# Phosphorus: a bottleneck for yield boosting

## How to model phosphorus effect on plant growth?

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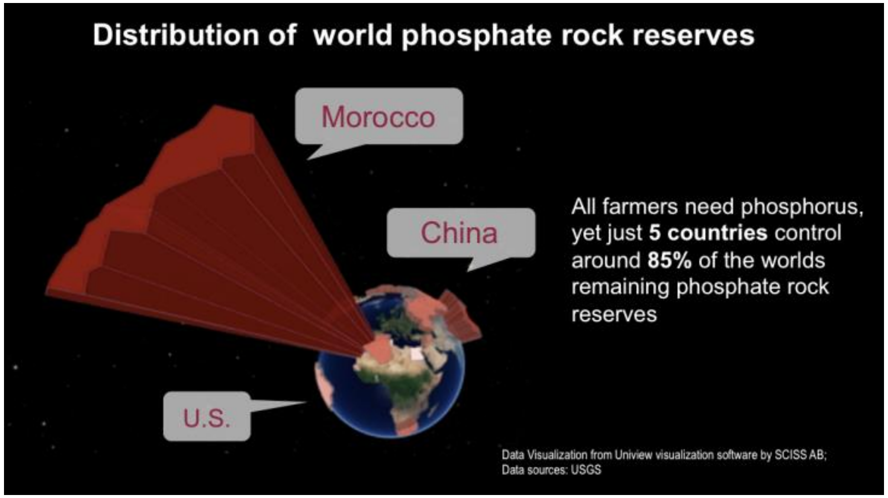
AgMIP The Agricultural Model Intercomparison and Improvement Project
cirad AGRICULTURAL RESEARCH FOR DEVELOPMENT
ICRISAT Science with a human face
UF UNIVERSITY of FLORIDA

# OUTLINE

- Context
  - Why is it important?
  - What has been done in phosphorus modelling?
- Experimentation
  - Need of data
- Modelling work
  - DSSAT CSM-CERES-Sorghum coupled to a P module
- Conclusion

# Phosphorus a bottleneck for yield booting?

- In the world *(Cordell et al. 2009-2015)*
  - Depleted in 50–100 years
  - Peak in phosphorus production is predicted to occur around 2030
  - 90% of global demand for phosphorus is for food production

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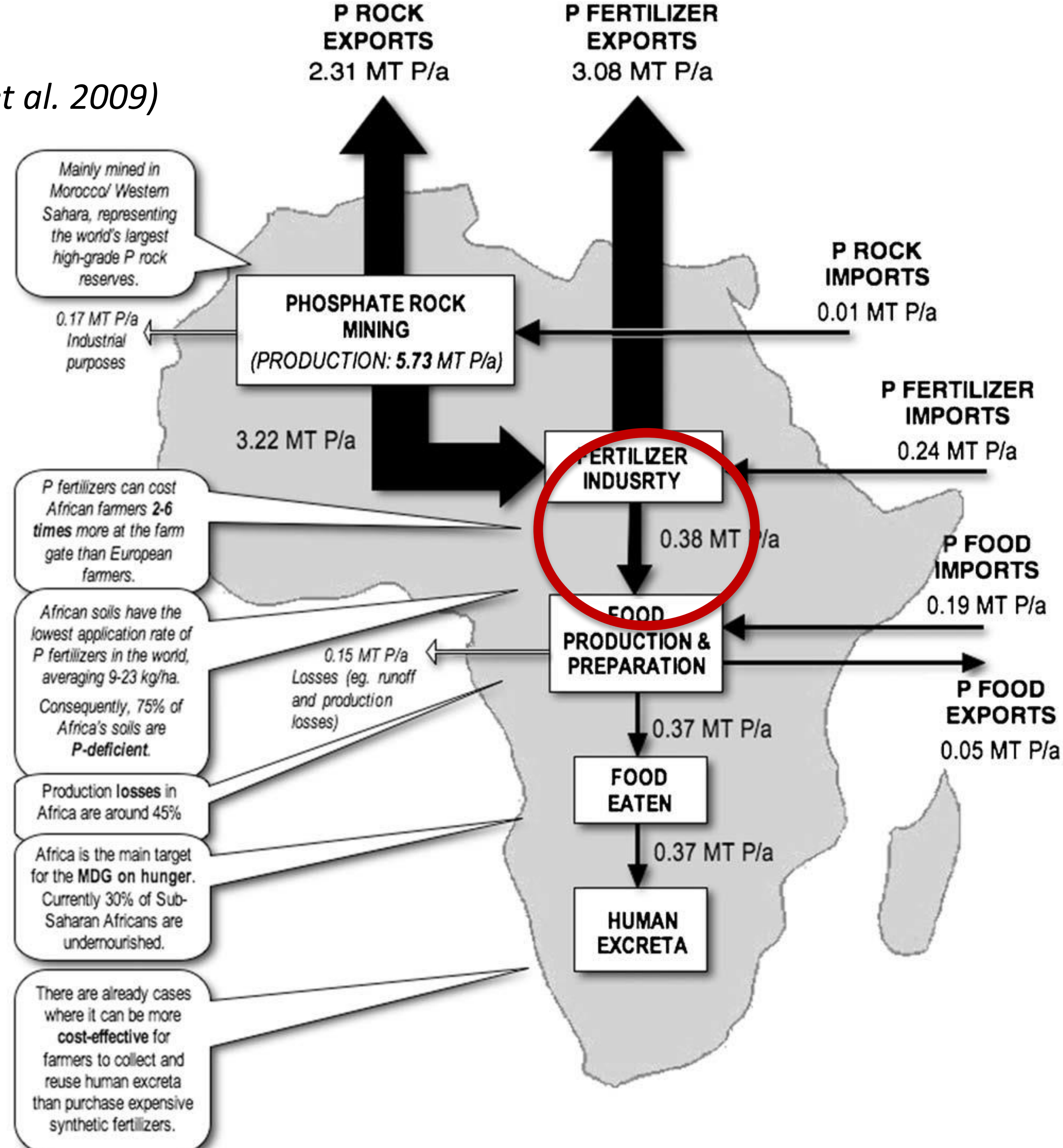
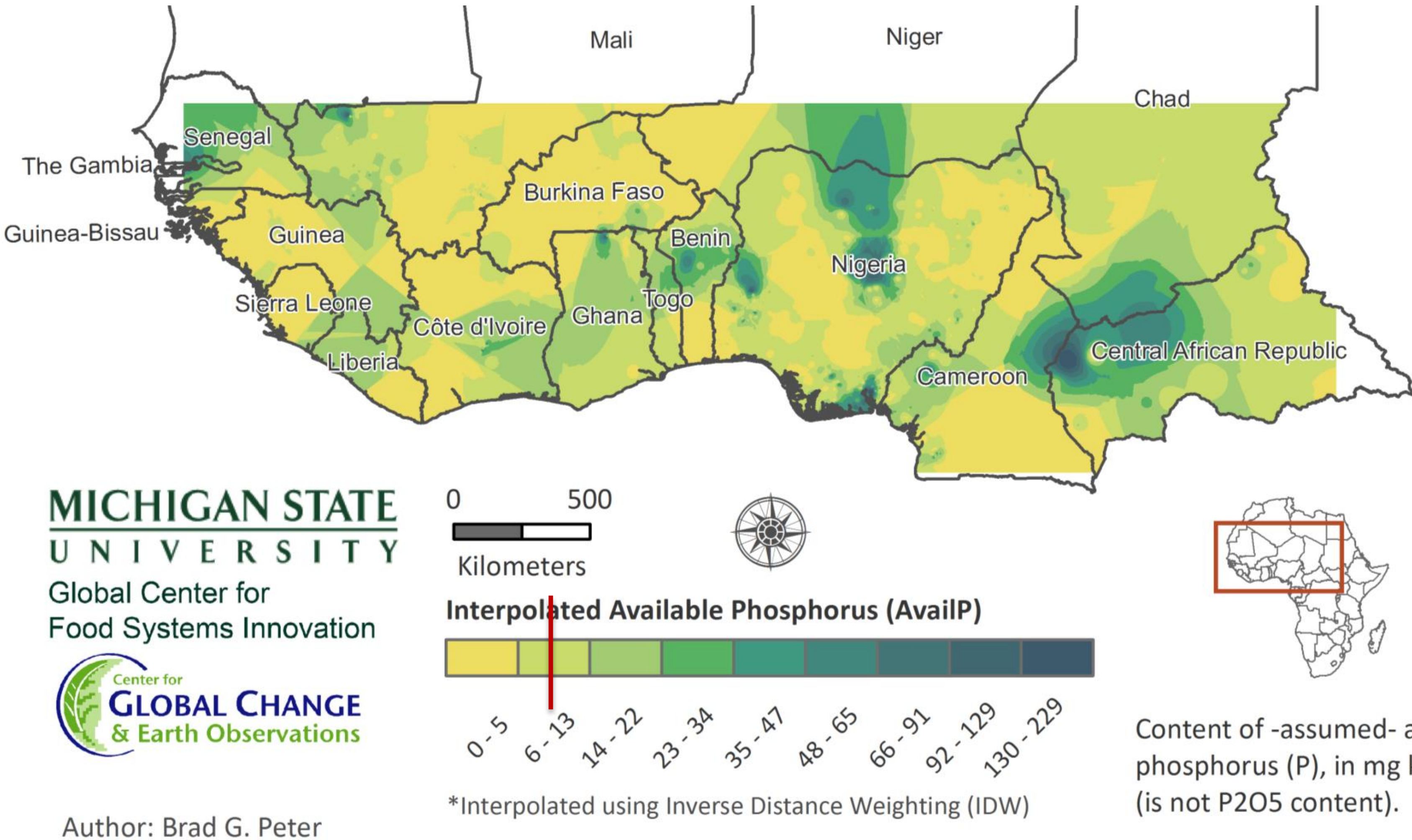
- In Africa *(Cordell et al. 2009)*

- P fertilizers more expensive
- Soils have the lowest application rate
- 75% of soil are P-deficient

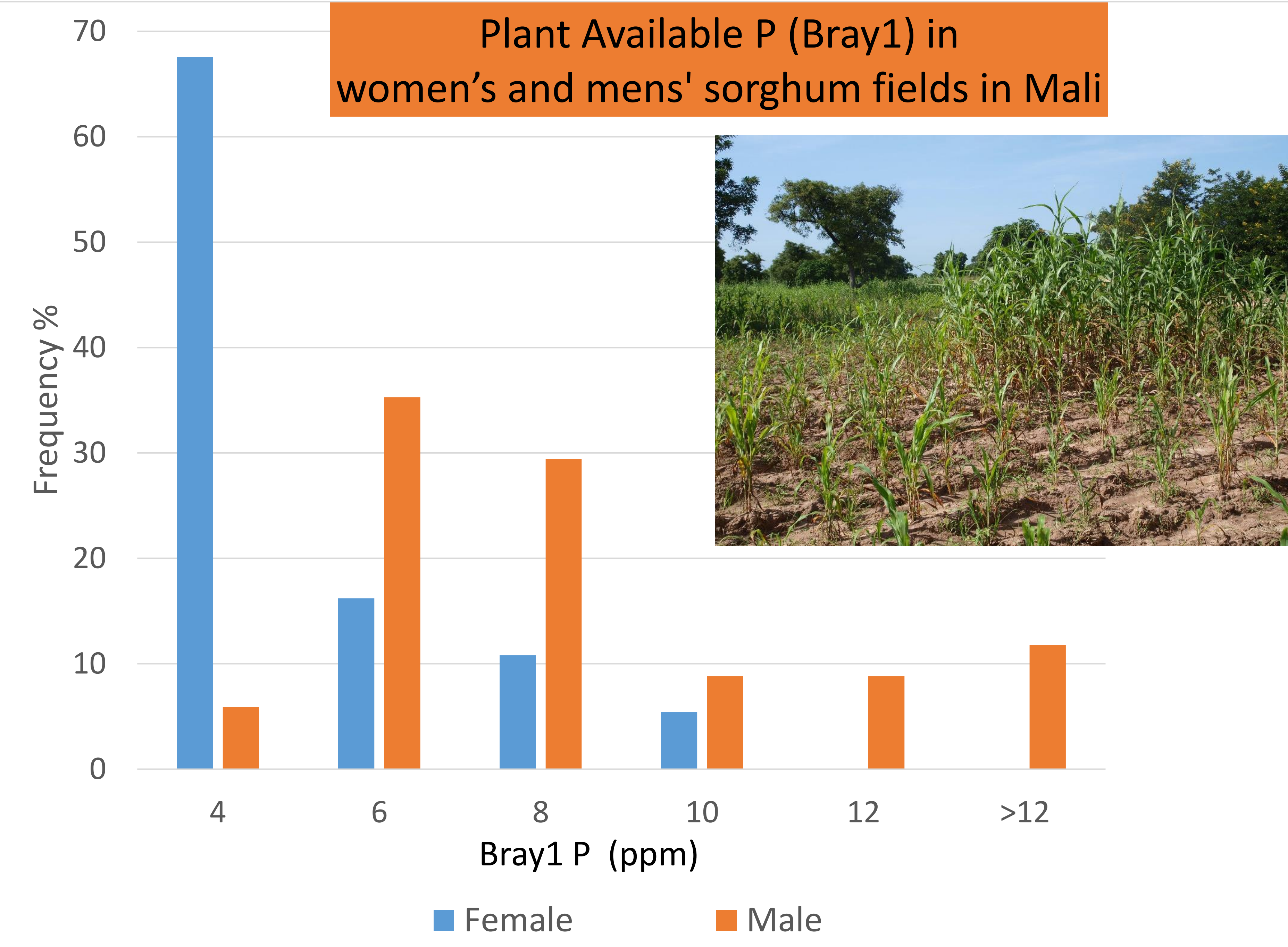


# Phosphorus a bottleneck for yield boosting?

- In West Africa



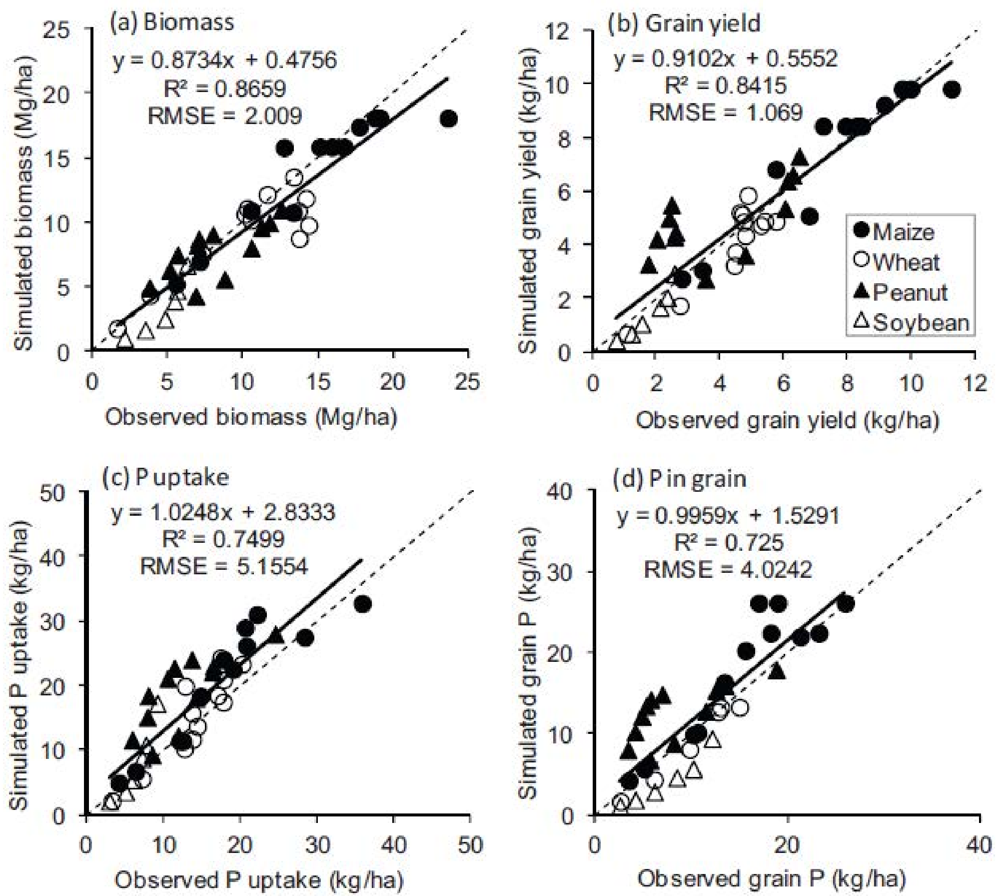

Content of -assumed- available phosphorus (P), in mg kg-1, (is not P2O5 content).



Plant Available P (Bray1) in
women's and mens' sorghum fields in Mali
Frequency %
70
60
50
40
30
20
10
0
4
6
8
10
12
>12
Bray1 P (ppm)
Female
Male

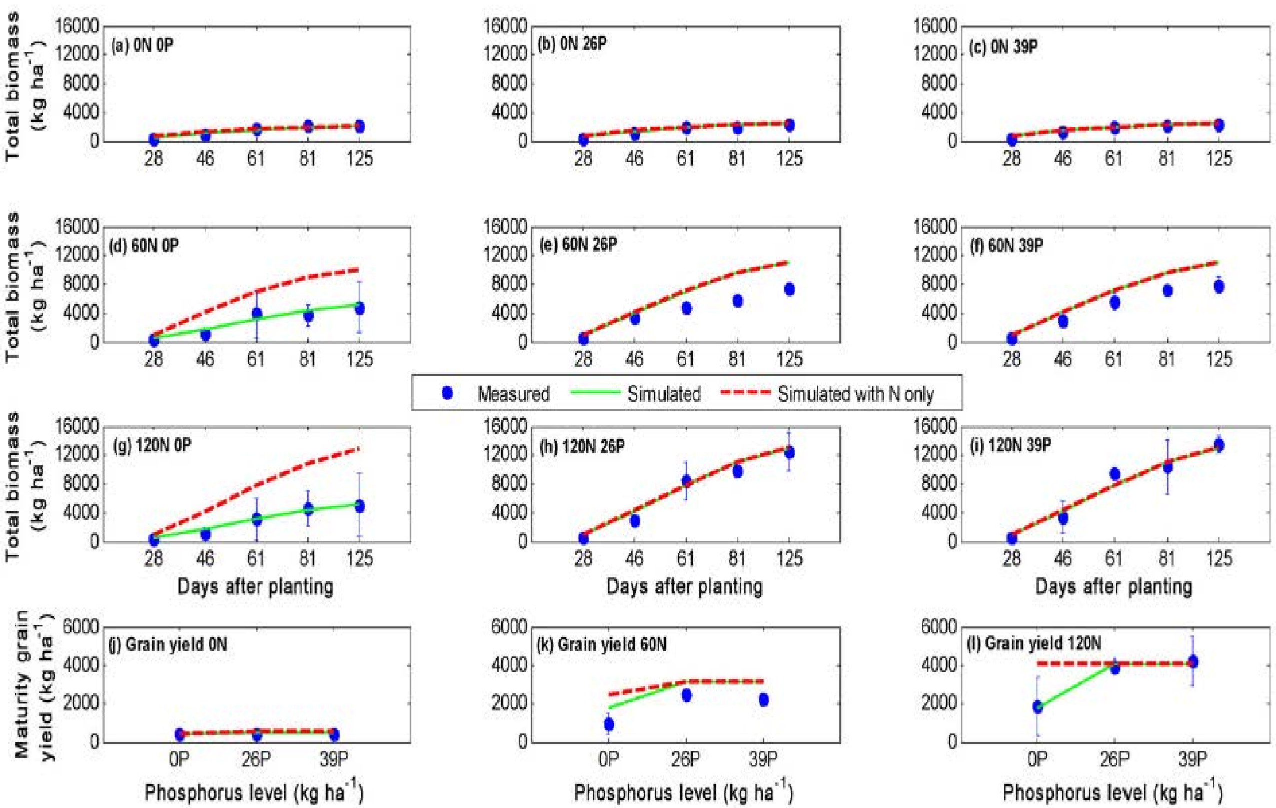
# What has been done in term of modelling

- APSIM: 1 main study ( rotation)



# What has been done in term of modelling

- DSSAT: 2 main studies (maize and groundnut)
  - Maize
  - Groundnut

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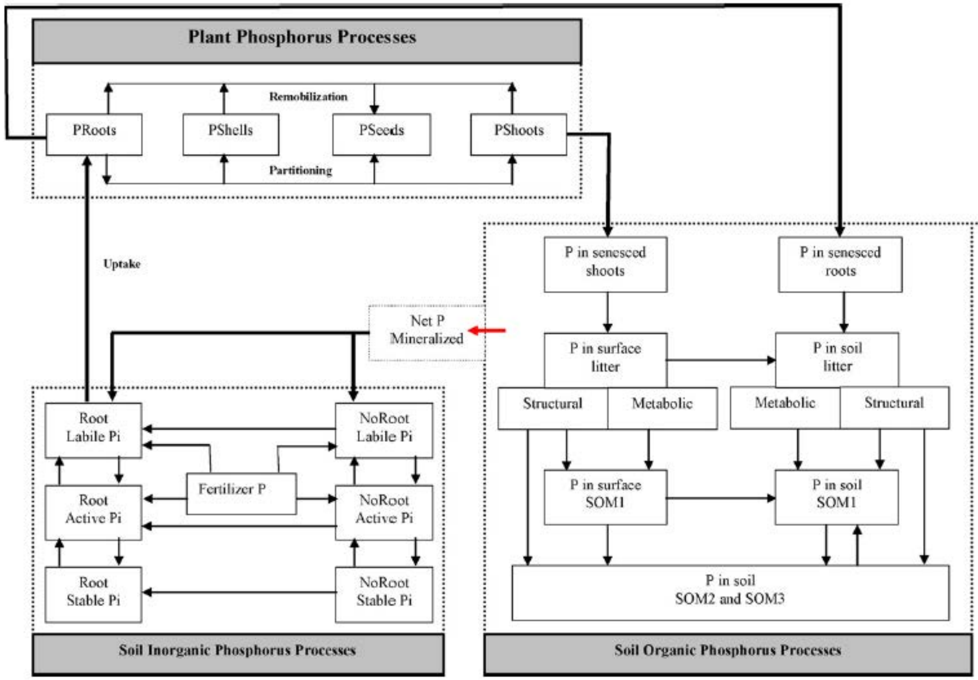


**Fig. 1.** Summary of processes in the integrated soil–plant phosphorus model in DSSAT. Arrows indicate the directions of flows.

DSSAT

APSIM

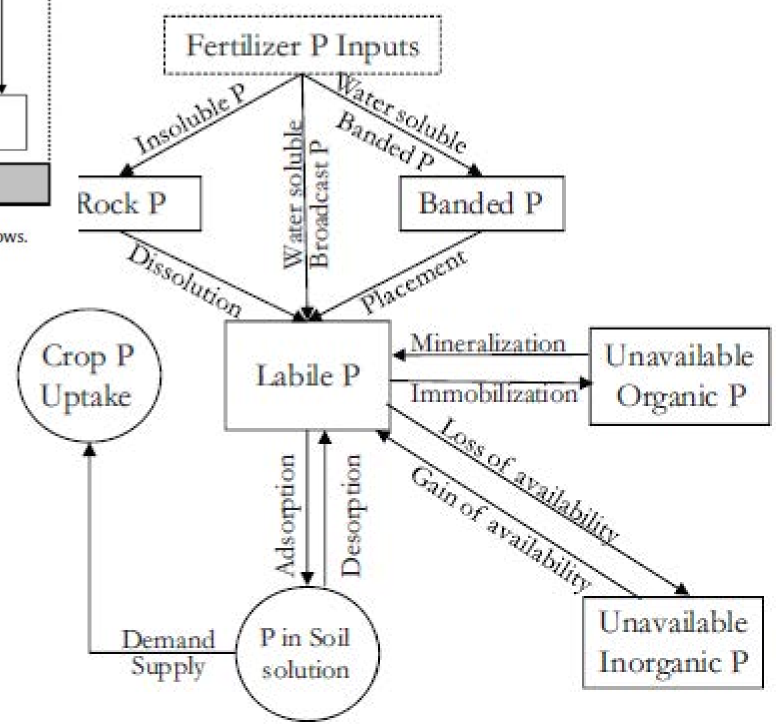


**Fig. 1.** Diagrammatic structure of APSIM SoilP module, and the simulated processes.

# P module in DSSAT Sorghum model
(choice for this work)

- Transformation rates depend on soil characteristic ( clay content, pH, calcium carbonate content)
- P in the soil solution is influenced by : Texture, water content and organic C
- P in plant based on P optimal and minimum concentration
- P stress on photosynthesis and vegetative partitioning

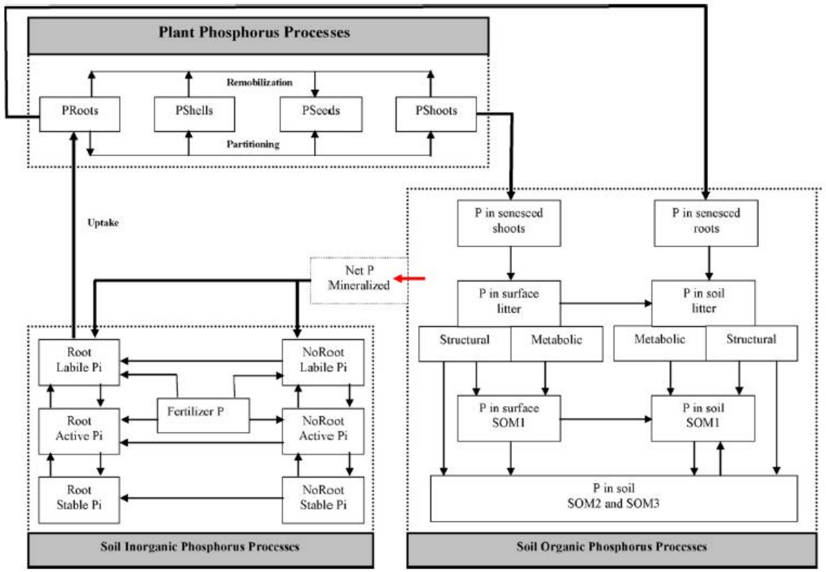

Fig. 1. Summary of processes in the integrated soil–plant phosphorus model in DSSAT. Arrows indicate the directions of flows.

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# Limitations of the previous studies:  data!!!

- Collect data ( mostly in-season data)
- Understand the physiology of it: how P deficient affect plant growth?

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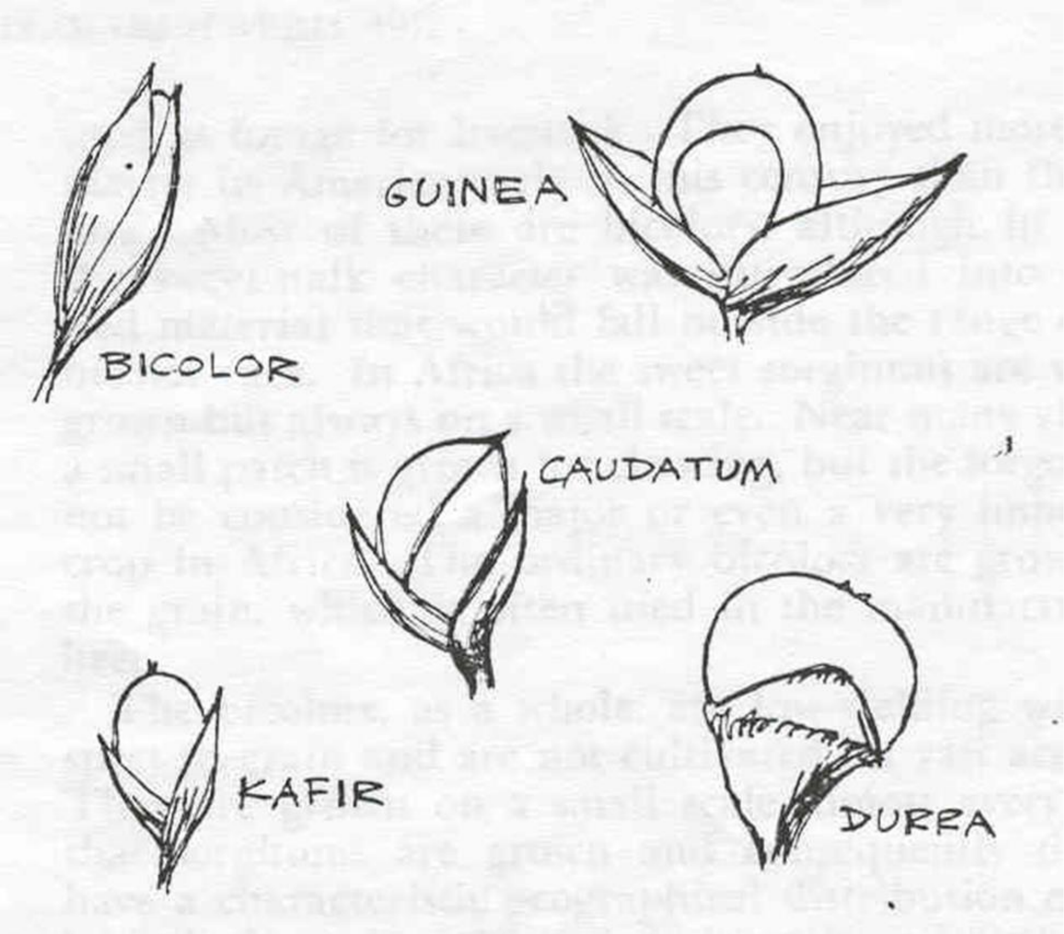
# Experiments of sorghum
## Use of local sorghums




# Guinea-race sorghums

- Photoperiod sensitivity for phenotypic plasticity
- Dropping-panicles, open glumes, corneous endosperm, reduced insect-mold complex
- Adapted to poor soil fertility conditions
- Local variety grain yields average 1 t/ha on-farm

Haussmann et al. 2012
Leiser et al. 2012

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# Phosphorus use efficiency in WA sorghum varieties

*(Leiser et al. 2014-2015)*

- Different varieties, different strategies:
  - Photoperiod (Pp) insensitive: higher P use efficiency
  - Pp sensitive varieties : higher P acquisition efficiency

- Ho: different varieties type have different strategies due to a different dynamics of **P uptake relative to aboveground growth change over time**

- Different growth pattern could impact early or late P uptake and thus adaptation to P limiting environment.

→Pp sensitive varieties bilinear rate of AGV growth (slow down after 25 plastochrons, *Clerget et al. 2006*) but linear rate for rooting depth

# Four varieties

| Variety | Race/type | Cycle (days) | Sensitivity to PP | Plant height |
|---|---|---|---|---|
| **CSM63E** | Guinea | 90 | low | 2.5m |
| **Fadda** | Hybrid Guinea | 110 | Medium low | 3.5m |
| **Local (CSM355)** | Guinea | 110 | Medium high | 3.5-4m |
| **IS15401** | Guinea | 120 | high | 5m |



# Dataset


- 2014-2015 in Samanko, Mali
- 4 contrasting cultivars
- 2 P treatments

  High P (20ppm Bray) with 100kg.ha$^{-1}$ DAP at sowing and 50kg.ha$^{-1}$ urea at 45days

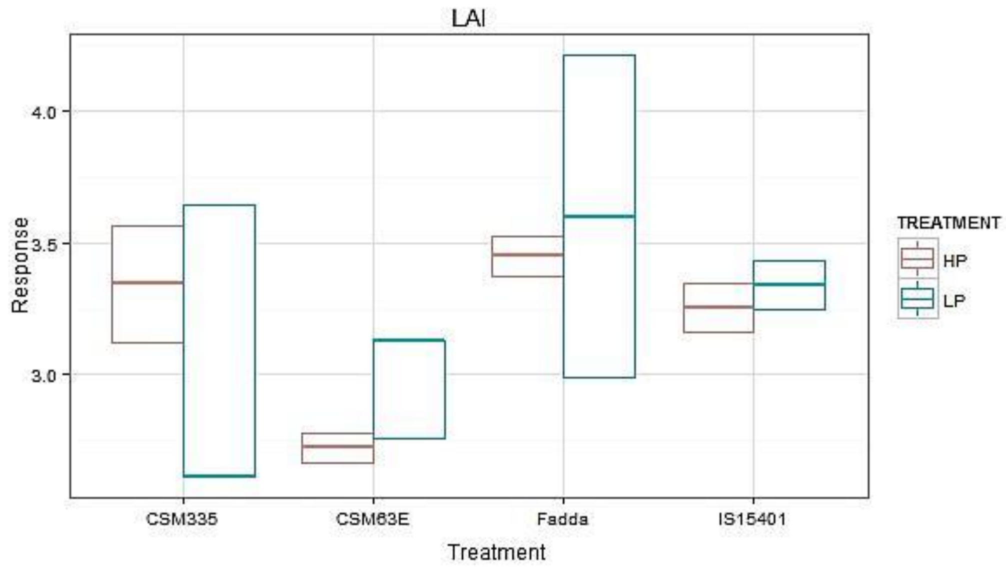
  Low P (4ppm Bray) with compensation DAP by urea for N at sowing and 50kg.ha$^{-1}$ urea at 45days

- Data sampling every 2 weeks:
  - Phenology
  - LAI
  - Biomass
  - P conc (2014)

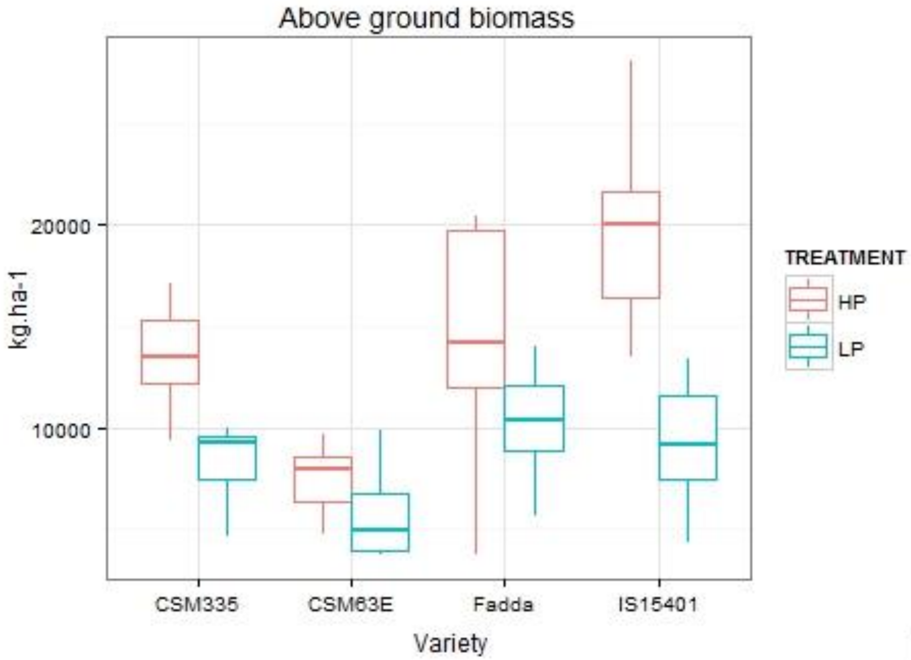

Photos©: Rik Schuiling / TropCrop-TCS

# Effect on crop growth and development

| ANOVA results: P value | | | |
|---|---|---|---|
| | LAI | AGB | Grain Yield |
| **variety** | 5.71e-06 *** | 0.000537 *** | 9.22e-05 *** |
| **P** | 0.579 | 8.53e-05 *** | 0.00037 *** |
| **variety*P** | 0.113 | 0.10092 | 0.10092 |

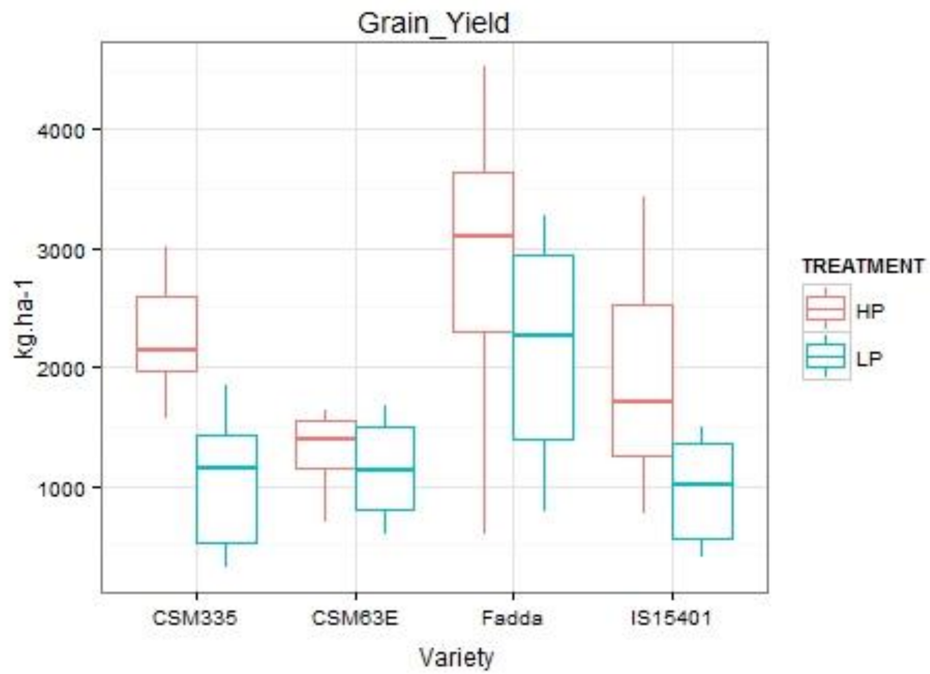


# Effect on crop growth and development




| | Aboveground biomass |
|---|---|
| CSM335 | 41% |
| CSM63E | 22% |
| Fadda | 39% |
| IS15401 | 59% |

| | Grain yield |
|---|---|
| CSM335 | 55% |
| CSM63E | 12% |
| Fadda | 27% |
| IS15401 | 49% |

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| | P uptake (2014) |
|---|---|
| CSM335 | 43% |
| CSM63E | 71% |
| Fadda | 32% |
| IS15401 | 59% |

# LINKING A PHOSPHORUS MODULE TO DSSAT CSM-CERES-SORGHUM AND EVALUATING IT FOR WEST AFRICAN CONDITIONS


**Adaptation of the CERES-sorghum to West African conditions: modelling the P response of contrasting genotypes**

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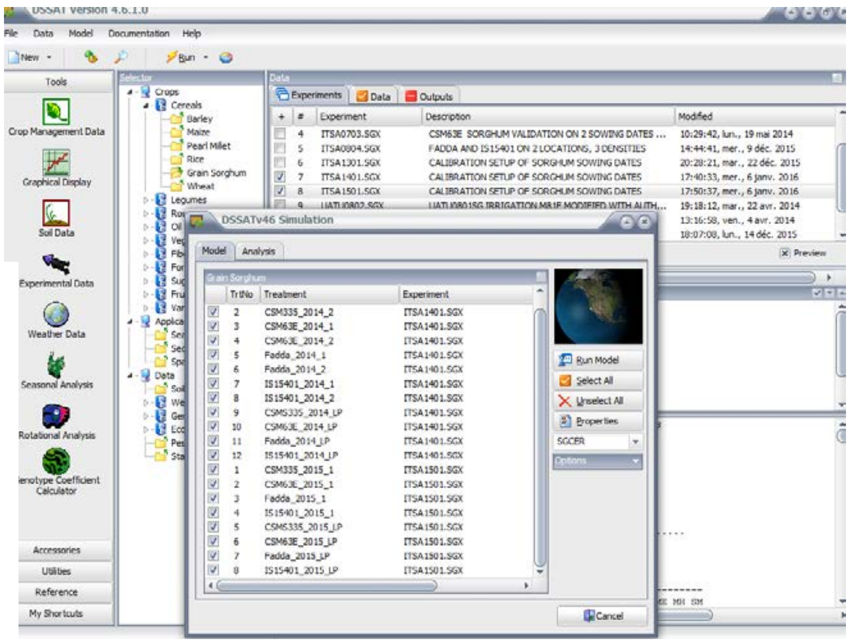
# All data included in DSSAT

- 16 simulations:
  - Weather samanko 2013-2014-2015
  - Soils: from B Clerget + adapted for P content
  - File X , T and A for (2013) 2014 and 2015
    - 4cult*2trt*2years = 16




```
ICRISAT, Samanko, Mali
@SITE
ICRISAT, Samanko
@ PAREA  PRNO  PLEN  PLDR  PLSP  PLAY HAREA  HRNO  HLEN  HARM.........
      0   -99   -99   -99   -99   -99     4     3     2 anual
@NOTES
 -99

*TREATMENTS                        -------------FACTOR LEVELS------------
@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM
 1 1 0 0 CSM335_2015_1              1  1  0  1  1  0  1  0  0  1  0  0  1
 2 1 0 0 CSM63E_2015_1              2  1  0  1  1  0  1  0  0  1  0  0  2
 3 1 0 0 Fadda_2015_1               3  1  0  1  1  0  1  0  0  1  0  0  3
 4 1 0 0 IS15401_2015_1             4  1  0  1  1  0  1  0  0  1  0  0  4
 5 1 0 0 CSMS335_2015_LP            1  2  0  1  1  0  2  0  0  1  0  0  1
 6 1 0 0 CSM63E_2015_LP             2  2  0  1  1  0  2  0  0  1  0  0  2
 7 1 0 0 Fadda_2015_LP              3  2  0  1  1  0  2  0  0  1  0  0  3
 8 1 0 0 IS15401_2015_LP            4  2  0  1  1  0  2  0  0  1  0  0  4

*CULTIVARS
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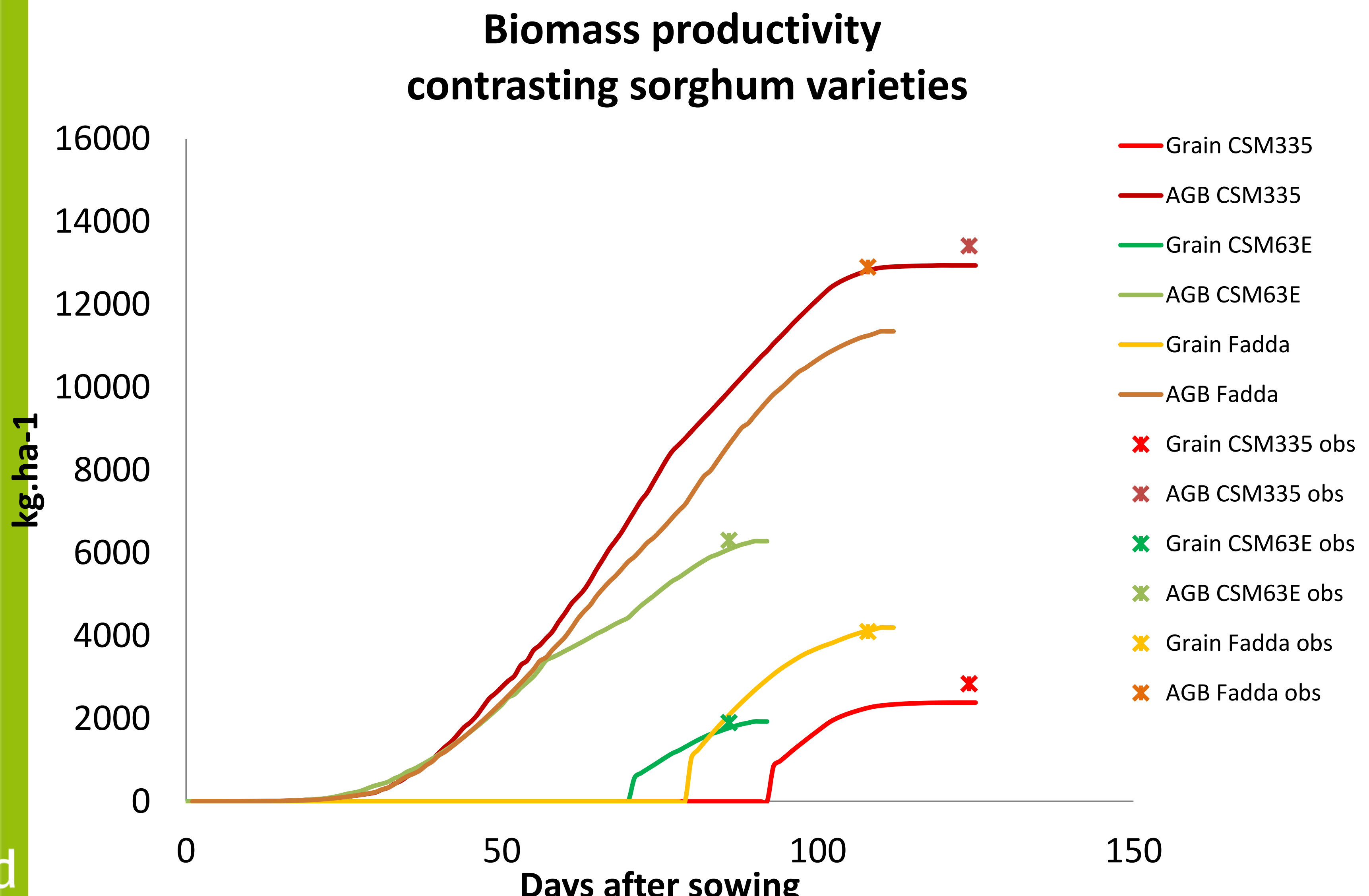
# Varieties calibration

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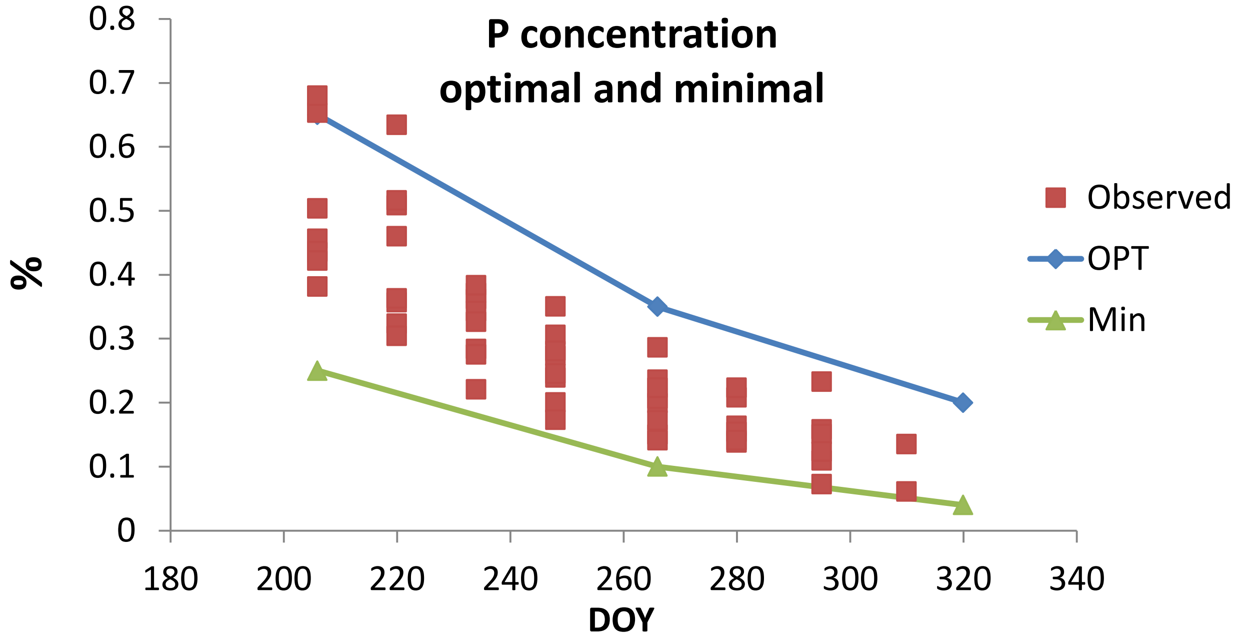
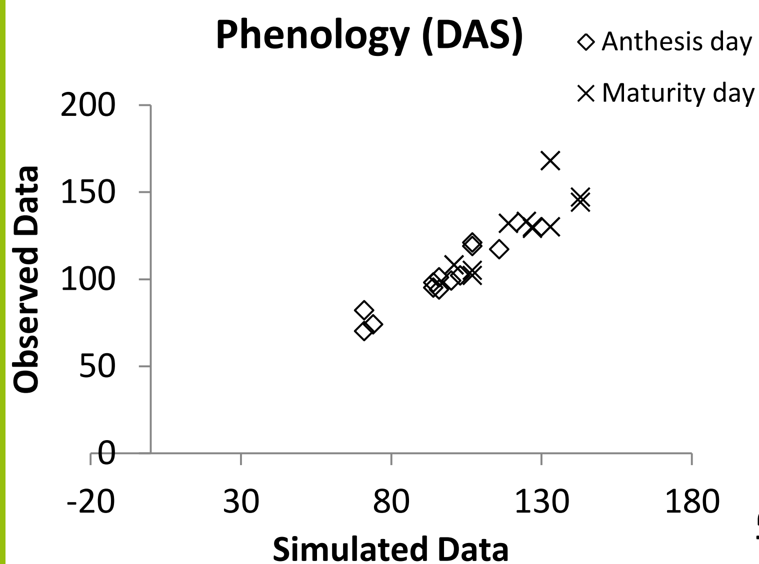
# Parametrization for P

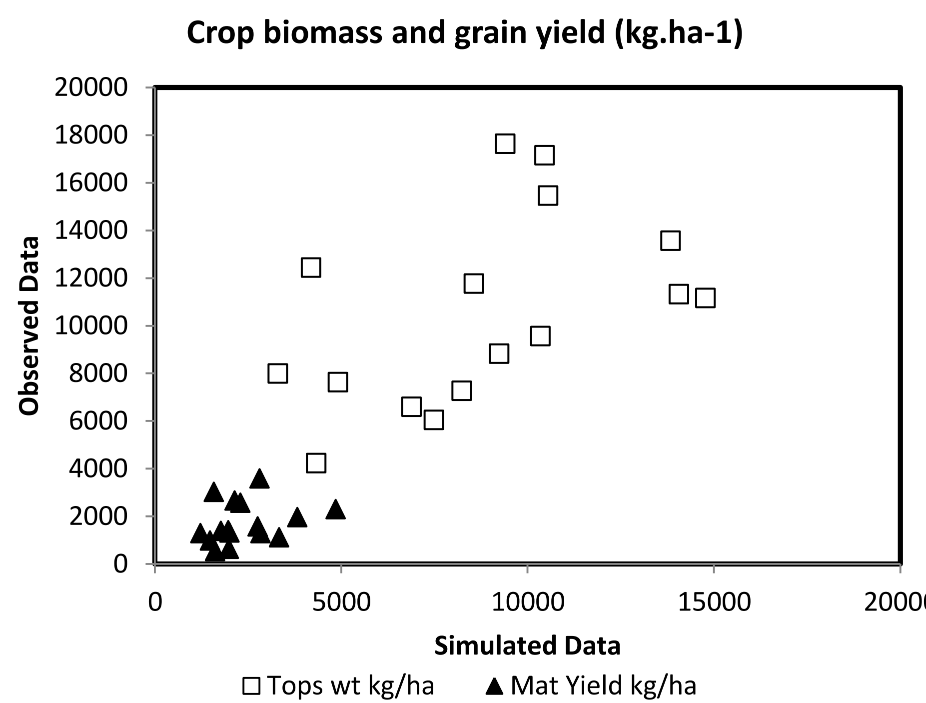



| Parameter | Definition | Value |
|---|---|---|
| SRATPHOTO | Photosynthesis sensitivity traits | 0.8 |
| SRATPART | Partitioning sensitivity traits | 0 |
| FractMobil | Maximum fraction of P which can be mobilized from leaf and stem per day | 0.1 |
| ROOTRAD | Radius of cylinder around roots from which soil P can be extracted (mm) | 20 |

# Model results at a glance

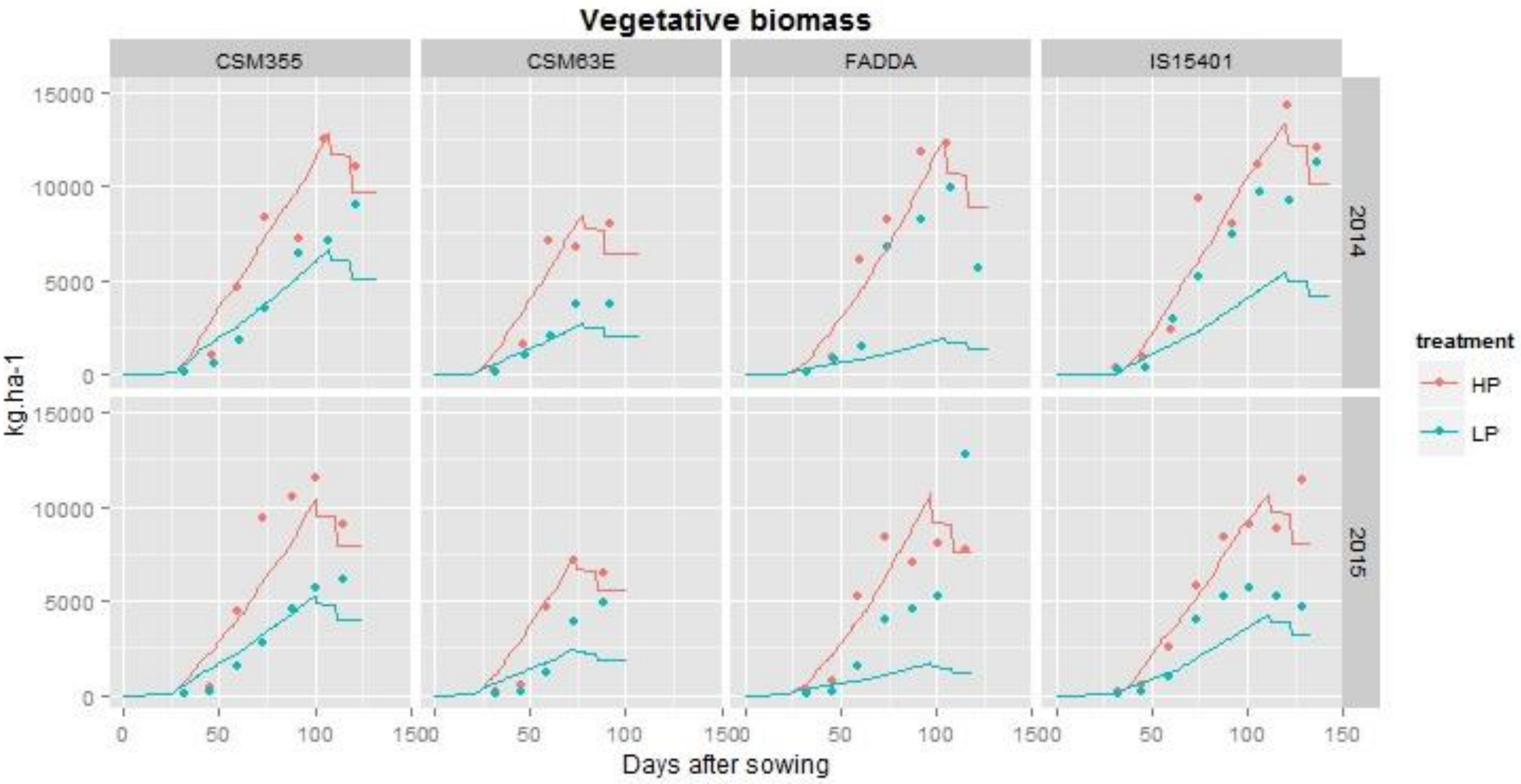
| Variable Name | Observed | Simulated | Ratio | RMSE | d-Stat. | Used Obs. |
|---|---|---|---|---|---|---|
| Anthesis day | 98 | 94 | 0.96 | 6.52 | 0.95 | 12 |
| Tops wt kg/ha | 11382 | 8784 | 0.85 | 5273 | 0.651 | 16 |
| Mat Yield kg/ha | 1718 | 2403 | 1.68 | 12737 | 0.47 | 16 |
| Maturity day | 131 | 124 | 0.949 | 13. | 0.81 | 16 |



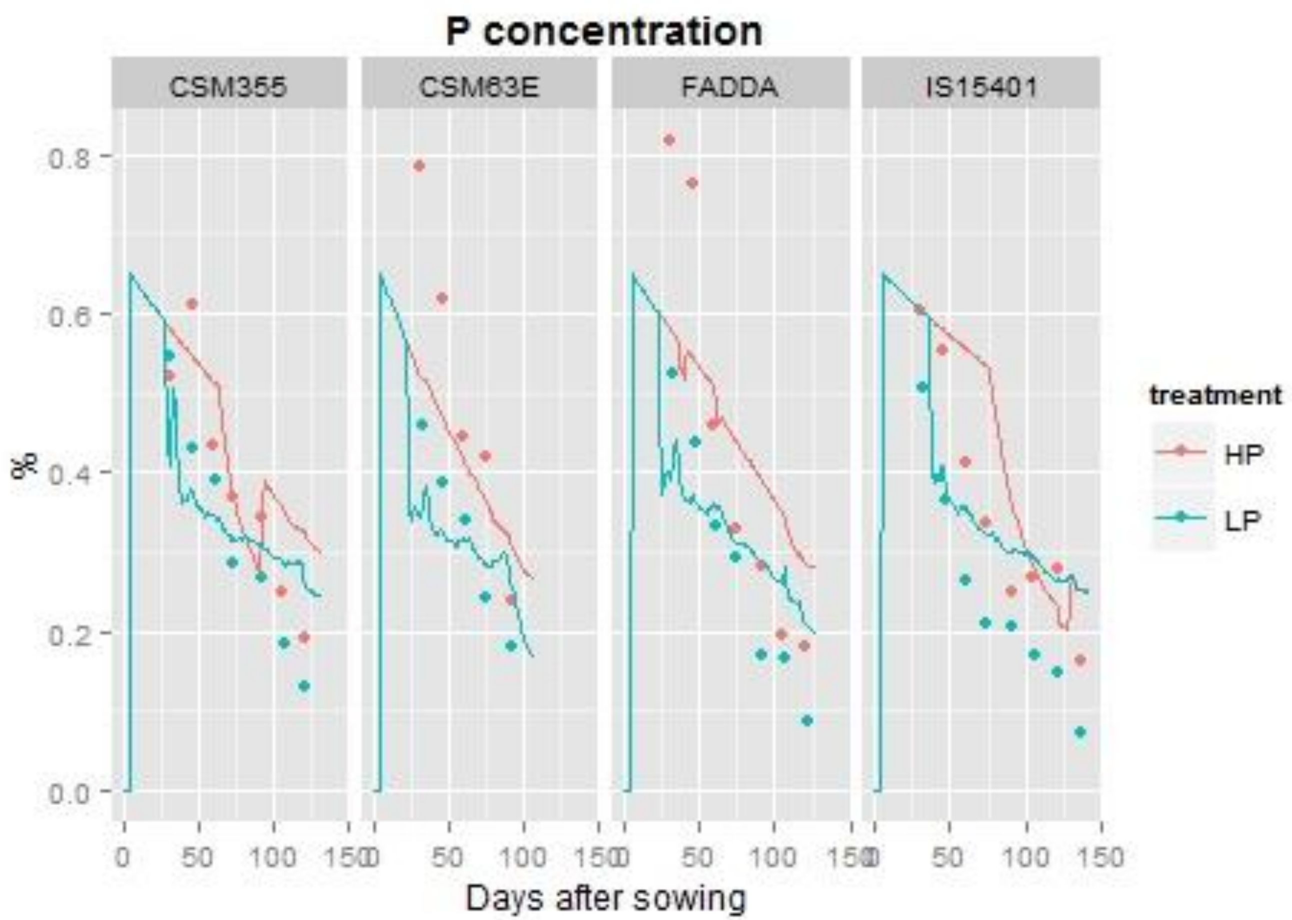



# Simulations

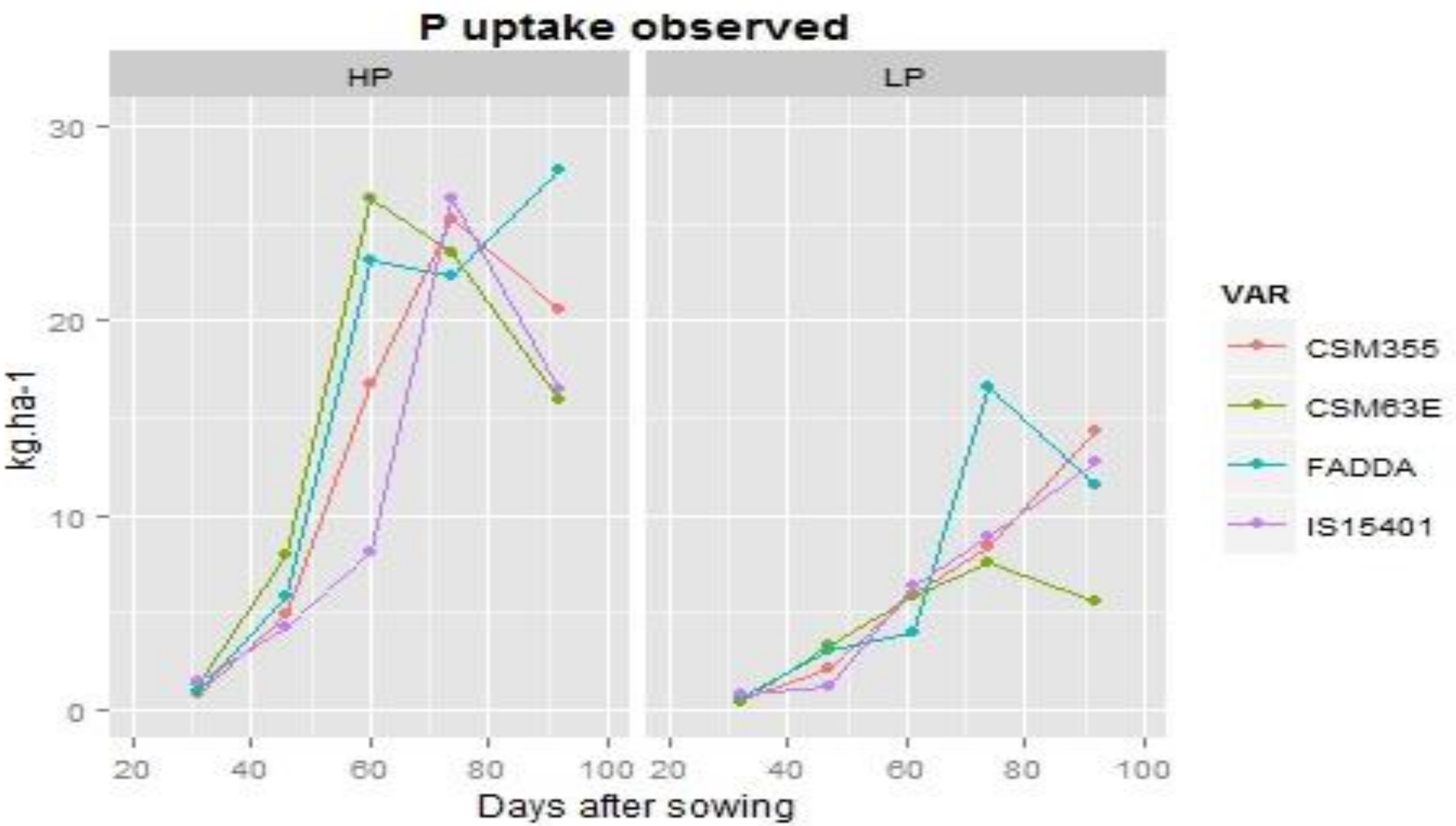
- Dynamics



# Simulations



# Two strategies: looking at the data



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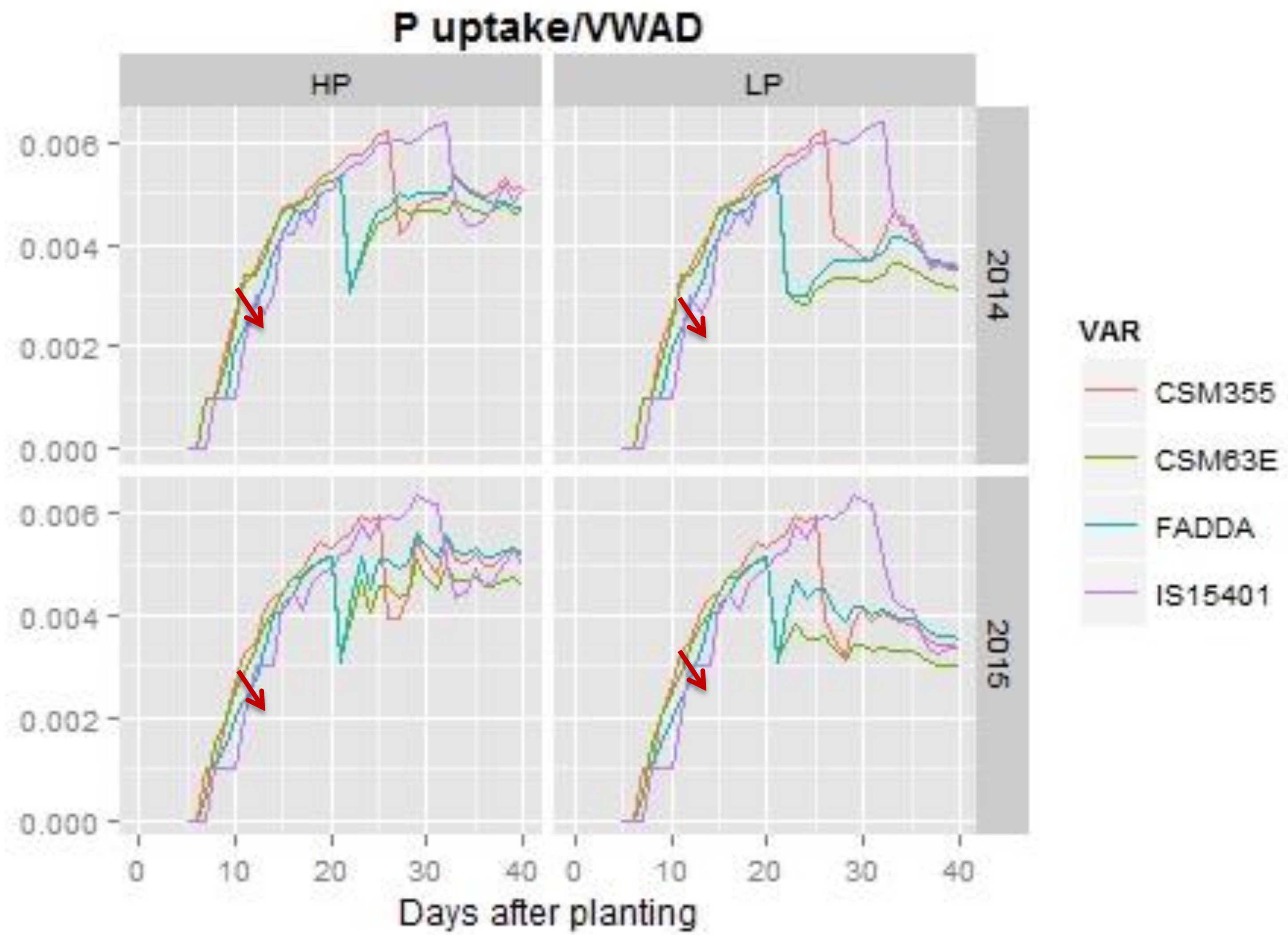


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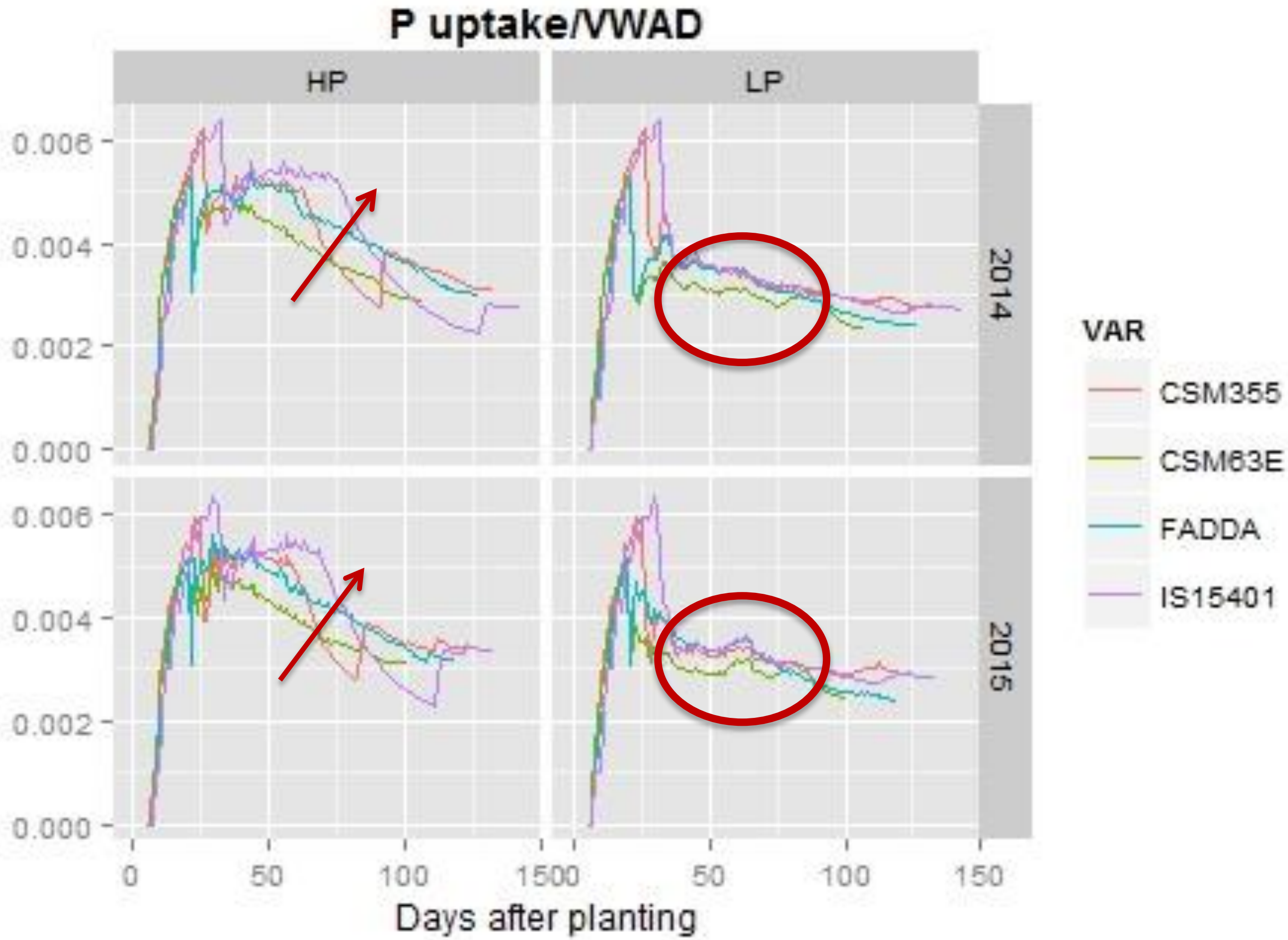
# Two strategies: looking at the simulations




Ho: different varieties type might have a different dynamics of **P uptake relative to aboveground growth change over time**

# Conclusion

- Achievements
  - P-aware sorghum model within DSSAT
  - Confirmation of 2 strategies in growth patterns for sorghum in WA

- Limitations
  - More data on P conc for 2015 to confirm the findings
  - The black box: the roots!

- Phosphorus a bottleneck for yield boosting:
  - YES: yield reduction from 30 to 70 % in sorghum in WA
  - BUT: plants adapt
    - Pp sensitive sorghum seems to limit its uptake at first, and then increases its uptake according to growth

# Thanks for your attention

**QUESTIONS/ COMMENTS**

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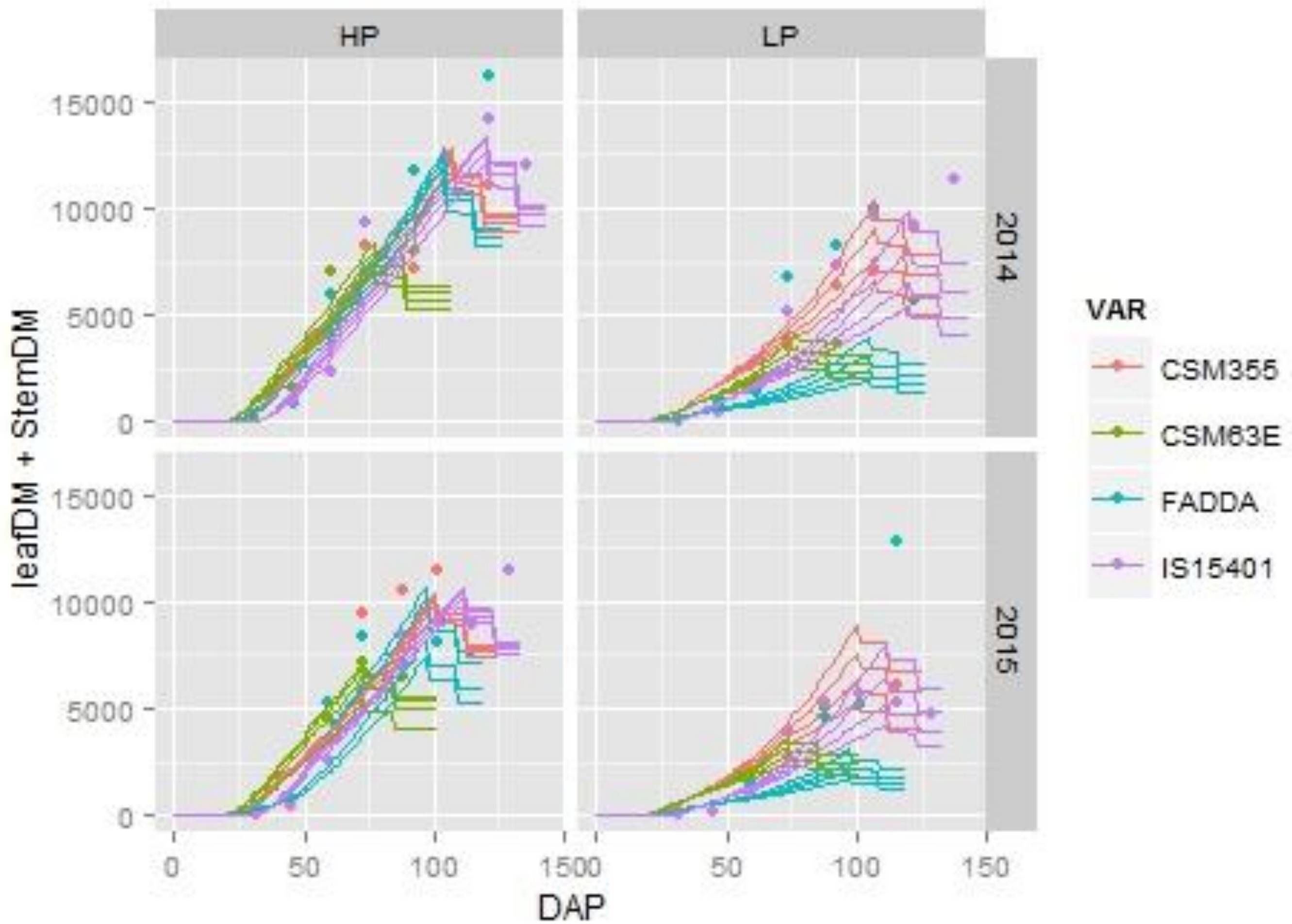
# Sensitivity to roots



# P stress factors