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 $\rightarrow$ 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

**CLIMATE**
- Precipitation
- Temperature
- Radiation

**SOIL**
- Water
- Carbon
- Nutrients, ...

**PLANT**
- Biomass, Yield, Quality

**MANAGEMENT**
- Fertiliser
- Irrigation
- Residue, ...

**ENV. IMPACTS**
- GHG emissions,
- Nutrient leaching,
- Soil fertility, ...

**GENETIC**
- Species/Cultivar
- Env. Requirements
- Res. use efficiency

**Gaseous emissions**
- CO₂, NOx, N₂O, Ar, CH₄

**Soil properties**
- SOM, N, salinity, erosion
# Evolution of Crop Modelling

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

- APSIM (Agricultural Production Systems sIMulator) (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

2 Genotypes
- Facultative wheat *Xenos*
- Winter wheat *Capo*

5 Sowing dates
- 3 in autumn, 2 in spring
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/bottlenecks
    - 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
Crop Models – Climate Change Impact Assessment

- Climate change impact on wheat in Austria
  - Groß-Enzersdorf
  - Baseline (1981-2010) CO₂ 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*

<table>
<thead>
<tr>
<th>Climate</th>
<th>Emission scenario</th>
<th>Sowing date</th>
<th>Nitrogen rate (kg/ha)</th>
<th>Nitrogen application at Zadoks stages (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>GS21</td>
</tr>
<tr>
<td>Baseline</td>
<td>A1B–B1</td>
<td>20 September (SD1)</td>
<td>80 (N80)</td>
<td>40</td>
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<tr>
<td>CGMR</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>IPCM4</td>
<td></td>
<td>20 October (SD2)</td>
<td>120 (N120)</td>
<td>40</td>
</tr>
<tr>
<td>MPEH5</td>
<td></td>
<td>20 November (SD3)</td>
<td>160 (N160)</td>
<td>50</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>200 (N200)</td>
<td>60</td>
</tr>
</tbody>
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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.

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

(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

Demographic pressure

Agricultural Production Systems

- Low and highly variable rainfall
- Water scarcity
- Limited arable land

- expansion of irrigated areas
- declining watertables
- soil degradation
Crop Models – Sustainability Assessment

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

(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)
Model-assisted Phenotyping

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

Simulated wheat yield (kg ha\(^{-1}\))
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

![Graph showing yield difference vs. difference in water uptake for Roma, Goondiwindi, and Oakey locations.](Manschadi et al 2006; Functional Plant Biology)
Improving Nitrogen-Use Efficiency

  - Sowing: Oct 20
  - Initial soil N = 35 kg
  - N-Fertiliser: N1(40 kg at Z22) = 40 kg
Improving Nitrogen-Use Efficiency

  
  - 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

  - 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

  - 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

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
  - Sustainability/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.)