Climatic changes and mineral nutrition of crop plants

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The opening of Pandora's Box: climate change impacts on soil fertility and crop nutrition in developing countries

Challenges to food security in developing countries in the 21st century

963 million people on our planet are underfed or malnourished including a 10% increase over the last 3 years due to rising food costs (FAO 2009)

Demand for food continues to increase while per capita arable land area dedicated to crop production continues to shrink because of population growth, urbanization and soil degradation

From the supply side, this imbalance is largely driven by edaphic constraints that result from inherently low soil fertility and/or soil degradation from unsustainable farming practices

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Talk Objectives

1) Provide an overview of two of the most important environmental impediments to food security in developing countries in the 21st century: soil constraints and climate change

2) Synthesize current understanding of how climate change (precipitation extremes and warming) is likely to affect crop nutrition in soils of the developing world

3) Explore examples of adaptation measures that are most likely to be effective in stabilizing crop yields grown under suboptimal soil conditions in future climates

Soil limitations to crop productivity in developing countries: chemical constraints

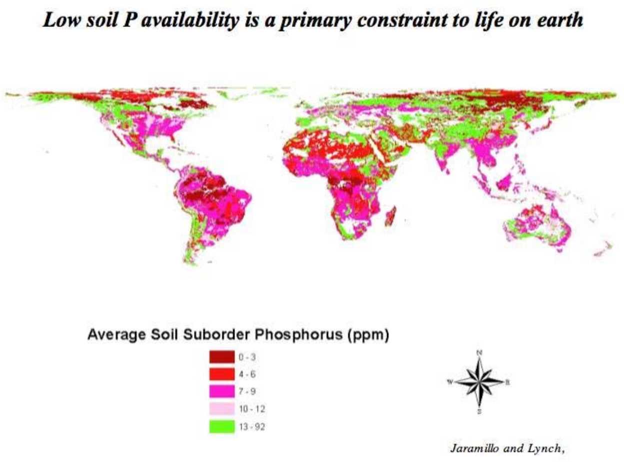
Tropical or sub-tropical climates: heavily weathered soils

Widespread deficiencies of N & P
Acidification: K, Ca, Mg deficiency & toxicities of Al & Mn

Arid and semi-arid regions

Deficiencies of P and transition metals: Fe, Cu, Mn, and Zn
Salinity stress

Low soil P availability is a primary constraint to life on earth



Soil limitations to crop productivity in developing countries: physical constraints

- Poor soil texture
  - Suboptimal soil moisture conditions
- Rockiness

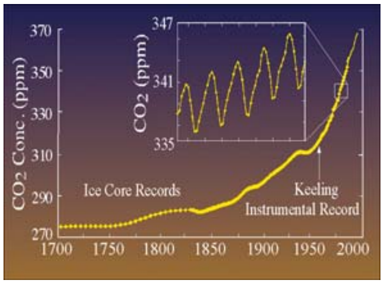
- Slope steepness
  - Erosion issues

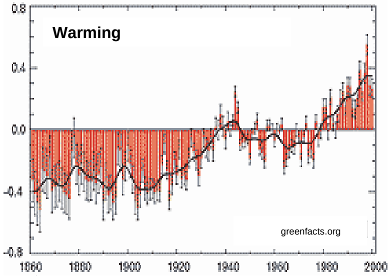
Combination of inherent soil limitations and soil degradation reduces soil function

	% Soil w/ major constraints	%Land degradation
Africa	85	77
Asia	70	74
Australia	81	61
Europe	69	91
North America	73	49
South America	81	78

Soil edaphic conditions and land degradation that place major constraints on crop yields. TERRASTAT.

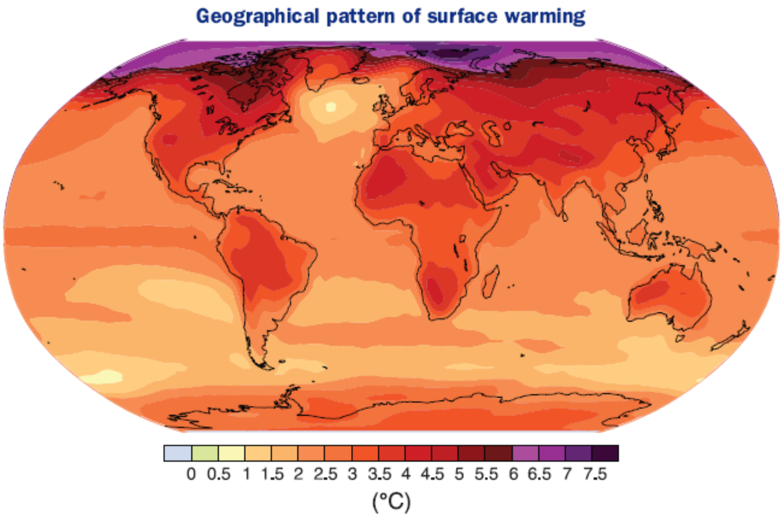
Climate change





Climate Changes projections in the 21st century

2-5°C increase in temperature

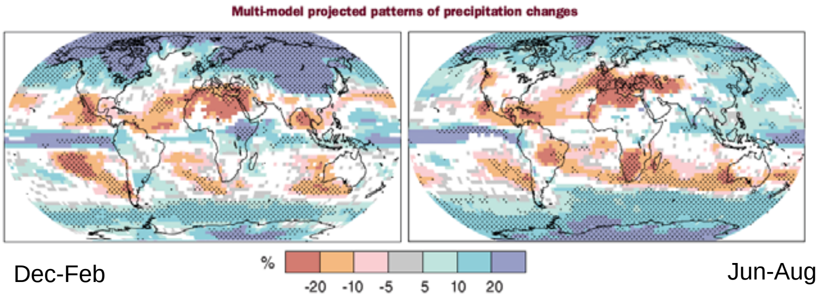


Climate Changes projections in the 21st century

Increases in extreme weather & more variable precipitation patterns

More frequent & intense droughts: intercontinental areas, subtropics
More intense precipitation events: flooding

Africa: increase in droughts expected decrease yields up to 50%
Asia: droughts and floods expected to have negative impacts on yield
Latin America: reduction in water available for agriculture



Climate impacts on soil processes & plant nutrition

"Implicit in discussions of plant nutrition and climate change is the assumption that we know what to do relative to nutrient management here and now but that these strategies might not apply in a changed climate."

(Brouder and Volenec 2009).

Climate interactions with plant nutrition

Process	Climate variable	Nutrient affected
Transpiration driven mass flow	**CO2, RH, precip, temp**	**NO3, SO4, Ca, Mg, Si**
Root growth and architecture	**CO2, drought , soil temp**	**All nutrients, esp P, K**
Root symbiosis	**CO2, drought, temp**	**N, P, Zn**
Root exudates	**CO2**	**Al tox, metal uptake, P**
Tissue dilution	**CO2**	**Stress responses, nutrient cycling, nutritive value**
Growth responses	**CO2, drought, temp**	**N, P: “no clear pattern”**

Drought impacts on soil processes & plant nutrition

Water dependent diffusion and mass flow of nutrients to the roots slows with increasing soil moisture deficit

Impaired root growth decreases the capture of less mobile nutrients such as phosphorus

Drought inhibits N-fixation in legume crops and disrupts N cycling by soil bacteria

Root-mycorrhizae symbiosis is not overly sensitive to moderate soil moisture deficits

Part of the benefit provided by mycorrhizae under drought conditions is associated with increase in nutrient transfer to the roots

Excessive precipitation impacts on soil processes & plant nutrition

High intensity rainfall events can be a major source of erosion leading to loss of nutrient rich top soil and surface broadcast fertilizer

Nitrate leaching

Waterlogged soils become hypoxic

- O2 dependent active transport of nutrients slows
- change in soil redox status can lead to Mn, Fe and Al toxicity
- N losses through denitrification when nitrate is used as alternative electron acceptor in the absence of oxygen

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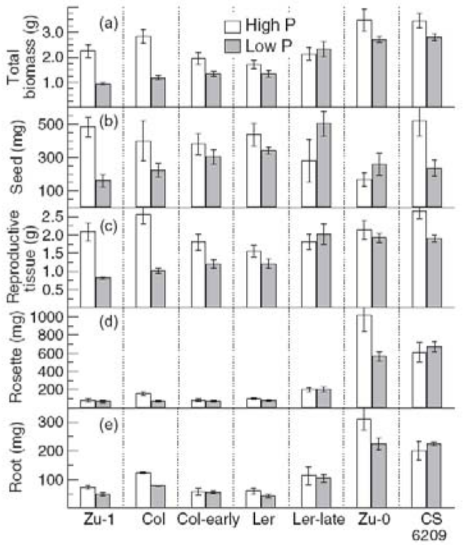
Warming impacts on plant nutrition will vary depending on soil moisture conditions

With adequate moisture soil warming increases rates of ion diffusion and transpiration driven mass flow of nutrients

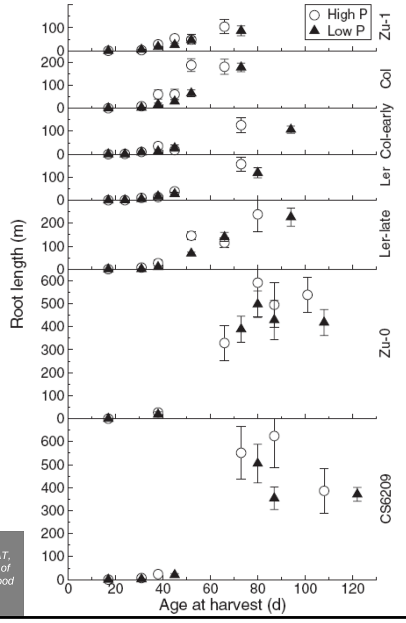
Heat driven evapotranspiration that results in soil moisture deficits will slow ion diffusion

High temperatures that result in extreme vapor pressure deficits, may reduce mass flow of nutrients by triggering stomatal closure

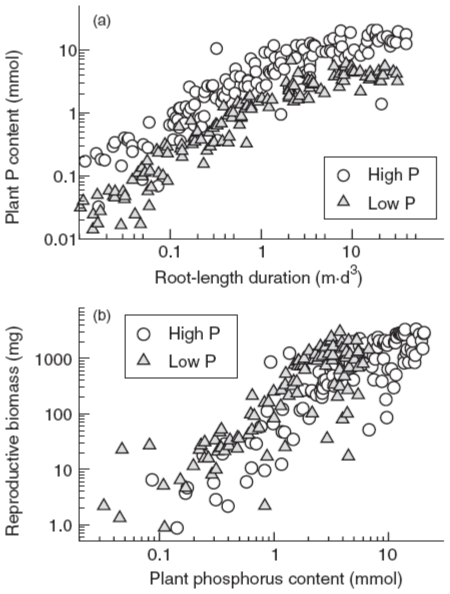
Extended phenology (lengthened vegetative growth) allow plants to minimize the effects of P deficiency



Root extension increases substantially in the later growth phases



Rapid root growth in late development promotes P uptake which is correlated with reproduction

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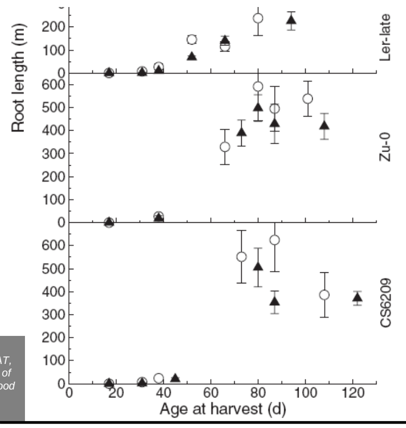
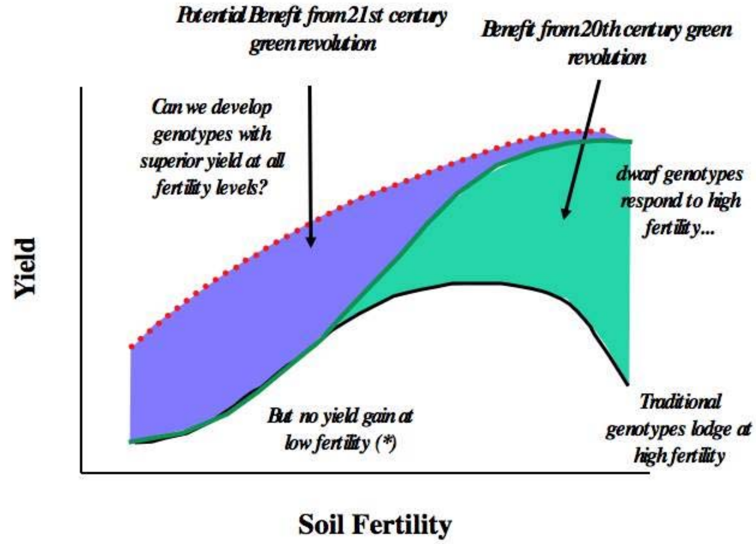
Shifting plant phenology in response to global change

Elsa E. Cleland[1], Isabelle Chuine[2], Annette Menzel[3], Harold A. Mooney[4] and Mark D. Schwartz[5]

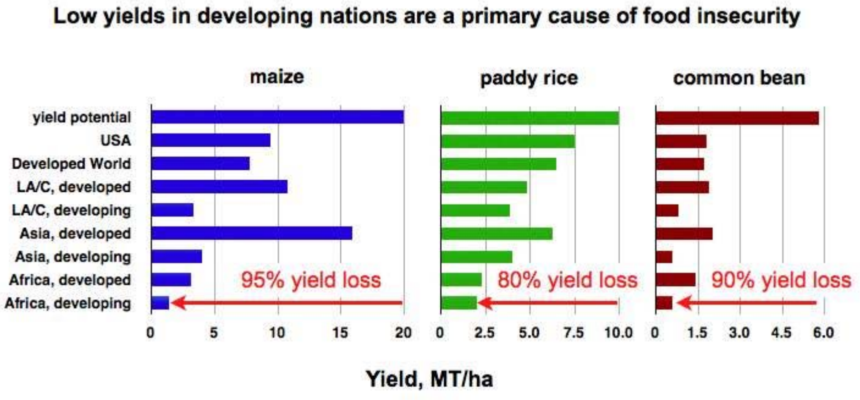
Climate warming accelerates plant phenology



A second green revolution?



Low input agriculture is the single largest human occupation, and productivity in these systems is strongly limited by water and nutrients


Low yields in developing nations are a primary cause of food insecurity

stress causes substantial yield losses in rich nations, and in developing nations is the primary limitation to agricultural productivity

Key components of a second green revolution

Integrated Nutrient Management

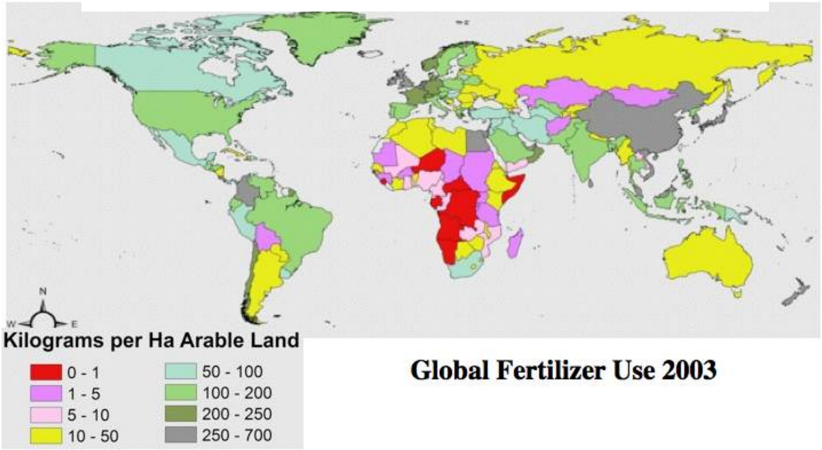
Fertilization
- cost, access?
- soil acidification?

Soil management
- erosion control
- rotations, mulches, etc
- poor adoption- skill, labor, land, time?

Adapted germplasm
- Al tolerance
- P efficiency
- Mn tolerance
- Ca, Mg, K efficiency
- **Water stress tolerance** →

What are the key traits and the molecular basis for those traits?

Fertilization is not a solution for poorest nations



Global Fertilizer Use 2003

compiled from World Bank data

Soil management: increase soil organic carbon using mulches and rotations

Estimates are that the world has lost 55-90 Petagrams of soil organic carbon (SOC) through land conversion from natural to agricultural ecosystems

Soil organic carbon (SOC) is positively correlated with crop productivity

High SOC enhances soil water holding capacity, increases soil fertility through cation exchange and mineralization processes and improves soil structure

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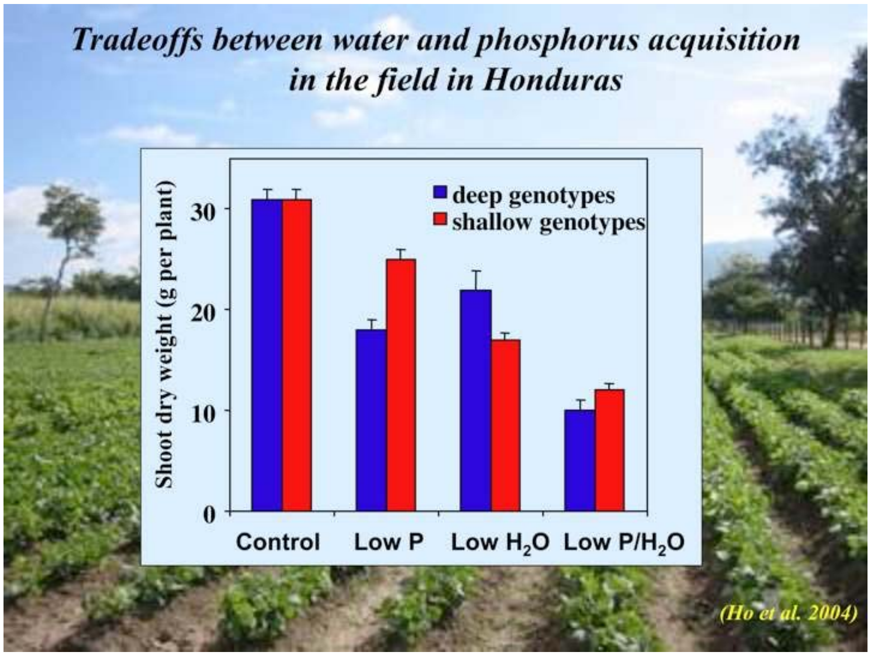
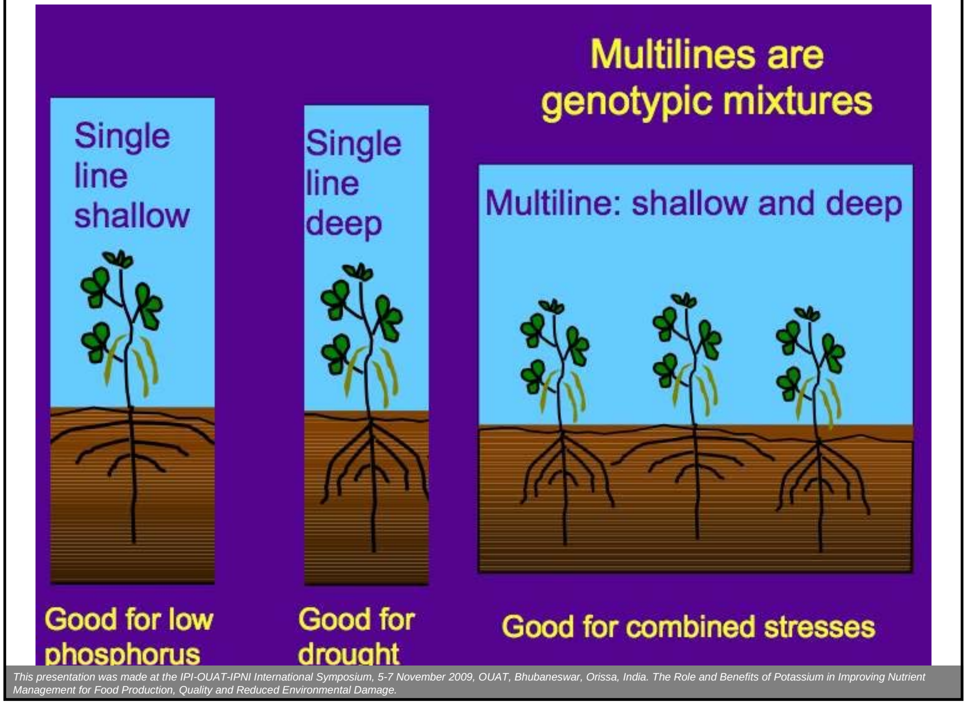
Root architectural traits: tradeoffs between water and nutrient acquisition



Tradeoffs between water and phosphorus acquisition in the field in Honduras

(Ho et al. 2004)

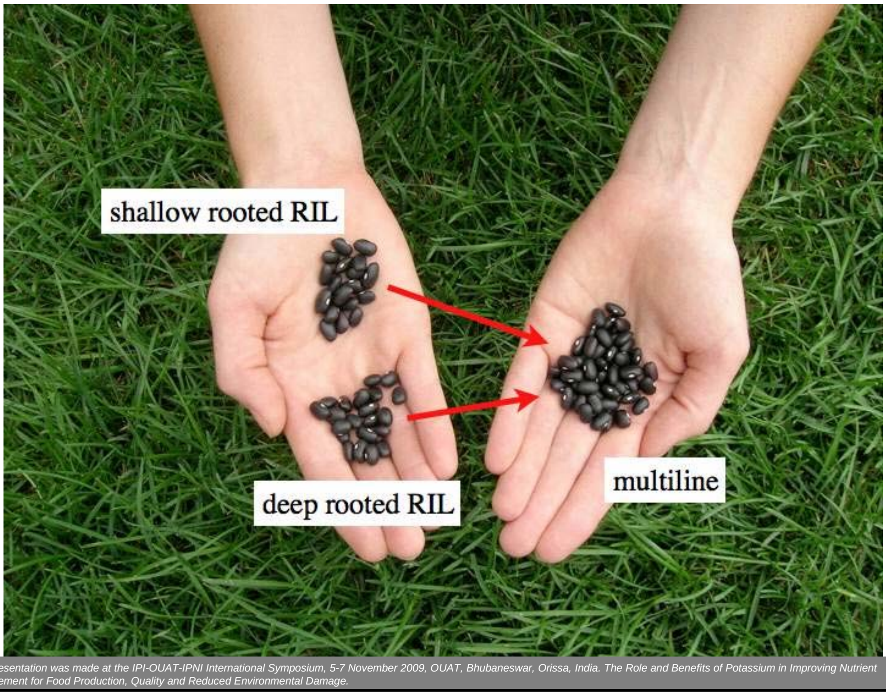


Multilines are genotypic mixtures

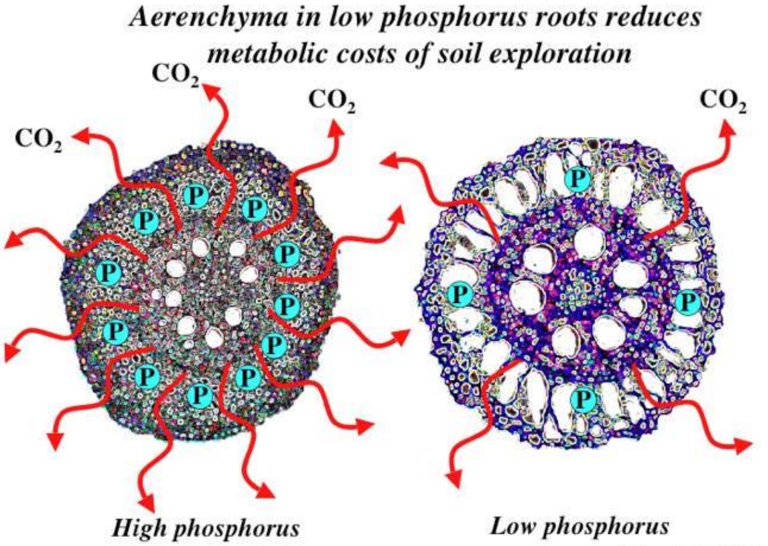
Good for low phosphorus

Good for drought

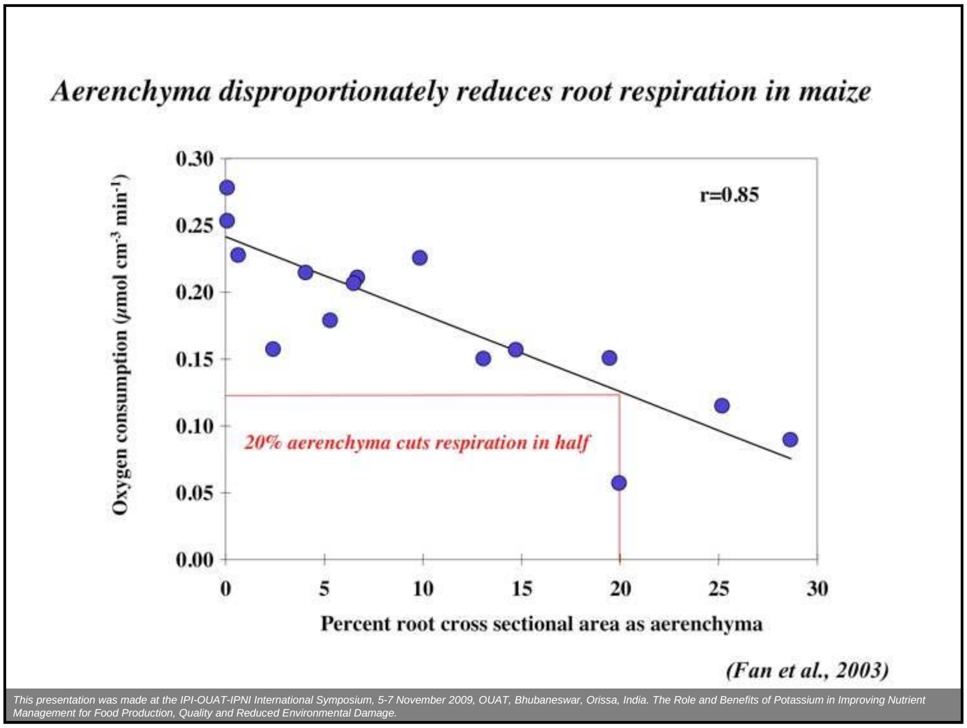
Good for combined stresses



Root architectural traits: aerenchyma


Aerenchyma in low phosphorus roots reduces metabolic costs of soil exploration

(Fan et al., 2003)

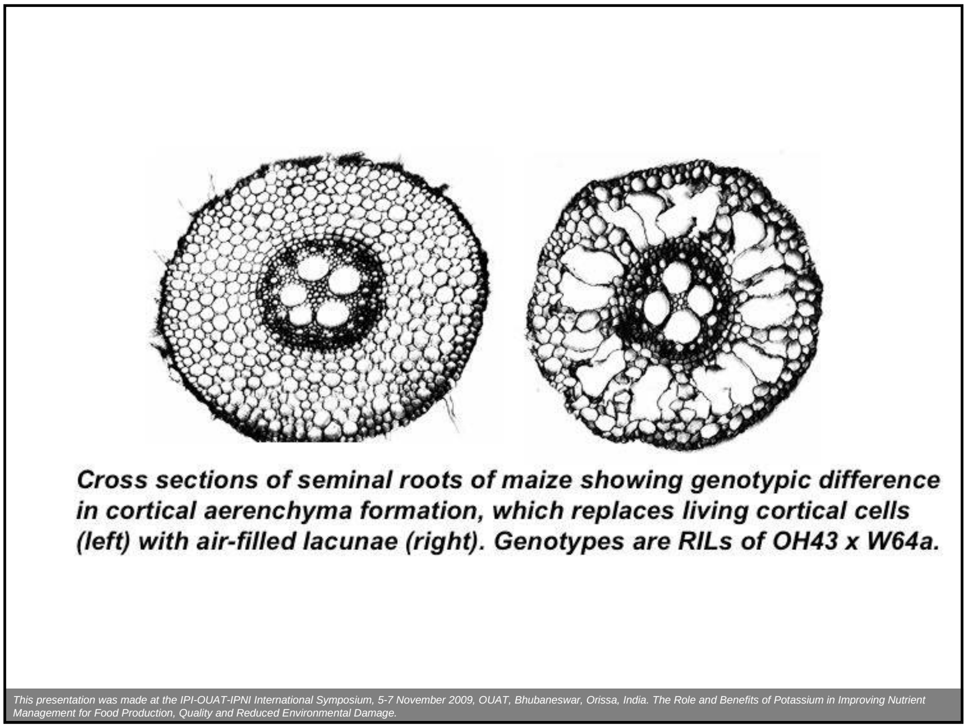


Aerenchyma disproportionately reduces root respiration in maize

(Fan et al., 2003)

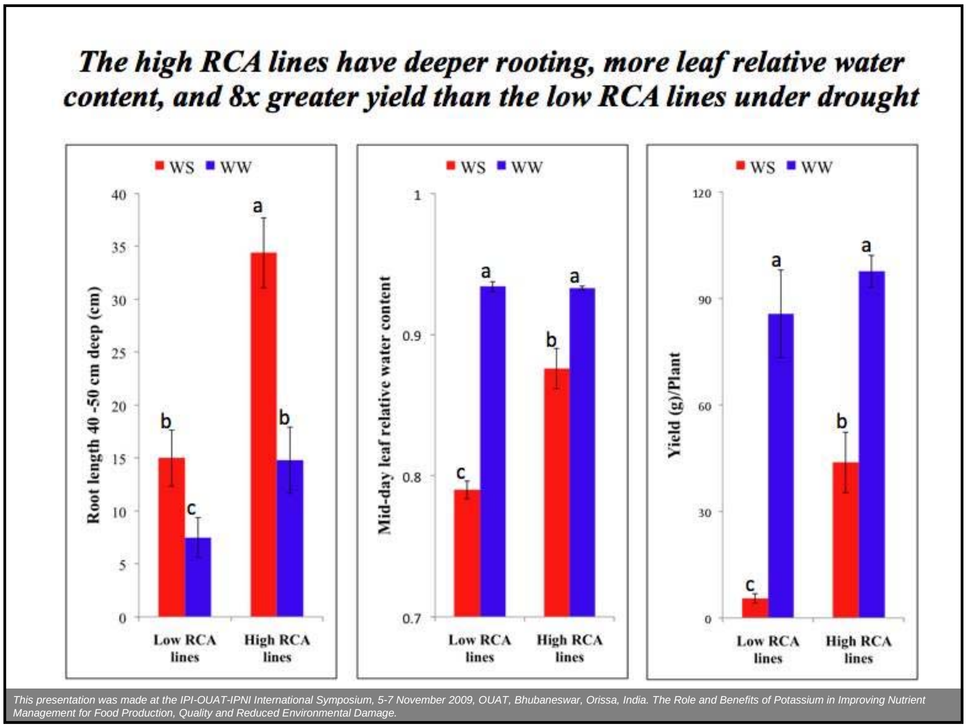
Can root cortical aerenchyma improve drought tolerance of maize?

research of Jinming Zhu



Cross sections of seminal roots of maize showing genotypic difference in cortical aerenchyma formation, which replaces living cortical cells (left) with air-filled lacunae (right). Genotypes are RILs of OH43 x W64a.

This presentation was made at the IPI-OUAT-IPNI International Symposium, 5-7 November 2009, OUAT, Bhubaneswar, Orissa, India. The Role and Benefits of Potassium in Improving Nutrient Management for Food Production, Quality and Reduced Environmental Damage.



The high RCA lines have deeper rooting, more leaf relative water content, and 8x greater yield than the low RCA lines under drought

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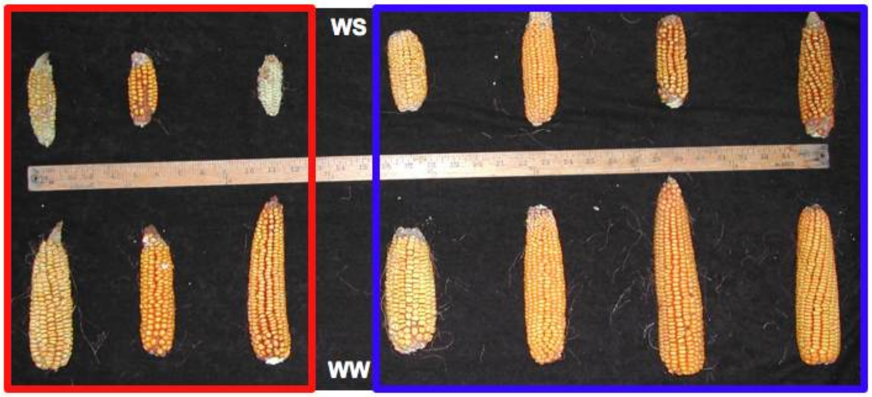
Individual Plant Yield

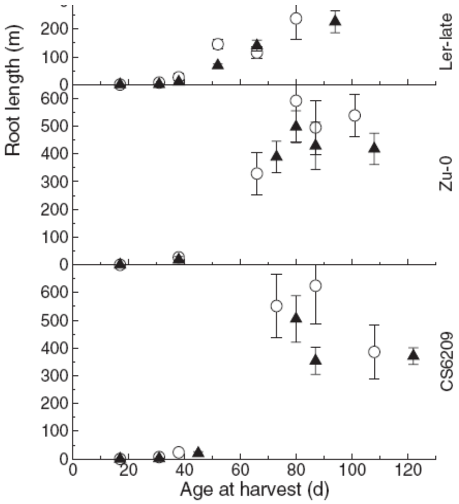
RILs with less RCA

RILs with more RCA



Genotypes with extended phenology can increase P acquisition & counterbalance warming

Climate warming accelerates plant phenology



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