Improving Phosphorus-Use Efficiency in Crop Plants

Priv.-Doz. Dr. Ahmad M. Manschadi

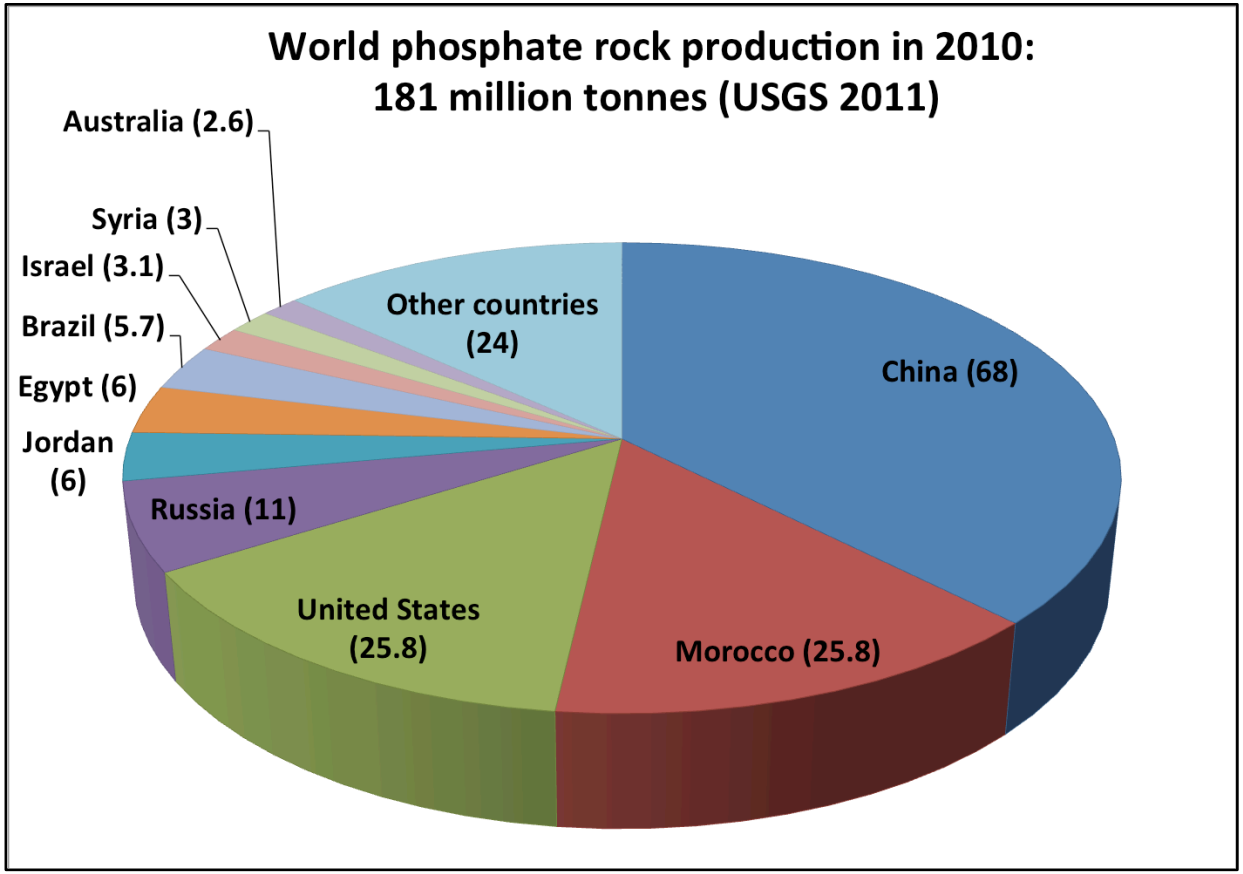
BOKU University

Department of Crop Sciences

Crop Physiology & Nutrition

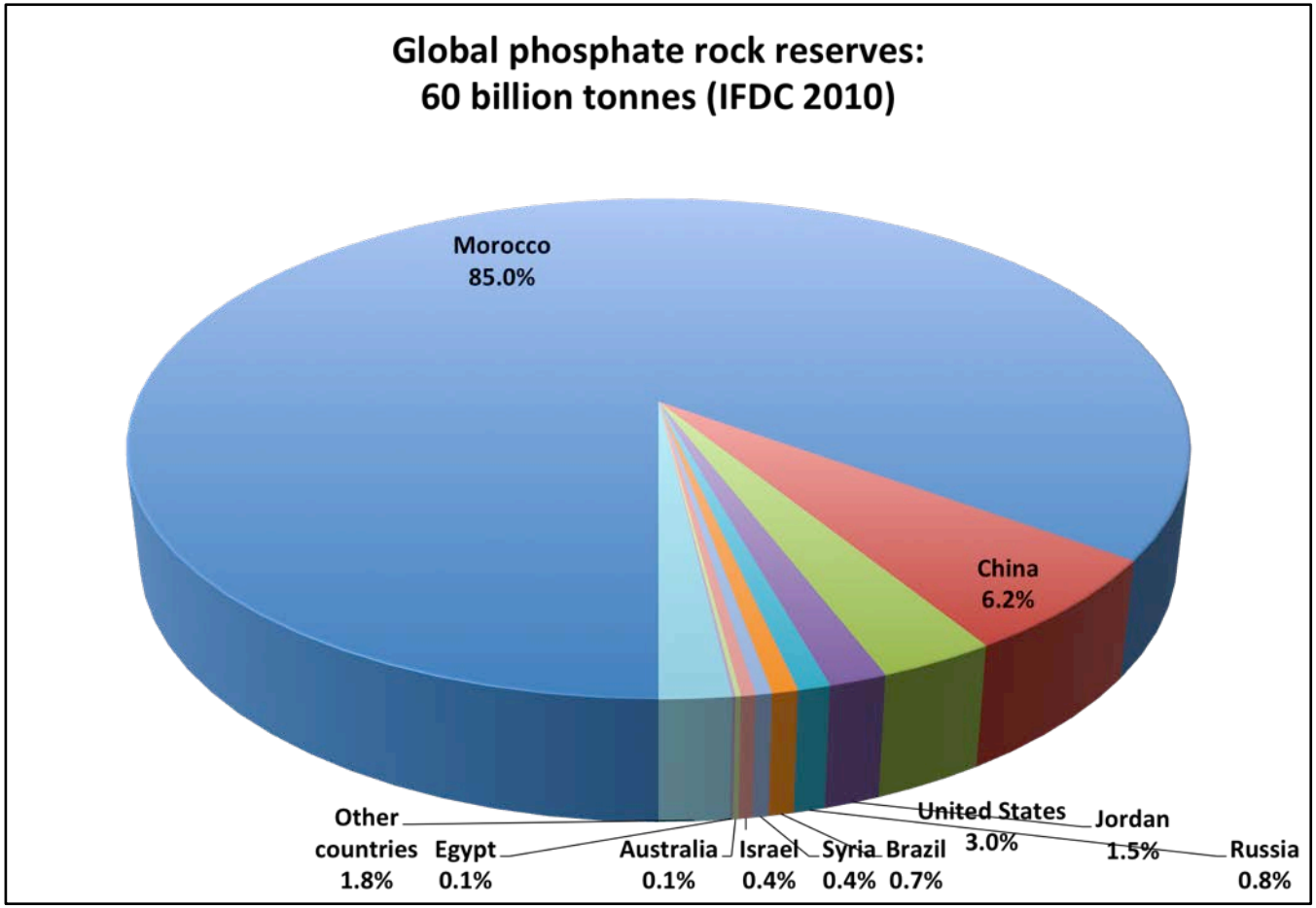
Phosphorus

- Phosphorus (P): essential and unsubstitutable nutrient
- Non-renewable resource: decreasing global P reserves; increasing P-fertiliser prices
- Two-third of the world PR production: 4 countries
- European Union (EU): P import 1.4 Mt (2010)



Phosphorus scarcity

- Global commercial phosphate rock reserves: will be depleted within a century
- Concerns about global P security
- **Challenge: Improving P-use efficiency**



Drought stress

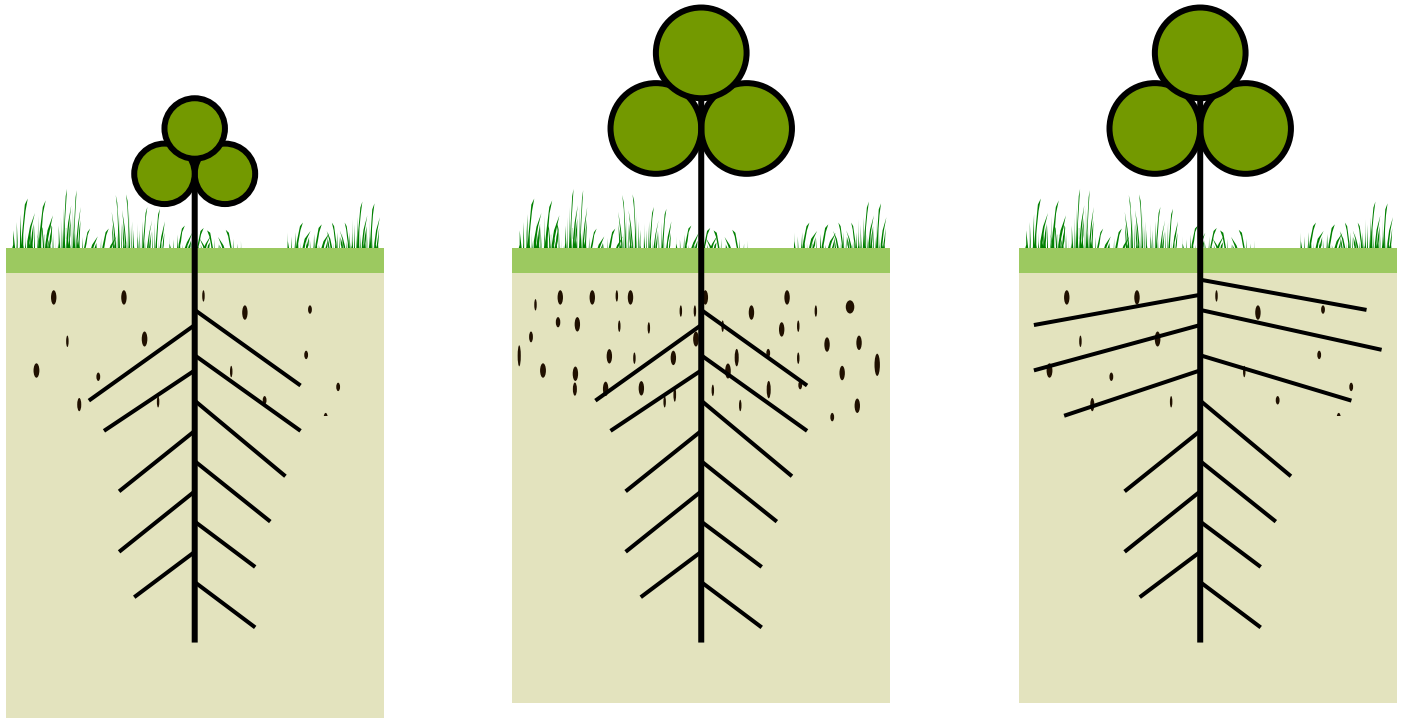
- Likely to increase due to climate change and variability
- **Danube / Pannonian Basin**
- Large areas of Austria, the Czech Republic, Slovenia, Hungary and Slovakia
  - Irrigation – increasing area and rates
  - Drought-tolerant varieties (Trnka et al. 2010)

- **Critical-P requirement**:

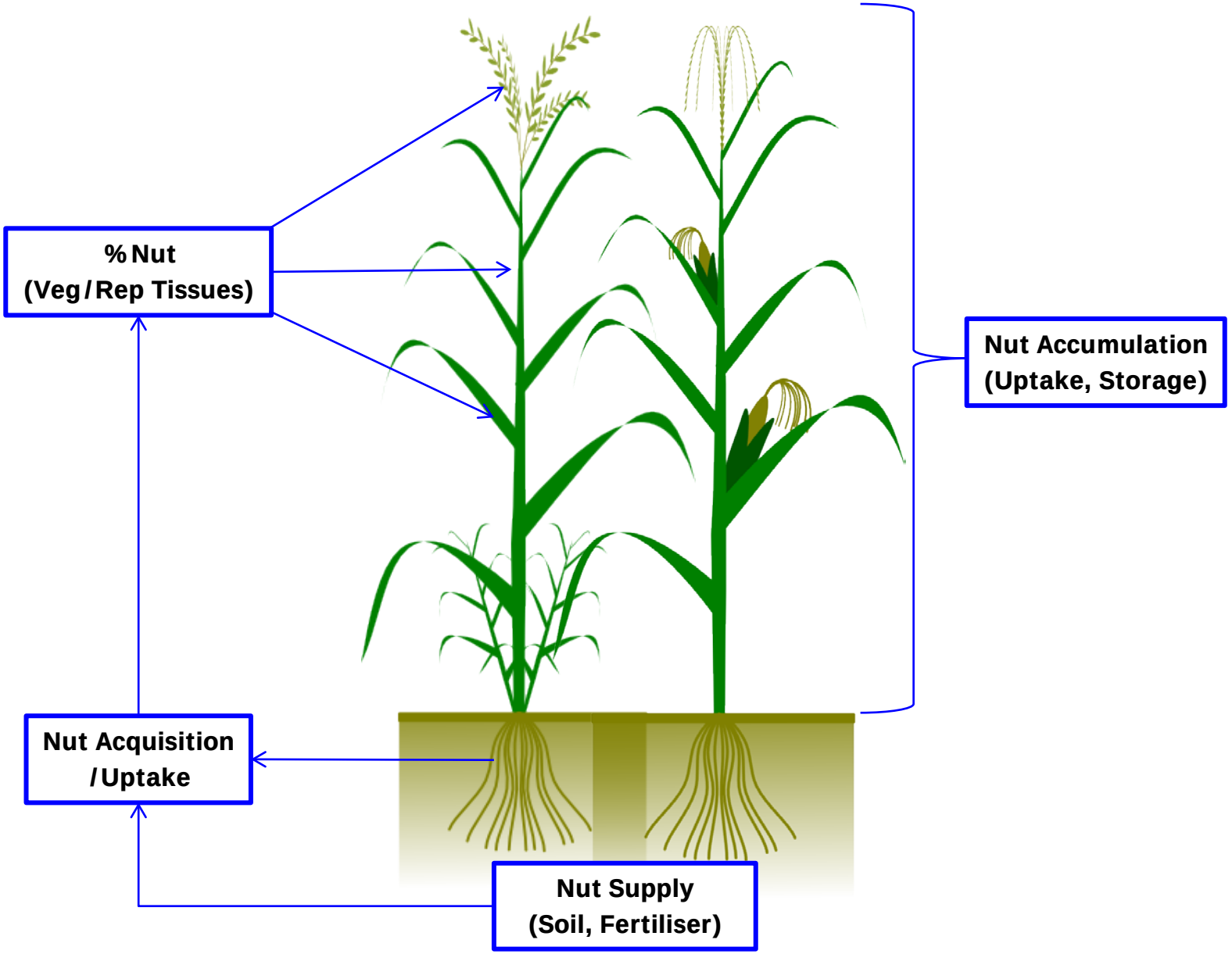
  Soil fertility level corresponding to 90-95% of maximum crop yield

  Soil P at this level is used with maximum efficiency

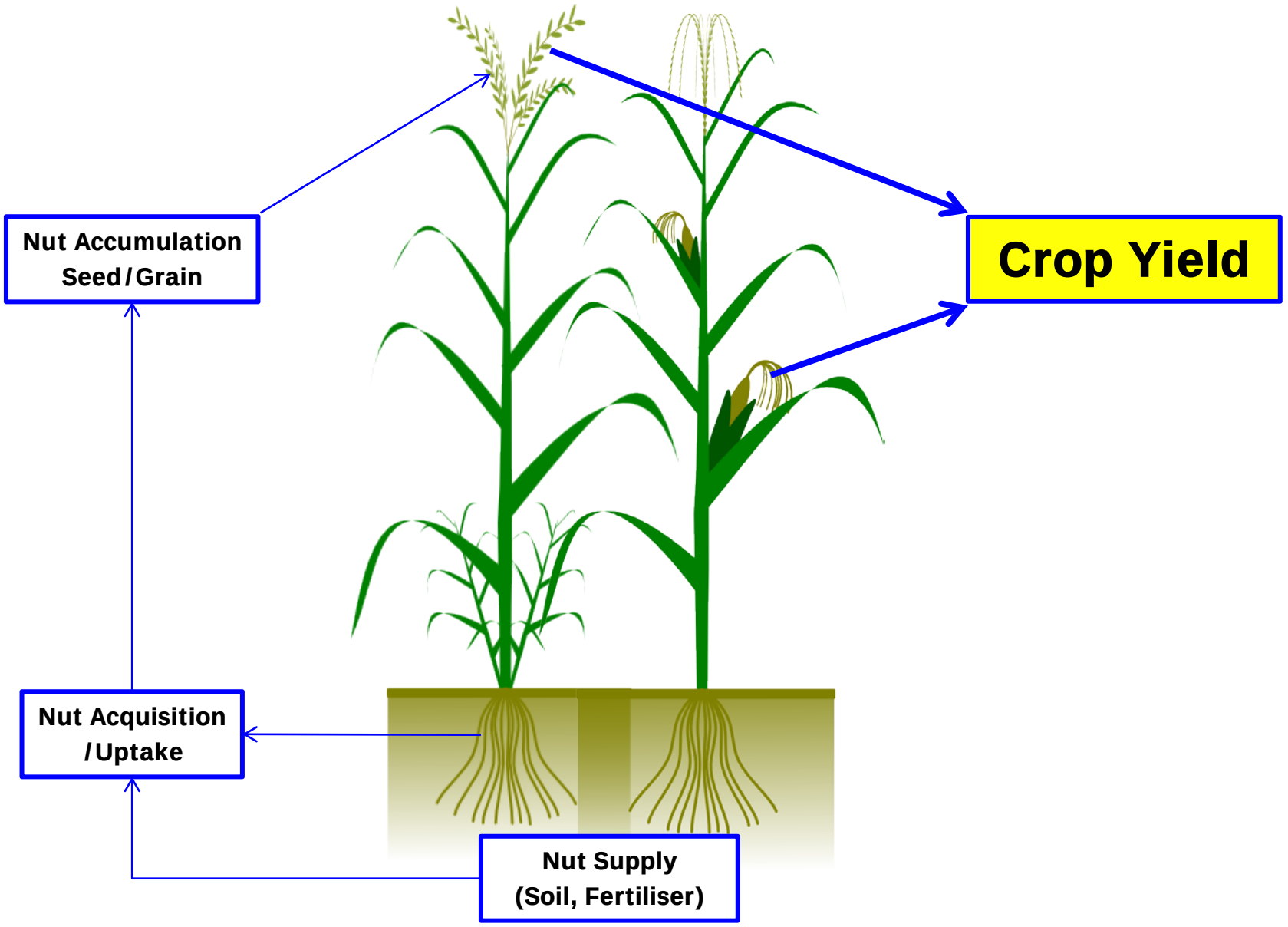
Standard genotype		**P-efficient genotype**
Soil P < Critical level	Soil P = Critical level	**Lower critical-P requirement**



Nutrient uptake and distribution



Nutrient uptake and distribution



- **Nutrient-use efficiency**: Crop yield per unit of nutrient supply from soil and fertiliser

  - **Nutrient-acquisition efficiency** (**NutAE)** –

    Total nutrient in the above-ground plant organs at maturity per unit of nutrient supply

  - **Nutrient-utilisation efficiency** (**NutUtE)** –

    Crop seed yield per unit of nutrient taken up

    The internal efficiency with which the absorbed nutrient is utilised to produce yield

$$NutUE = NutAE \times NutUtE$$

Nutrient-utilisation efficiency (NutUtE)

$$NutUtE = \frac{Y_{seed}}{Nut_{seed}} \times NutHI = \frac{1}{\%Nut_{seed}} \times NutHI = \frac{NutHI}{\%Nut_{seed}}$$

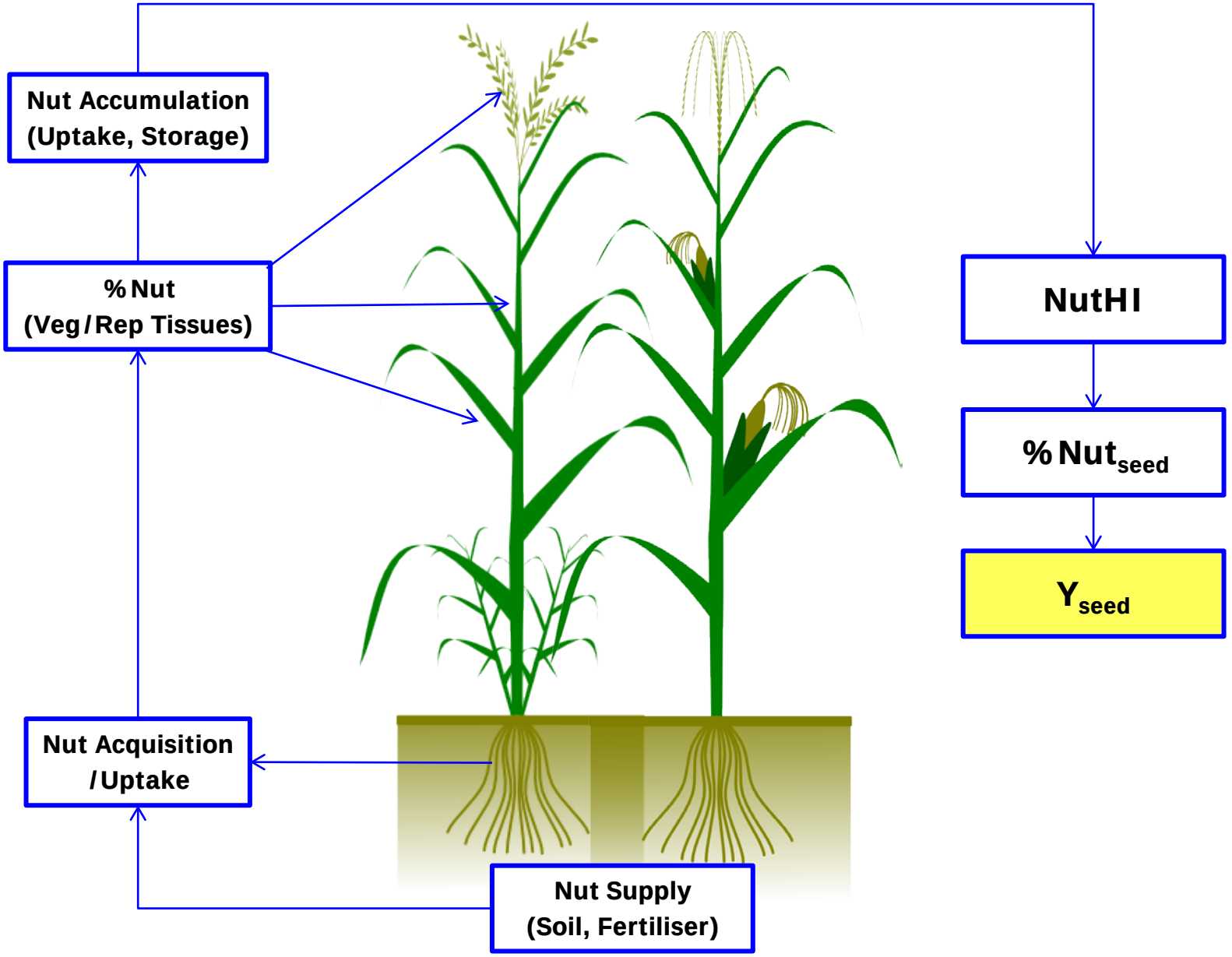
- **NutHI**: fraction of total accumulated nutrient in the plant that is allocated to the seed
- **Nut_{seed}**: accumulated nutrient in the seed (kg Nut ha^{-1})

$$Y_{seed} = Nut_{accum} \times \frac{NutHI}{\%Nut_{seed}}$$

- **Nut_{accum}**: total accumulated nutrient in the plant (kg Nut ha^{-1})

(Manschadi et al. 2014)

Nutrient-use efficiency (NutUE)



Phosphorus-use efficiency (PUE)

- **Reduction in grain %P**
- **Increase in phosphorus harvest index (PHI)**

$$Y_{seed} = Nut_{accum} \times \frac{NutHI}{\%Nut_{seed}}$$

Reducing seed P concentration?

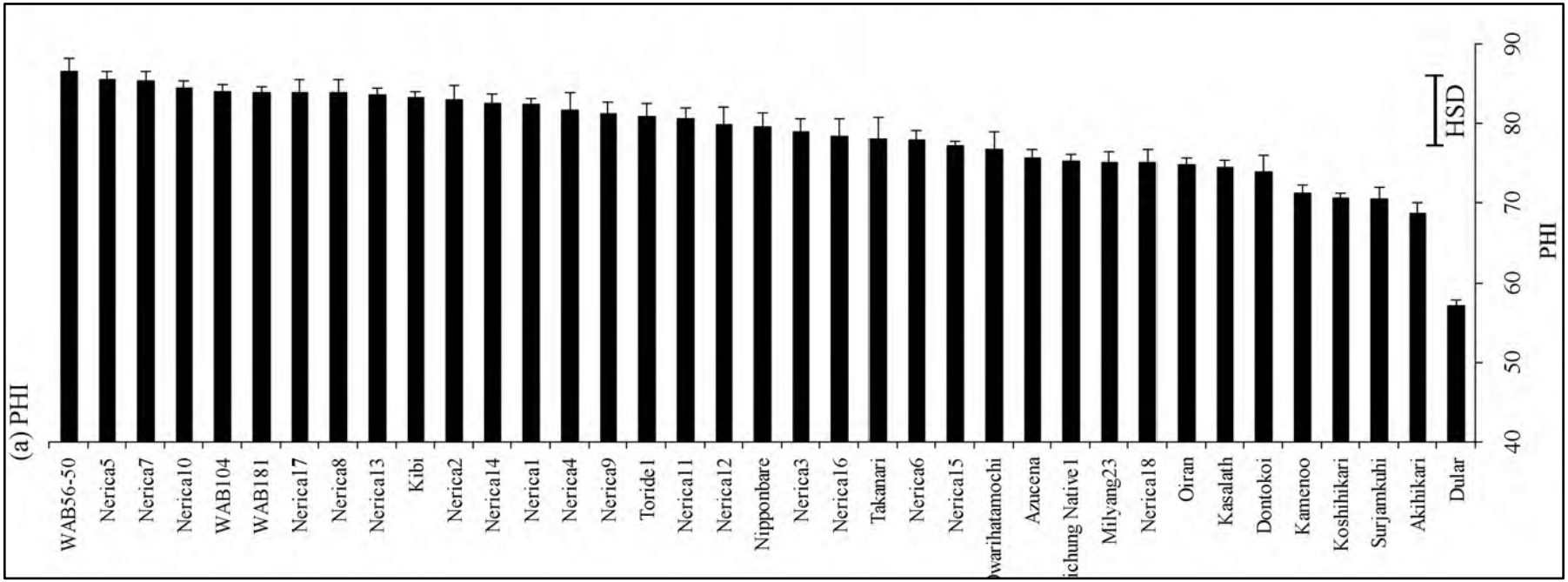
- Phytic acid: major organic storage form of P (75% of total seed P)
- Phytate salts (K, Mg, Ca, Fe, Zn): non-available for humans and monogastric animal
- Excretion of phytate: environmental hazard and waste management problem
- Breeding low phytic acid crop genotypes?
- **Ratio of P to other nutrients; seed germination; human health???**

(Manschadi et al. 2014)

Phosphorus-use efficiency (PUE)

- Reduction in grain %P
- **Increase in phosphorus harvest index (PHI)**

Rice: genotypic variability in PHI (57 – 87)



(Rose et al. 2010)

Phosphorus-use efficiency (PUE)

- Reduction in grain %P
- Increase in phosphorus harvest index (PHI)
- **Increasing P accumulation (Nut_{accum})**

- Upper limit for P acquisition and storage (per-unit-area basis):

  amount of vegetative mass x tissue P concentration

- **Phosphorus-use efficiency (PUE)**
  - Reduction in grain %P
  - Increase in phosphorus harvest index (PHI)
  - **Increasing P accumulation (Nut_{accum})**

- **Management**: plant population density, water/nutrients supply, length of growth period

- **Genetics**: photosynthetic capacity, partitioning of photosynthates, P concentrations
  - Uptake of P fertiliser: 15 – 30% in the year of application
  - P-adaptive traits:
    - **R:S biomass ratio**
    - **Production and secretion of phosphatases and organic acids**
    - **Symbiotic associations with mycorrhizal fungi**
    - **Root architecture and root hairs**

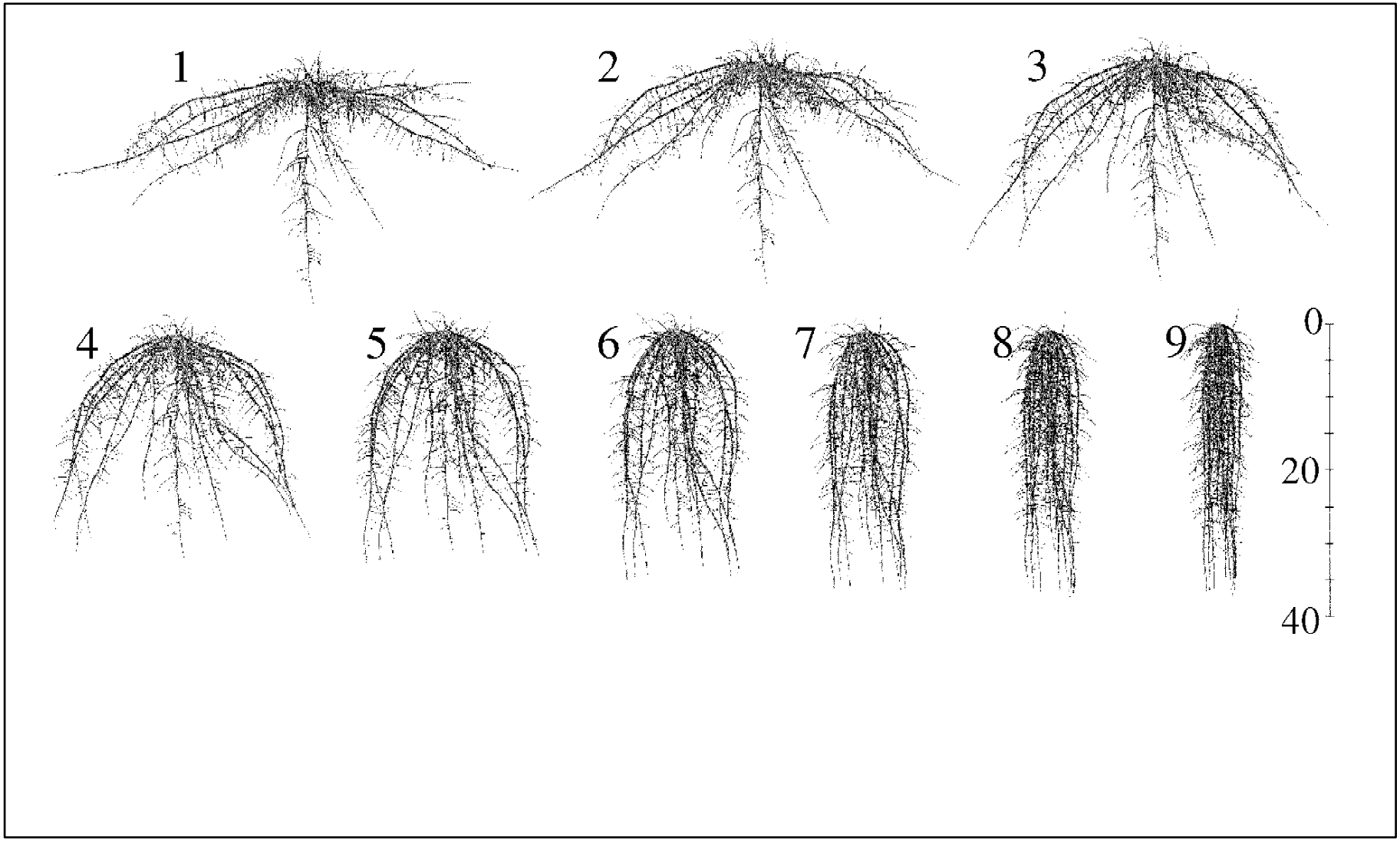
(Manschadi et al. 2014)

- **Root architecture:** spatial configuration of a root system
- **Diversity of root architecture**
  - **Root classes (types)**:
    tap root, basal roots, adventitious roots, and their respective laterals

ous root systems, typified by common bean, a dicot (**a**), and maize, a monocot (**b**)

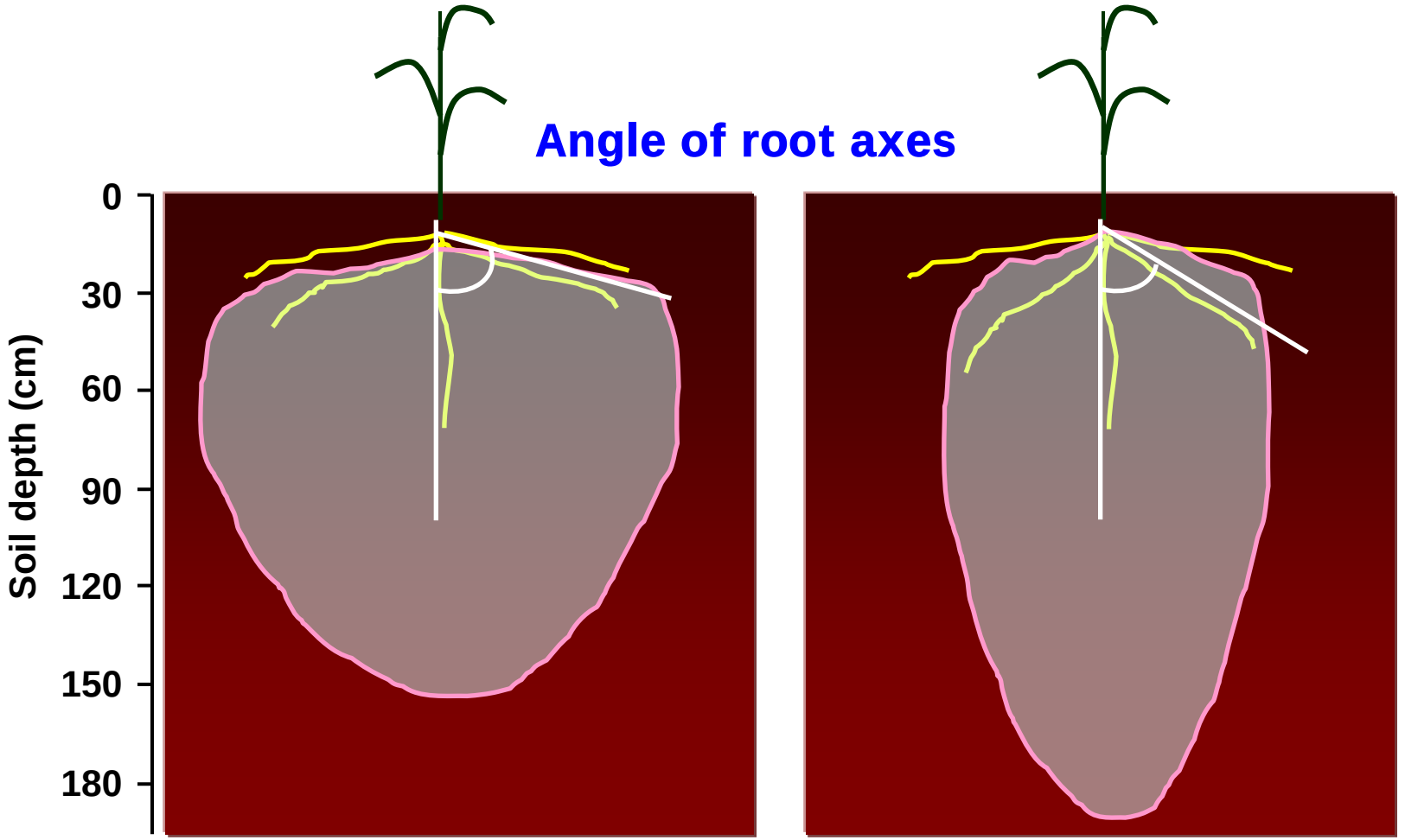
(Lynch 2005)

- Root system architectures of common bean differing in basal root gravitropism



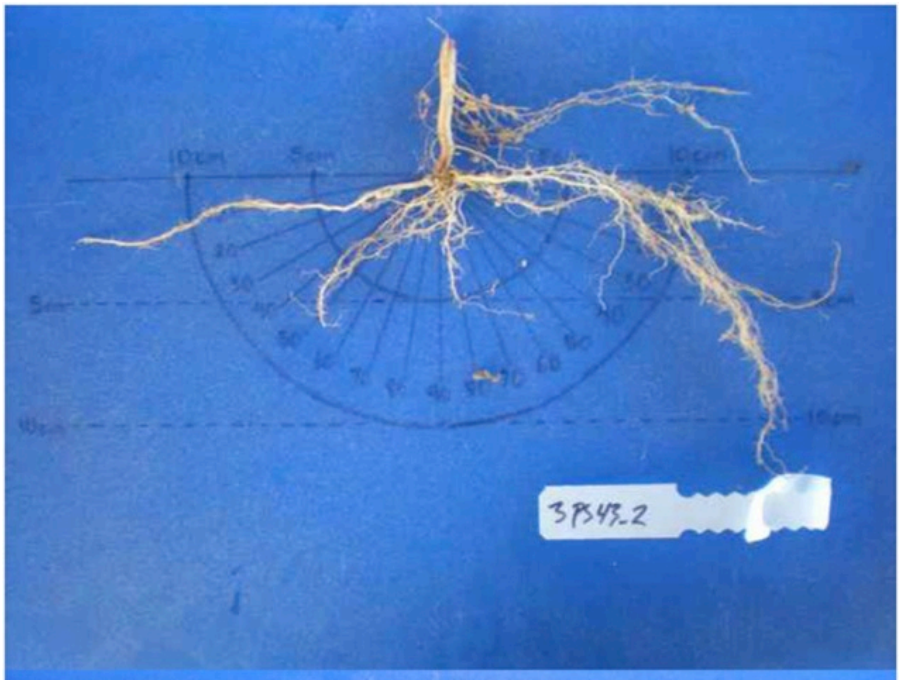
Root growth angle (RGA)

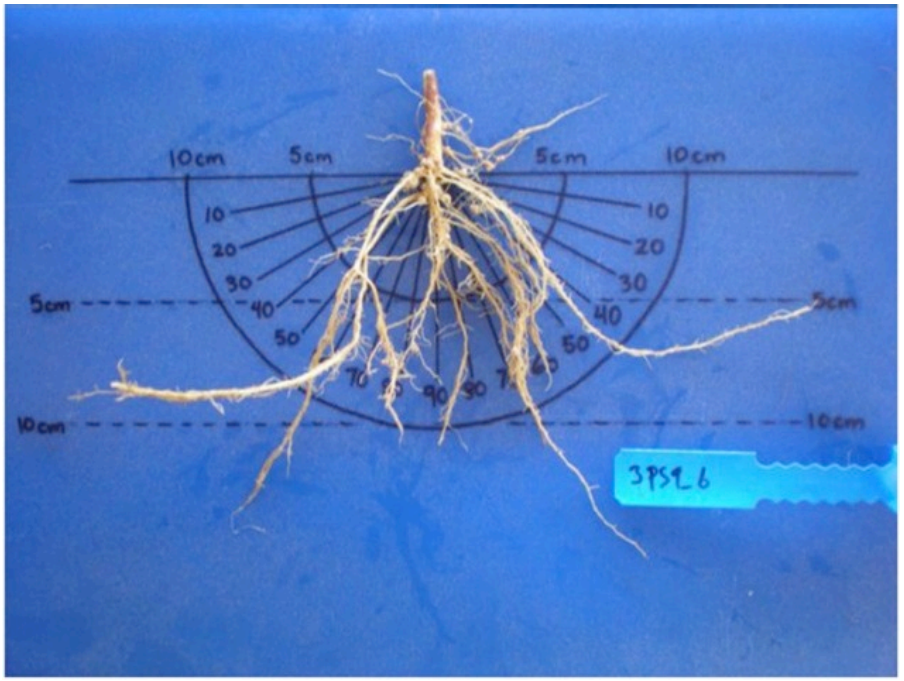
- In maize, bean, and soybean: shallower RGA of axial roots increase P acquisition



(Manschadi et al. 2013)

- RGA accounts for up to 6-fold variation in P acquisition and 3-fold variation in bean yield in low-P soils
- **Shallow versus deep basal RGAs in two common bean genotypes grown in the field**





(Lynch 2011)

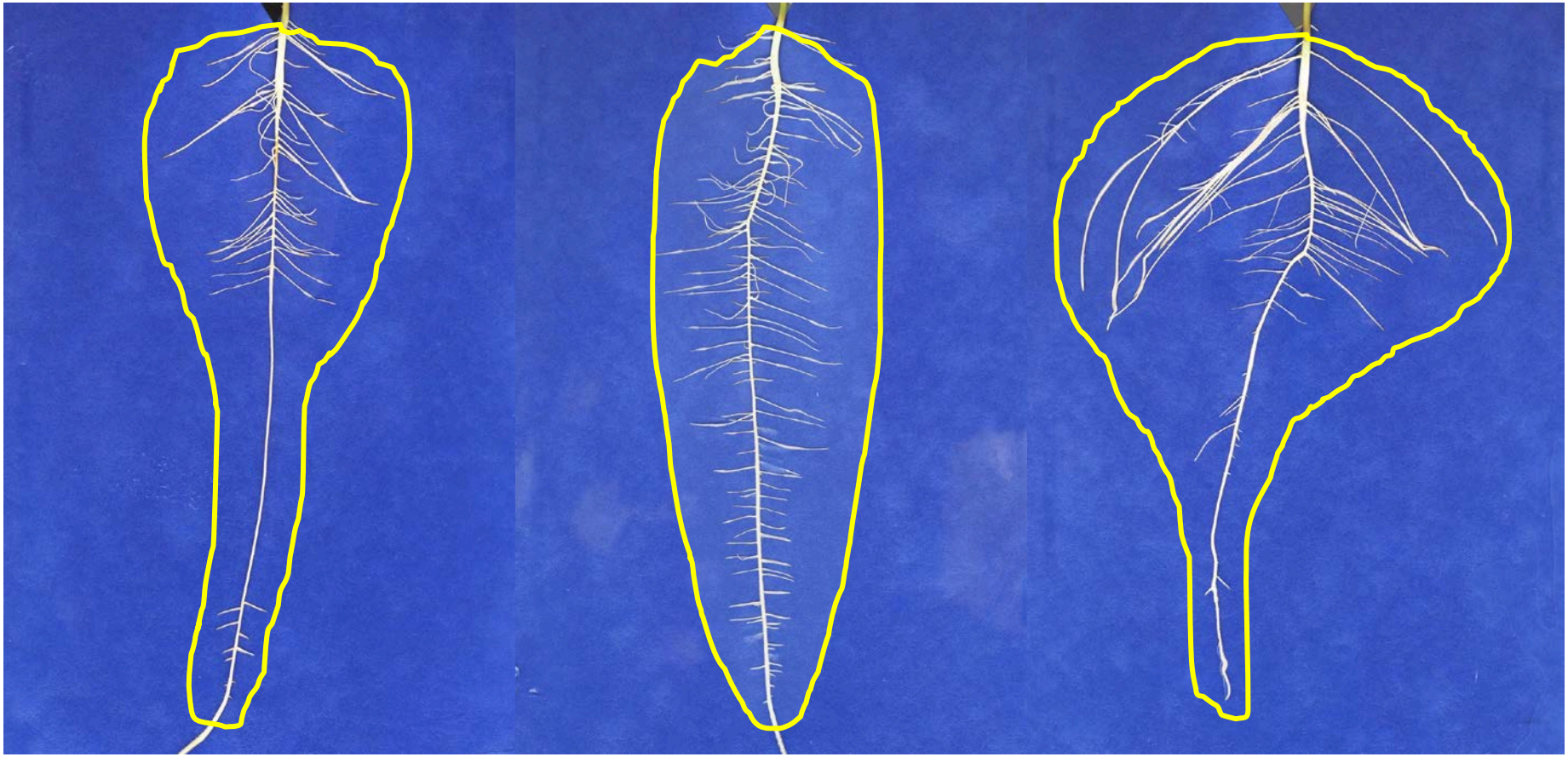
- Soybean:

  P-efficient varieties grow much better than standard varieties under P-deficient soils

(Wang et al. 2010)

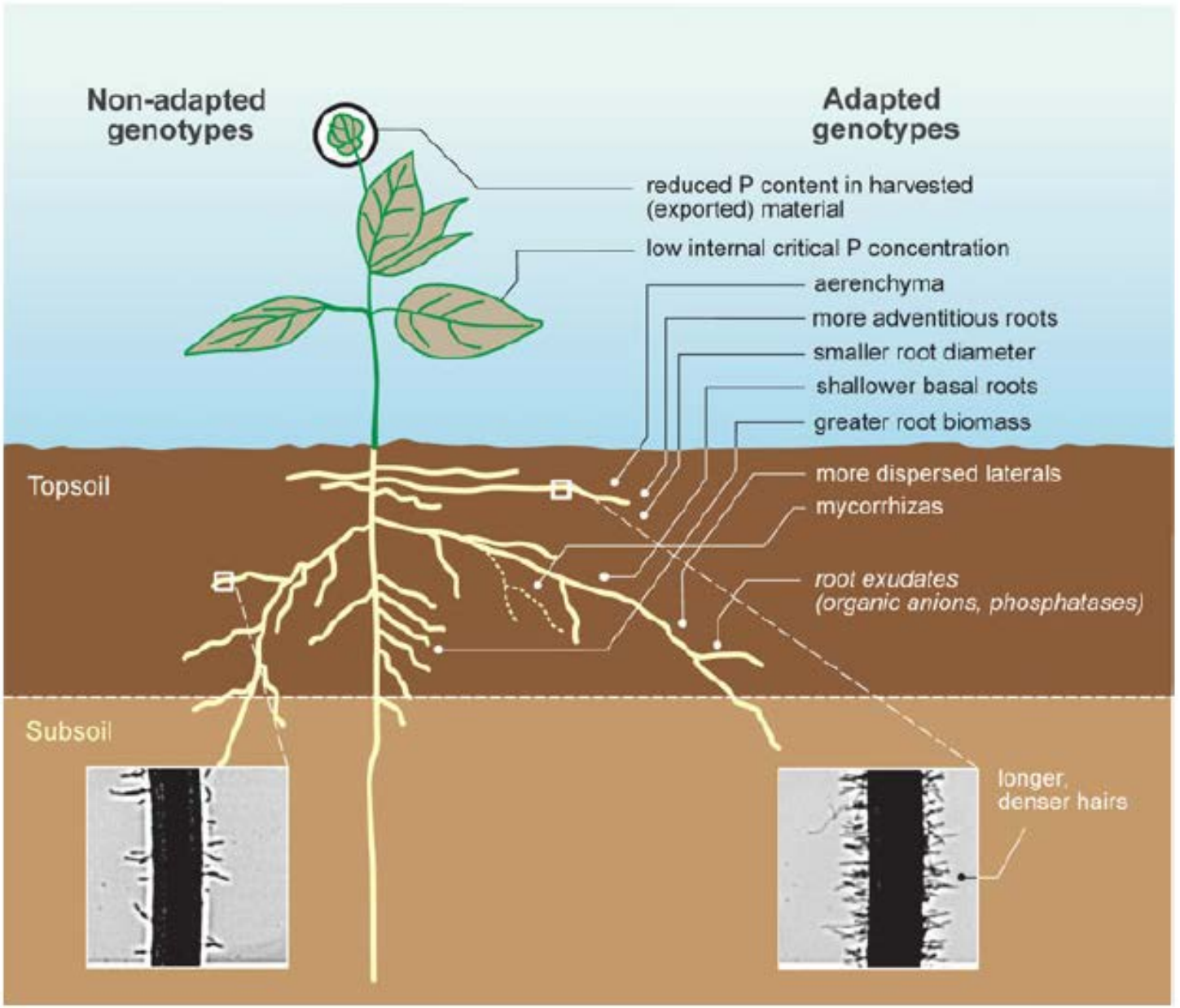
- Screening soybean germplasm

- Soybean:
  - Contrasting basal root growth angle & number; lateral branching pattern



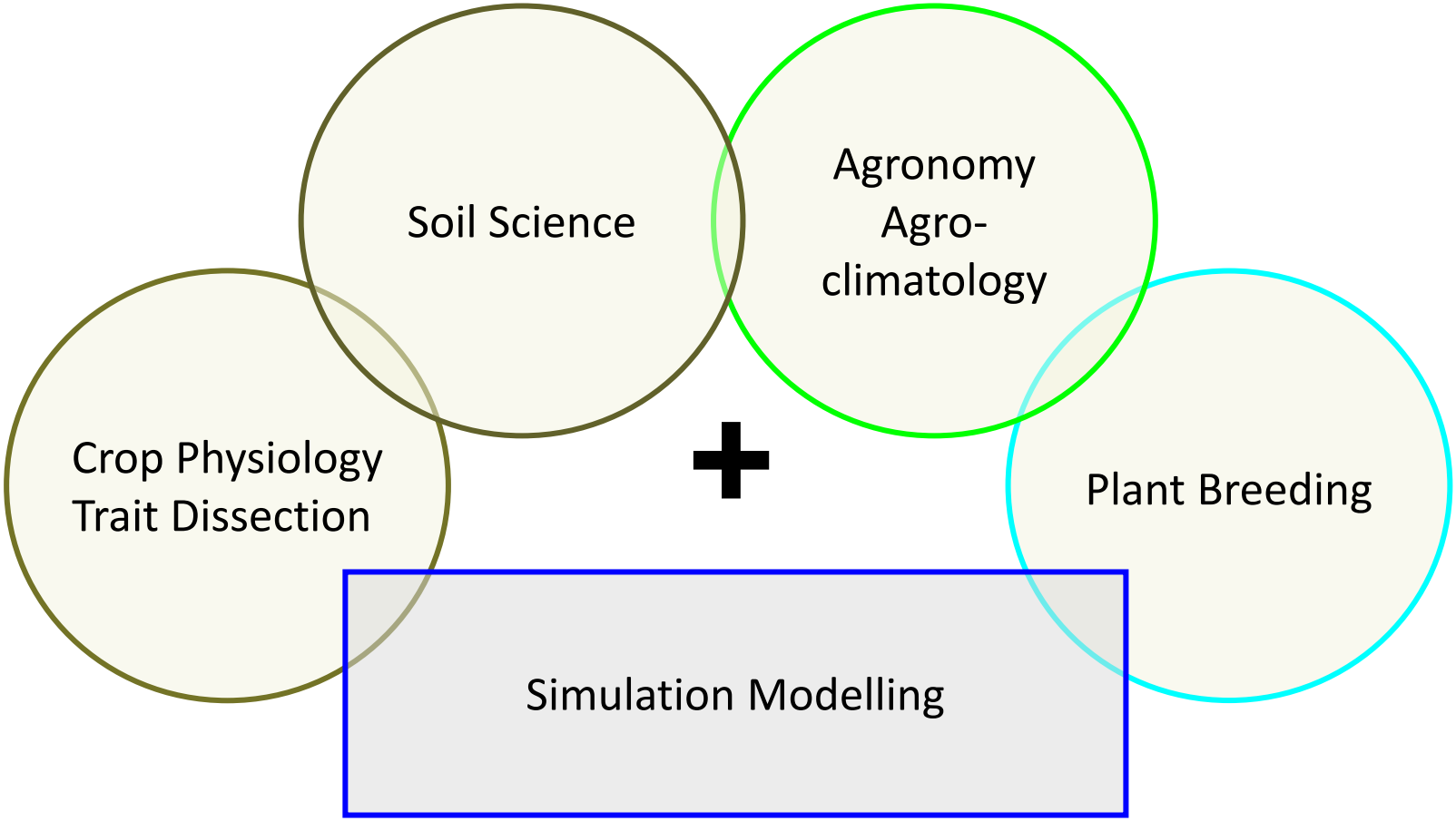
- Organic soybean crop, Raasdorf, 2013
  - Row spacing, root architecture, phosphorus acquisition

- Root phenes associated with genotypic differences in adaptation to low P

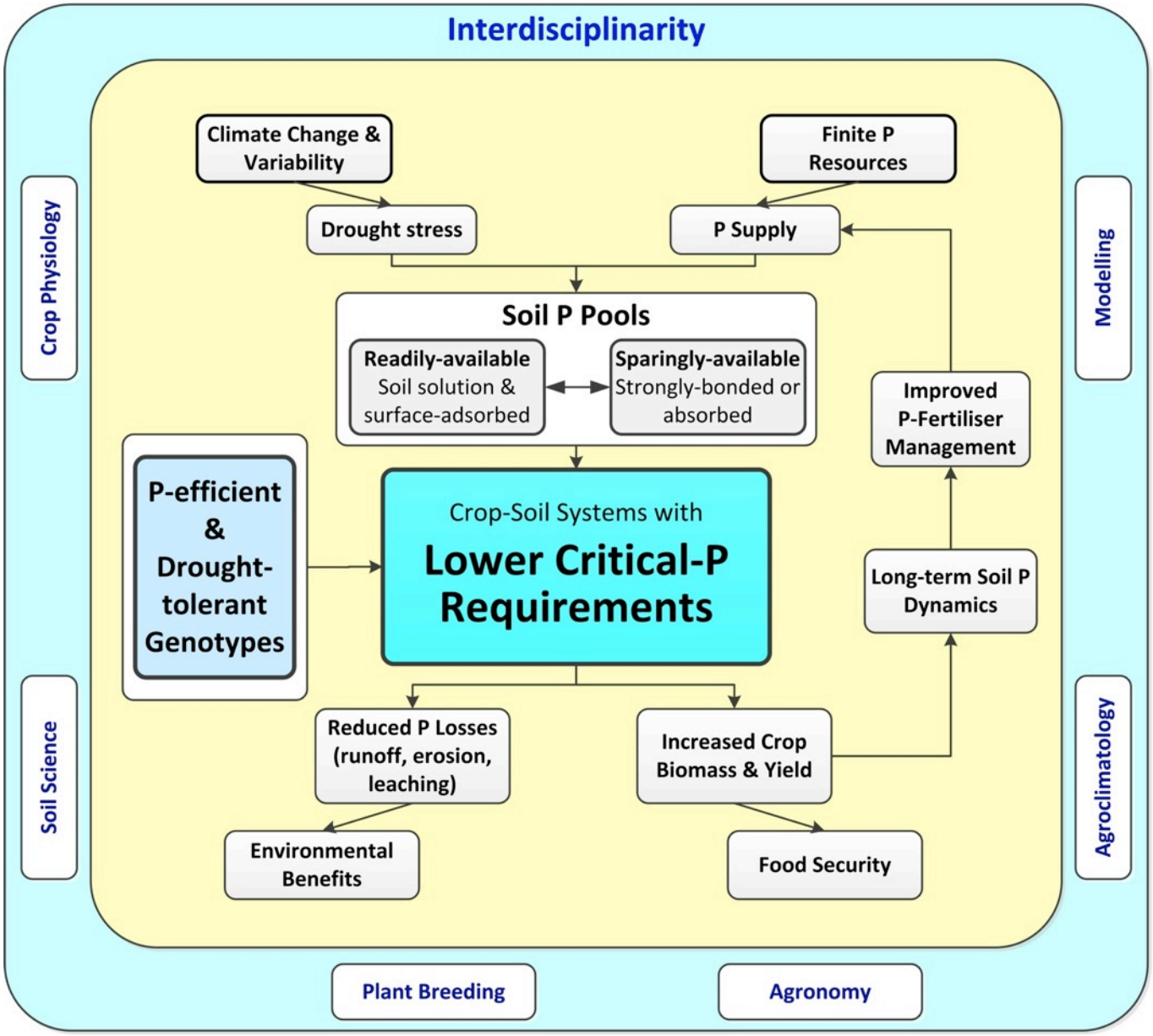


(Lynch 2007)

- Nutrient (P)-use efficiency: MULTI-Genic trait
- Integrated crop improvement strategy



Integrated crop improvement strategy



Contents lists available at ScienceDirect

Field Crops Research

journal homepage: www.elsevier.com/locate/fcr

Developing phosphorus-efficient crop varieties—An interdisciplinary research framework

Ahmad M. Manschadi [a,*], Hans-Peter Kaul [a], Johann Vollmann [b], Josef Eitzinger [c], Walter Wenzel [d]

[a] University of Natural Resources and Life Sciences, Vienna, Department of Crop Sciences, Division of Agronomy, Konrad Lorenz Str. 24, 3430 Tulln, Austria
[b] University of Natural Resources and Life Sciences, Vienna, Department of Crop Sciences, Division of Plant Breeding, Konrad Lorenz Str. 24, 3430 Tulln, Austria
[c] University of Natural Resources and Life Sciences, Vienna, Department of Water, Atmosphere and Environment, Institute of Meteorology, Peter-Jordan-Str. 82, 1190 Vienna, Austria
[d] University of Natural Resources and Life Sciences, Vienna, Department of Forest and Soil Sciences, Institute of Soil Research, Konrad Lorenz Str. 24, 3430 Tulln, Austria