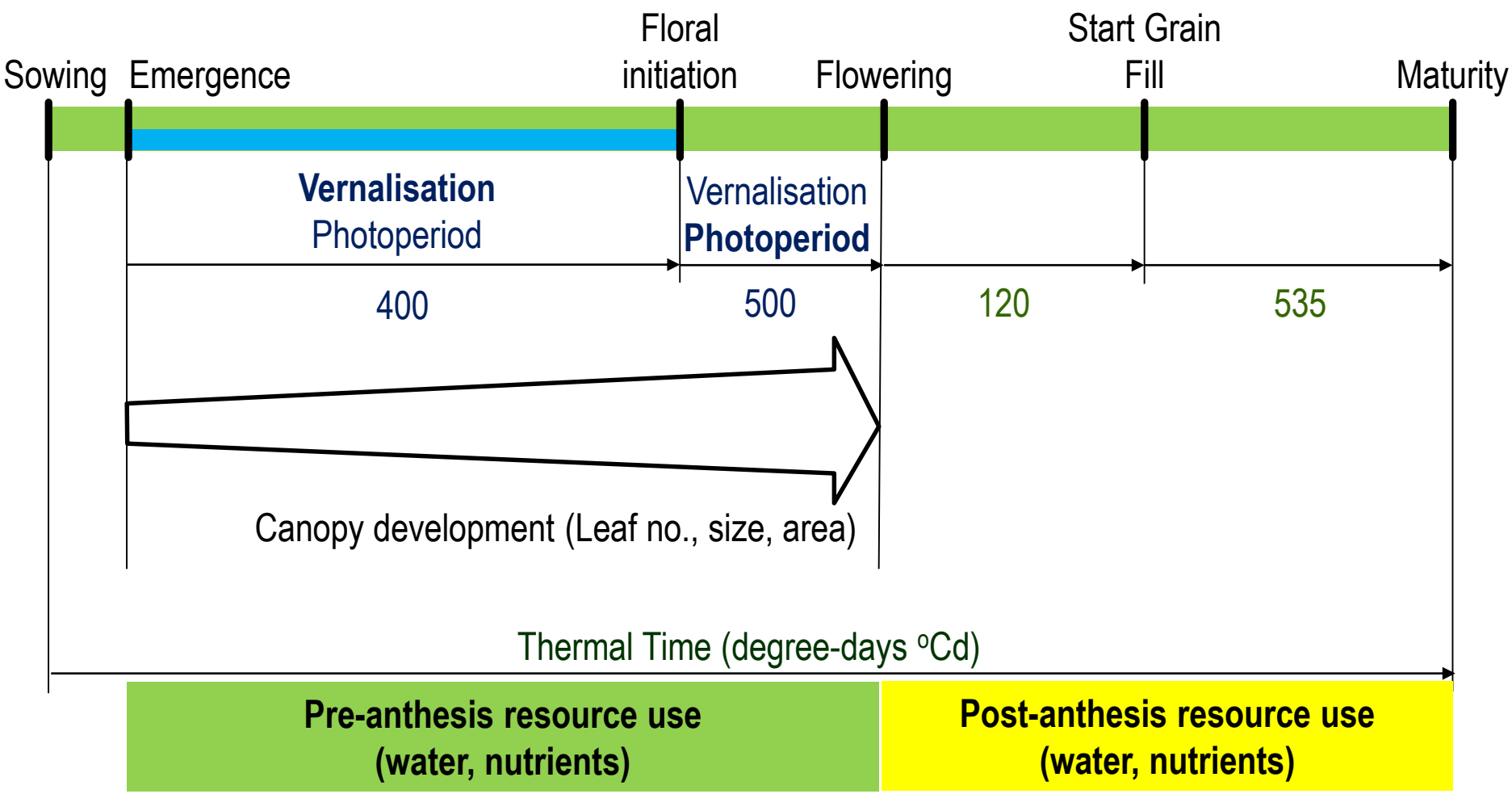

(Guo et al. 2015)

# Parameterisation of APSIM

- Field experiment: 2013/14 at Raasdorf experimental fields of BOKU

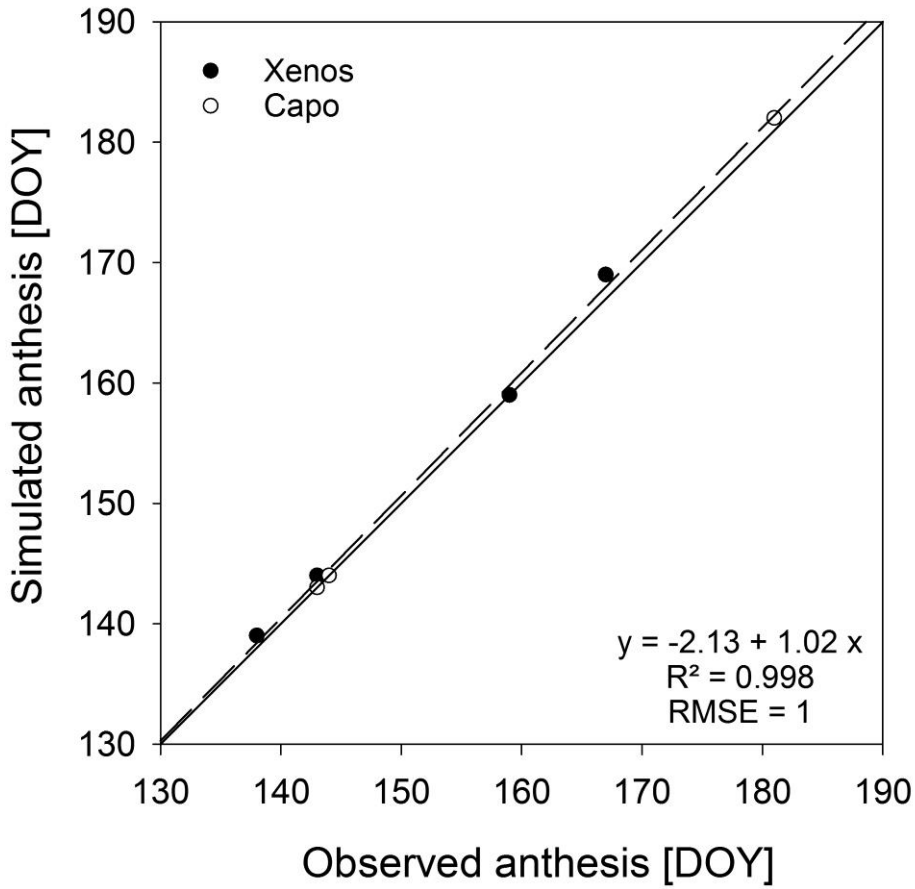
# Parameterisation of APSIM

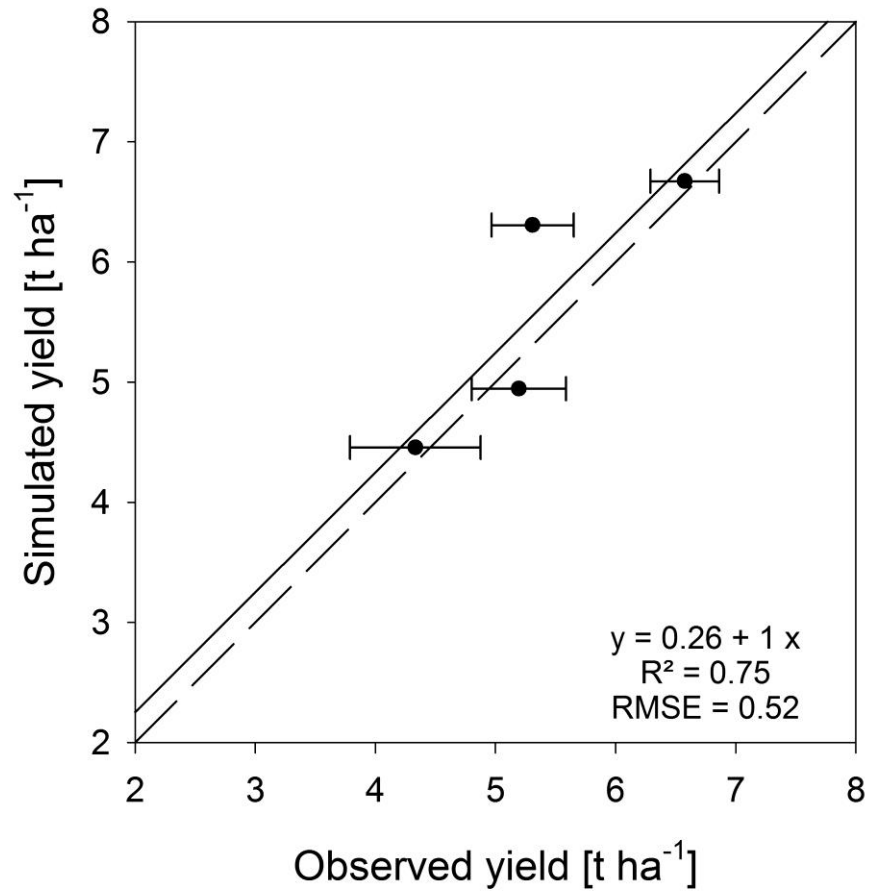
- **Wheat phenology:**
  - *VernSens* & *PhotopSens*: 1.0 & 4.2
  - Duration of developmental phases in thermal time



# Parameterisation of APSIM

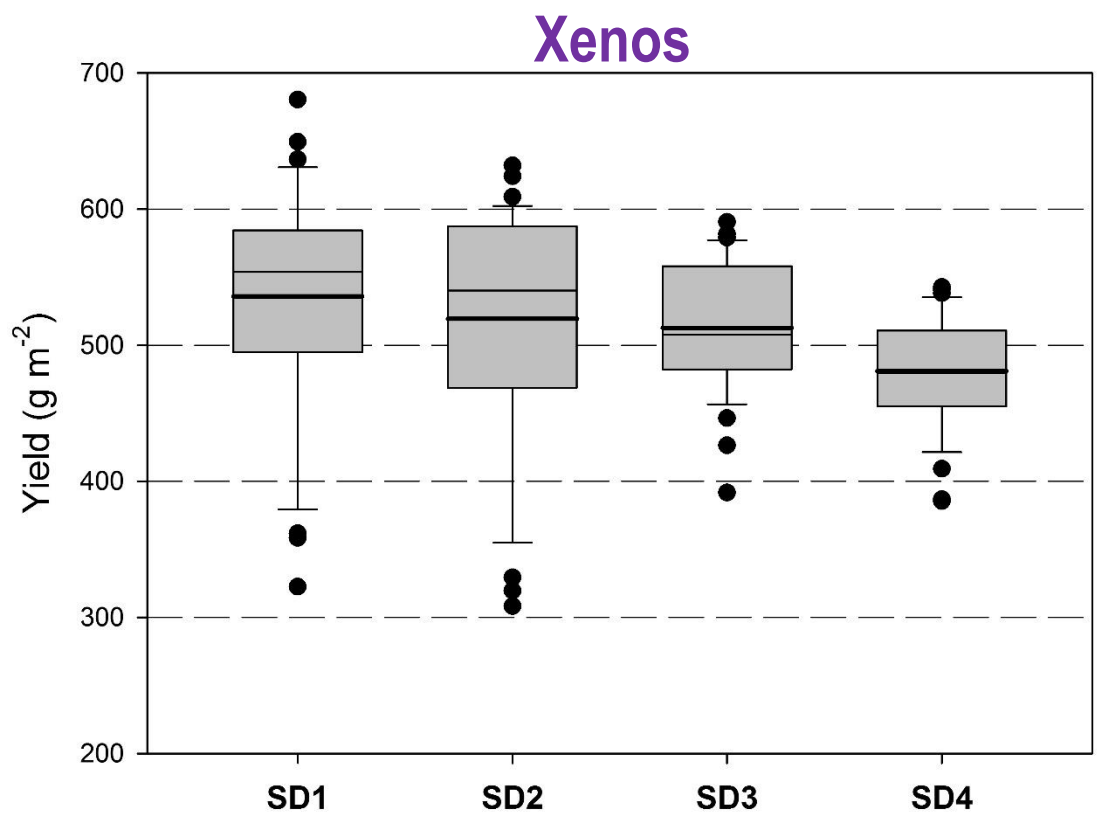
- **Xenos**: simulated vs observed anthesis date and final grain yield



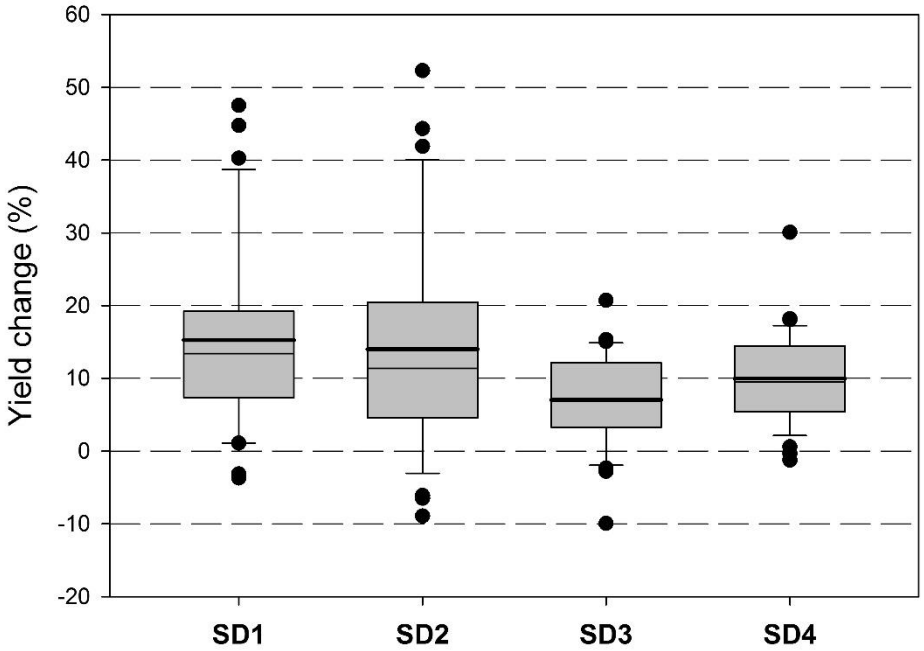
# Exploring Optimum Anthesis Date

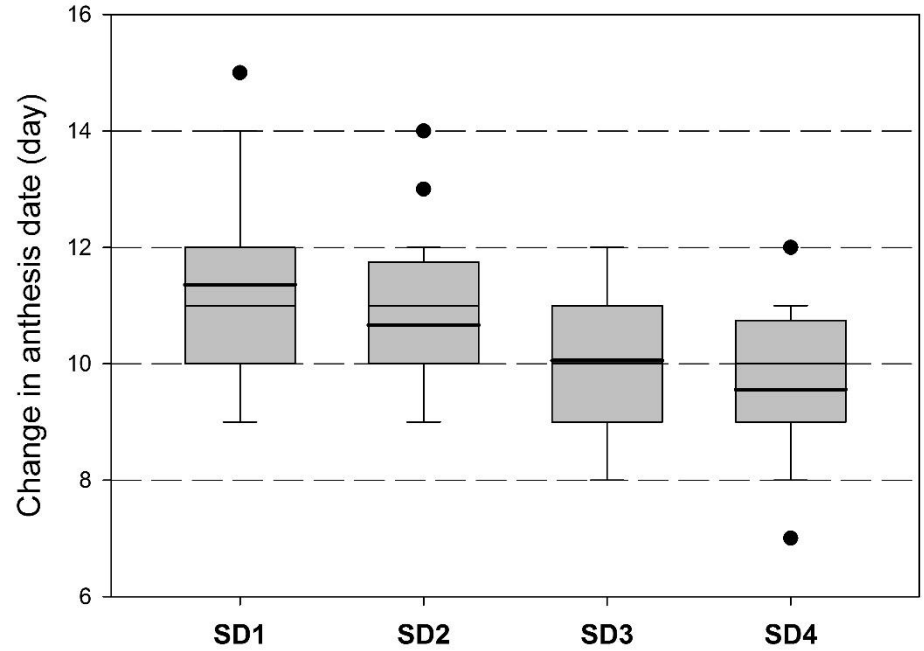
- APSIM + Historic weather data (1980-2016)
- Changing anthesis thermal time: ±30%; ±20%; ±10%
  - Genotype: **Xenos** **G1** **G2** **G3** **G4** **G5** **G6**
  - Anthesis (°C): **900** **630** **720** **810** **990** **1080** **1170**
  - Sowing dates: **SD1**:Sep26 **SD2**:Oct17 **SD3**:Mar04 **SD4**:Apr01



# Exploring Optimum Anthesis Date

- Earlier flowering → Lower yield
  - Genotype: **Xenos** **G5**
  - Anthesis (°C): **900** **1080 (+20%)**



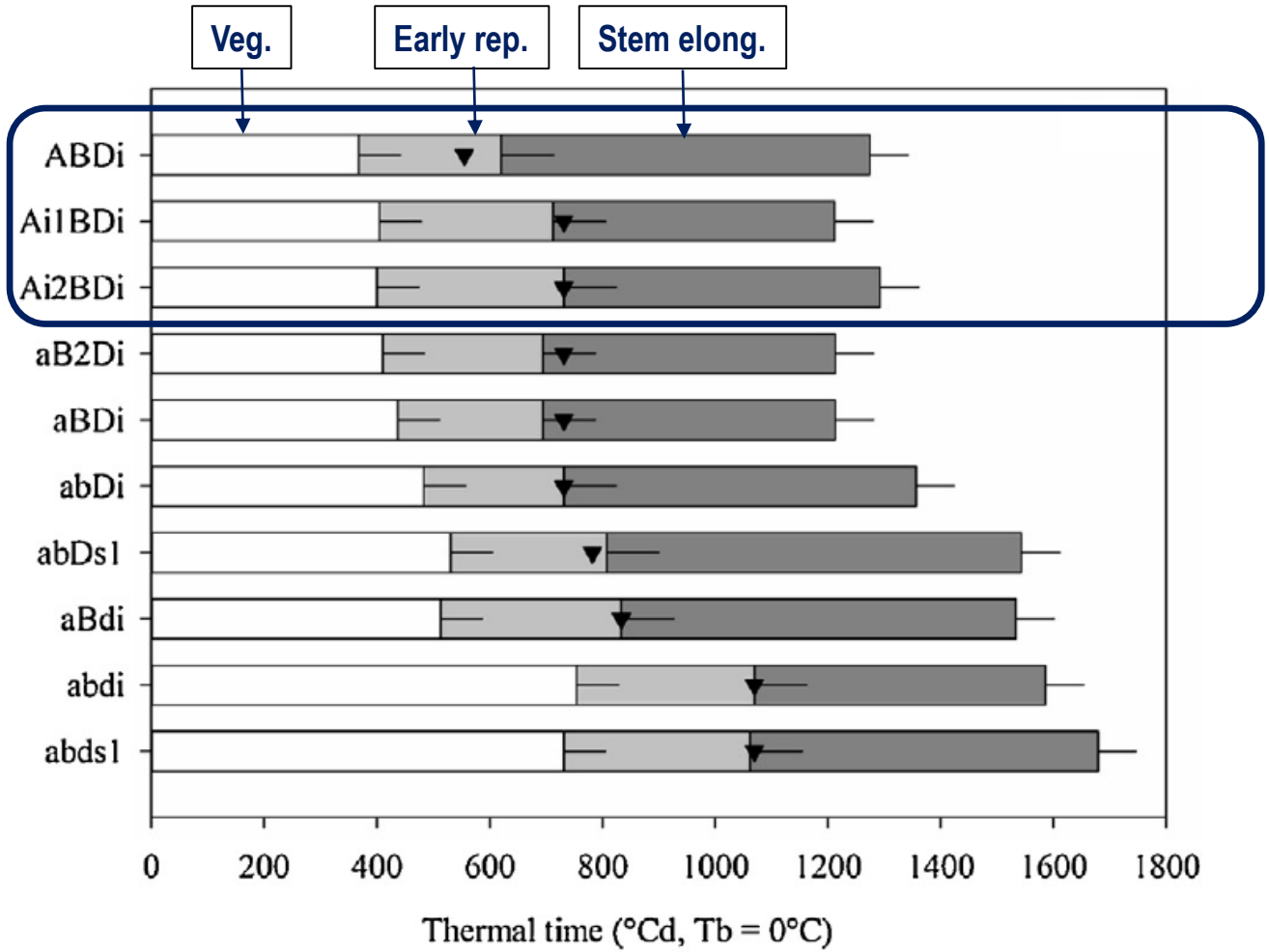



# Variation in the Duration of Pre-Anthesis Phases

- Allelic combinations of VRN1 and PPD1 genes:

  similar anthesis date with different duration of pre-anthesis phases

- **Hypothesis**: Extending stem elongation (SE) → Increased yield potential

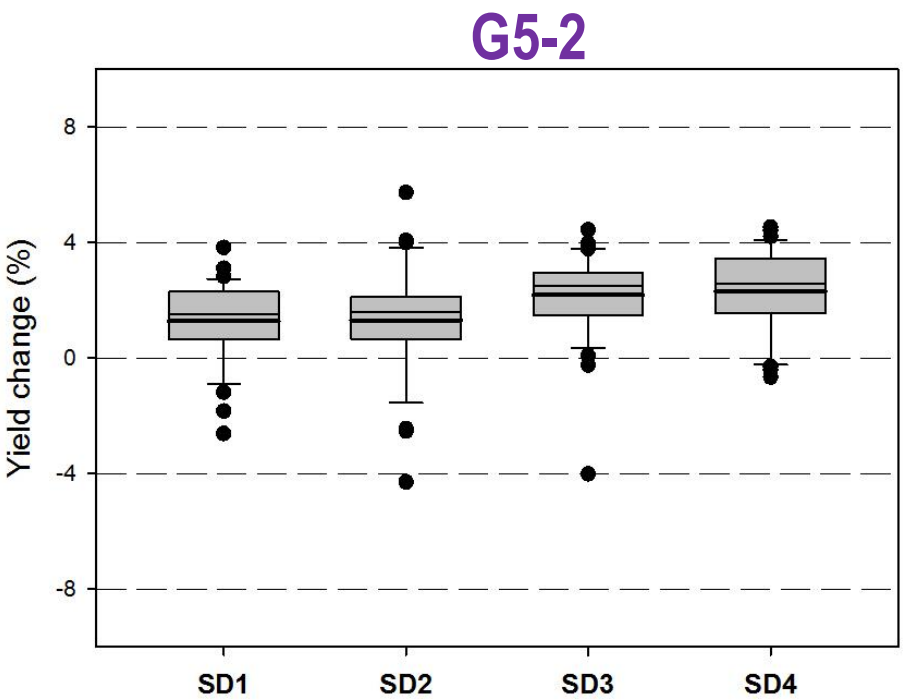


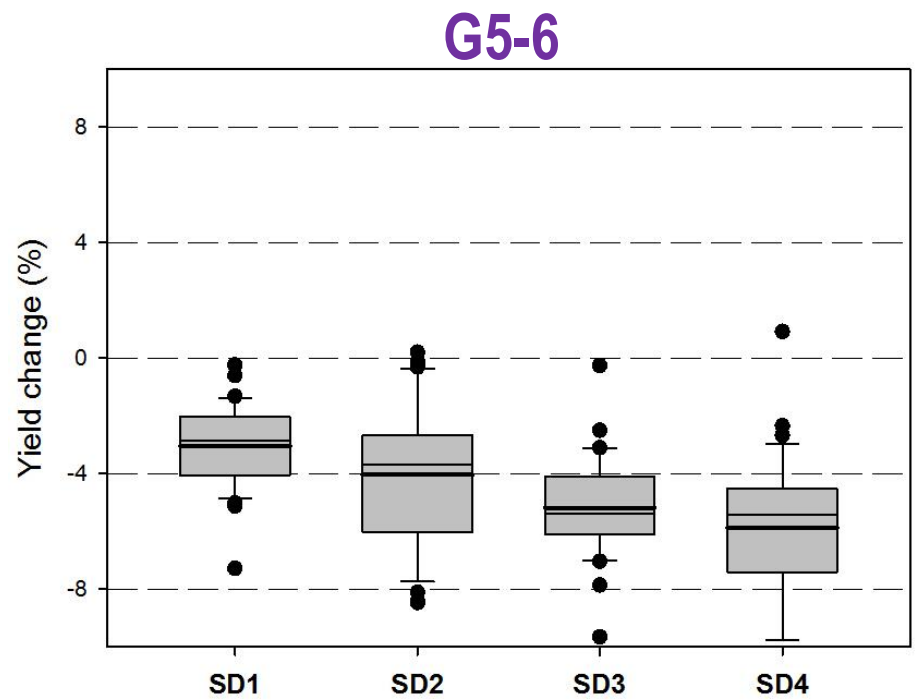

(Steinfort et al. 2017)

# Testing the Hypothesis of Extending Stem Elongation

- Maintaining anthesis date (G5: 1080 °Cd)
- Changing Phase I & II (°Cd): -/+120; -/+80; -/+40; +/-40; +/-80; +/-120

| Genotype: | **G5** | **G5-1** | **G5-2** | **G5-3** | **G5-4** | **G5-5** | **G5-6** |
|---|---|---|---|---|---|---|---|
| Phases I: | **480** | 360 | 400 | 440 | 520 | 560 | 600 |
| Phases II: | **600** | 720 | 680 | 640 | 560 | 520 | 480 |



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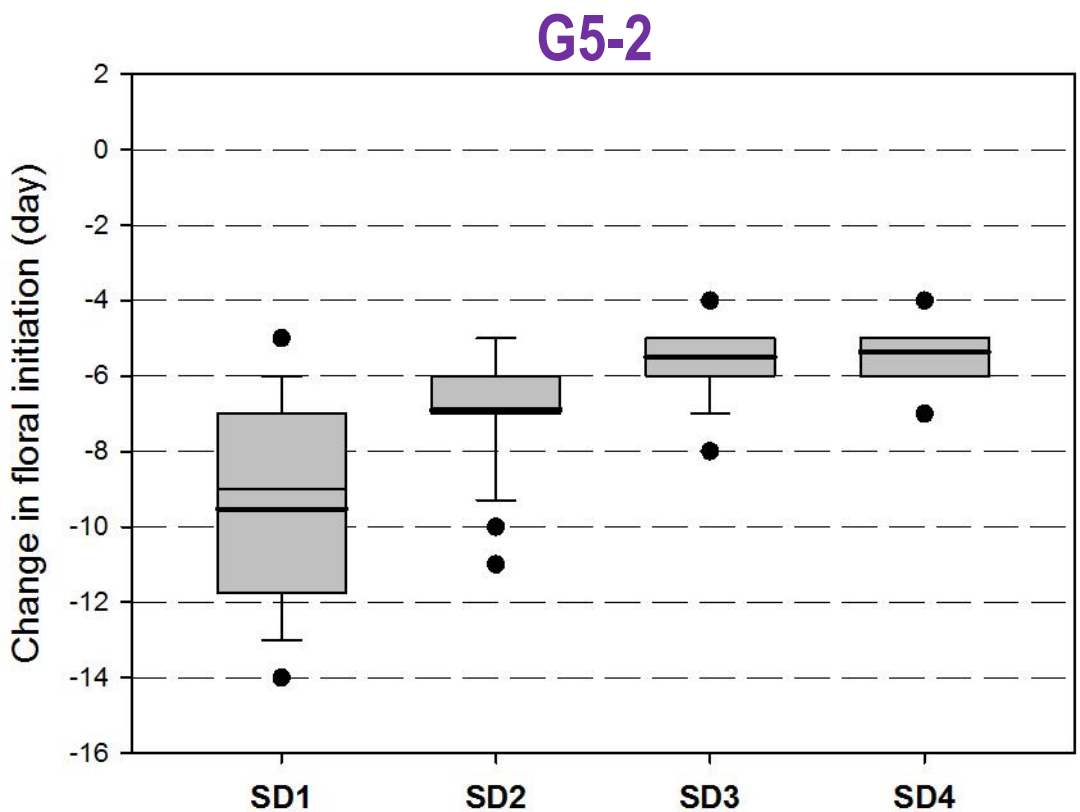

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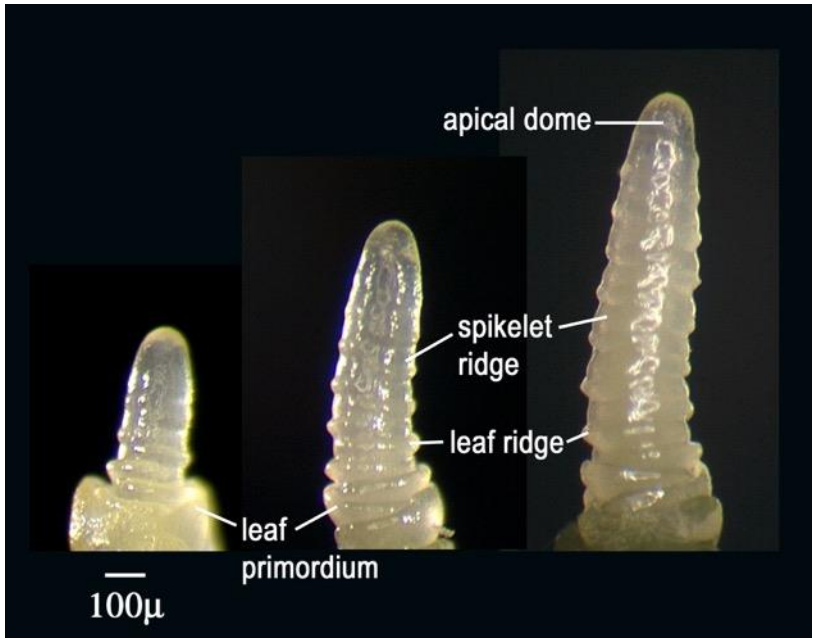
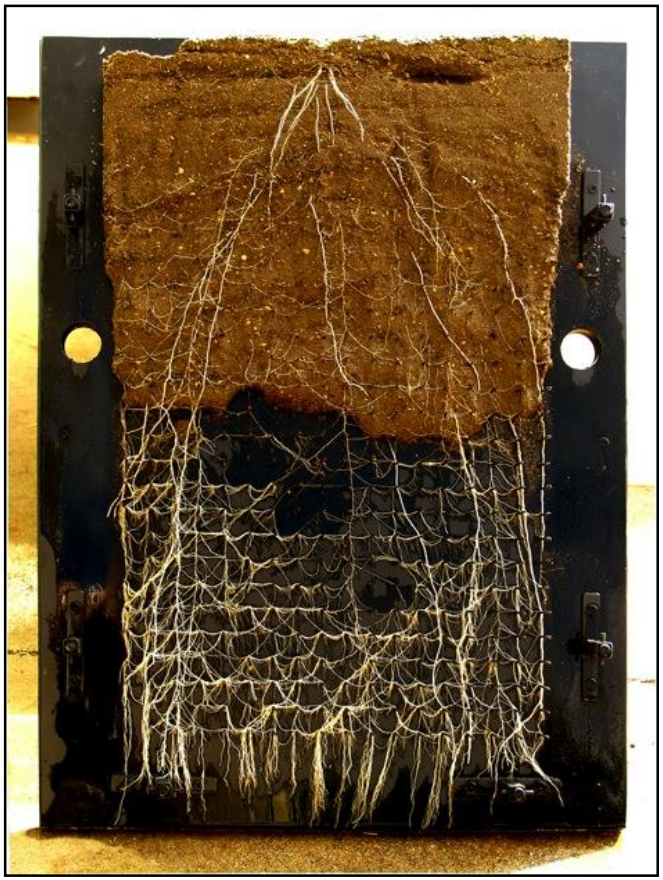
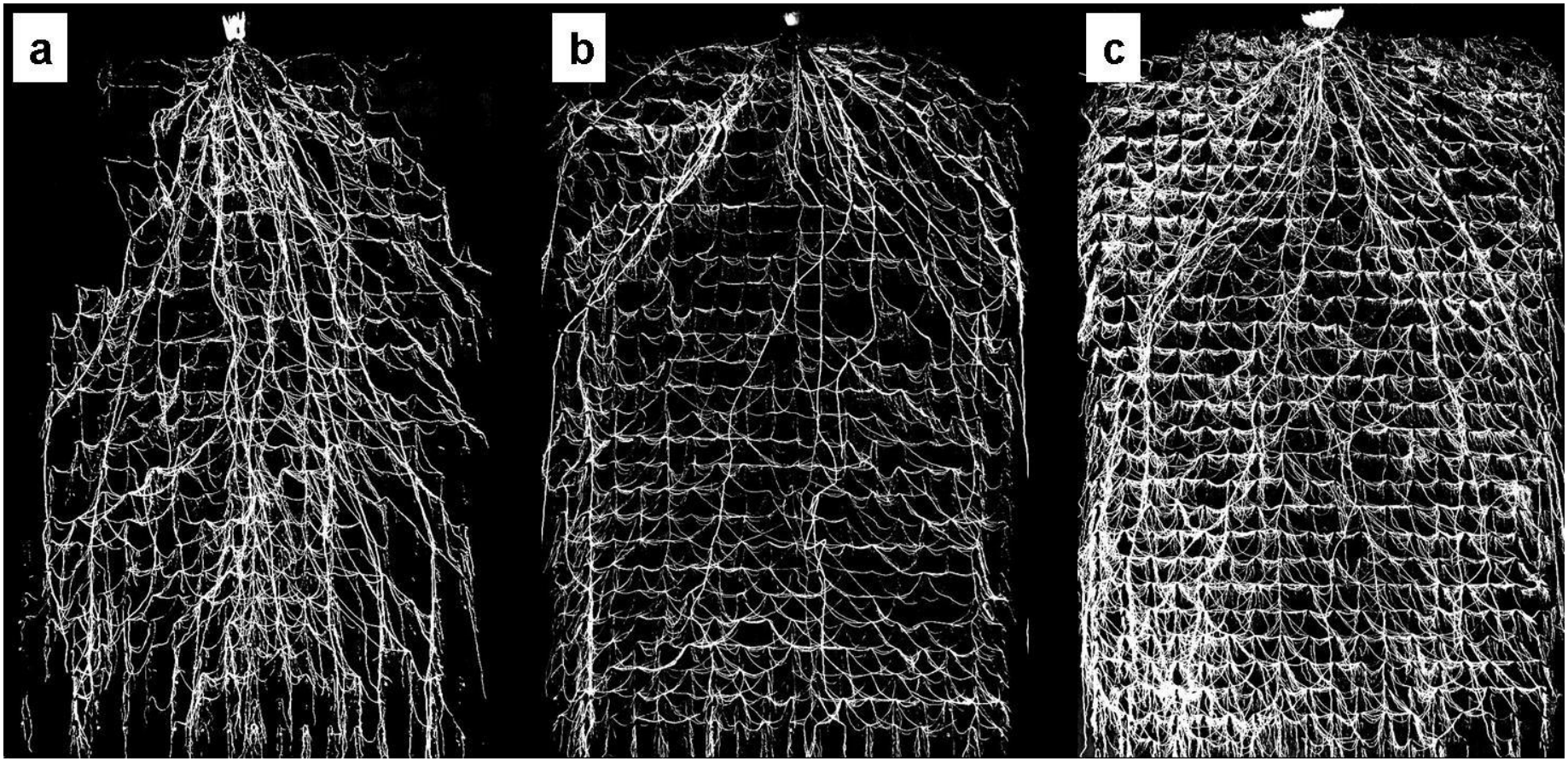



**Root Architecture**
(wheat)



# Root Architecture & Acquisition of Soil Resources

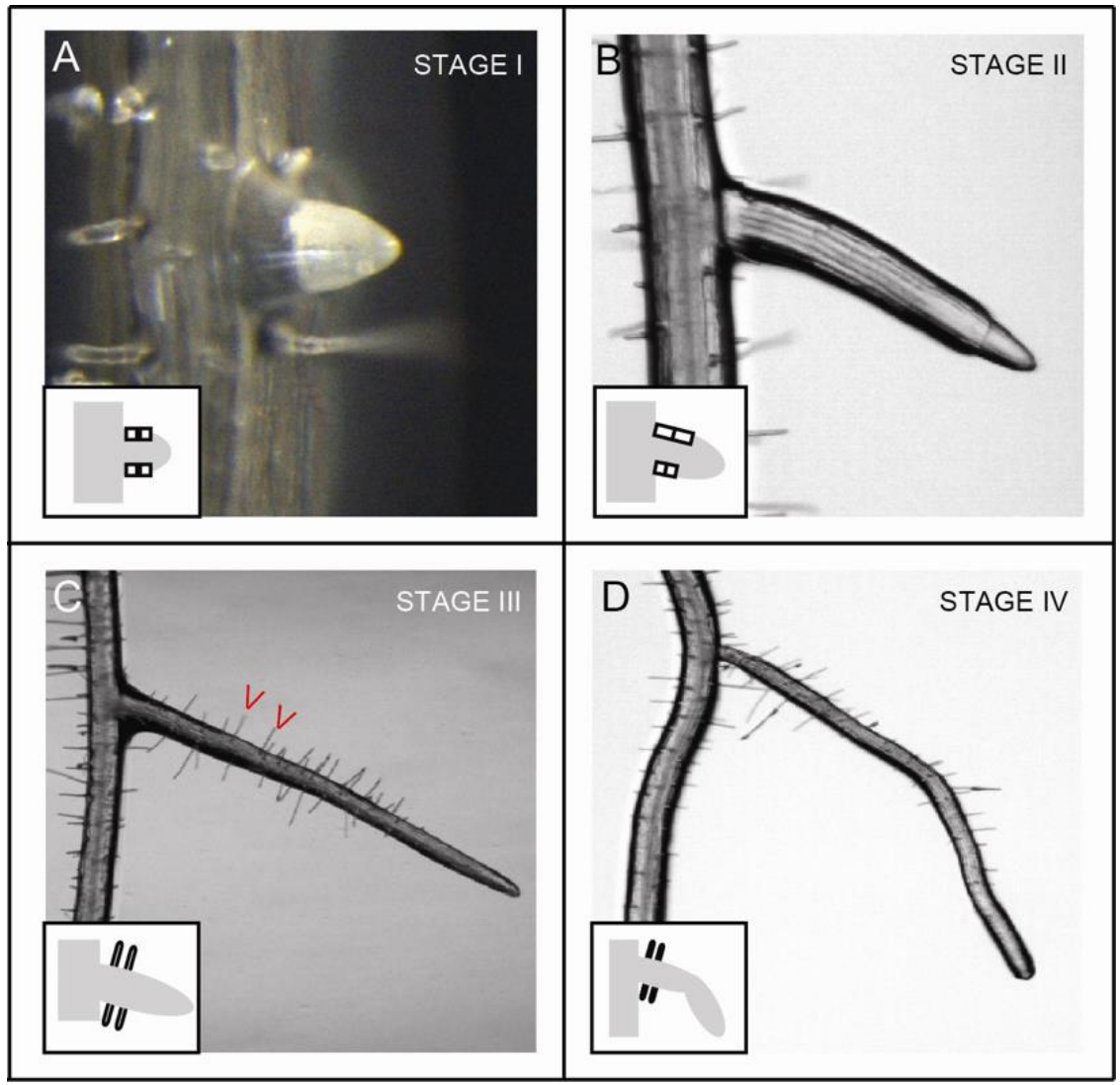
**Drought-tolerant wheat genotype** **Standard wheat cultivar** **Barley**




(Manschadi et al 2008; Plant Soil)

# Root Architecture & Acquisition of Soil Resources

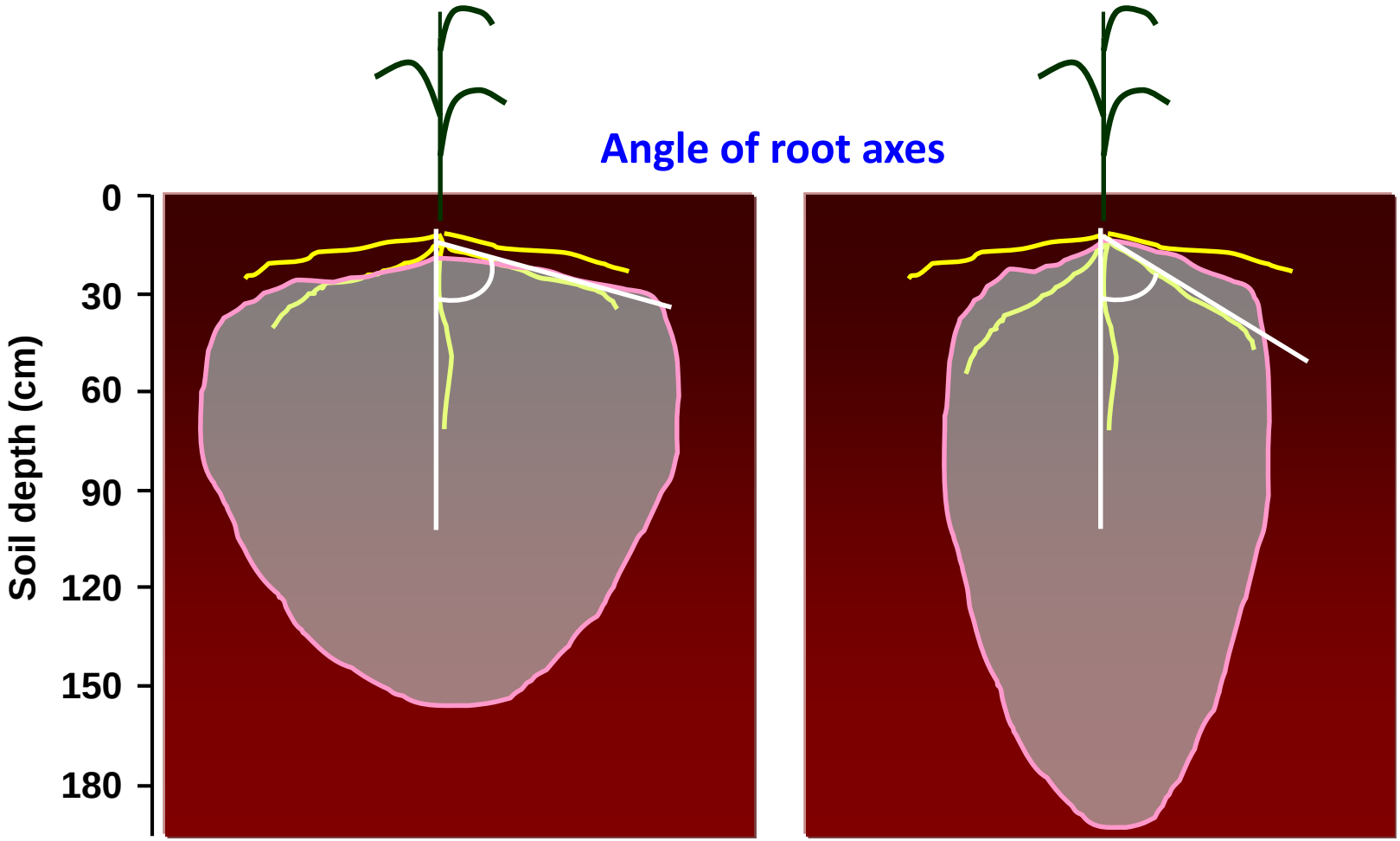
- Phytohormone auxin induces asymmetric growth in the elongation zone → Growth angle




(Rosquete et al. 2013, Current Biology)

# Root Architecture & Acquisition of Soil Resources

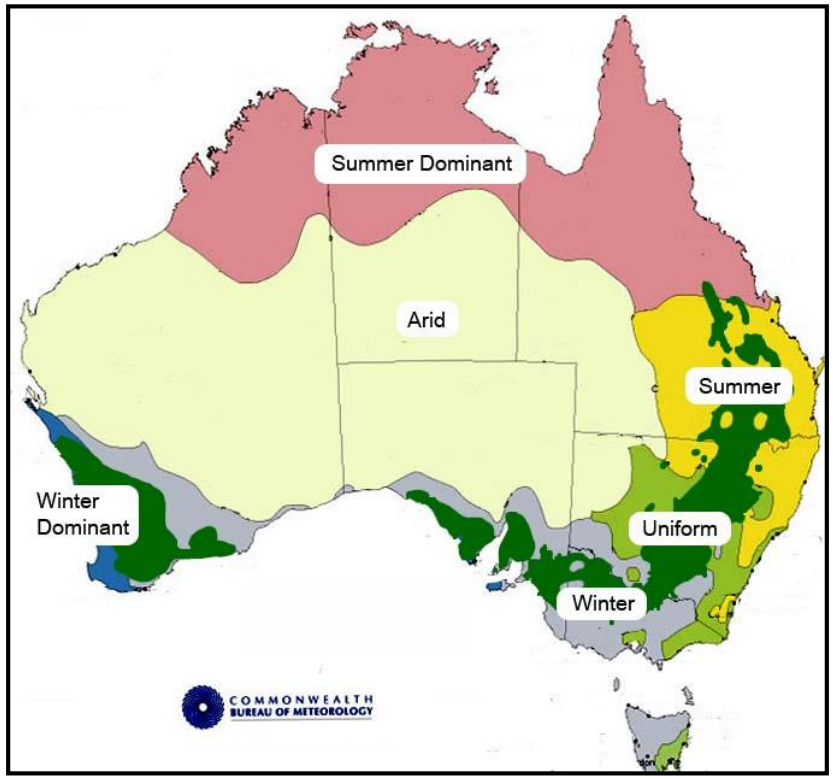
- Drought adaptation
  - Wide root angle → shallow root architecture (winter-rainfall environments)
  - Narrow root angle → compact deep root architecture (summer-rainfall environments)

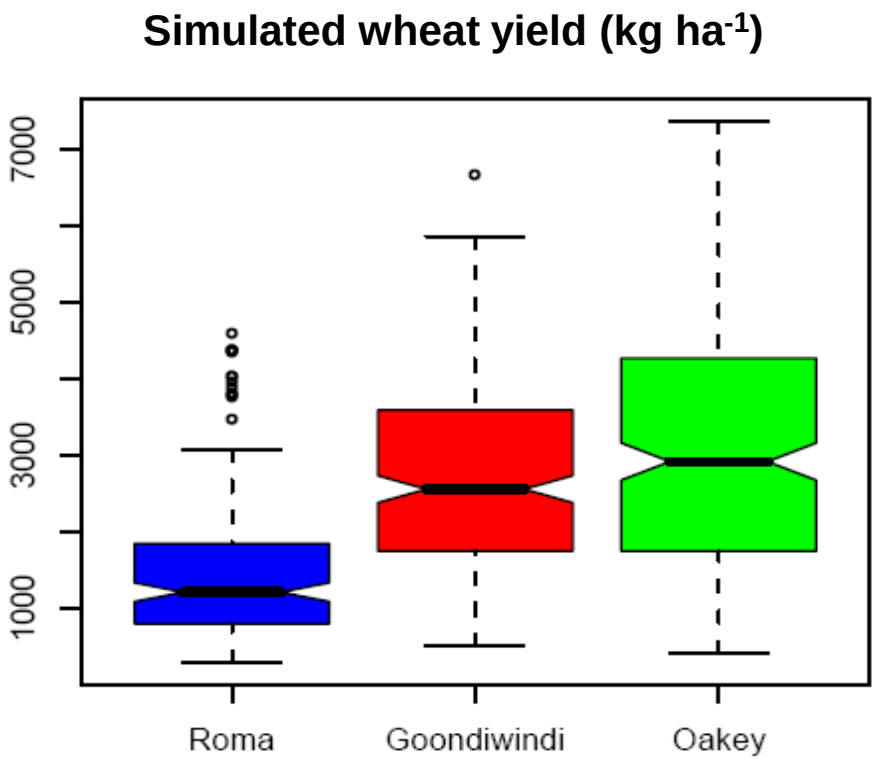



(Manschadi et al 2013; Plant Root, The Hidden Half)

# Root Architecture & Drought Adaptation

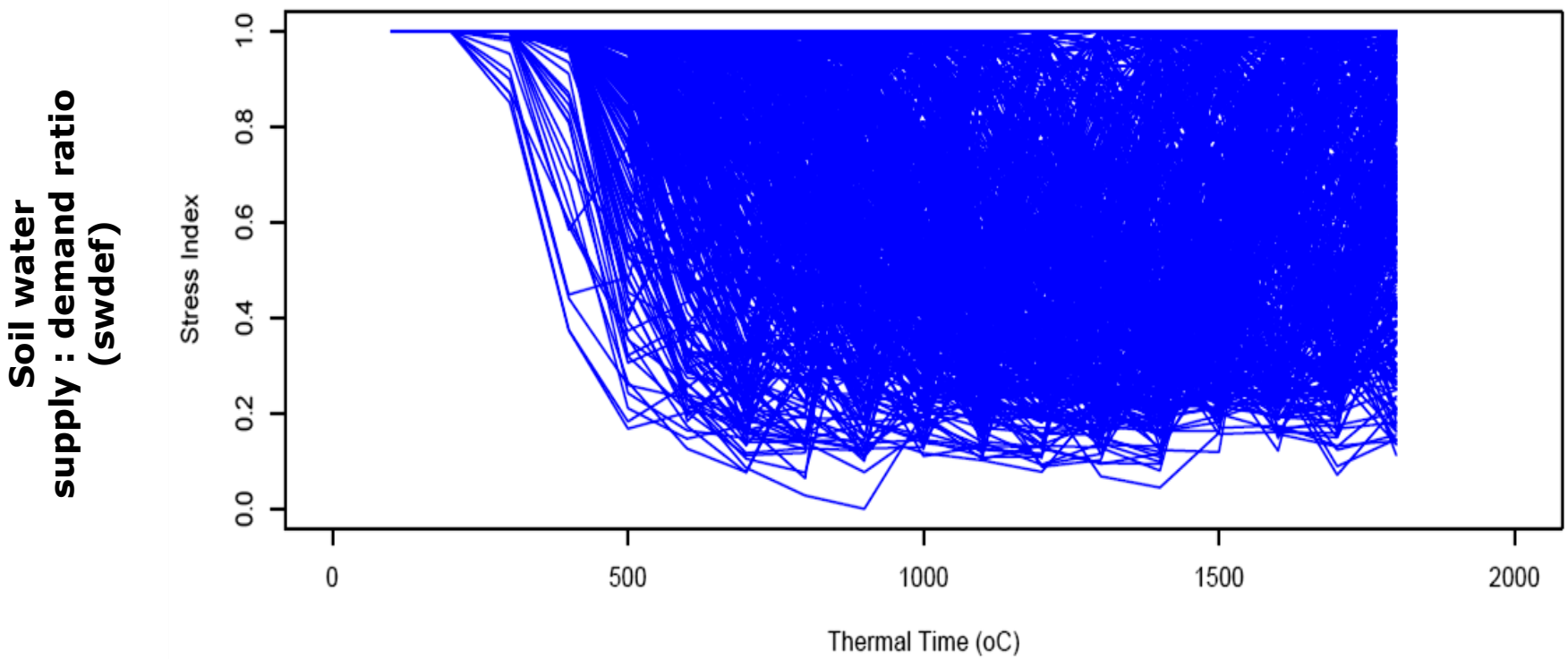
- Linking APSIM with
  - Historical climate records
  - Representative soil characteristics
  - Crop cultivar – **standard** variety vs **root-modified** genotype



# Characterising Drought Environment Types

- Pattern analysis of water stress index



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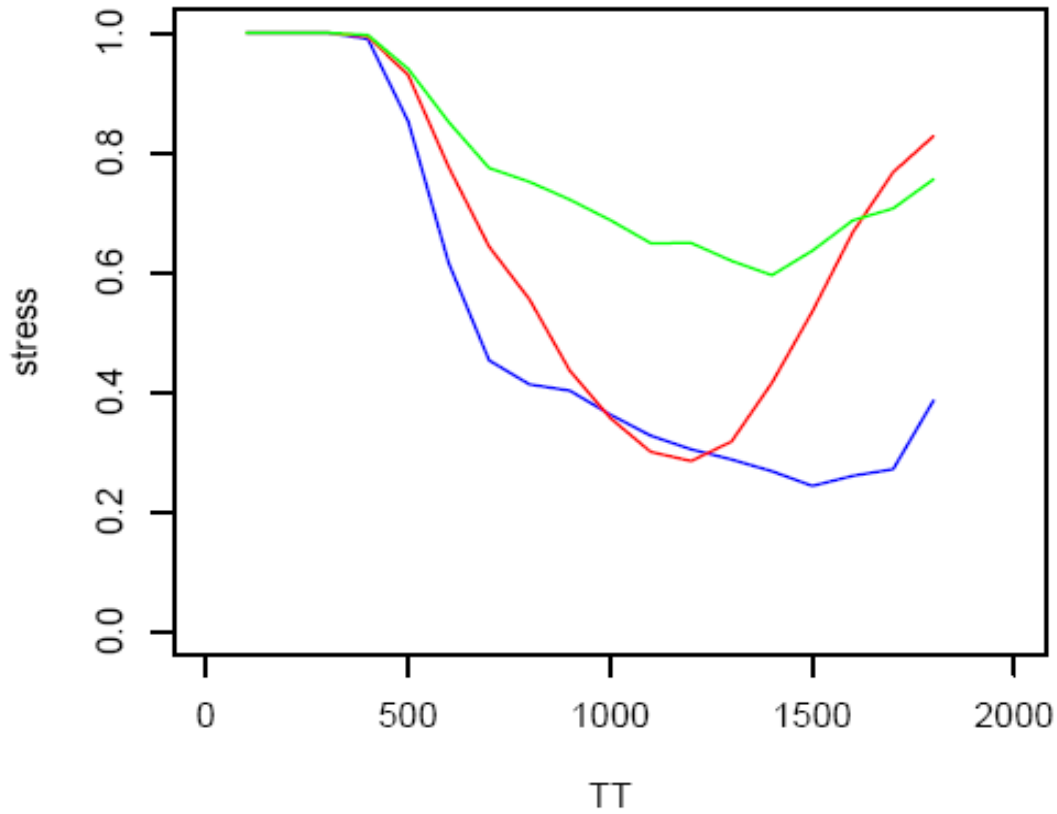


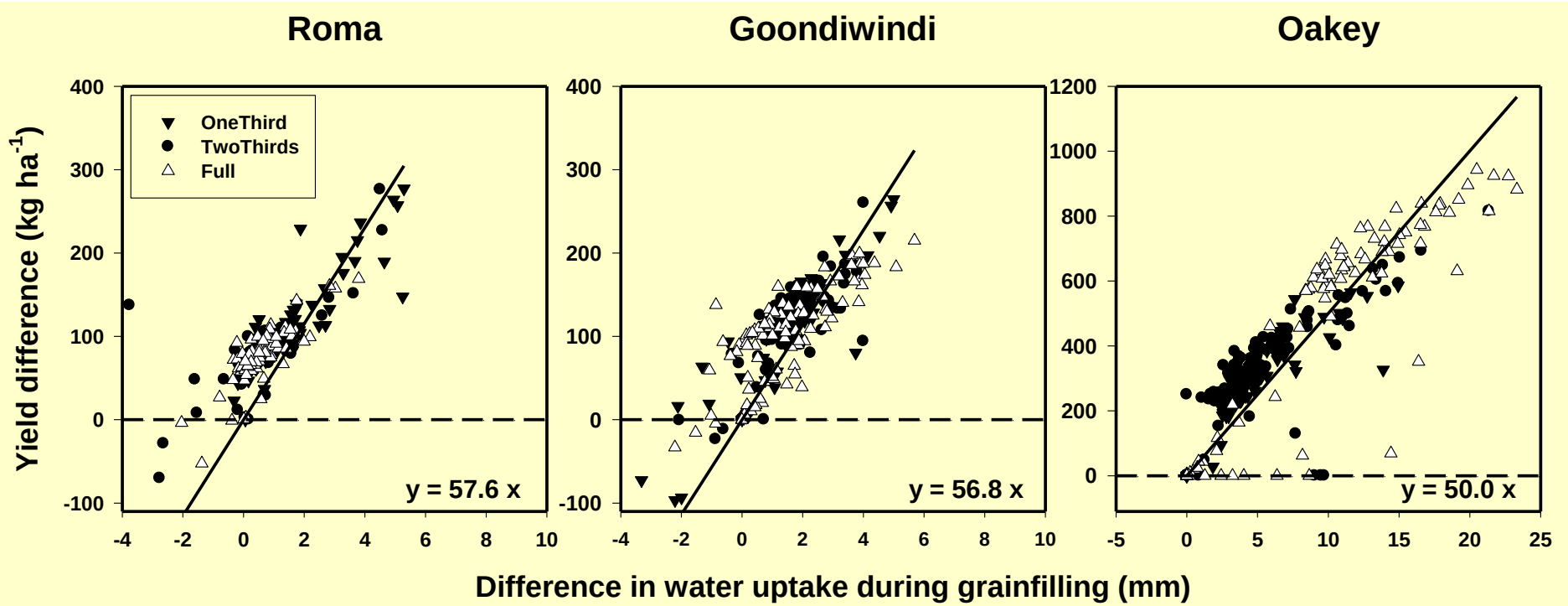

**E3 – Low terminal stress**

**E2 – Mid-season stress**

**E1 – Severe terminal stress**

# Root Architecture & Drought Adaptation

- Simulated effect of root traits modification on wheat yield (Standard vs. RM genotype)
- Greater water uptake during grain filling
- **Water-use efficiency for grain yield = 50 – 60 kg ha$^{-1}$ mm**




(Manschadi et al 2006; Functional Plant Biology)

# Conclusions

- Crop physiological models:
    - Indispensable tools for better understanding of G x E x M interactions
    - Bridging the G-to-P predictability gap
- Effective & parsimonious modelling ←→ Model parameterisation
- High-quality multi-environment datasets (soil, crop, climate, management)
- Dissection of complex phenotypes (maturity type, stay-green, leaf canopy vigour, root architecture) into more simple, heritable & stable physiological traits & QTLs
    - APSIM-Plant module: > 400 state variables
- Interdisciplinarity is the key to success