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Plant Phenomic Infrastructure

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Key Figures

- App. 50 mio. Euro annual turnover (app. 60% external grants)
- 100 Professors and Associate professors
- 100 Assistant professors and Postdocs
- 120 Technicians & Admin. Staff
- 180 PhD students
- 1100 BSc and MSc students
- > 300 peer-review articles per year
A phenotype is any observable characteristic or trait of an organism, such as its morphology, development, biochemical or physiological properties.

Phenomics is the field of research studying the results from the expression of plant genes as well as the influence of environmental incl. managed factors and the interactions between the genes these factors
Phenomics: Genotype x Environment x Management

Abiotic factors
- Wind
- Sun
- Temp
- Precipitation

Biotic factors
- Insect pests
- Fungal pathogens
- Weeds

Management
- Rotation
- Cultivation
- Seed date
- Seed rate
- Fertilizer
- Pesticide
- Irrigation
- Harvest

Plant population
- Inter/intraspecific competition

Biotic + abiotic factors (soil)
- Water
- Soil structure
- Nutrients

Multi-dimensional
Spatial temporal resolution
Through-put
Spatial-temporal plant processes and structure

Diagram with axes labeled as follows:
- X-axis: Genes
- Y-axis: Sec.
- Dm
- ha

Nodes labeled:
- Genes
- Cell
- Organ
- Plant
- Crop
- Field

Legend:
- nm
- Dm
Phenotypic integration - Functional traits
Crop Traits

Abiotic factors
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Yield
- Radiation Use Efficiency (RUE)
- Nutrients Use Efficiency (NUE)
- Water Use Efficiency (WUE)
# Non-destructive plant/crop measurement

<table>
<thead>
<tr>
<th>Plant/Canopy</th>
<th>Root</th>
<th>Seed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Measurement</strong></td>
<td><strong>Measurements</strong></td>
<td><strong>Measurements</strong></td>
</tr>
<tr>
<td>- Multi/Hyperspectral imaging</td>
<td>- Root area/volume</td>
<td>- Number of panicles</td>
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<tr>
<td>- Chlorophyll fluorescence</td>
<td>- Root length/depth</td>
<td>- Total number of seeds per plant</td>
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<tr>
<td>- Thermal imaging</td>
<td>- Thickness</td>
<td>- Number of fertile seeds</td>
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<tr>
<td>- Leaf area</td>
<td>- Branching</td>
<td>- Seed weight</td>
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<tr>
<td>- Leaf angel</td>
<td></td>
<td>- Seed yield</td>
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<tr>
<td>- Stem/internode length</td>
<td></td>
<td>- Seed width, length and area</td>
</tr>
<tr>
<td>- Plant/Canopy height</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- 3-D characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Calculated variables</strong></td>
<td><strong>Calculated variables</strong></td>
<td></td>
</tr>
<tr>
<td>- Light interception</td>
<td>- Growth rate</td>
<td></td>
</tr>
<tr>
<td>- Growth rate of leaves, stems, plant or plants</td>
<td>- Root biomass</td>
<td></td>
</tr>
<tr>
<td>- Dry weight of leaves, stems, flowers or plant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Shoot biomass</td>
<td>- Shoot/root</td>
<td></td>
</tr>
<tr>
<td><strong>Estimated traits</strong></td>
<td><strong>Estimated traits</strong></td>
<td></td>
</tr>
<tr>
<td>- Yield</td>
<td>- Shoot/root</td>
<td></td>
</tr>
<tr>
<td>- RUE/NUE/WUE</td>
<td>- Compactness</td>
<td></td>
</tr>
<tr>
<td>- Harvest index</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Facilities:
- Growth chambers
- Greenhouses
- Lysimeter and semifield
- Experimental fields

1st level IT:
Locations differ, but are within the building or near the field/station.
- Stationary phenotyping units (Copenhagen, Frederiksberg, Tåstrup)
- Mobile phenotyping units (Tåstrup)

2nd level IT:
Centralized server room.
- Phenotyping server(s) (Lemmatec or other solution)
- Phenotyping server (our own system to accommodate other sensors than e.g. Lemmatec, sensor testing, and other specific requests from researchers)

3rd level IT:
Backups.
Kept separate from server room in 2nd level IT.
- Processed data (All data as text, some images. Some log files)
- Raw data (All data as text, all images. Complete log files)
- Processed data (All data as text, some images, maybe video. Some log files)
- Raw data (All data as text, all images, all videos if any. Complete log files)

Climate station data unit (Tåstrup)
Climate station server

Processed data (Climate data as text. Some log files)
Raw data (Climate data as text. Complete log files)
Data infrastructure

Planning → Measuring

Results → Raw data → Meta data → Historical data

Analyses → Processing

System Integration
Modelling phenotypic integration

Integration of:
- Management actions
- Environmental variables
- Genetic coefficients

Yin, Struik & Kropff (2004) TIPS 9, 426-432. modified
Example RUE hypothesis

1. Crop RUE is the same at the species level i.e. varietal differences in accumulation of biomass and yield depends on varietal specific growth parameters, the interactions with biotic and abiotic variables and the management.

2. RUE of a crop is a function of several interacting physiological phenomena.

3. Accurate estimation of growth parameters and RUE under optimal growth conditions is required to predict dry matter accumulation and yield near the genetic growth potential.

4. A positive and significant association between RUE and mean temperature as external factors is observed during the vegetative period.

5. Drought responses at the cell and tissue level effect biomass production and RUE.

6. Gains in seed yield are driven by increases in RUE and partitioning efficiencies.

The research hypothesis and objective is driving the system design. We measure only when needed, and what is needed.
Trial Planning Systems

A trial is created for:
- design
- protocol
- spatial-temporal res.
- Processing algorithm
- Statistical methods

Feedback from the platforms and the analysis ➔ trial adjustments

Data stored

The system loop is complete.
The research hypothesis and objective is driving the system design.
We measure only when needed, and what is needed.

Imaging Platforms (manned and unmanned)

- In the field,
- greenhouse,
- root screening

Detailed Data Analysis

- University
- Agricultural Testing Centre
- Technology transfer company
- Industry

Using several types of data analysis and presentation platforms, e.g. a Genome+Phenotype Browser.

All raw data archived
Multispectral Imaging Platform (PhenoField)
Selected wavelengths

Phenofield measure reflectance in wavelengths: 465 nm, 500 nm, 525 nm, 590 nm, 615 nm, 625 nm, 660 nm, 740 nm and 850 nm.

(Prabhakar et al., 2012)
Development of a Mobile Multispectral Imaging Platform for Precise Field Phenotyping

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Spectral signature
Vegetation signature

Spring wheat varieties, 100 kg N/Ha

Spring wheat varieties, 200 kg N/Ha
RUE (Radiation Use Efficiency)

Mathematical models

Christensen & Goudriaan (1993)

Purcell, 2000
Example of RUE difference

\[ y = 2.7545x + 66.236 \quad R^2 = 0.971 \]

\[ y = 1.9021x + 133.32 \quad R^2 = 0.9574 \]

\[ H_{DM} \quad (g\cdot m^{-2}) \]

Accumulated Intercepted PAR (MJ m^{-2})

Field 25, Clay loam
Field 26, Sandy loam

Wang et al. 2013
Conclusions

• Phenomics is the research on genotype x environmental x management interactions

• Phenomic research require
  – Hypothesis and objectives before design and measurements
  – Choice of spatial-temporal resolution
  – Choice of processing algorithm and statistical methods
  – Modelling phenotypic integration e.g. physiological traits, crop traits
  – Phenomic infrastructure
  – Data management
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