Resource Availability and Plant-to-Plant Competition in Maize:

Implications for 21st Century Maize Genetic and Agronomic Improvement

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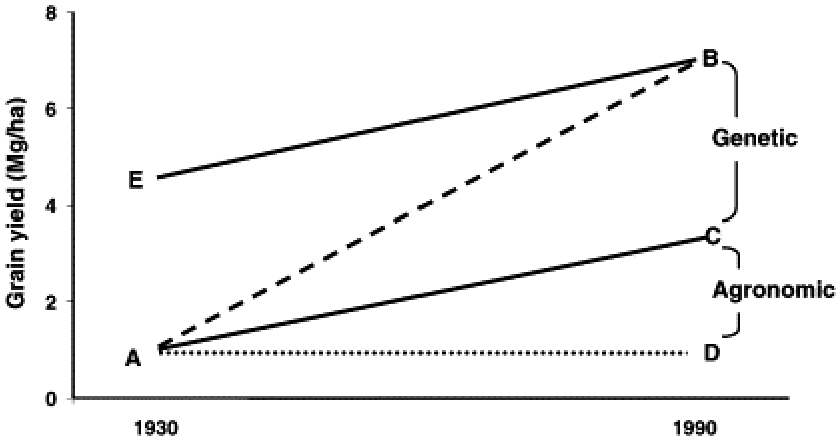
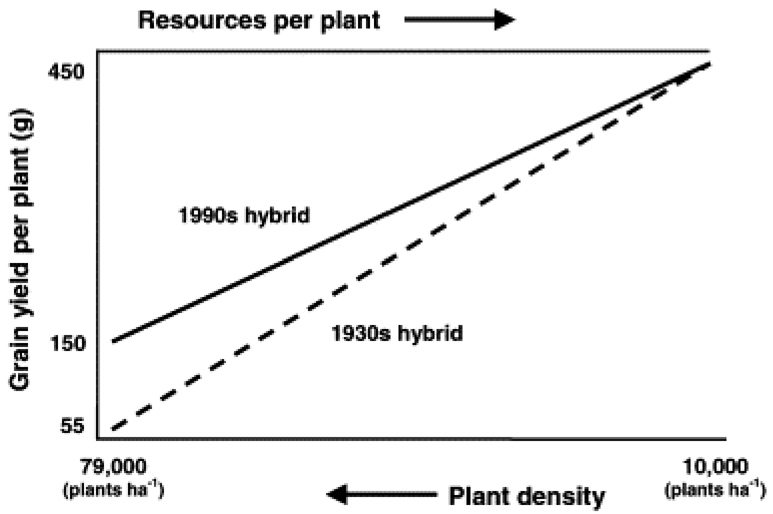
Introduction: Historical Trends

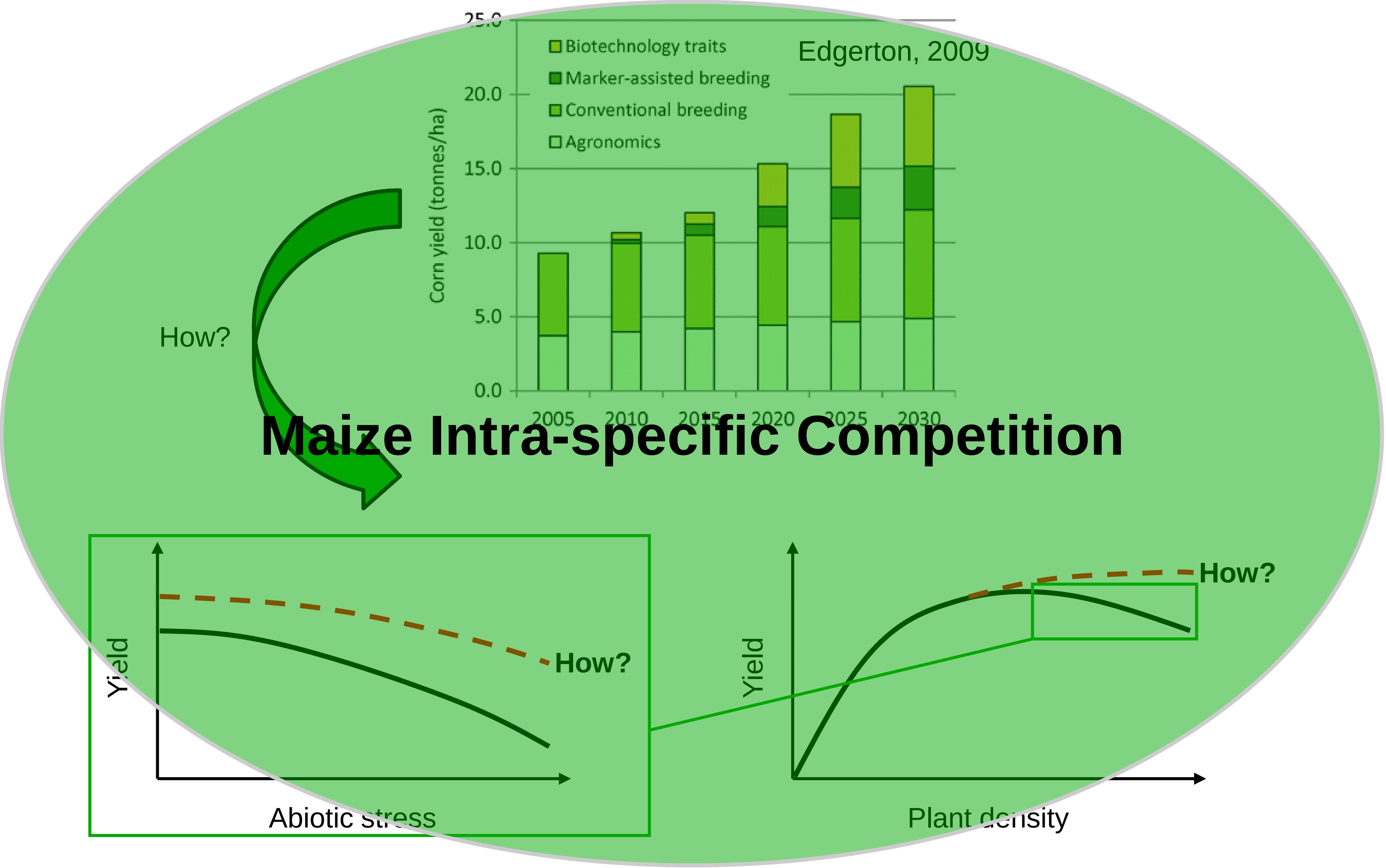
- **Pronounced maize (*Zea mays* L.) grain yield improvement**
  - Genetics (60%)
  - Agronomics (40%)
  - Genetics x agronomics (100%)
- **Improved maize environmental stress tolerance**
  - Biotic (e.g., insect feeding) and abiotic stresses [e.g., low soil nitrogen (N), drought]
  - High plant densities
- **High plant densities**
  - Reduced per-plant resource availability
  - Intense plant competition
  - Increased barrenness and per-plant growth and developmental variability
  - Pronounced plant hierarchies
    - Dominated/unsuccessful plants
    - Dominant/successful plants
  - Ultra-high plant densities → lower yield





Tollenaar and Lee, 2002

Introduction: Goals and Emphases



Introduction: Study Justification

- **Enhanced stand uniformity and reduced plant hierarchies**
- **Multi-faceted solutions**
  - Altered eco-physiology
  - Trait-mediated pest control
  - Twin-row planting pattern
  - High N fertilization rates
- **Theory and Justification**
  - Increasing N fertilizer costs and N environmental concerns
  - Understand and improve maize resource use efficiency and stress tolerance
  - Per-plant and canopy-level morpho- and eco-physiological understanding
  - Intense season-long plant hierarchy analysis
  - Temporal (e.g., emergence date, silking date) and spatial (e.g., plant spacing) aspects
  - High plant densities and varied N availability

Materials and Methods

Experimental Setup:

- 2005-2007
- Purdue University Agronomy Center for Research and Education (ACRE); West Lafayette, IN
- ~ 4,000 plants per year
- Fall strip-tillage
- John Deere RTK automatic guidance system
- 10-34-0 at 25 kg N ha^{-1}
- No intentional seeding delays, plant thinning, growth alteration, etc.

Treatments:

- Hybrid:
  - Pioneer 33N09
  - Pioneer 31G68
  - Pioneer 31N28
- Plant density:
  - 54,000 plants ha^{-1} (agronomic sub-optimal)
  - 79,000 plants ha^{-1} (≈ agronomic optimal)
  - 104,000 plants ha^{-1} (agronomic supra-optimal)
- Side-dress N rate (28-0-0):
  - 0 kg N ha^{-1}
  - 165 kg N ha^{-1} (V3) (≈ agronomic optimal N rate)
  - 330 kg N ha^{-1} [V3, V5 (equal split)]

Plant Hierarchy Definitions:

- Plants were ranked in ascending order.
- A plant was classified as dominated, intermediate, or dominant when its grain weight rank position was in the lowermost 25%, middle 50%, or uppermost 25% of the population of plants, respectively.

Materials and Methods

<u>Per-plant Measurements (partial list):</u>

- Emergence growing degree days (GDD)
- Plant available space
- Plant height (V5, V14, R1)
- Sixth-internode maximum stem diameter (V14, R1, R3, R6)
- Leaf chlorophyll/N content (i.e., SPAD) (V14, R1, R3, R5)
- Largest leaf length, width, and area (R1)
- Total green leaf area (R1)
- Green leaf area index (LAI) (R1)
- Green leaf area ratio (LAR) (R1)
- Total leaf number
- Anthesis and silking date
- Aboveground total biomass (R1, R6)
- Kernel number
- Individual kernel weight
- Grain weight
- Harvest index
- Vegetative biomass remobilization

<u>Canopy-level Measurements (partial list):</u>

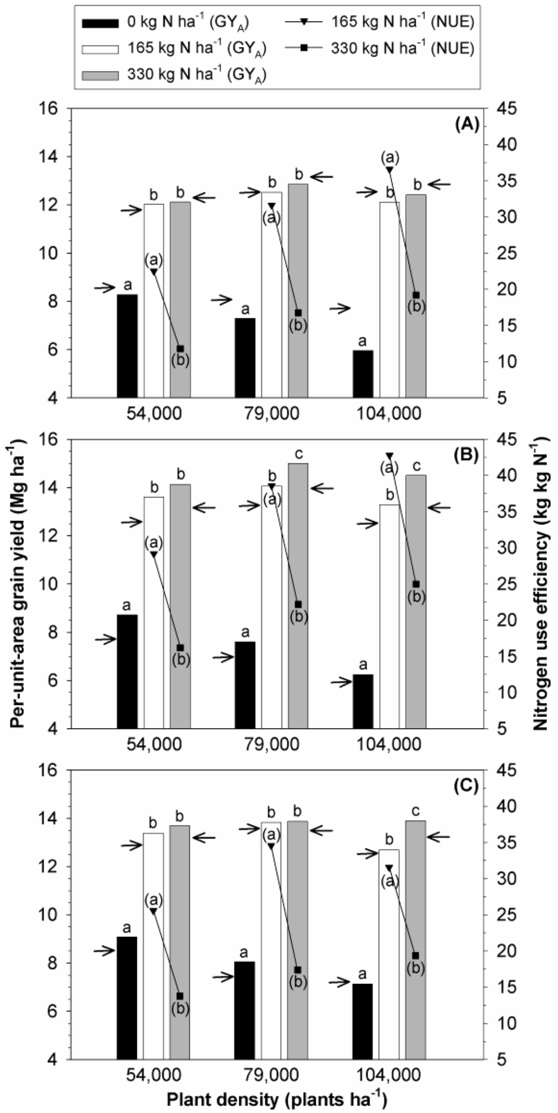
- Leaf chlorophyll/N content (i.e., SPAD) (V14; R1, R3, R5)
- Earleaf and biomass N concentrations (R1)
- Grain N, starch, sugar, amino-N, and protein levels
- Machine harvest grain yield

Per-unit-area Grain Yield and NUE

2005

2006

2007



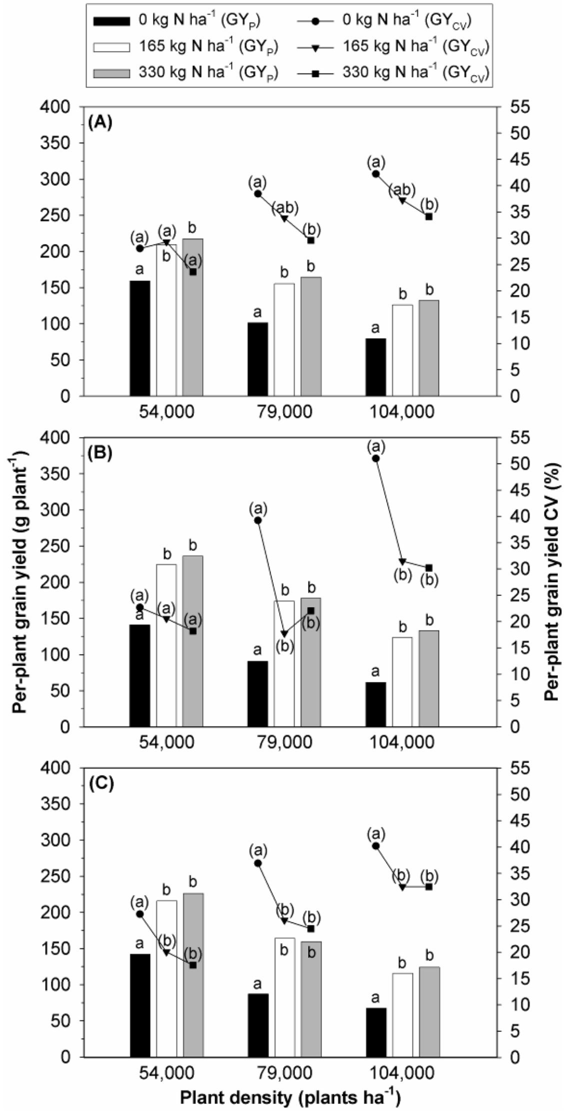
$NUE = AE_i = \Delta GY_A/\Delta N_R$

Per-plant Grain Yield Mean and CV

2005

2006

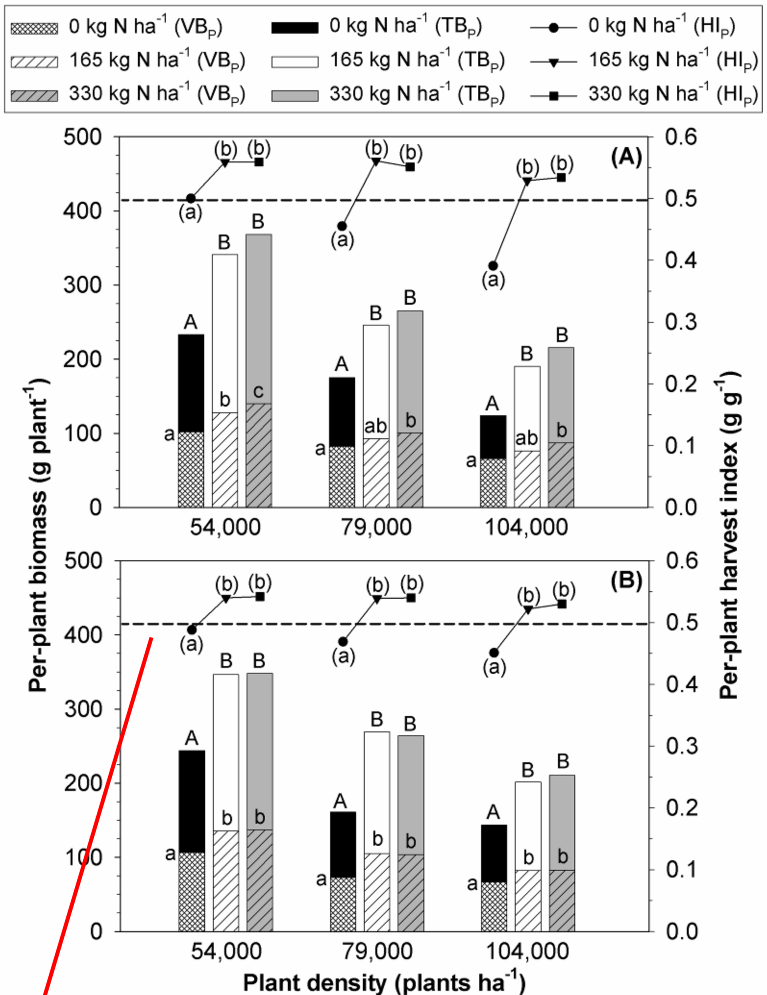
2007

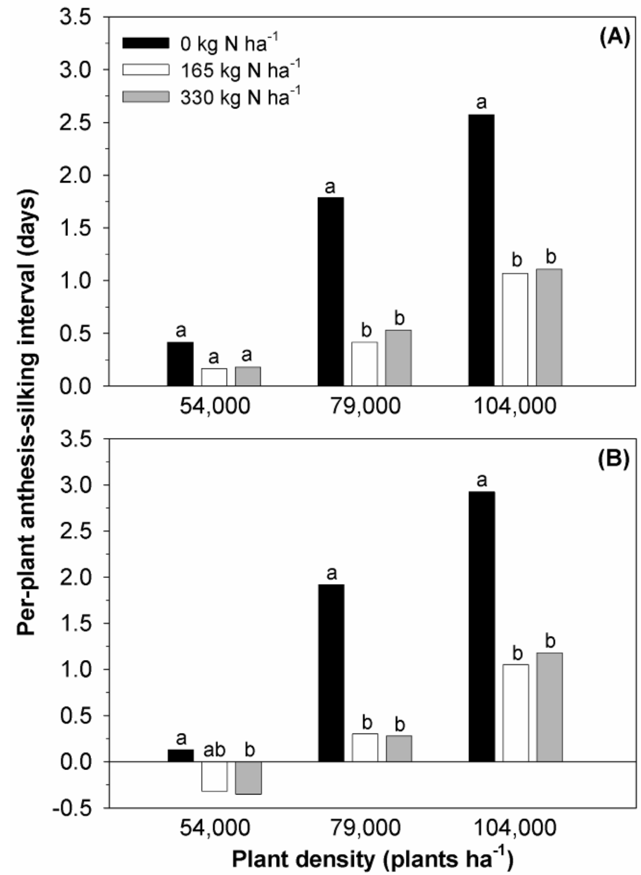


Per-plant Biomass, Harvest Index, and ASI

2006

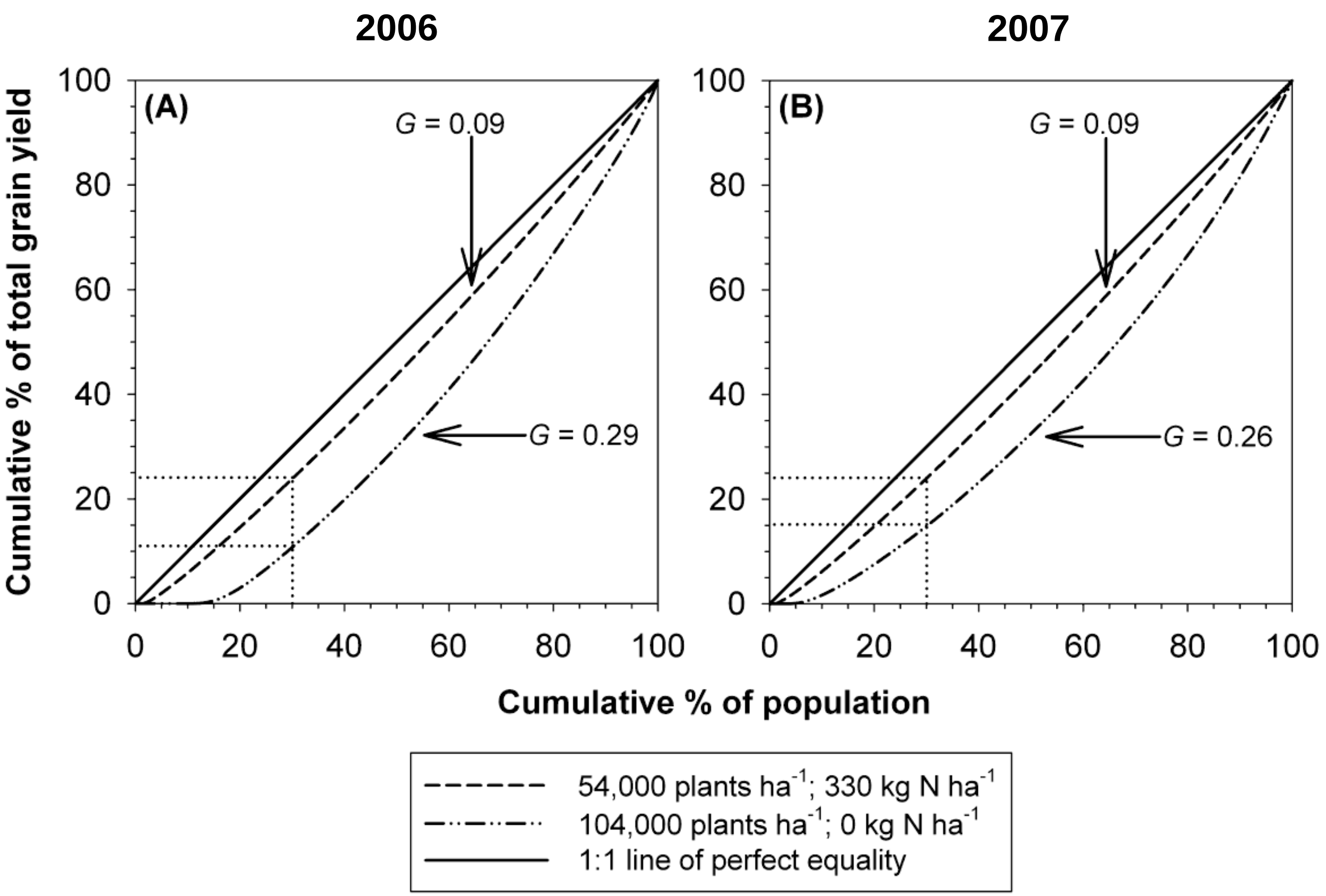
2007



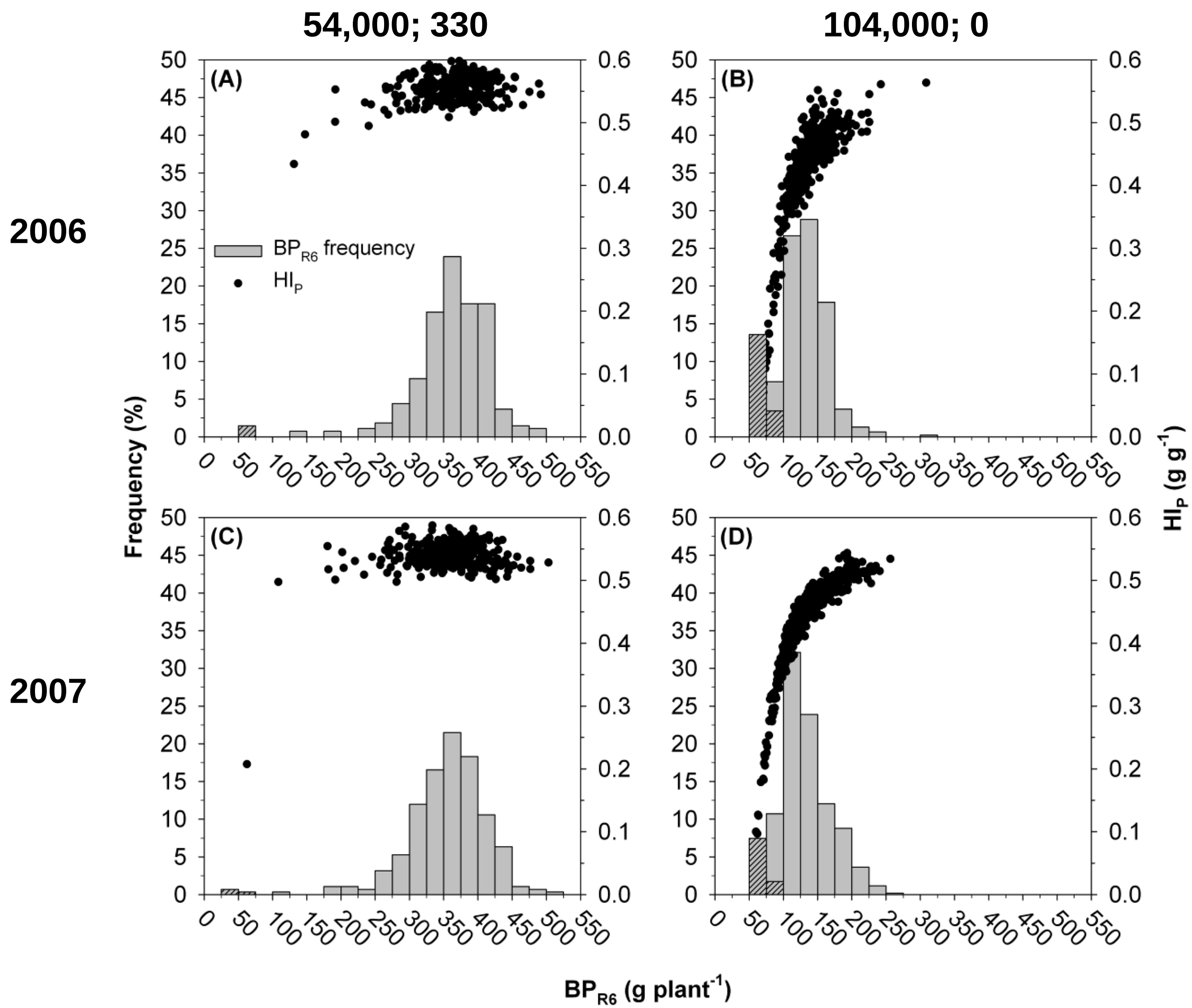


Commonly presumed harvest index of modern North American hybrids.

Per-plant Grain Yield Inequality



Per-plant Total Biomass and Harvest Index



Study Conclusions

- **Modern hybrids displayed:**
  - Strong N responsiveness.
  - Relatively high NUE.
  - High crowding tolerance when N was applied.
  - Low crowding tolerance when N was limiting.
  - Harvest index values greater than 0.5 when N was applied.
  - Plant density independence when N was applied.
- **High plant densities:**
  - Did not improve overall NUE.
  - Increased the downside risk to inadequate N availability.

Study Conclusions

- **Low yield in the highly competitive environment resulted from:**
  - Reduced production and activity of source tissues during the pre-silking period.
  - Decreased plant growth and poor biomass partitioning to the ear around the silking period.
  - Early remobilization of leaf N and accompanying reductions in photosynthesis during the grain-filling period.
  - Unequal resource sharing between plants.
  - Formation of pronounced plant hierarchies composed of dominated and dominant plants.
  - Enhanced plant-to-plant variability for a large number of phenotypic traits.

Study Conclusions

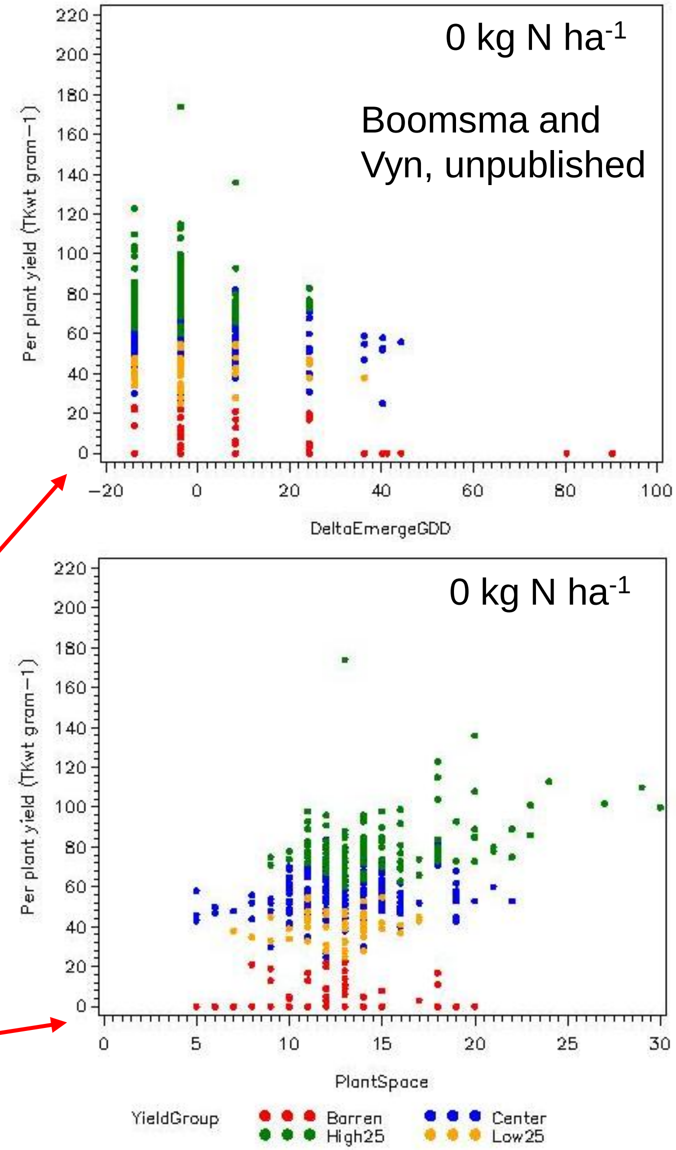
- **Symptoms of an individual plant's failure in high stress conditions:**
  - Delayed vegetative and reproductive development.
  - Lower pre-silking source tissue production.
  - Preferential pre-silking biomass partitioning to leaf versus stem tissue.
  - Reduced ability to exploit available space.
  - Lower pre- and post-silking leaf N levels.
  - Premature leaf chlorophyll losses.
  - Reduced post-silking vegetative assimilate remobilization.
  - Decreased biomass partitioning to the developing ear around and after the critical period bracketing silking.

Canopy

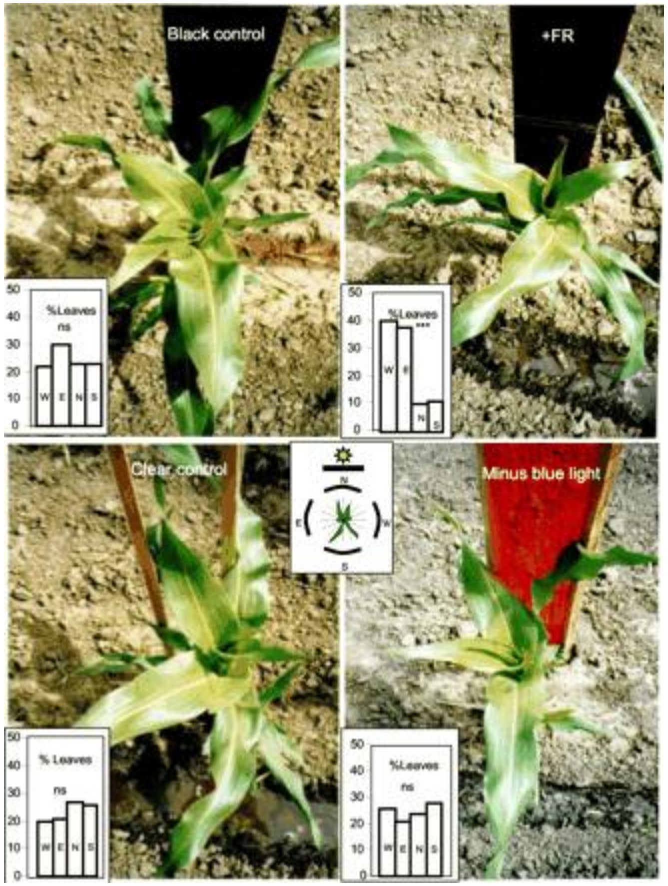
Dominated Plants

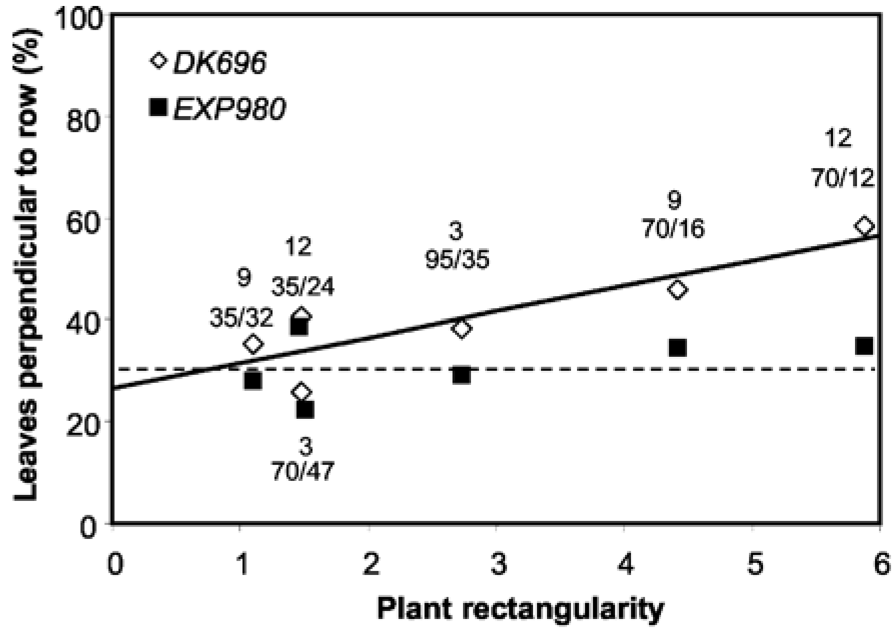
Study Conclusions

- **Keys for an individual plant's success in high stress conditions:**
  - Effectively competing for solar radiation through pre-silking stem elongation.
  - Maintaining relatively high rates of pre-silking biomass accumulation.
  - Sustaining ear biomass accumulation during the critical period bracketing silking.
  - Producing a relatively large leaf area with high leaf N levels for sustaining plant and ear growth.
  - Maintaining leaf N levels during the grain-filling period to ensure assimilate availability.
  - Limiting the premature remobilization of lower stem assimilates to root tissues.
  - Remobilizing vegetative assimilates for ear growth and development.
- **Non-issues <u>among all</u> densely-sown plants:**
  - Relatively early emergence.
  - Marginally greater available space.



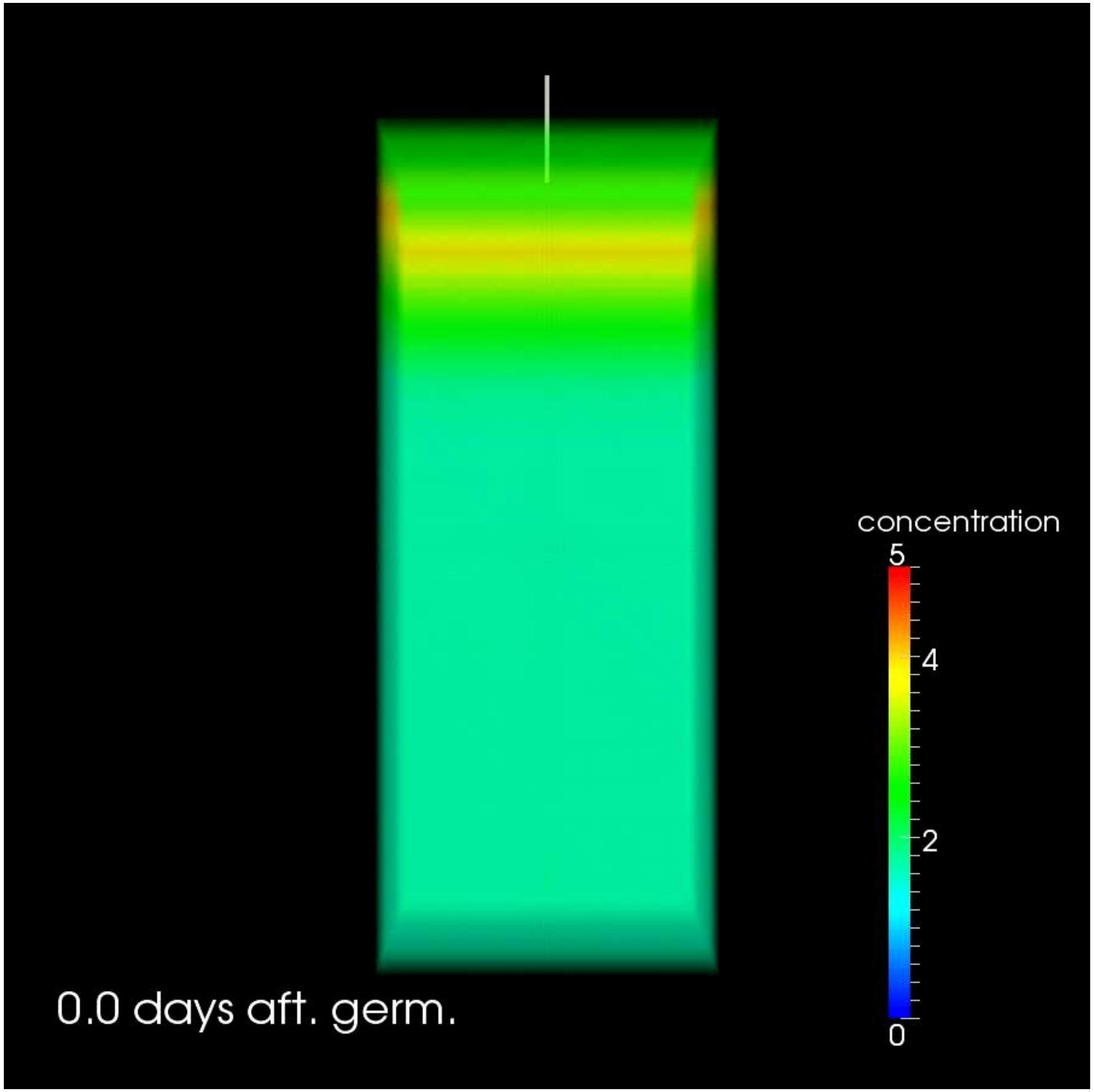
Causal Mechanisms: Aboveground Competition





Maddonni et al., 2002

Causal Mechanisms: Belowground Competition



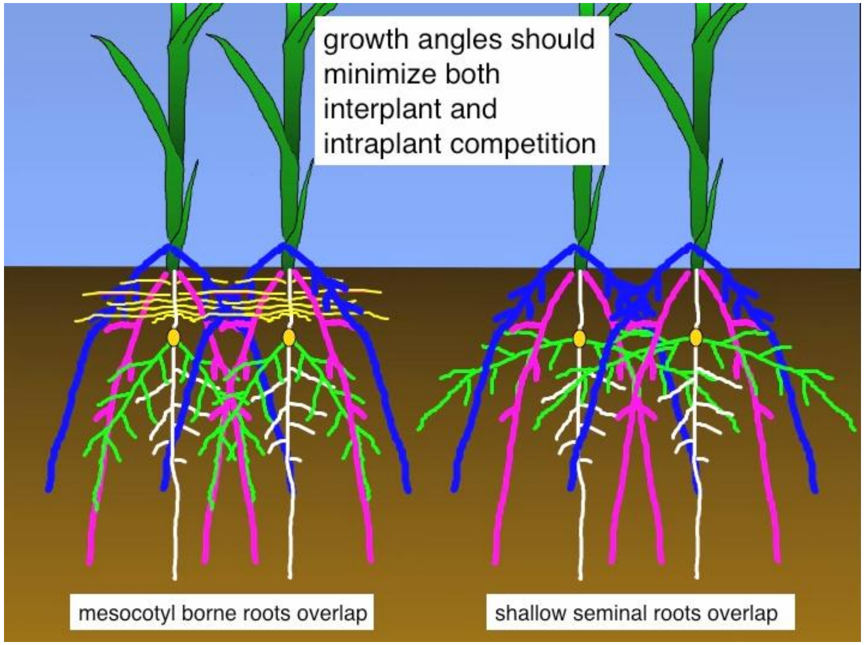
Work of
Jouke Postma

Causal Mechanisms: Belowground Competition

Work of
Jouke Postma

Avenues for Maize Improvement

- **Improve plant-to-plant uniformity**
  - Yield potential
  - Resource use efficiency
  - Stress tolerance
- **Reexamine the maize ideotype**
  - Canopy-level → per-plant level
  - Altered reproductive allometry
  - Plant plasticity (good and bad), efficient in-plant resource allocation, and growth redundancy
  - Compensatory growth habit
  - Biological altruism and Donald's ideotype
  - Belowground competition and ideotypes
  - Improved per-plant yield potential and prolificacy
- **Employ heuristic crop models**
  - Below-ground intra-specific competition
  - Spatial, temporal, and multi-resource components
  - Environmental and management aspects
  - Root-shoot interactions and in-plant/inter-organ resource allocation

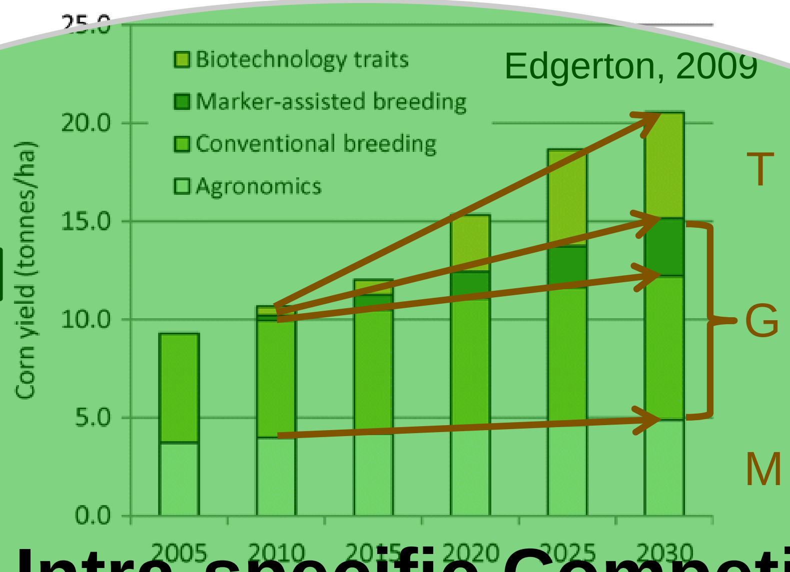


Avenues for Maize Improvement

- **Reevaluate maize agronomics**
  - High plant densities, plant density independence, and genotype plasticity
  - Site-specific management (landscape → individual plant)
- **Consider plant ecology and microeconomics**
- **Physiology: observe and chronicle → guide and predict**
- **Translational research**

Genomics/proteomics/metabolomics → phenomics → agronomics

Avenues for Maize Improvement



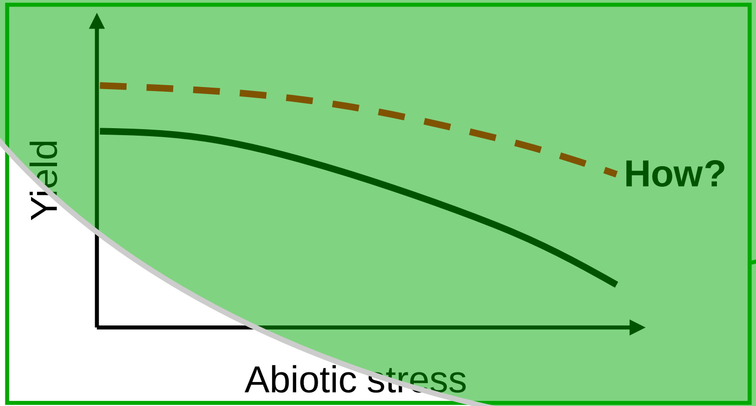
= G x T x E x M
= 100%

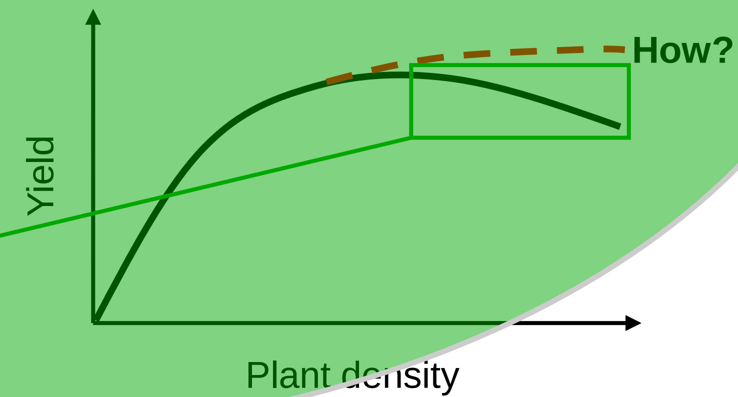
How?

- Yield Potential
- Resource Use Efficiency
- Stress Tolerance/Yield Stability

Maize Intra-specific Competition

E





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