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# Sensitivity analysis of dynamic crop models to assist crop science: assessing the impact of multiple traits on yield in Australian wheat.

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# Systems approach to crop improvement [1, 2]

Taking advantage of genotypes  $\times$  environment  $\times$  management (GEM) interactions

Canopy viewed as a system of cultivar (G), pedo-climatic factors (E) and management practices (M).

Problem: improving crop yield with uncertain climate

- ▶ agronomy: improve management practices (choose  $G+M|E$ )
- ▶ **genetics**: improve genetic material (change  $G|E+M$ )

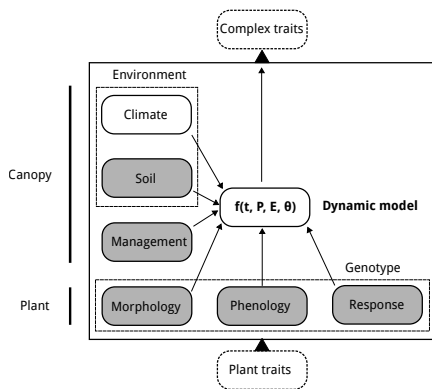
Tools

- ▶ experiments: hard to sample climatic variability
- ▶ models: genotypic determinism in crop models

# Systems approach to crop improvement

A methodology for screening crop model parameters usable as plant traits for breeding

1. Model: APSIM platform [3]
  - dissect complex traits
2. Explore
  - **screen:** sensitivity analysis
    - ▶ factors and distribution
    - ▶ numerical design
    - ▶ simulation and index computation
  - **search:** variance analysis
    - ▶ parameter  $\times$  environment
3. Optimization
  - parameter combination

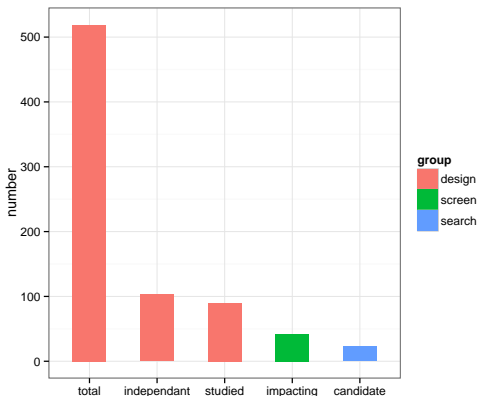


# Defining input factors

How many parameters in a typical crop model ?

## APSIM-wheat model

- ▶ ~ 500 parameters
- ▶ plant-related parameters
- ▶ 103 independant
  - 62 values
  - 41 functions
- ▶ 90 studied after grouping

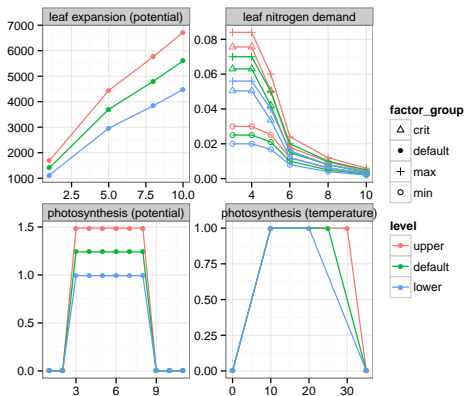


# Setting the variation range

How to keep biological meaning without going into 90 special cases ?

## Consensus

- ▶ 40% variation range
- ▶ 3 rules:
  1. scale single value
  2. scale y vector
  3. scale point in x or y vector



# Sampling method for parameter and environmental space

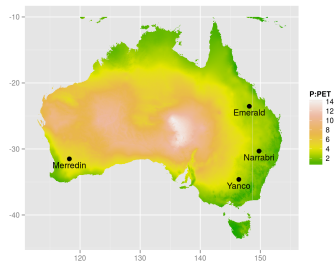
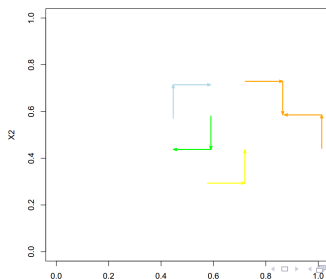
How to sample GEM landscape for wheat in Australia ?

## Genotypes (Parameters) $n = 9100$

- ▶ Morris method [4] (*sensitivity*)
- ▶ 6 levels by factor
- ▶ 100 random rep. of OAT designs

## Environments $n = 9000$

- ▶ 2 CO<sub>2</sub> levels
- ▶ 3 sowing dates
- ▶ 3 N fertilization amount
- ▶ 4 locations
- ▶ 125 years of climatic data



# Simulation and sensitivity index computation

## Simulation and output variables

- ▶ 8 output variables
- ▶ distributed computing in CSIRO ( $81.9 \times 10^6$  simulations)
- ▶ R packages *ncdf4*, *dplyr*

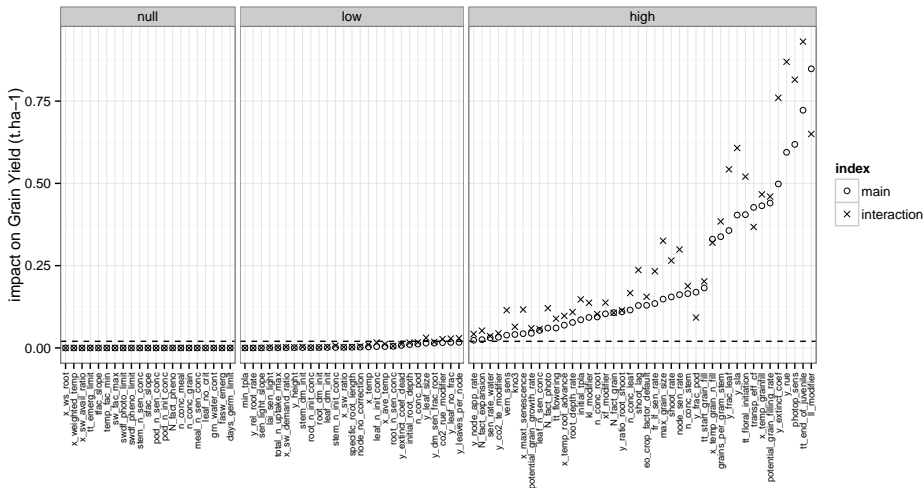
## Sensitivity indexes

- ▶ main ( $\mu^*$ ): estimation of the linear effects of inputs
- ▶ interaction ( $\sigma$ ): estimation of the non-linear/interaction effects



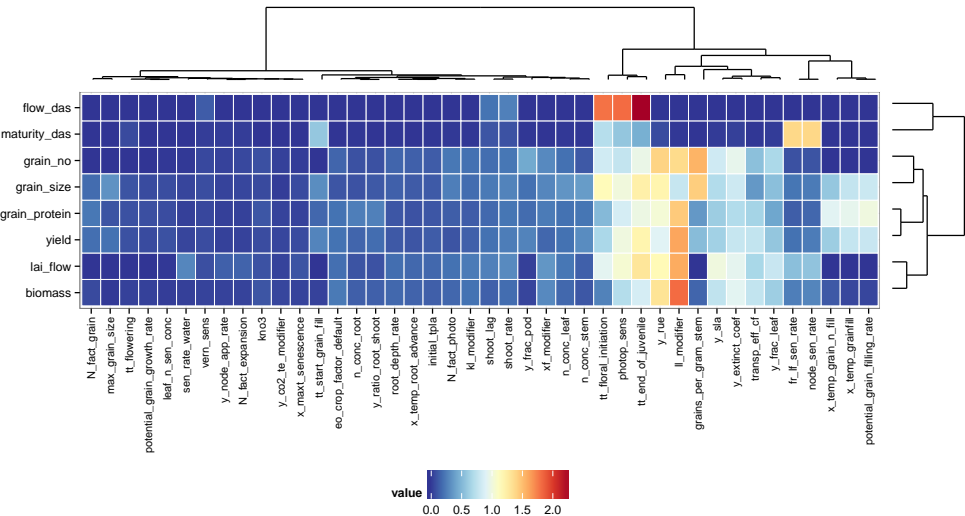
# Screening for impactful parameters

About a half of the parameters are not or weakly impacting yield in control conditions



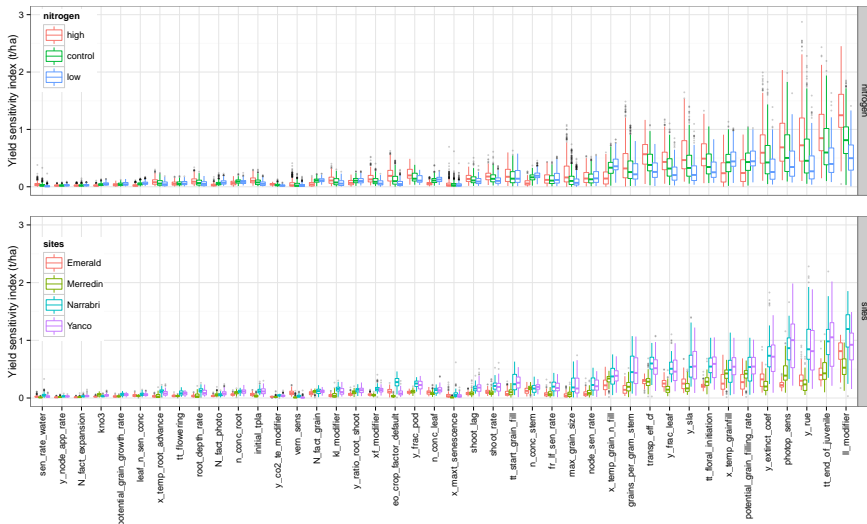
# Screening for impactful parameters

Parameters mainly impact specific output variables in control conditions



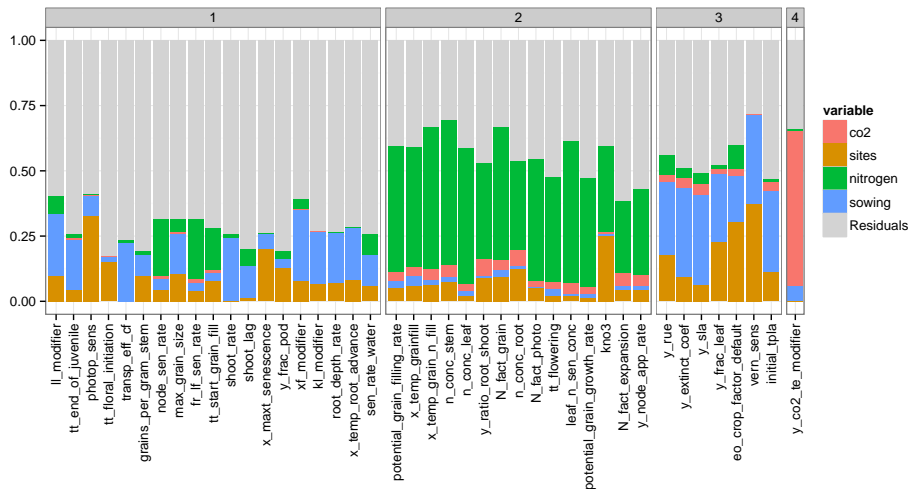
# Searching for candidate parameters

The impact of traits is strongly affected by environment and management



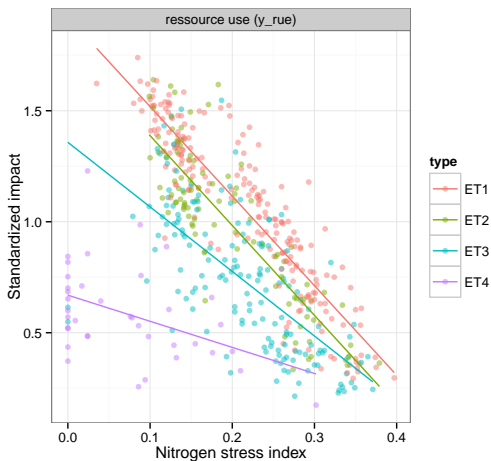
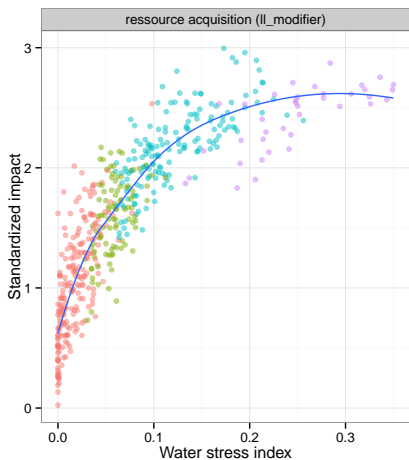
# Searching for candidate parameters

A subset of the most impactful parameters is less dependant to environmental effect



# Searching for candidate parameters

The impact of parameters is linked to resource availability



# Conclusions

## Numerical exploration

- ▶ low-impact parameters are targets for code refactoring
- ▶ methods to integrate  $G \times E$  interactions in breeding approaches

## UseR !

- ▶ numerical design, decoupling, index computation: *sensitivity* [5]
- ▶ data manipulation and visualization: *reshape2* [6], *dplyr* [7], *ggplot2* [8]
- ▶ reproducible code (markdown, *knitr* [9], github repository)

# References

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