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Application of Crop Models in Tactical and Strategic Decision-making in Farming Systems

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Outline

- Evolution of crop modelling
- Application of crop models

  (strategic and tactical decision analysis and support)

  - Climate change impact assessment & adaptation options
  - Long-term effects of crop rotations (productivity and sustainability)
  - Plant breeding and crop improvement
  - Improving Nitrogen-use efficiency
- Conclusions

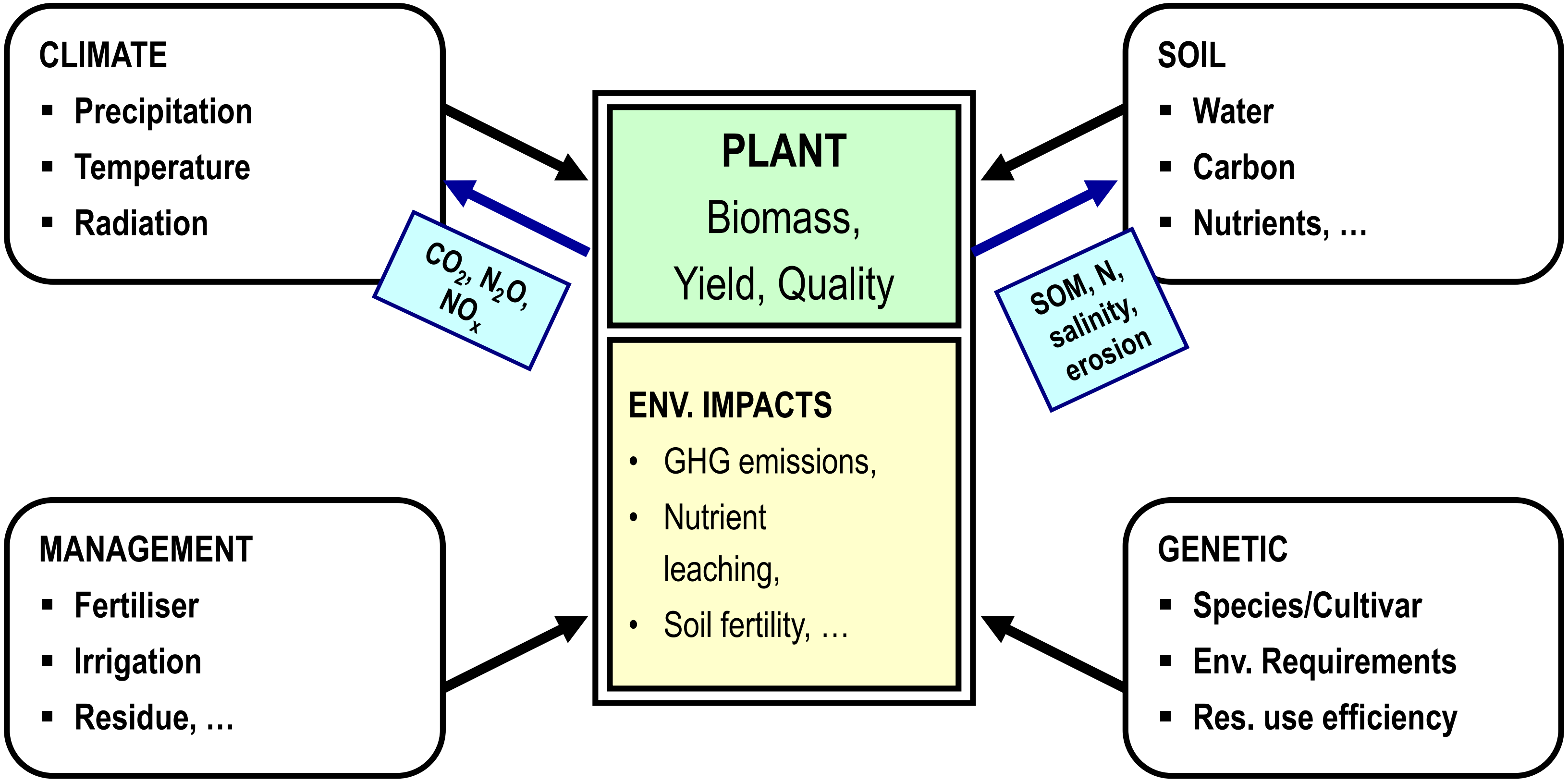
Key Global Issues Facing Agricultural Research and Development

- Population growth: 8.5 billion people by 2030
- Urbanisation → changes in diet
- Water scarcity & droughts
- Soil degradation and desertification
- Decreasing biodiversity
- Competition between food/feed crops and energy plants
- Climate change: extreme weather events (droughts and floods)

- **There are no quick fixes to these problems**
- **Need for a holistic, interdisciplinary systems approach**

Crop Growth & Development Models

- A model is a simplified representation of a system
- Integrate physiological understanding within a mathematical framework
  - Empirical/Regression/Statistical models
  - Process-based/Mechanistic models

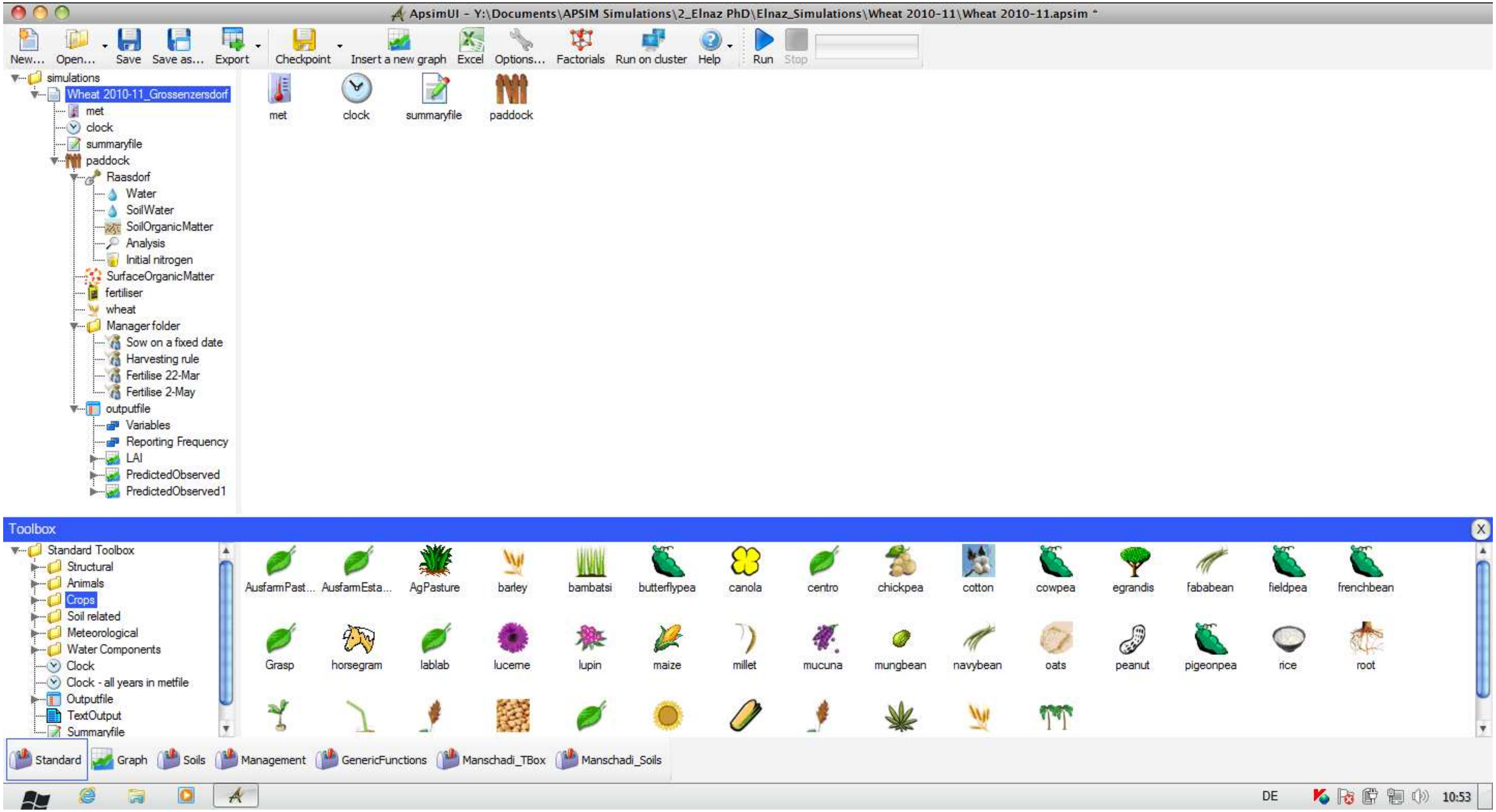


Evolution of Crop Modelling

1970s	- First simple, process-based models emerged (deWit, Ritchie)
1980 - 1985	- Comprehensive crop simulators becoming available (SUCROS, CERES, CROPGRO) - First generation systems simulators (NTRM, **EPIC**)
1985 - 1990	- Widespread training and usage of these models - Integrated applications 'packages' e.g. **DSSAT** - Advances in simulation of long-term soil processes (**CENTURY**) - Limitations of stand-alone crop models becoming obvious
1990 – 1995	- Greater capability to address systems issues appearing (**APSIM**, CropSyst, later revisions of DSSAT) - Greater recognition of the need for improved software engineering procedures - Optimistic application to agricultural systems analyses
1995 – present	- Development of new modules and utilities - Improving model structure and design

Crop Models - Capabilities

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



Parameterisation of Crop Models

- Adaptation (parameterisation) of models for the local environment
  - Plant genetic characteristics
  - Soil properties
  - Crop/Soil management practices

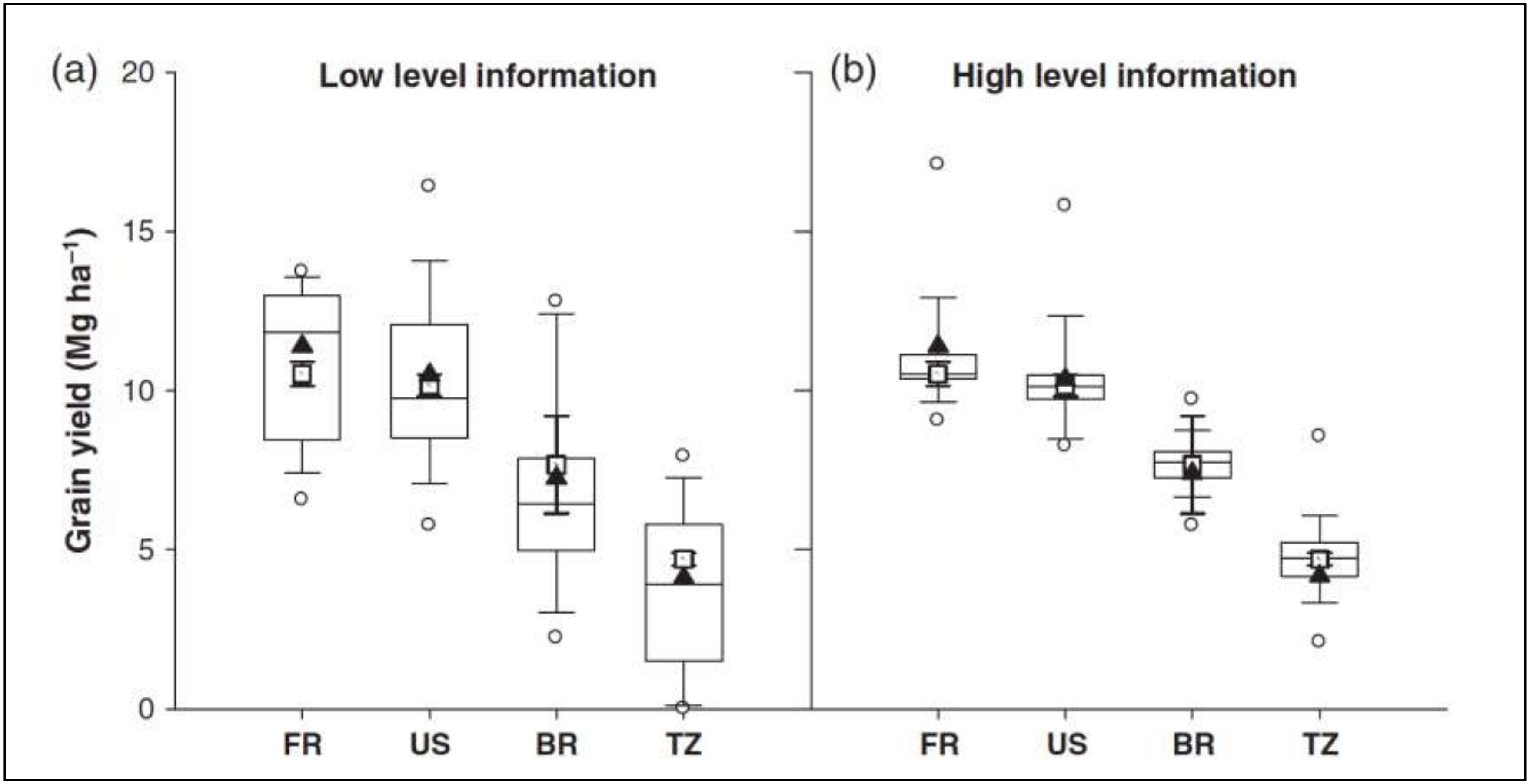
Parameterisation of Crop Models

- Parameterisation of APSIM-Wheat for eastern Austria

Parameterisation of Crop Models

- Adaptation (parameterisation) of models for the local environment

Observed and simulated one year maize grain yield for four locations using 17 maize simulation models and two levels of input information for model parameterisation



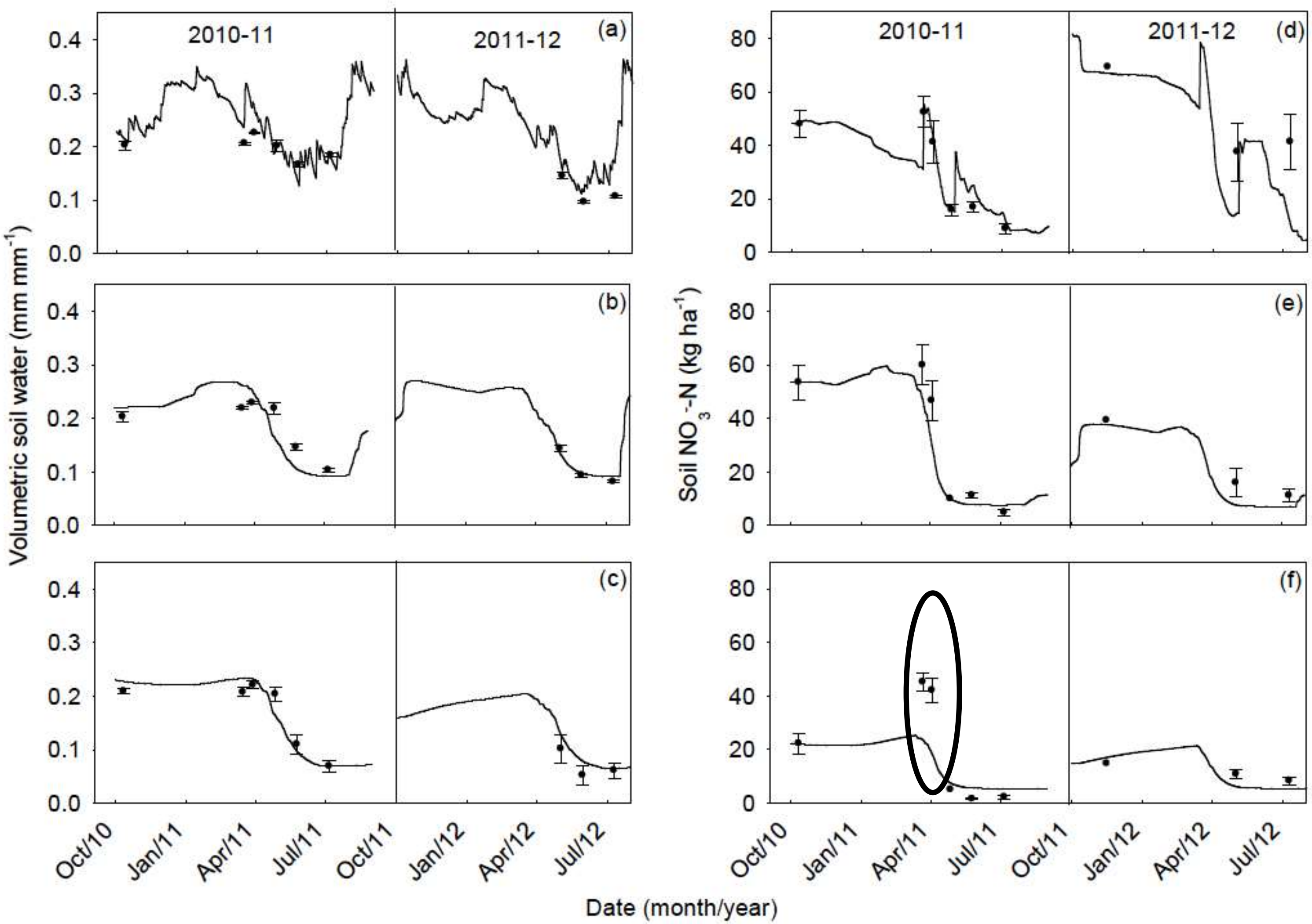
(Bassu et al. 2014; Global Change Biology)

Crop Models - Applications

- Applications of crop models:
  - **Analytical tools for assessing the quality of empirical datasets**
  - Strategic analysis and decision support
    - Estimating yield potential (agro-ecological zoning)
    - Yield gap analysis – identification of problems/bottelnecks
    - **Climate change impact assessment & adaptation options**
    - **Long-term effects of crop rotations (productivity and sustainability)**
    - **Plant breeding and crop improvement** – identification and evaluation of adaptive traits
  - Tactical decision support
    - Optimising crop management (sowing time/density etc.)
    - Irrigation scheduling
    - **Fertiliser scheduling (Improving Nitrogen-use efficiency)**

Crop Models as Analytical Tools

- Assessing the quality of empirical datasets



(Ebrahimi et al. 2016)

Crop Models – Climate Change Impact Assessment

- Climate change impact on wheat in Austria
  - Groß-Enzersdorf
  - Baseline (1981-2010) CO_2 concentration: 385 ppm
  - Climate change scenarios (2035-2065) from three Global Circulation Models

Table 3. *Factorial combinations of climate models with emission scenarios and management treatments for simulation experiment*

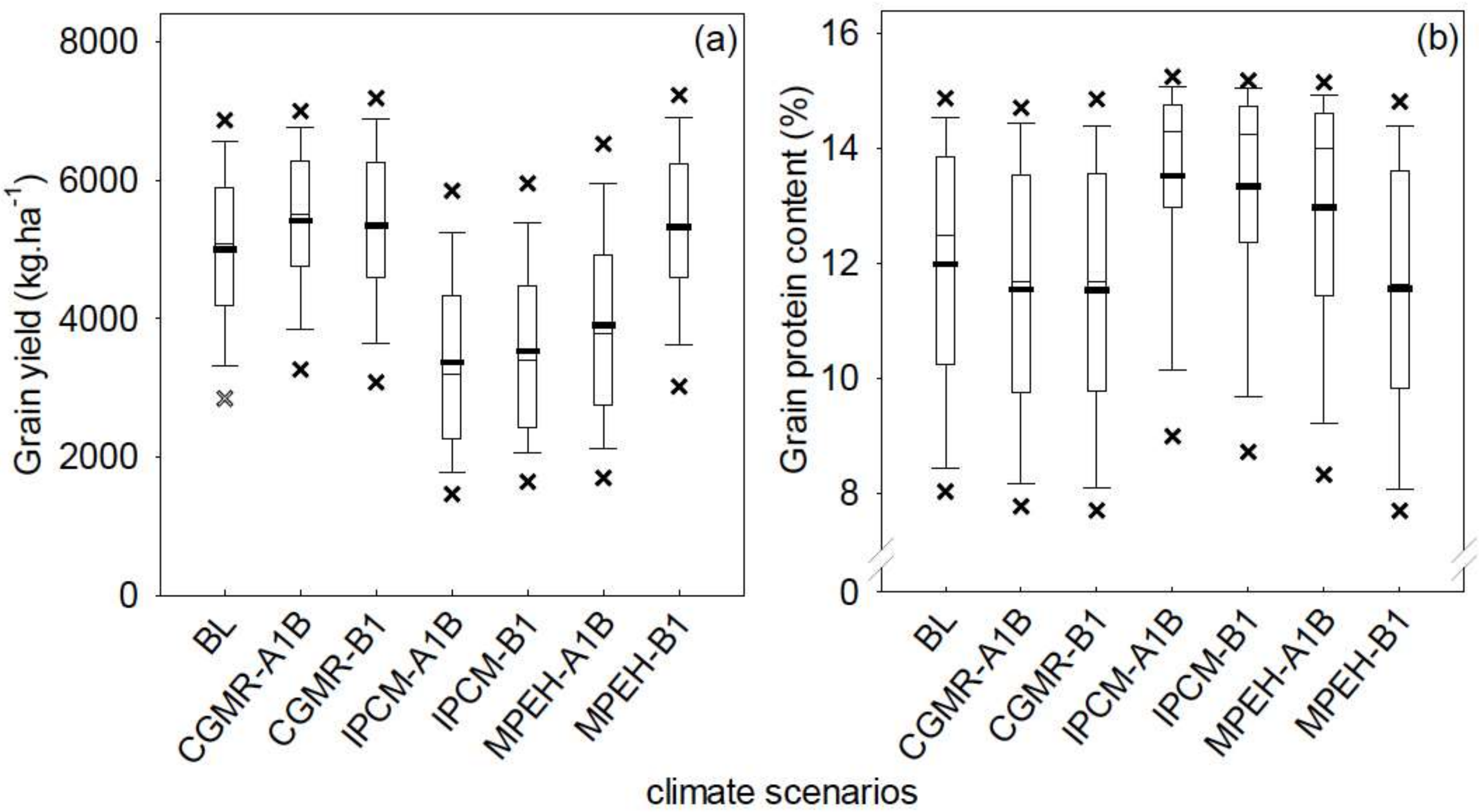
Climate	Emission scenario	Sowing date	Nitrogen rate (kg/ha)	Nitrogen application at Zadoks stages (kg/ha)		
				GS21	GS31	GS51
Baseline	A1B–B1	20 September (SD1)	80 (N80)	40	40	0
CGMR						
IPCM4		20 October (SD2)	120 (N120)	40	40	40
MPEH5		20 November (SD3)	160 (N160)	50	50	60
			200 (N200)	60	60	80

GS, growth stage.

(Ebrahimi et al. 2016)

Crop Models – Climate Change Impact Assessment

- Simulated wheat grain yield
  - No changes under CGMR projections
  - 30% reduction under IPCM4 projections



(Ebrahimi et al. 2016)

Crop Models – Climate Change Impact Assessment

- Climate change effects on wheat phenology
- N fertiliser application dates will be earlier in the future

Table 6 Simulated average days after sowing of fertiliser application at target Zadoks stages under baseline (1981-2010) and IPCM4 climate scenario with two emission scenarios for 2035-2065 as affected by sowing date.

Climate scenario-Sowing date	Z22	Z31	Z51
BL-SD1	67	203	233
BL-SD2	164	190	216
BL-SD3	145	161	186
IPCM4-A1B-SD1	38	187	217
IPCM4-A1B-SD2	138	179	203
IPCM4-A1B-SD3	126	151	174
IPCM4-B1-SD1	47	198	228
IPCM4-B1-SD2	154	186	211
IPCM4-B1-SD3	138	158	182

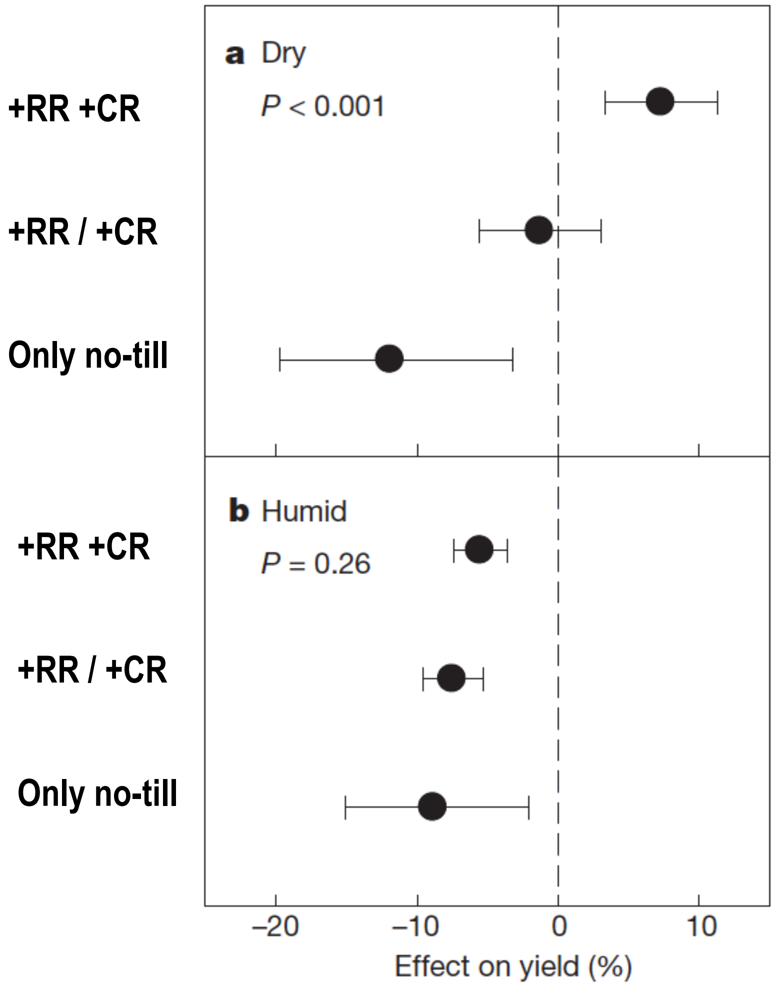
(Ebrahimi et al. 2016)

Crop Models – Sustainability Assessment

- Long-term effects of crop rotations (productivity and sustainability)
  - **Conservation agriculture (CA)**:
    - Direct planting of crops (no-till)
    - Permanent soil cover (residue retention, RR)
    - Crop rotation (CR)

Crop Models – Sustainability Assessment

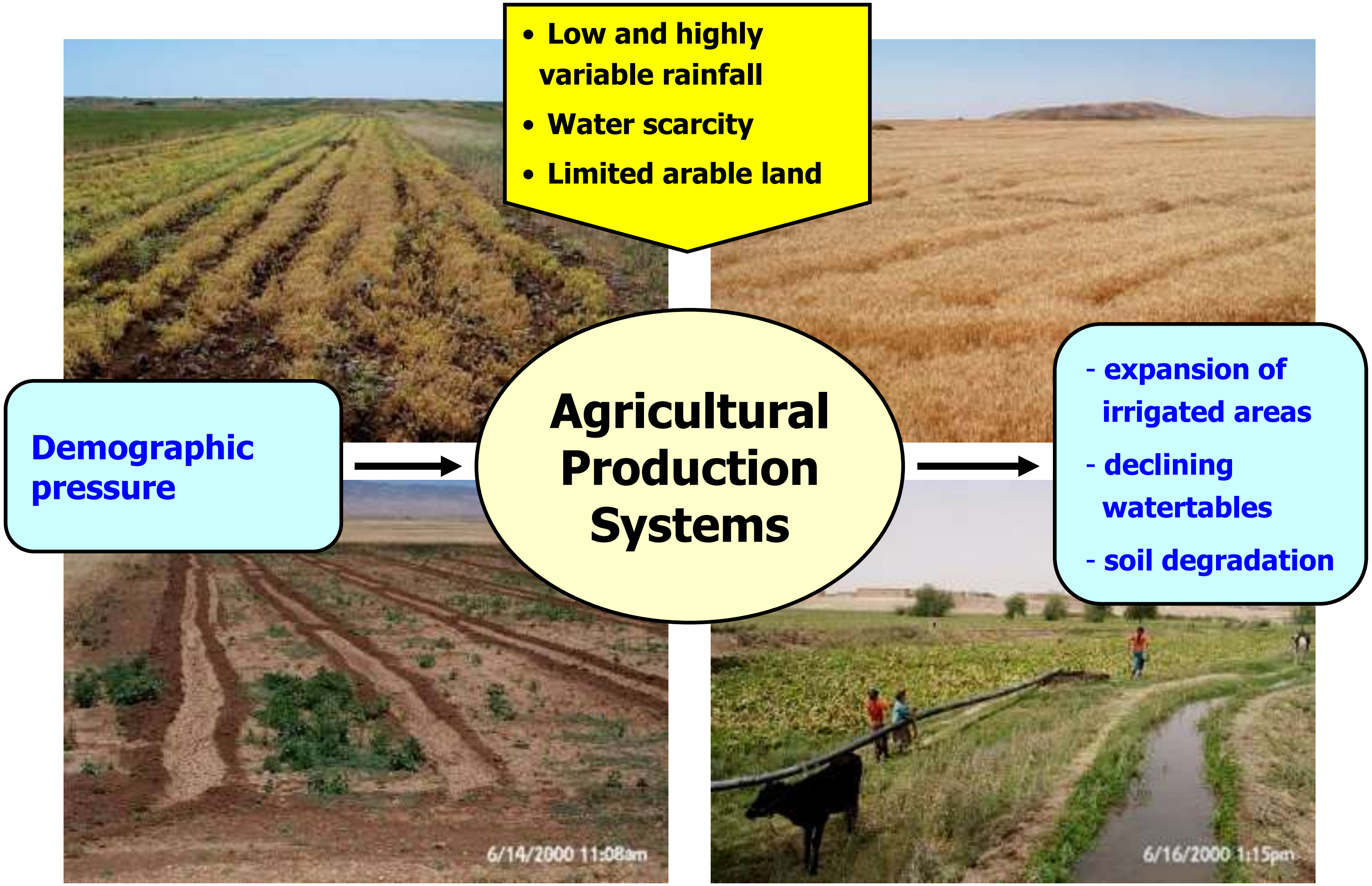
- Global meta-analysis (610 studies across 48 crops and 63 countries):
  No-till + residue retention (RR) and crop rotation (CR) → Significant increase in rainfed crop productivity in dry climates



(Pittelkow et al. 2015, Nature)

Crop Models – Sustainability Assessment

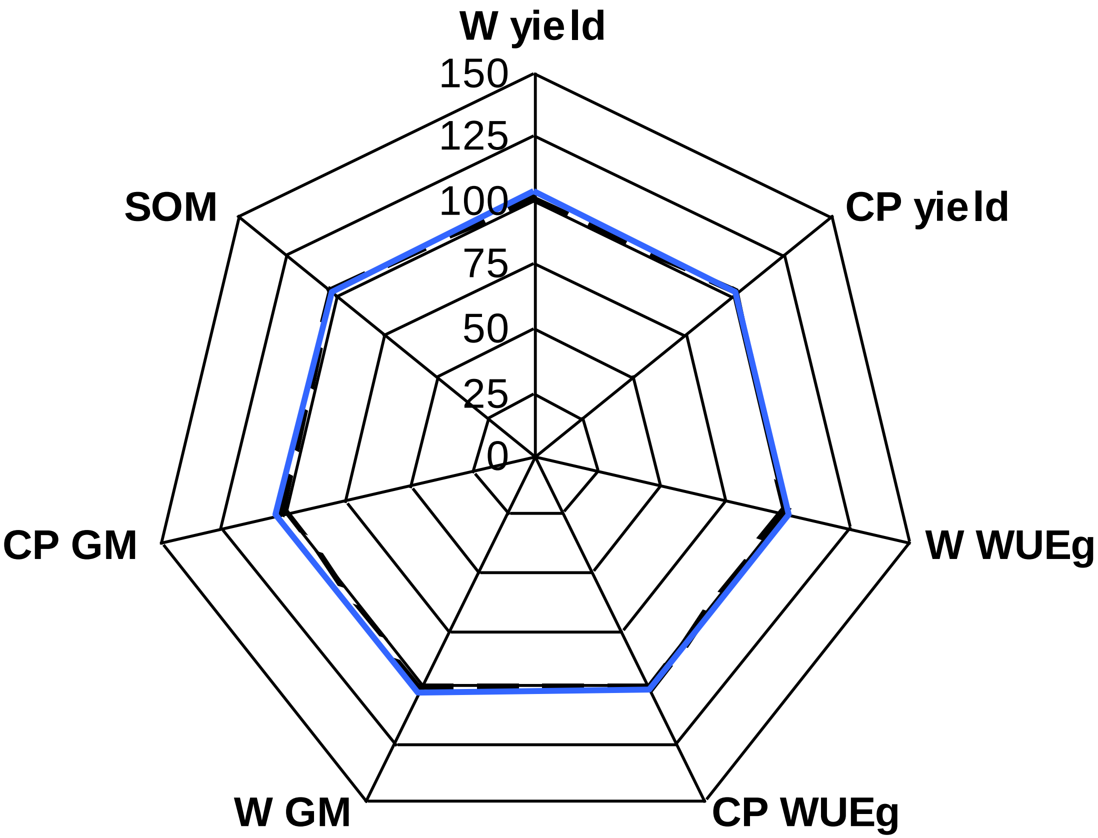
- Sustainability of wheat-based cropping systems in semi-arid Mediterranean environments



Crop Models – Sustainability Assessment

- Simulating effects of CA on wheat (W) & chickpea (CP) using APSIM
- Sustainability polygon – long-term simulations

Conventional tillage & 50 kg N/ha

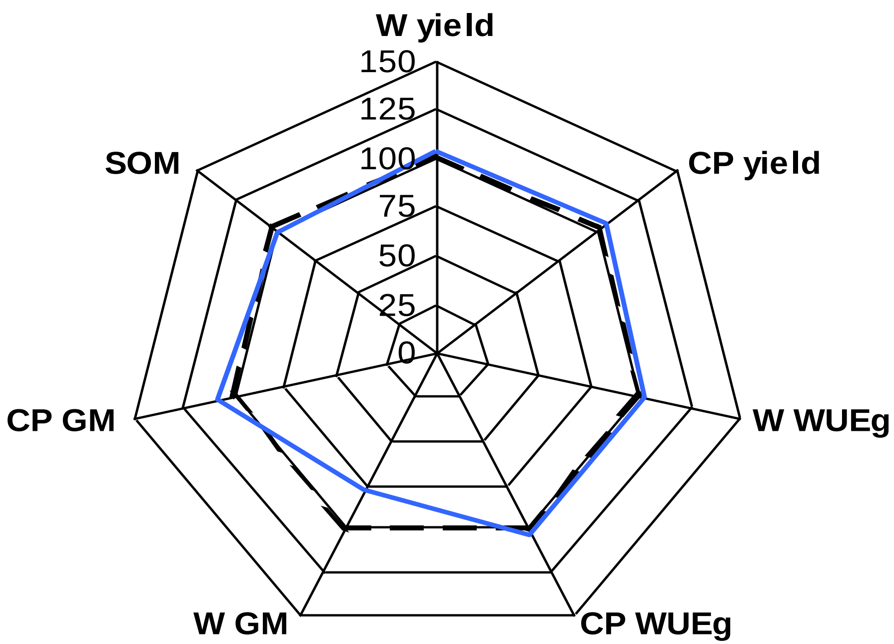


(Moeller et al. 2014; Sustainability)

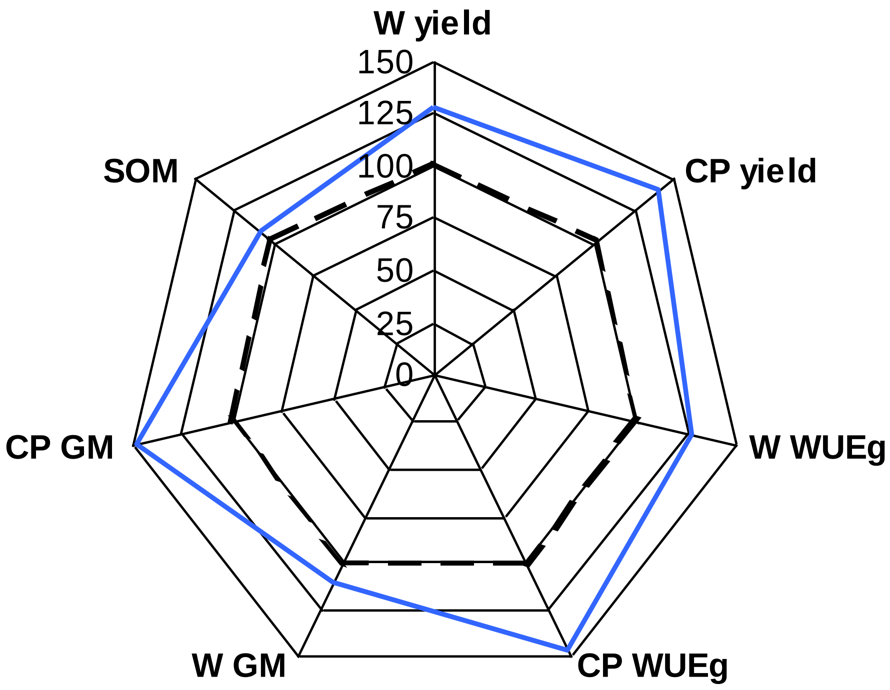
Crop Models – Sustainability Assessment

- Simulating effects of CA on wheat (W) & chickpea (CP) using APSIM

Burned-Conventional tillage



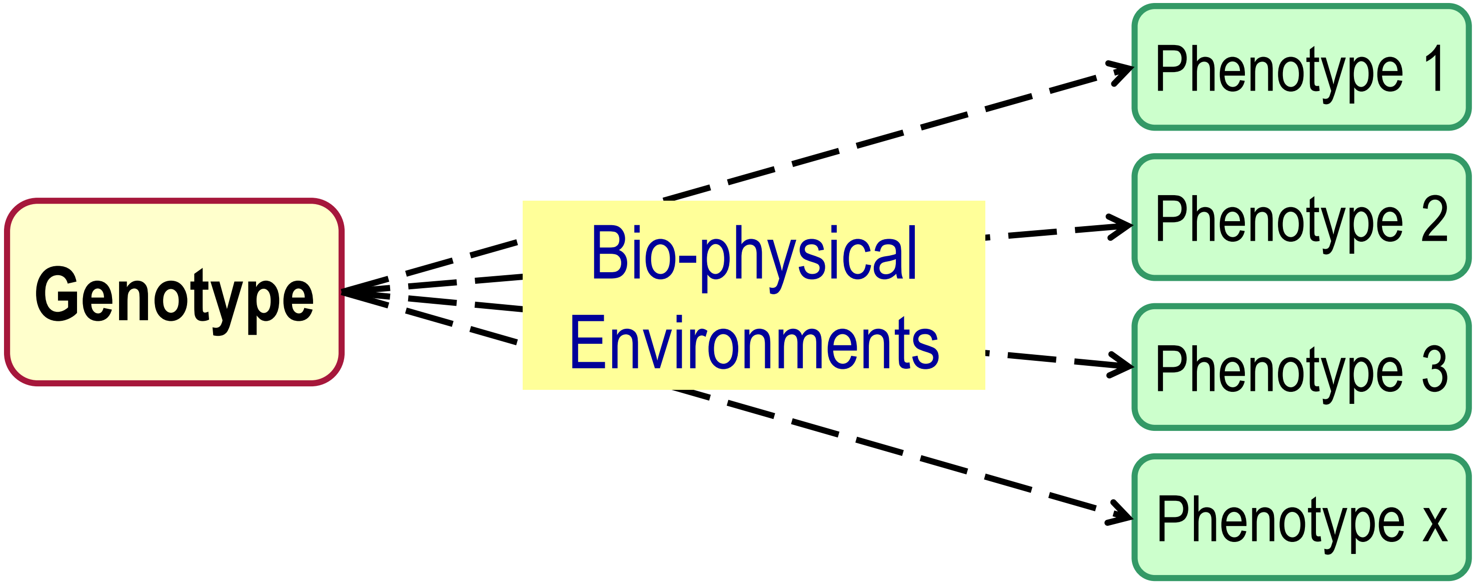
Mulch-tillage



(Moeller et al. 2014; Sustainability)

Model-assisted Phenotyping

- Plant breeding and crop improvement
- Genetic variation not consistent among environments (G x E interaction)

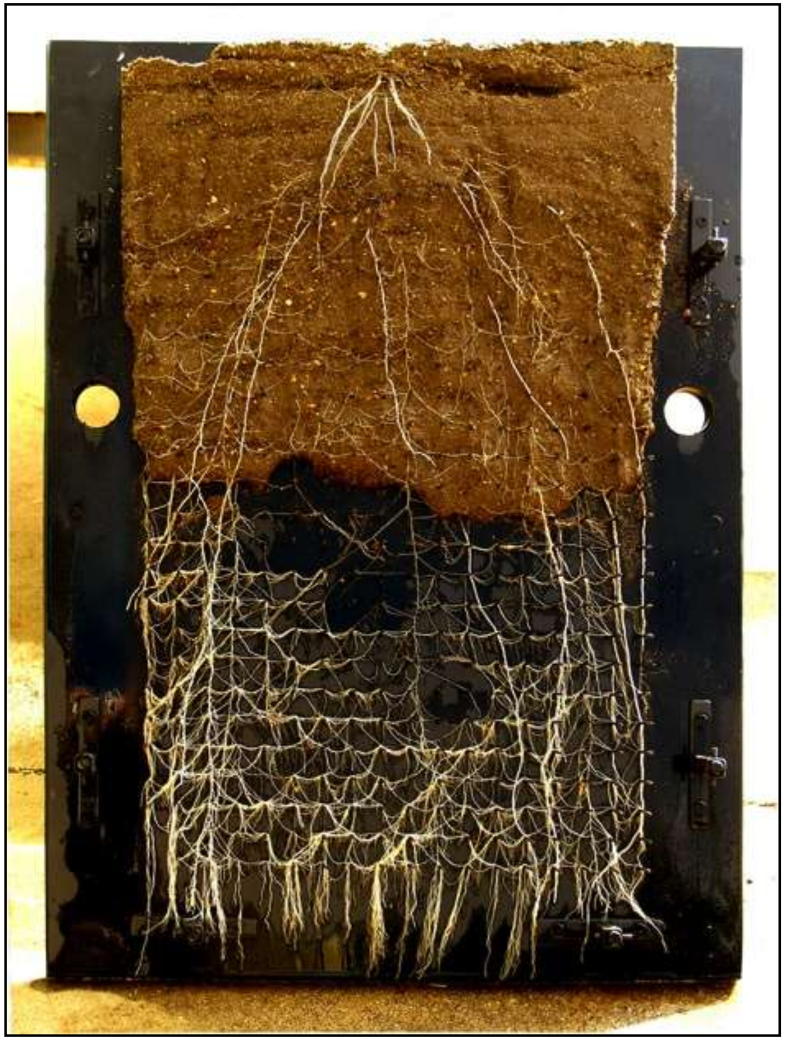


- Water- and nutrient-use efficiency: multi-genic traits (G x G, G x E, G x E x M)
- **G-to-P predictability gap – Major constraint to crop improvement (breeding)**

Model-assisted Phenotyping

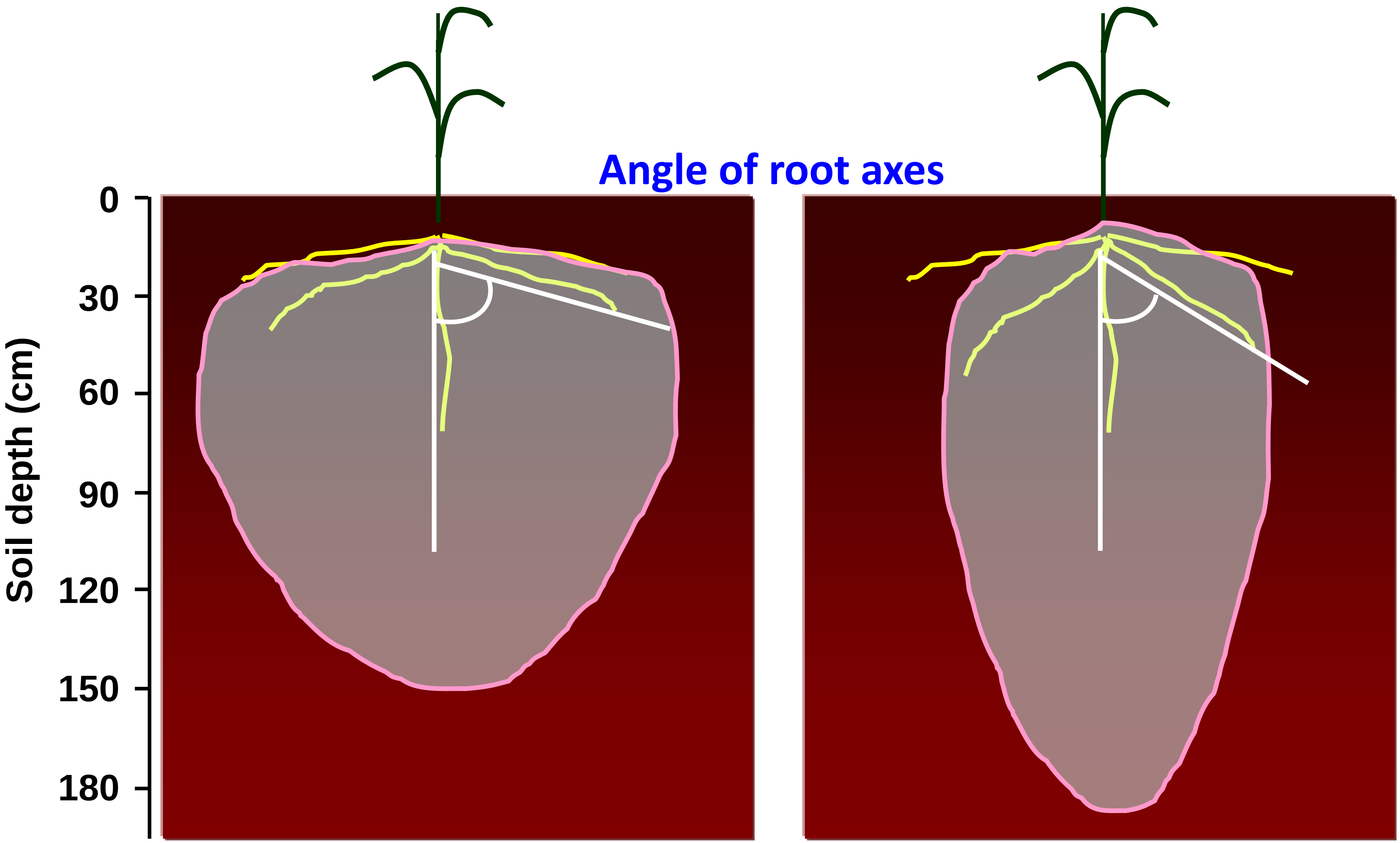
- Simulating emergent consequences of genotypic variation in:

Root Architecture



Model-assisted Phenotyping

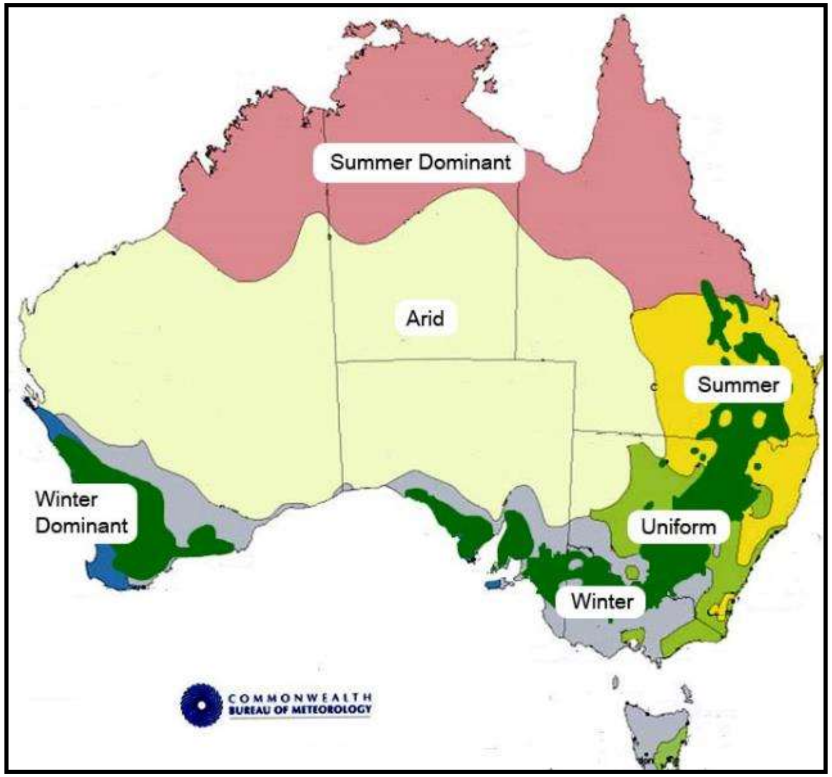
- Drought adaptation
  - Wide root angle → shallow root architecture (winter-rainfall environments)
  - Narrow root angle → compact deep root architecture (summer-rainfall environments)

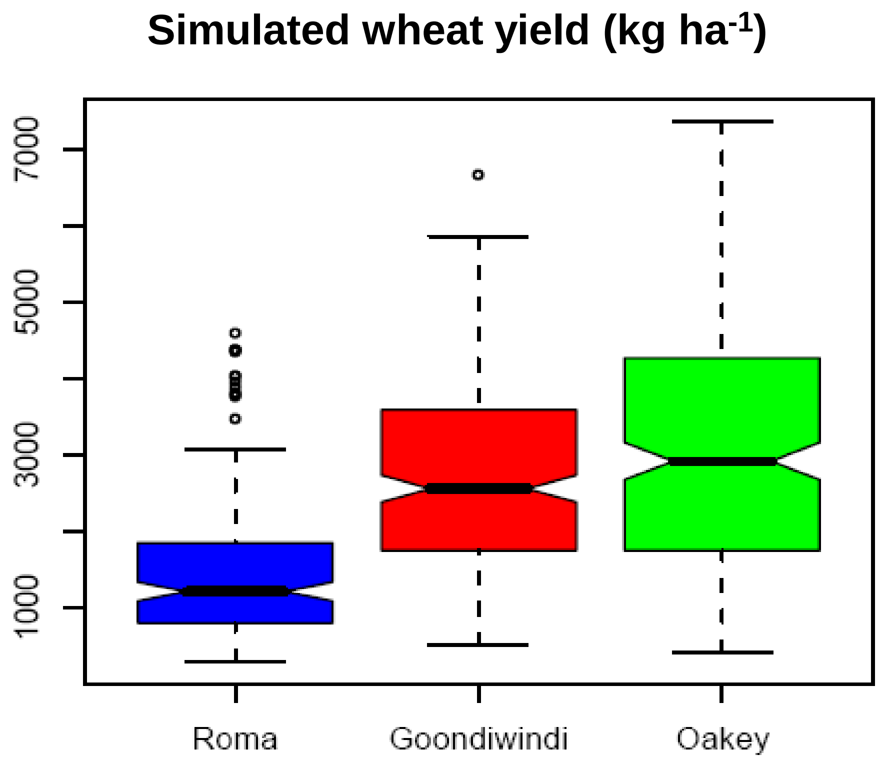


(Manschadi et al 2013; Plant Root, The Hidden Half)

Model-assisted Phenotyping

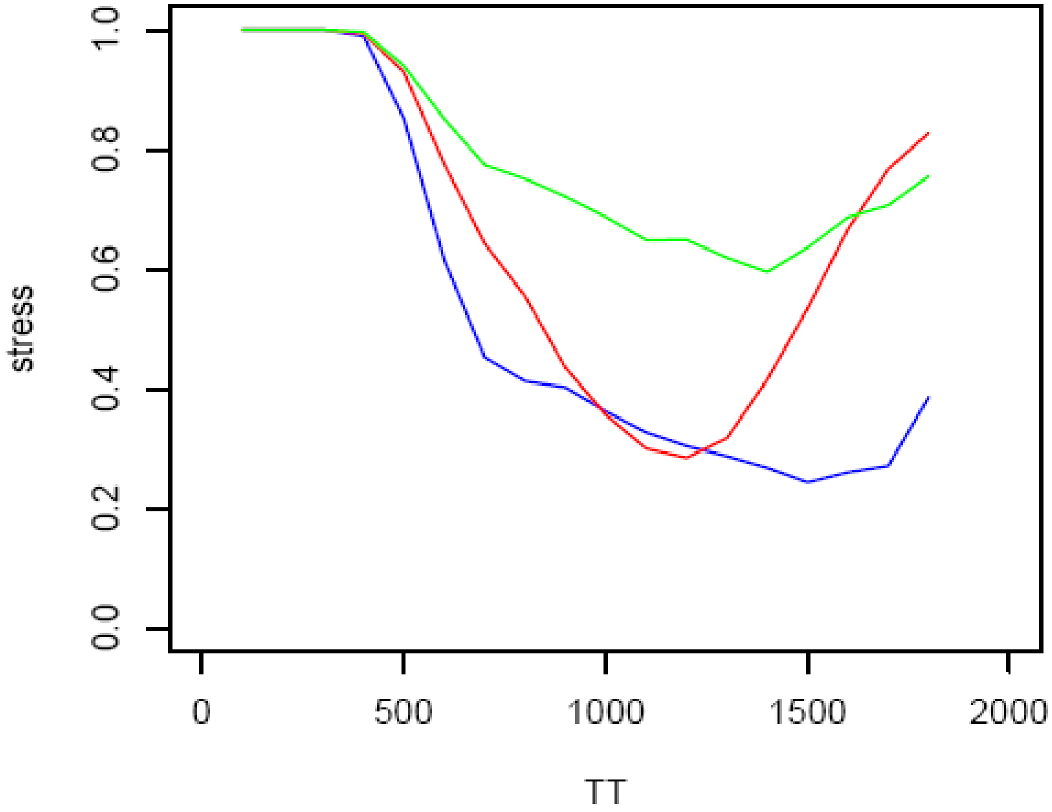
- Linking APSIM with
  - Historical climate records
  - Representative soil characteristics
  - Crop cultivar – **standard** variety vs **root-modified** genotype





Model-assisted Phenotyping

- Pattern analysis of water stress index
- Characterising Drought Environment Types



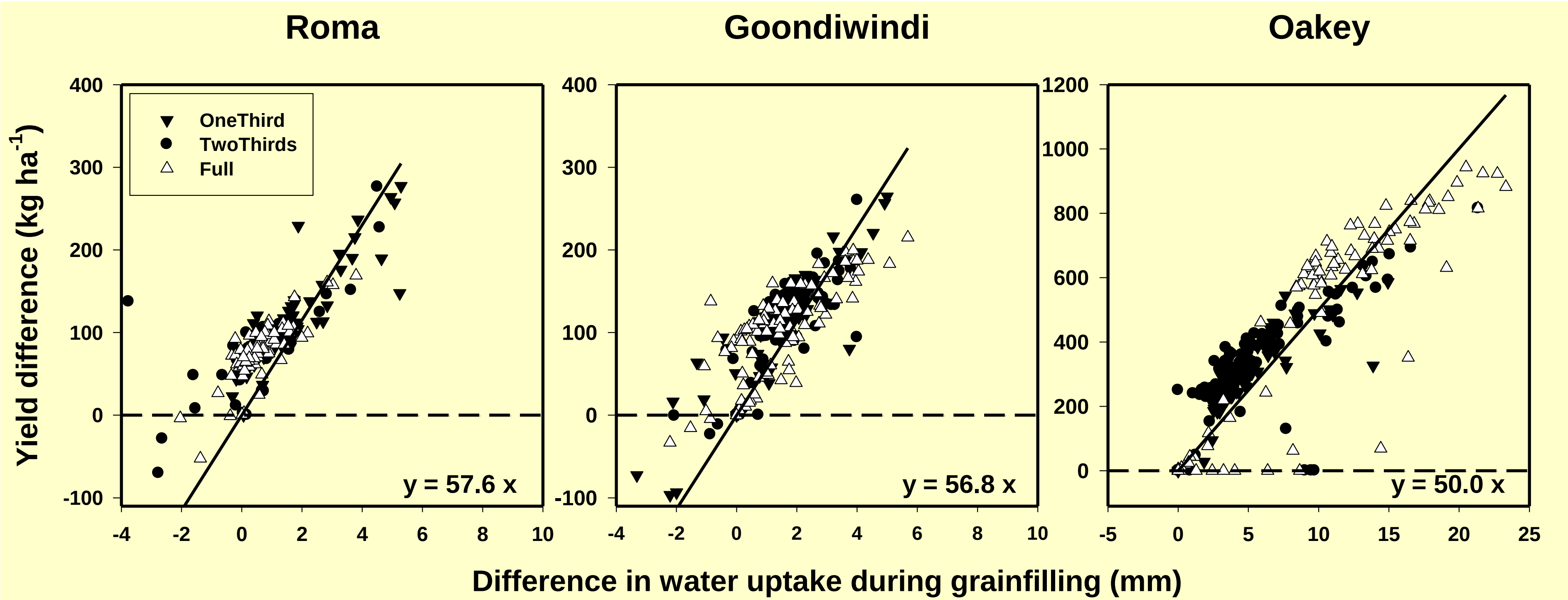
E3 – Low terminal stress

E2 – Mid-season stress

E1 – Severe terminal stress

Model-assisted Phenotyping

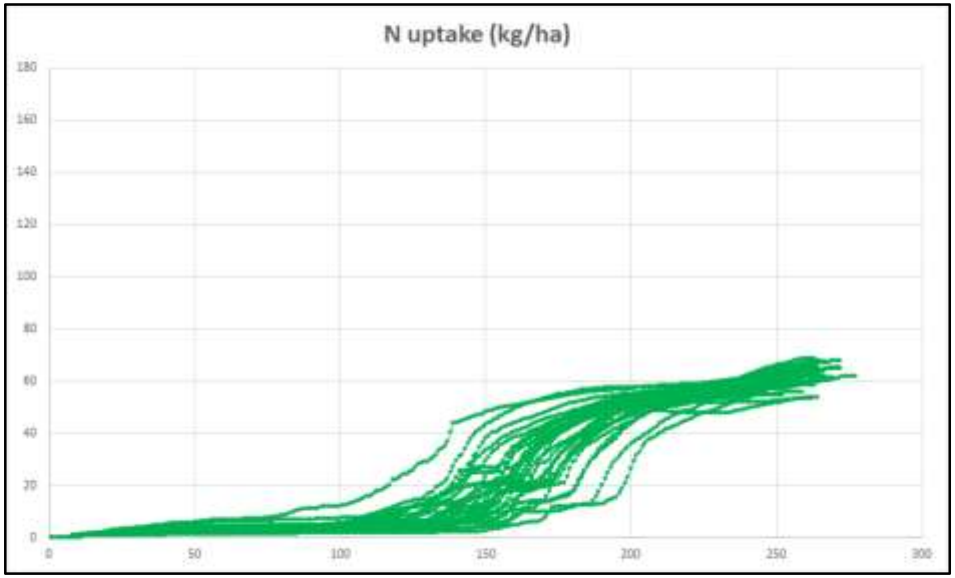
- Simulated effect of root traits modification on wheat yield (Standard vs. RM genotype)
- Greater water uptake during grain filling
- **Water-use efficiency for grain yield = 50 – 60 kg ha^{-1} mm**

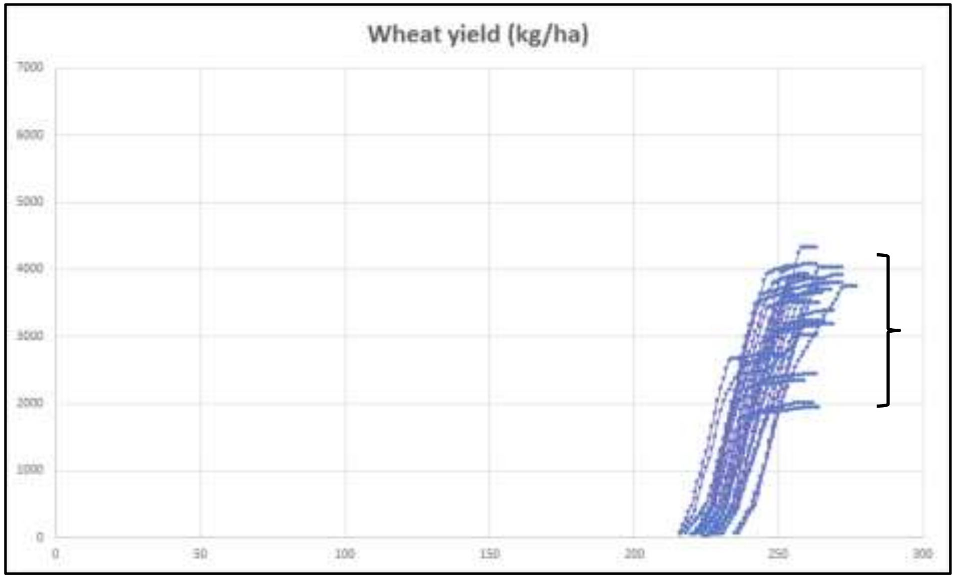


(Manschadi et al 2006; Functional Plant Biology)

Improving Nitrogen-Use Efficiency

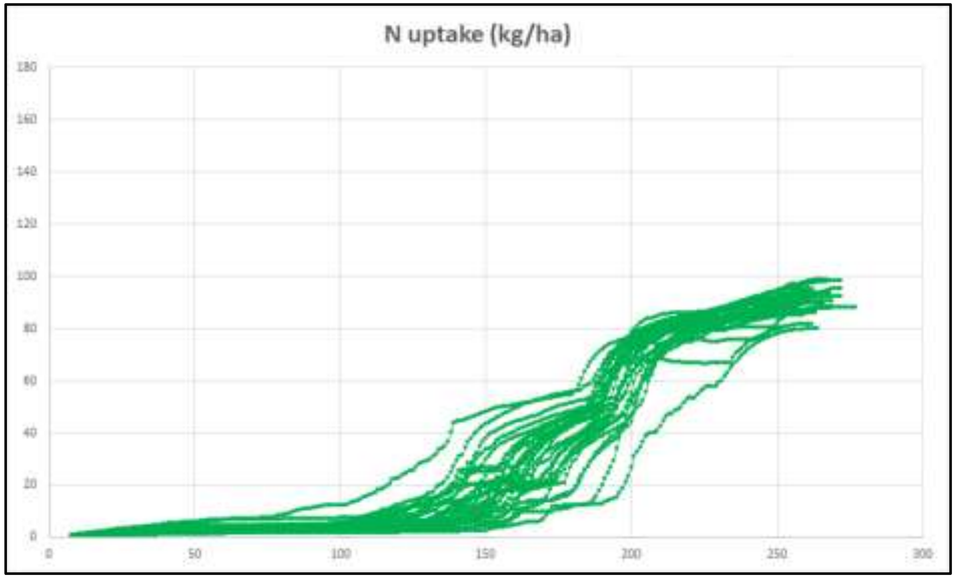
- Wheat simulations: GE, 1980 – 2011
  - Sowing: Oct 20
  - Initial soil N = 35 kg
  - N-Fertiliser: N1(40 kg at Z22) = **40 kg**

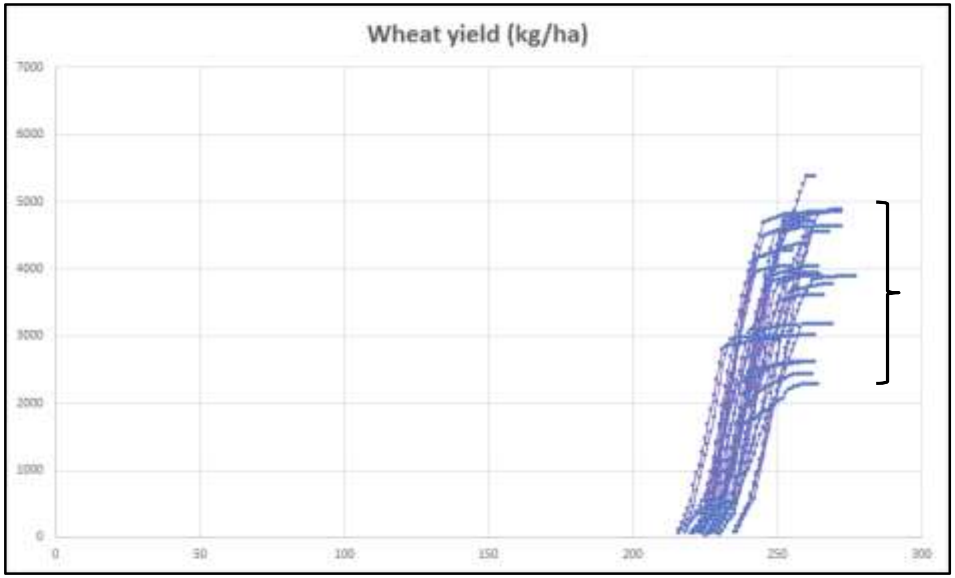




Improving Nitrogen-Use Efficiency

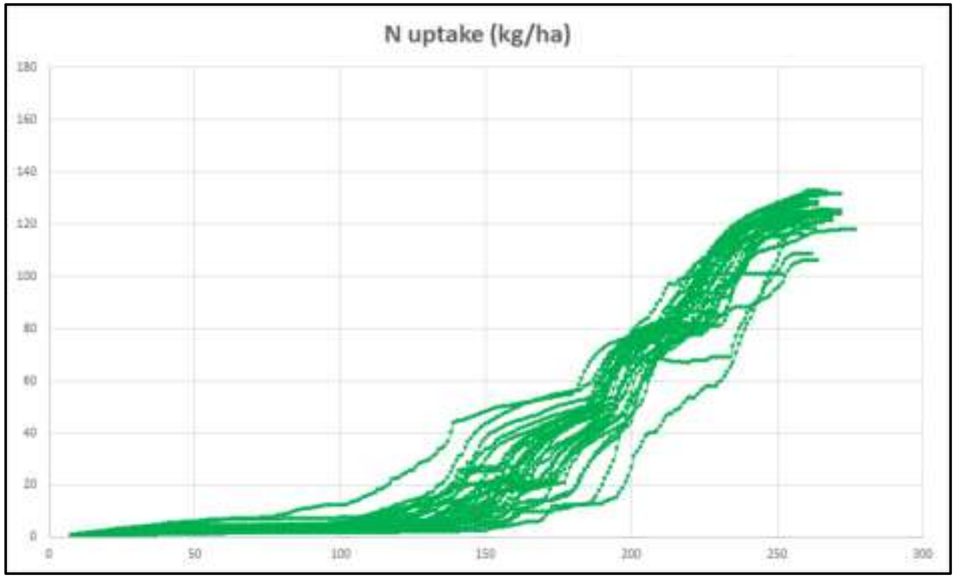
- Wheat simulations: GE, 1980 – 2011
  - Sowing: Oct 20
  - Initial soil N = 35 kg
  - N-Fertiliser: N1(40 kg at Z22); N2(40 kg at Z31) = **80 kg**

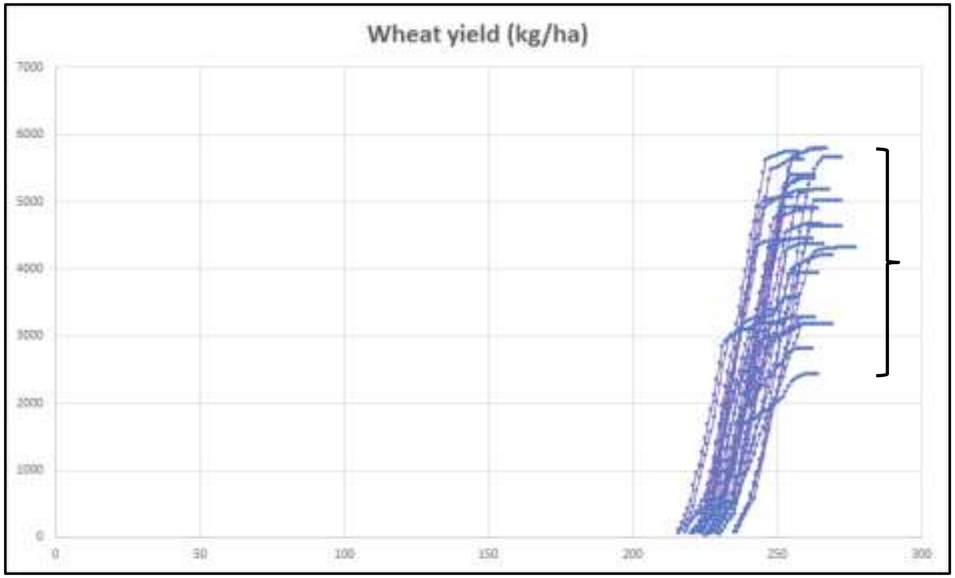




Improving Nitrogen-Use Efficiency

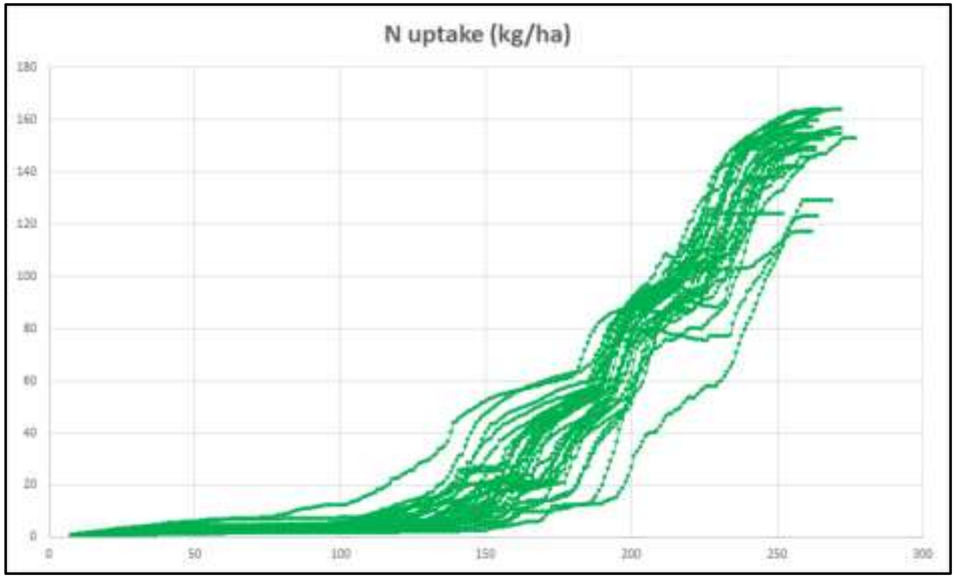
- Wheat simulations: GE, 1980 – 2011
  - Sowing: Oct 20
  - Initial soil N = 35 kg
  - N-Fertiliser: N1(40 kg at Z22); N2(40 kg at Z31); N3 (40 kg at Z51) = **120 kg**

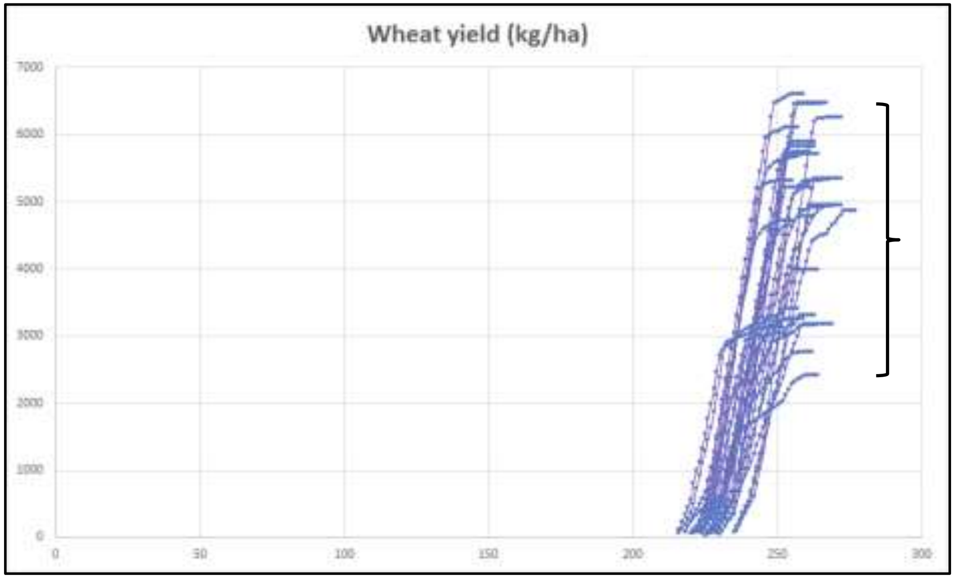




Improving Nitrogen-Use Efficiency

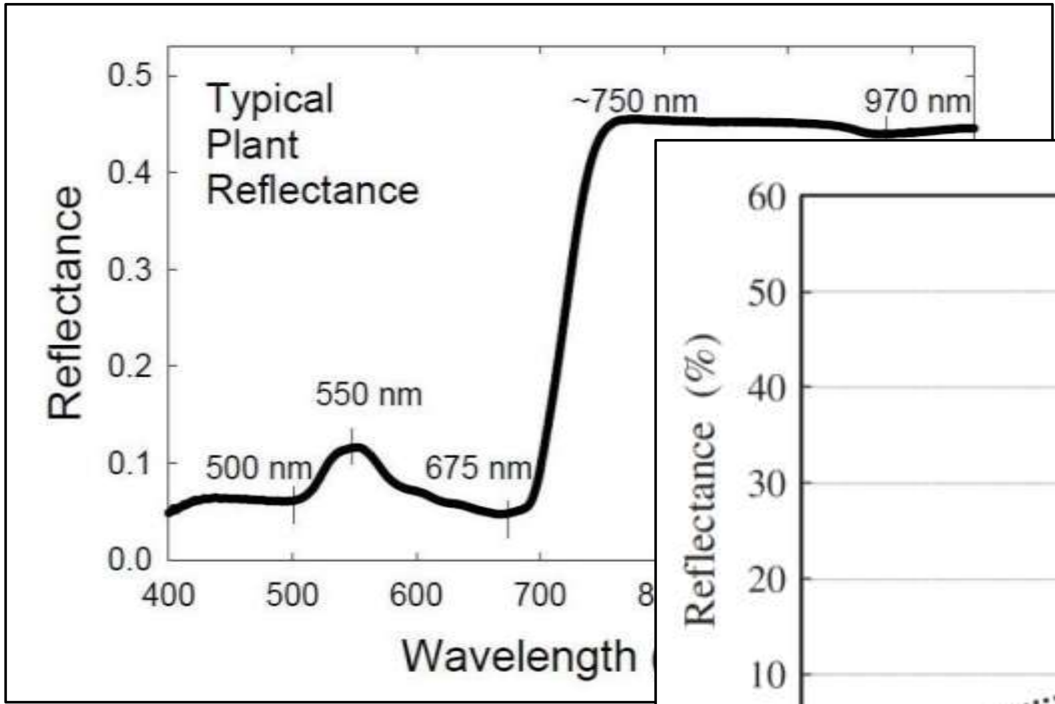
- Wheat simulations: GE, 1980 – 2011
  - Sowing: Oct 20
  - Initial soil N = 35 kg
  - N-Fertiliser: N1(50 kg at Z22); N2(50 kg at Z31); N3 (60 kg at Z51) = **160 kg**



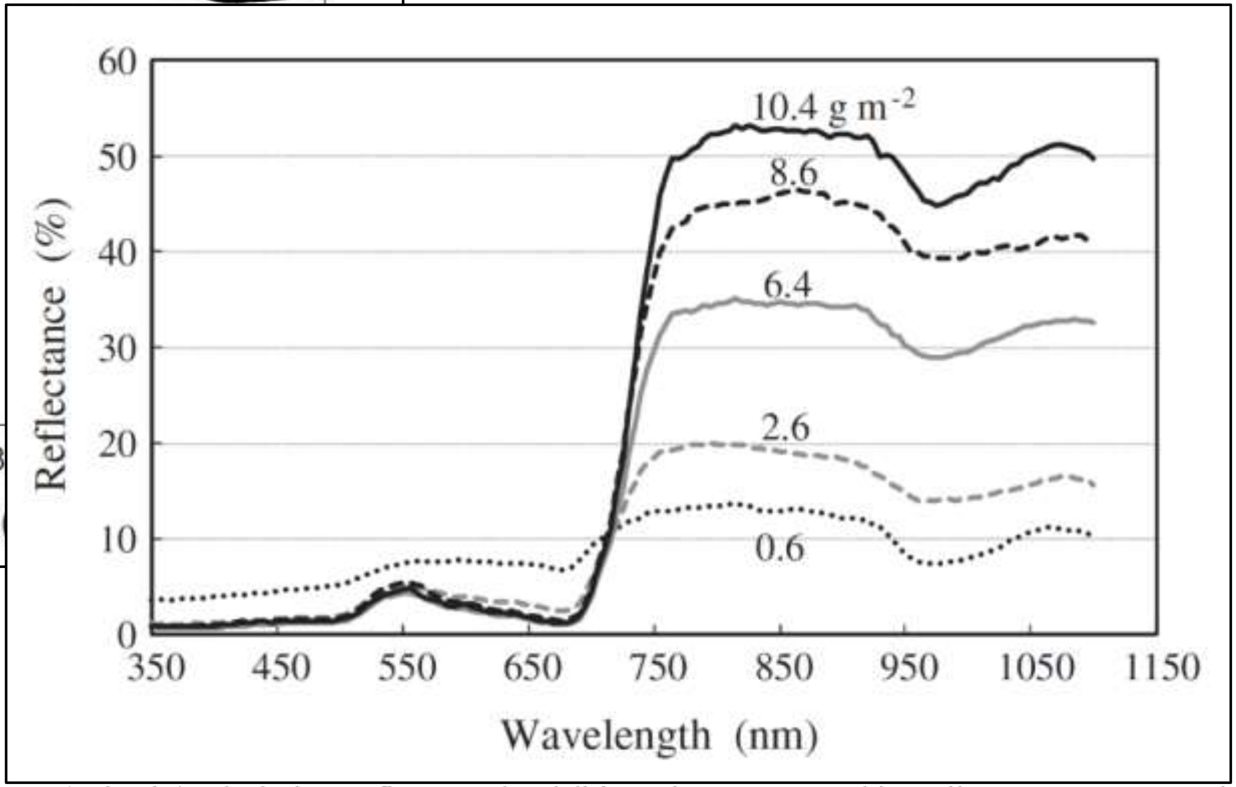


Remote Sensing of Crop N Status

- Typical plant reflectance
  - Chlorophyll absorbs most of the visible light (400 - 700 nm)
  - Cell structure reflects near-infrared light (NIR, 700 - 1300 nm) - considerable scattering at mesophyll cell wall interfaces



(Mulla 2013)



http://www.stellarnet.us/wp-content/uploads/typical-plant-reflectance-in-visible-and-NIR-range-with-StellarNet-spectrometer.jpg

Remote Sensing of Crop N Status

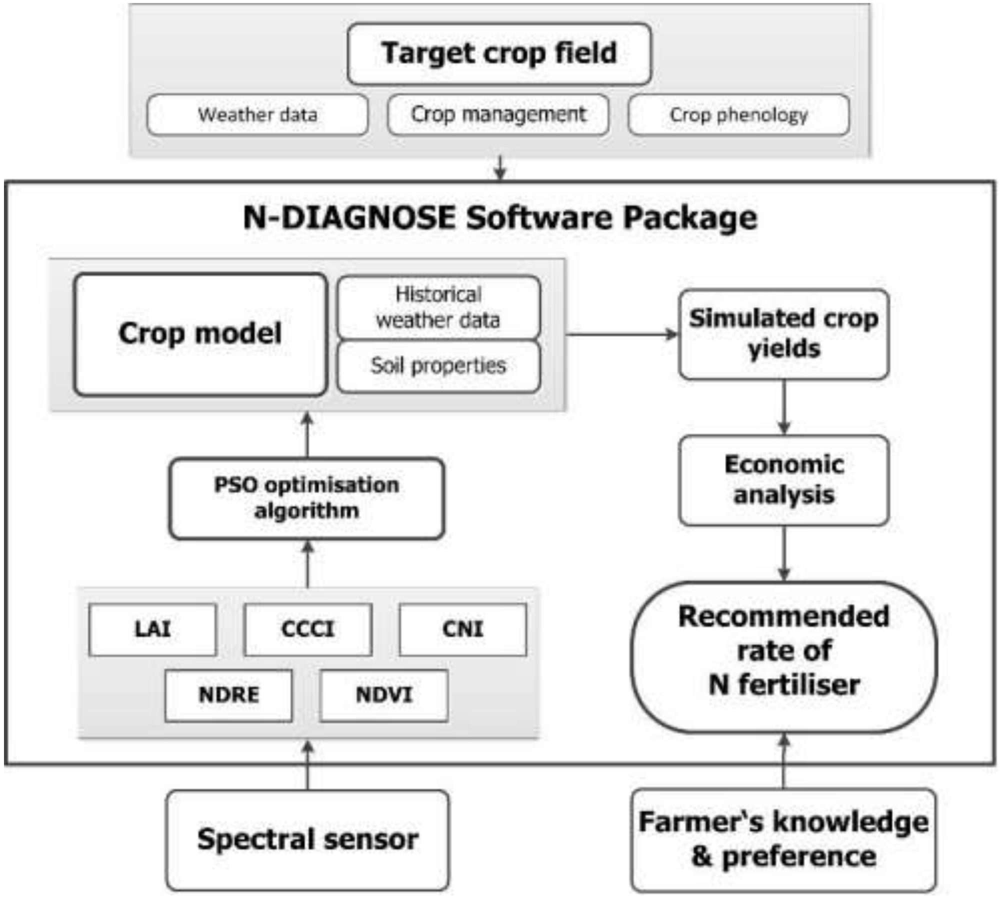
- Spectroradiometers: Measure spectral radiance across various spectral ranges

Remote Sensing of Crop N Status

- Spectroradiometers: Measure spectral radiance across various spectral ranges

Improving Nitrogen-Use Efficiency

- **FARM/IT** - Designing and developing web-based ICT components for improving the management (tactical and strategic) and optimisation of conventional and organic farming systems
- Application of remote sensing in N-fertiliser scheduling (N-Diagnose)



Conclusions

- System analysis vs. quick fixes to problems
- Crop simulation models: valuable tools in agricultural R&D
- Model parameterisation: high-quality multi-environment datasets (soil, crop, climate, management)
- Diverse range of applications
  - Climate change impact assessment
  - Sustainabilty/Productivity analyses
  - Crop improvement
  - Water/Nutrient management
- Model improvements: research on crop responses to extreme weather events (heat stress, drought)
- Training in development and application of crop models
- Establishing an interdisciplinary R&D unit
  - Coordinating country-wide data collection and compilation
  - Building links with stakeholders (policy makers, agricultural advisors, private companies, etc.)