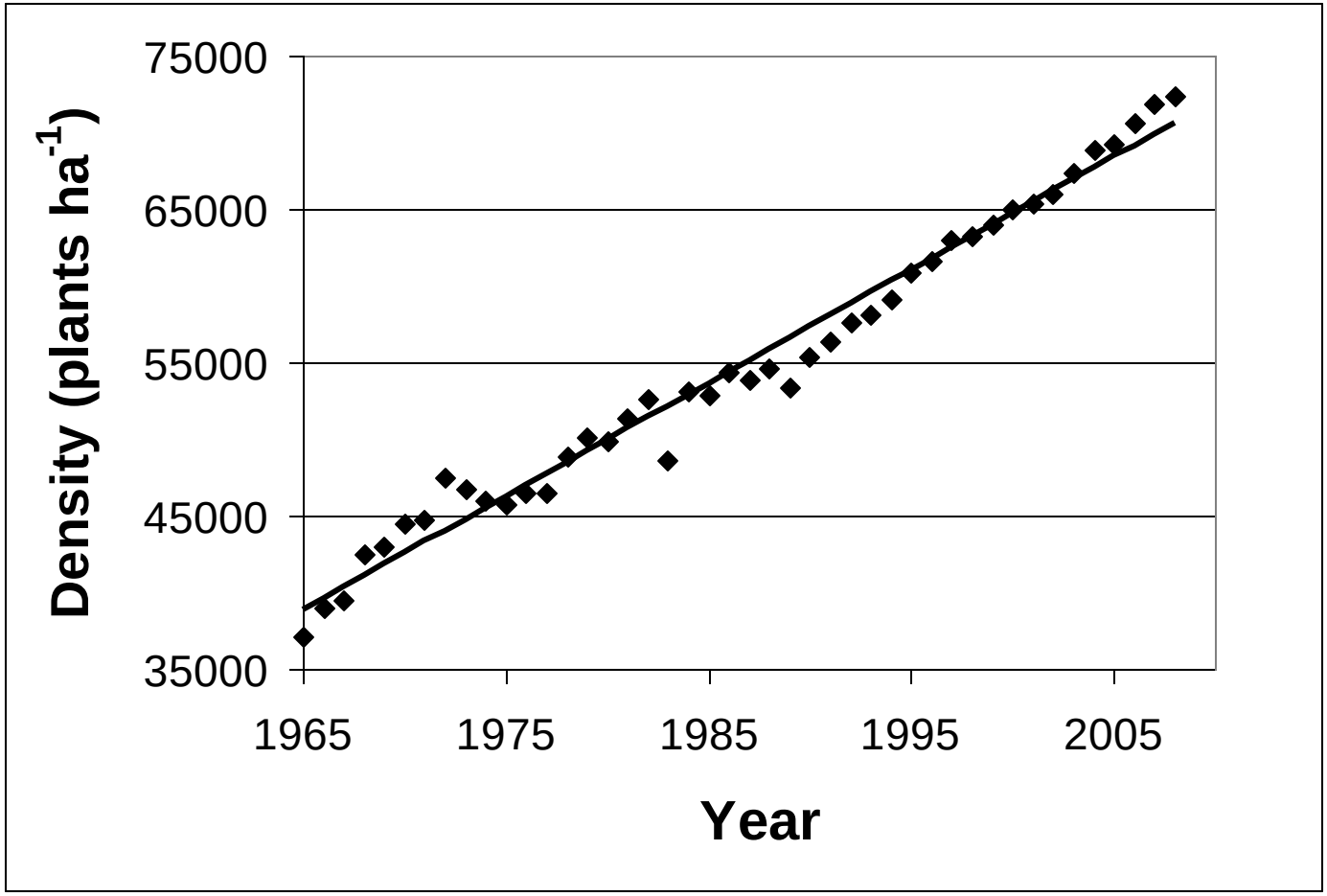
Inheritance of Adaptation to High Plant Density in Iowa Stiff Stalk Synthetic

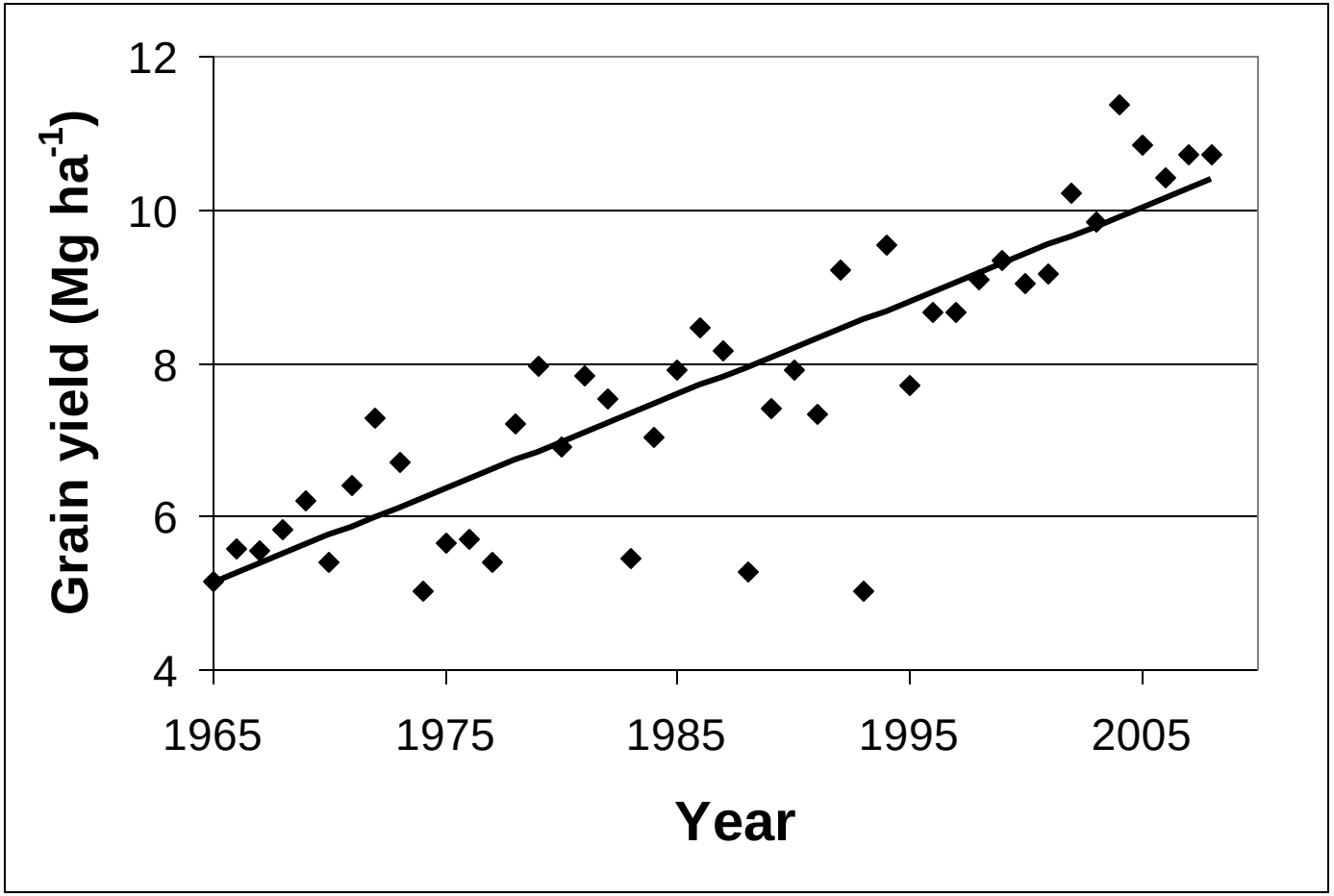
Jode Edwards
USDA ARS
Jode.Edwards@ARS.USDA.GOV

Iowa Plant Density: 1965-2008



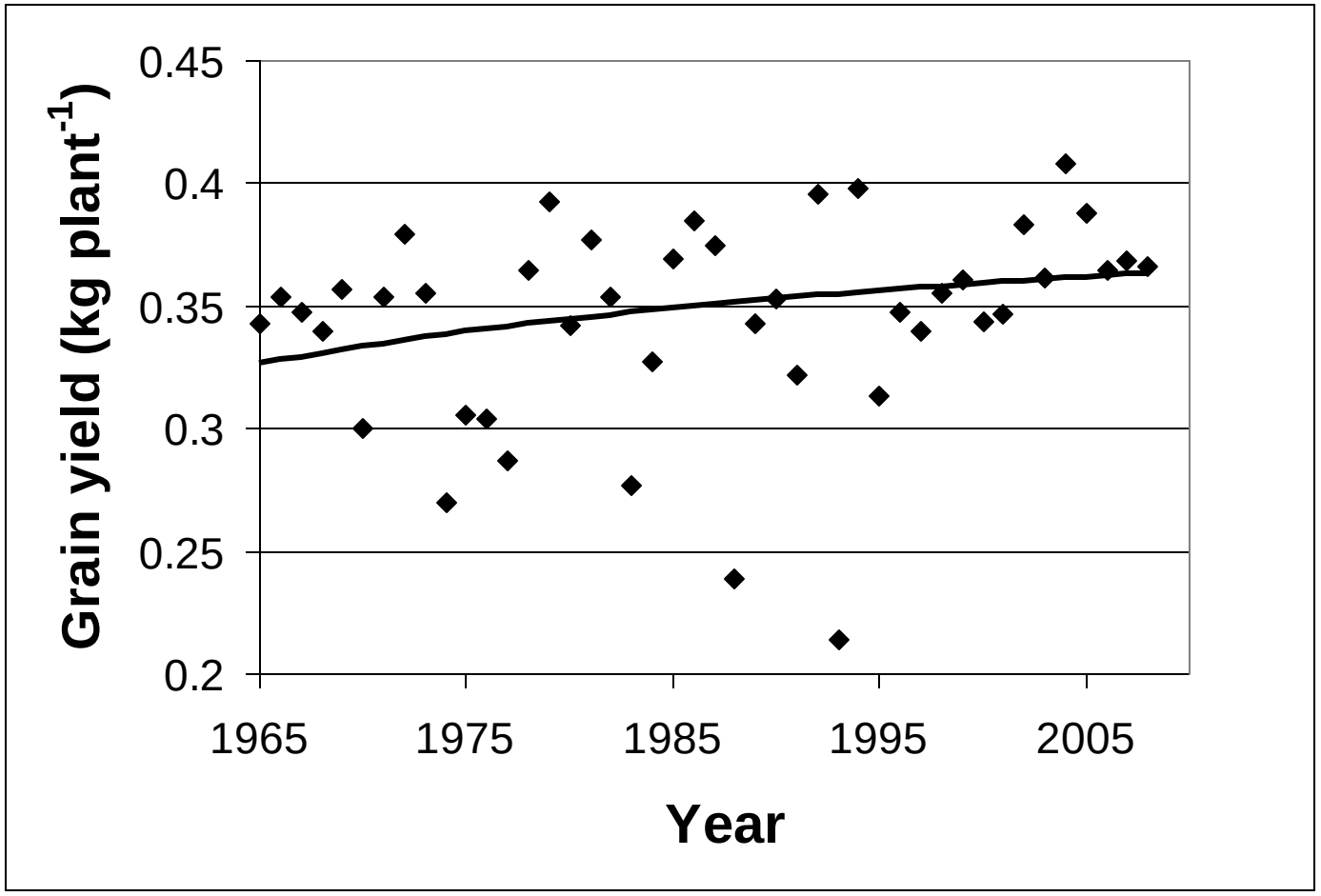
Source: USDA National Agriculture Statistics Service (NASS)

Iowa Grain Yield: 1965-2008



Source: USDA National Agriculture Statistics Service (NASS)

Iowa Grain Yield per Plant



Density Contribution to Yield

- Increase in density 1965 - 2008

  3.2 plants m^{-2} = 82% increase

- Increase in yield 1965 - 2008

  5.6 Mg Ha^{-2} = 102% increase

  0.037 kg $plant^{-2}$ = 11% increase

- Yield increases could be interpreted as an increase in adaptation to high plant density

Era Hybrid Studies

- Duvick (2005) numerous phenotypic changes in commercial hybrids based on era hybrid studies
  - Reduced silking anthesis interval
  - Fewer tassel branches
  - More erect upper leaves
  - Reduced barrenness
- These phenotypes contribute to adaptation to high plant density

Adaptive Phenotypes

- Upright leaves
  - 50% of full sunlight intensity = 80% of photosynthetic rate at full sunlight
  - Upright upper leaves permit more light to penetrate the canopy
- Reduced tassel branch number
  - Duncan et al. (1967) estimated tassels could block enough sunlight to reduce photosynthesis by 19%

Do Tassels Block Sunlight?

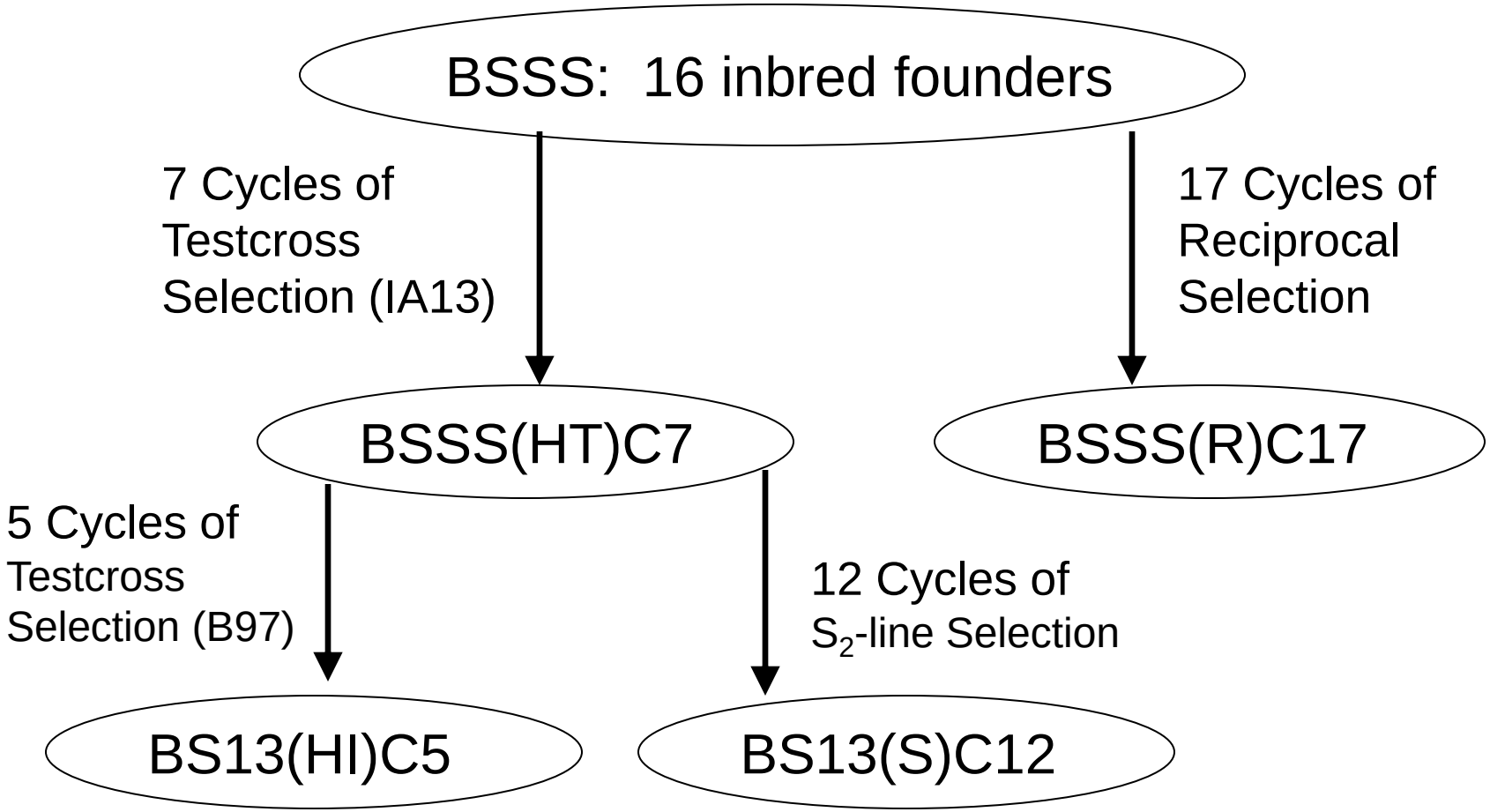
Adaptive Phenotypes

- Anthesis silking interval (ASI)
  - Modern hybrids have shorter intervals between anthesis and silking
  - Increased by high plant density in unadapted hybrids
- Barrennes
  - Modern hybrids have reduced barrenness
  - Increased by high plant density in unadapted hybrids

Inheritance of Adaptation

- Era hybrid studies and other physiological studies were primarily descriptive
- Less is known about inheritance of adaptive phenotypes, especially gene action

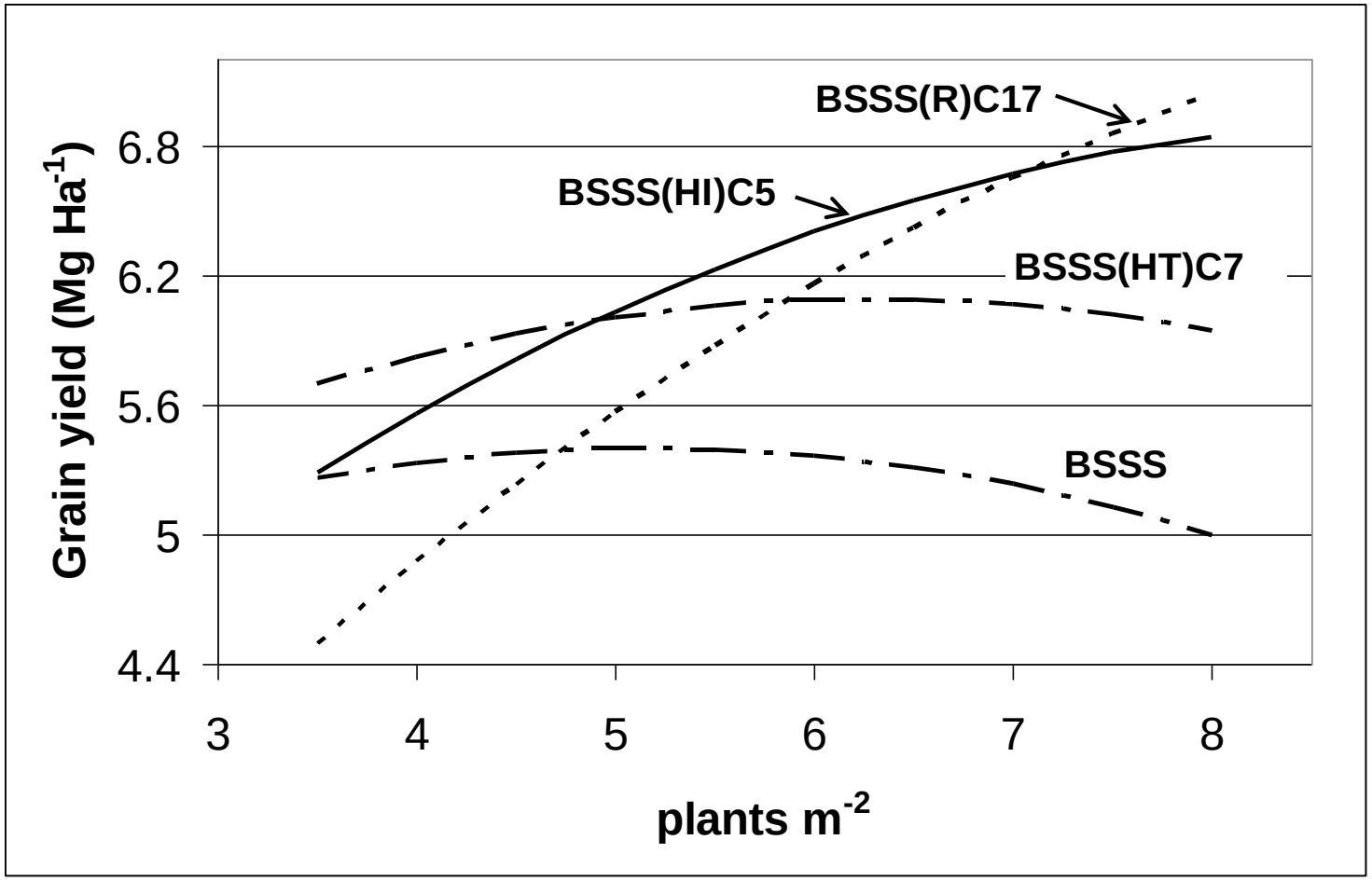
The Lab Rat: Iowa Stiff Stalk



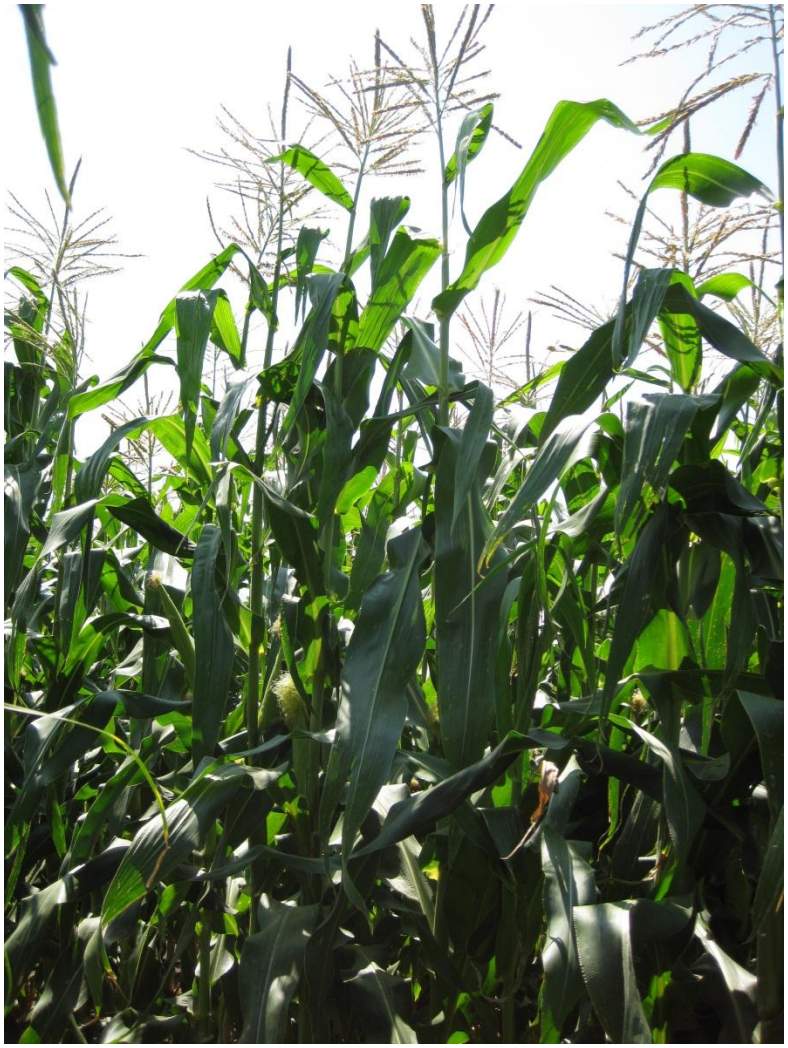
Why BSSS?

- Primary selection criteria was agronomic performance
  - grain yield, grain moisture, lodging resistance
- Selection has increased adaptation to high plant density in BSSS
- Progenitors, all cycles of selection, and complete records on the selection program are available
- Closed population

Density Response in BSSS Populations
(Brekke et al., 2011)



BSSS



BSSS(R)C17

Objectives

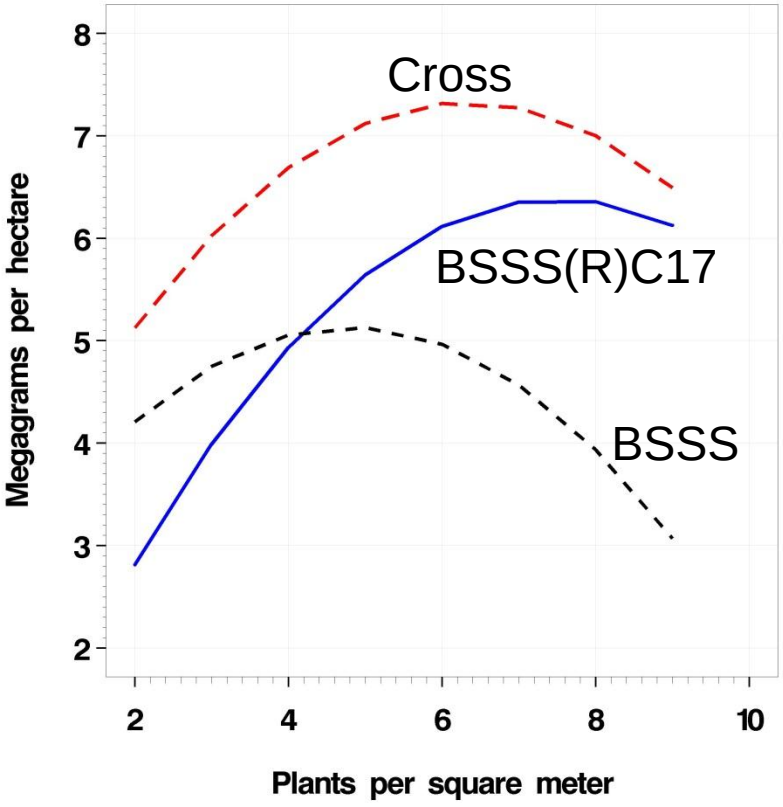
- **Determine mode of inheritance of adaptation to high plant density in BSSS**
  - **Breeders null hypothesis: favorable yield alleles are dominant**
- Map regions and candidate genes for adaptation to high plant density
- Apply genetic information to utilization of unadapted germplasm

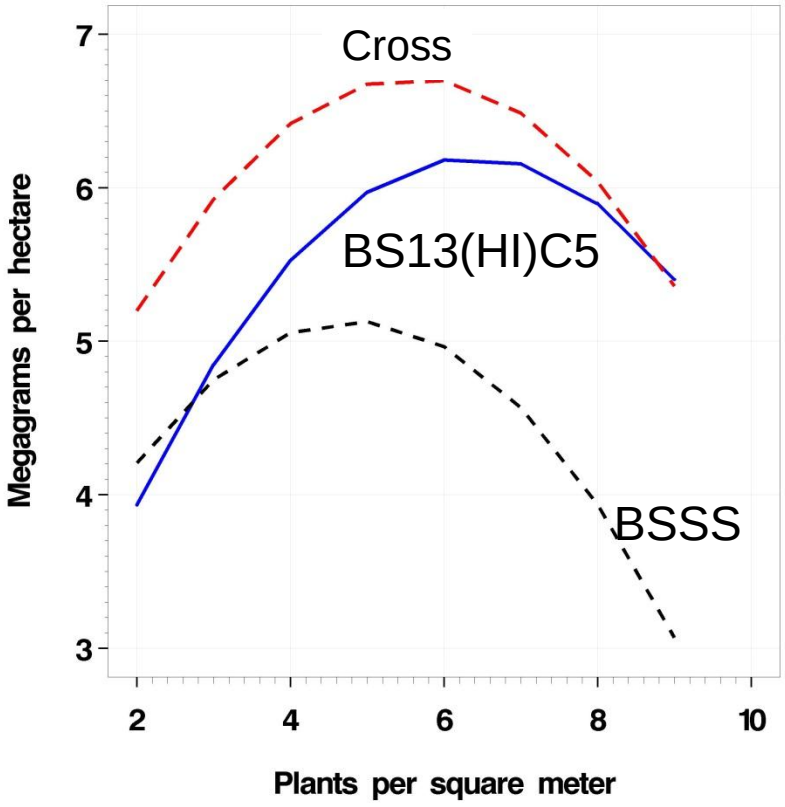
Procedures

- Crossed unadapted populations to adapted populations
  - BSSS x BSSS(R)C17, BS13(HI)C5, B97
  - BSCB1 x BSSS(R)C17, BS13(HI)C5
- Four plant densities: 3.8, 5.7, 7.7, 9.6 plants m^{-2} (1 plant m^{-2} = 4047 plants $acre^{-1}$)
- Split-plot design with density as whole plot
- Two replications at four locations

Grain Yield

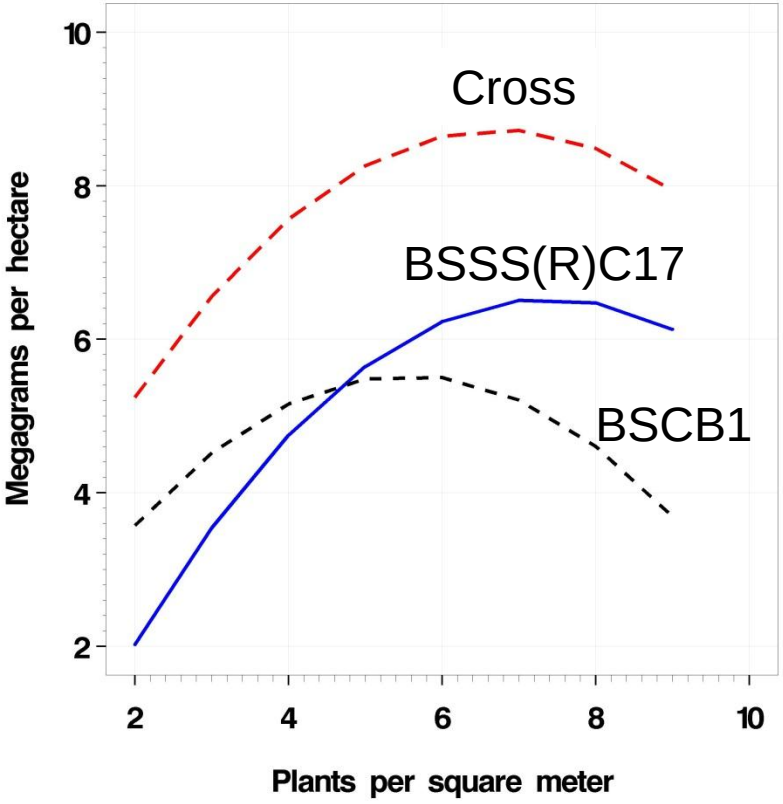
8 environments

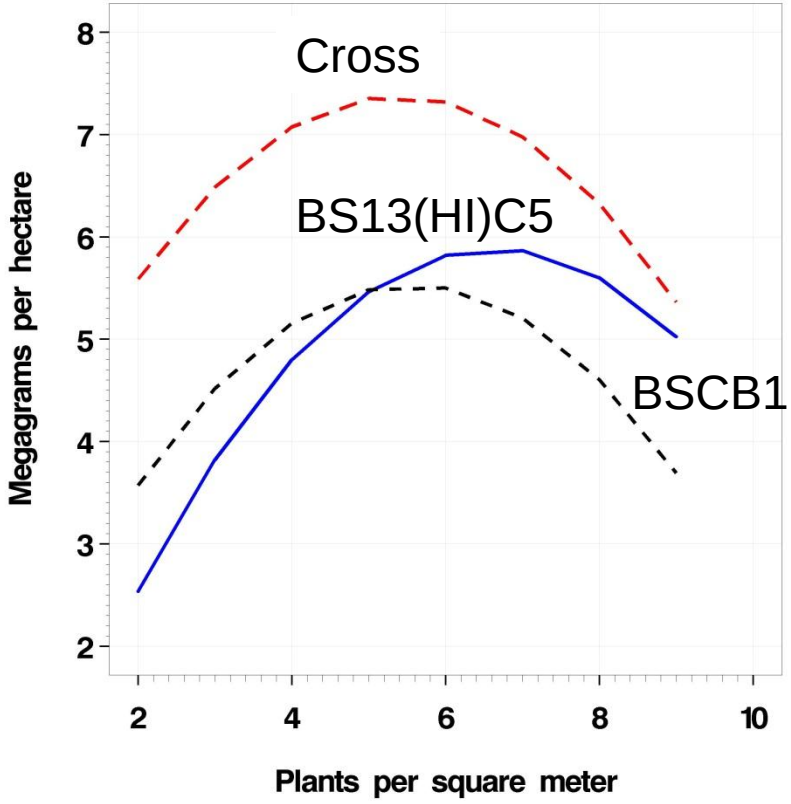




Grain Yield

4 environments

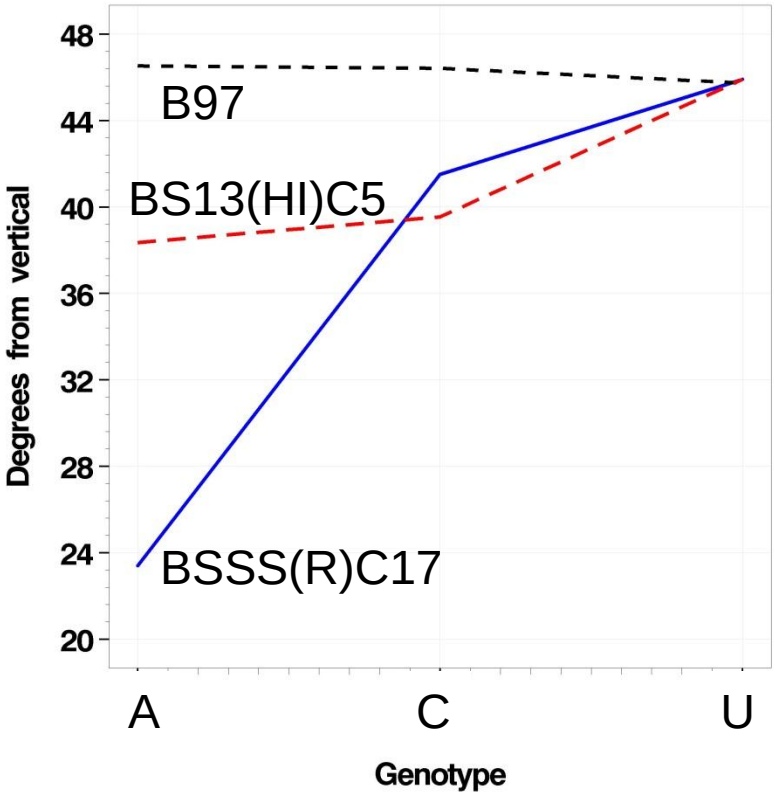




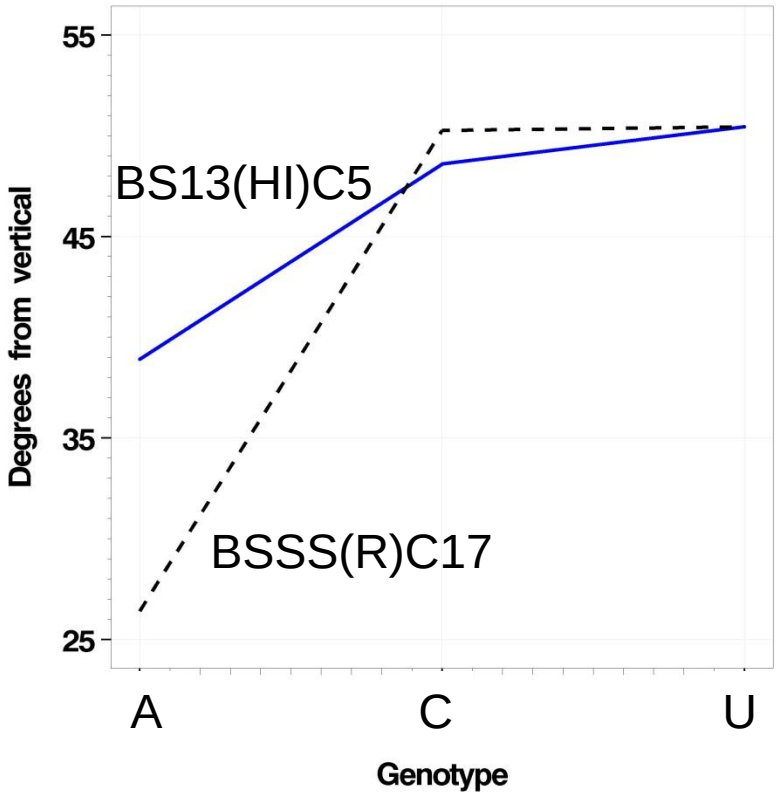
Flag Leaf Angle

2 environments

BSSS



BSCB1

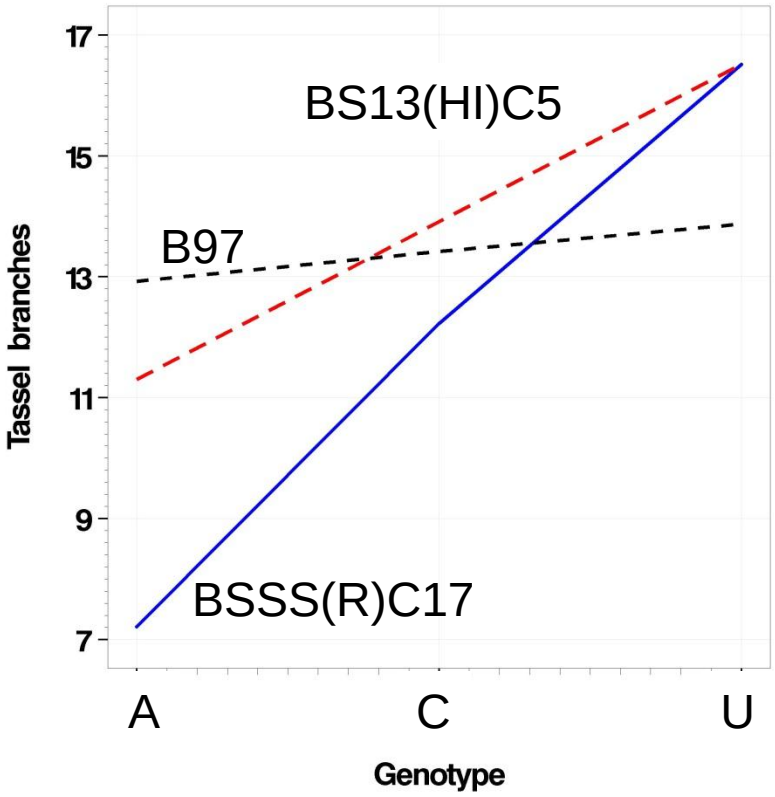


A=adapted; C=cross; U=unadapted

Tassel Branch Number

2 environments

BSSS



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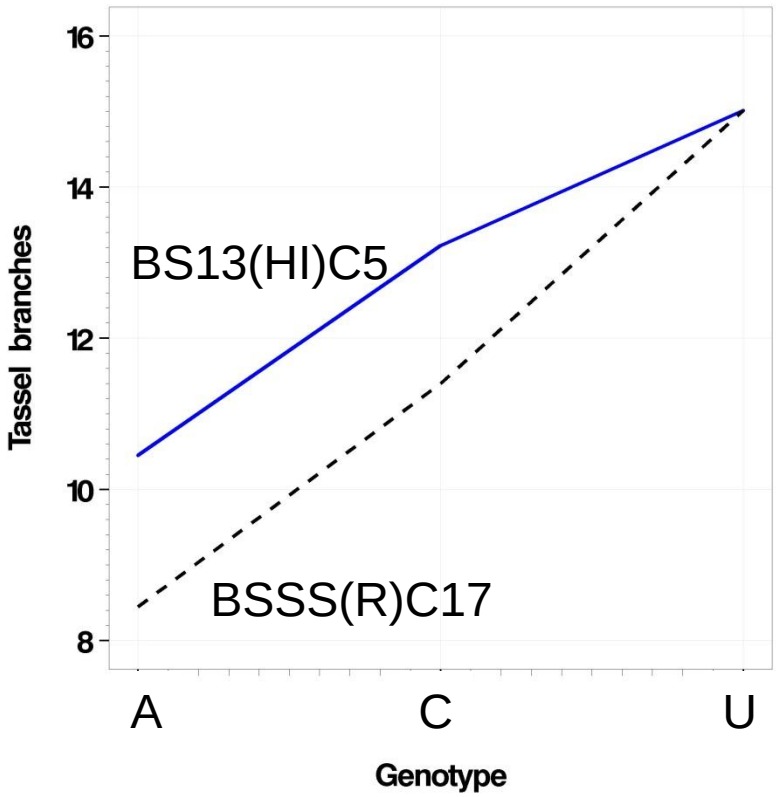

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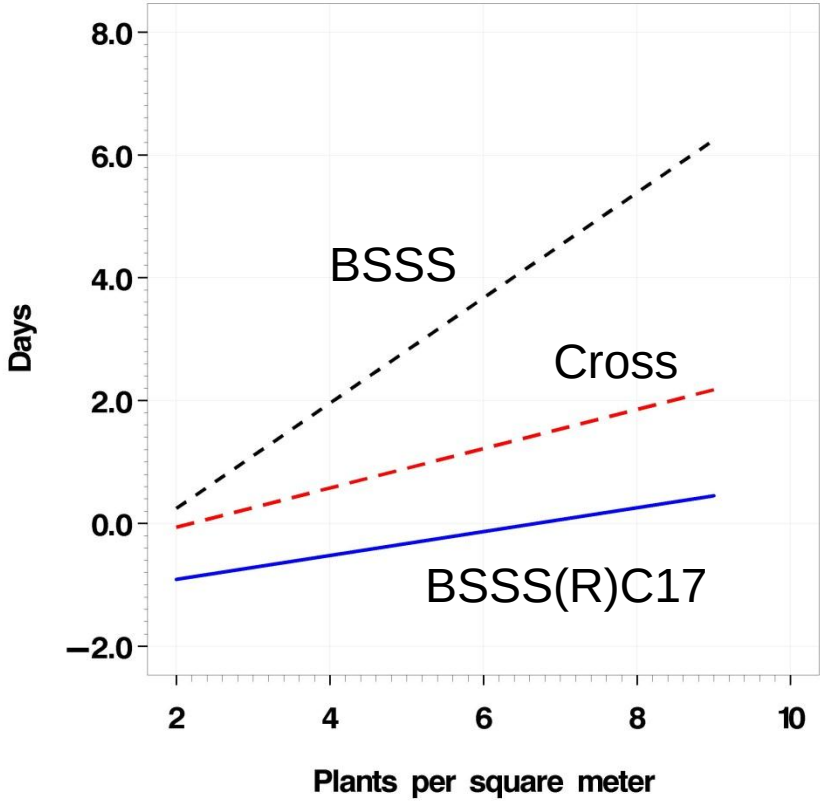
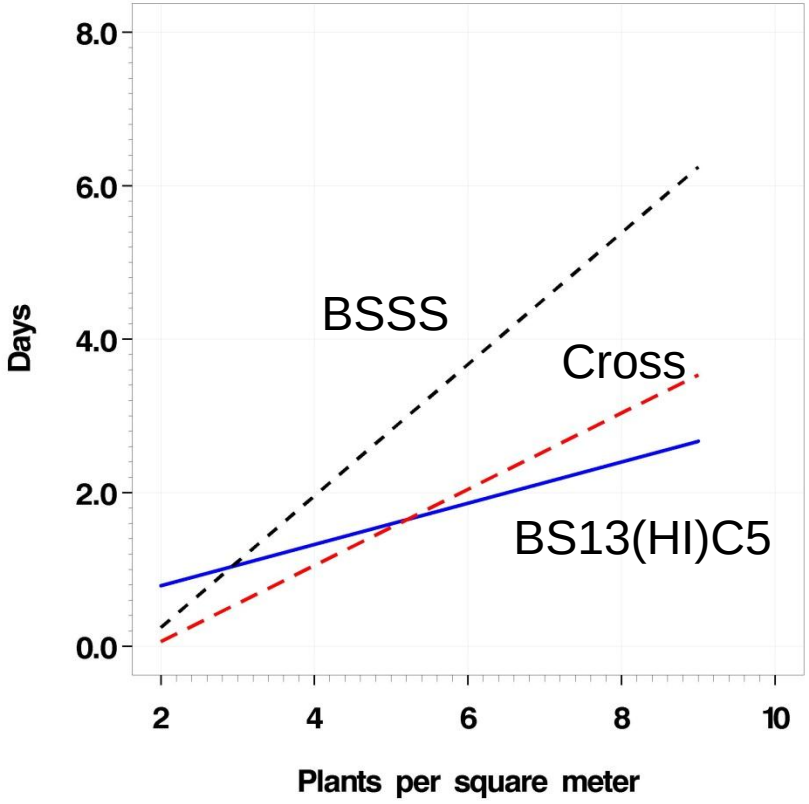
Anthesis-Silking Interval

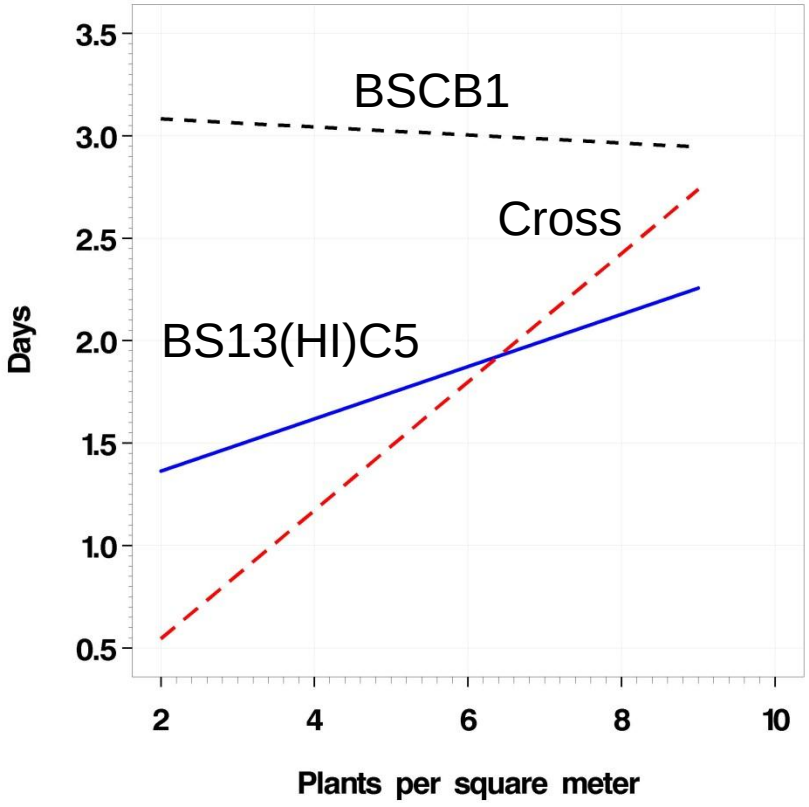
2 environments

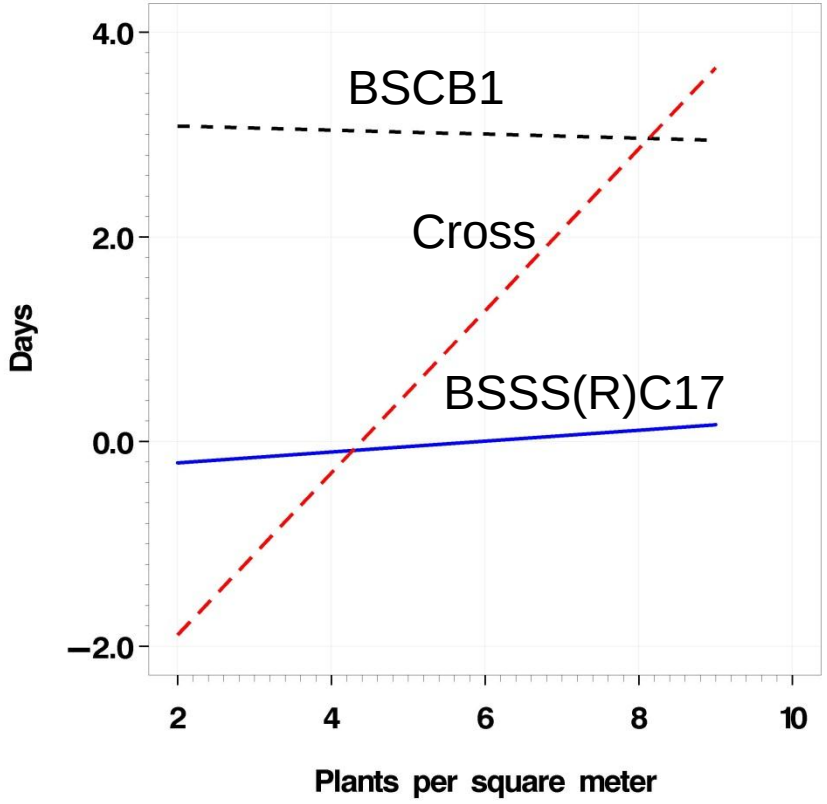




Anthesis-Silking Interval

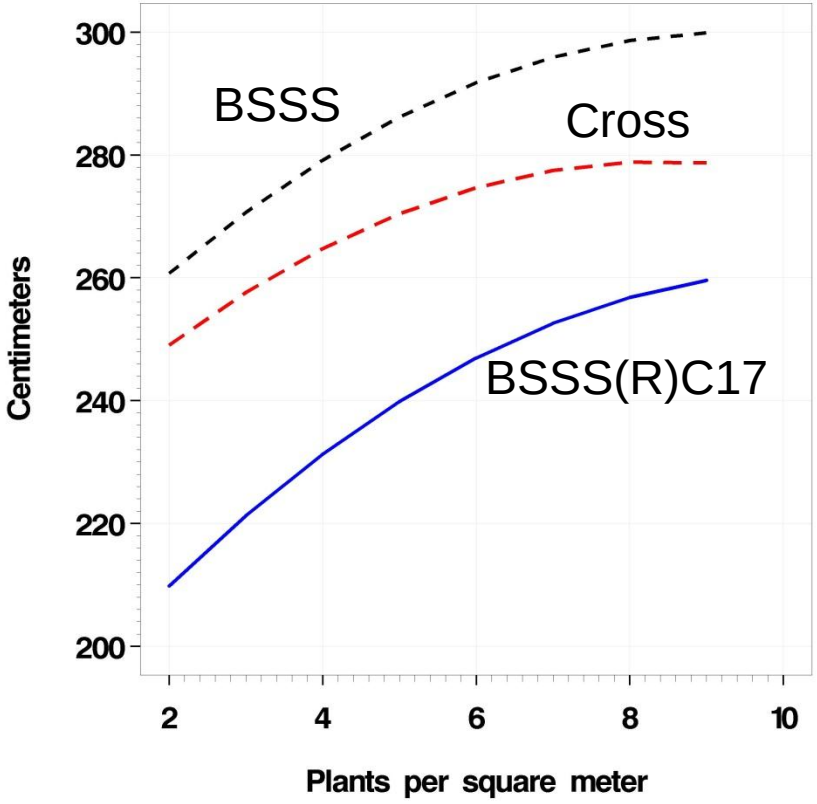
1 environment

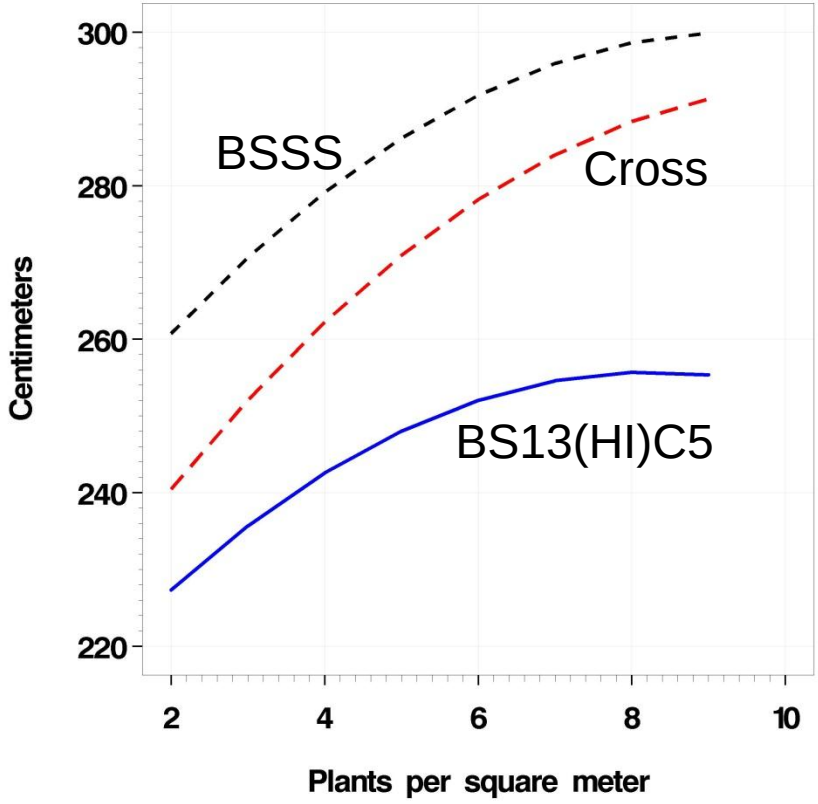




Plant Height

1 environment





Inheritance of Density Response

- Grain yield
  - partially recessive to partially dominant
  - Cross always intermediate to parents
- Upright flag leaf: Recessive or additive
- Tassel branch number: Additive
- ASI
  - Dominant in BSSS crosses
  - Underdominant in BSCB1 crosses (need more data)
- Plant height: inconclusive (need more data)

Discussion

- Generation means analysis
  - Only averages of gene action are estimable
  - Dominant and recessive alleles at different loci may cancel
- Need more environments, replications, and densities
- Need a formal parameter to summarize density responses to declare a particular response curve dominant or recessive

Discussion

- Ubiquitous heterosis has led to a dogmatic connection between ‘favorable’ and ‘dominant’
- Walejko and Russell (1977), Crosbie and Mock (1979):
  - B73 did not mask unfavorable alleles in crosses to BSSS
  - Interpreted this observation in terms of allele frequencies as opposed to gene action
- Recessive adaptation alleles are much more difficult to find and we haven’t looked for them

Choice of Tester

- A body of literature has developed around choosing weak, i.e., recessive, testers
- If there are recessive adaptation alleles, an unadapted tester may mask adaptation
- Breeders generally choose the best tester
- Quantitative genetics may be catching up to breeders

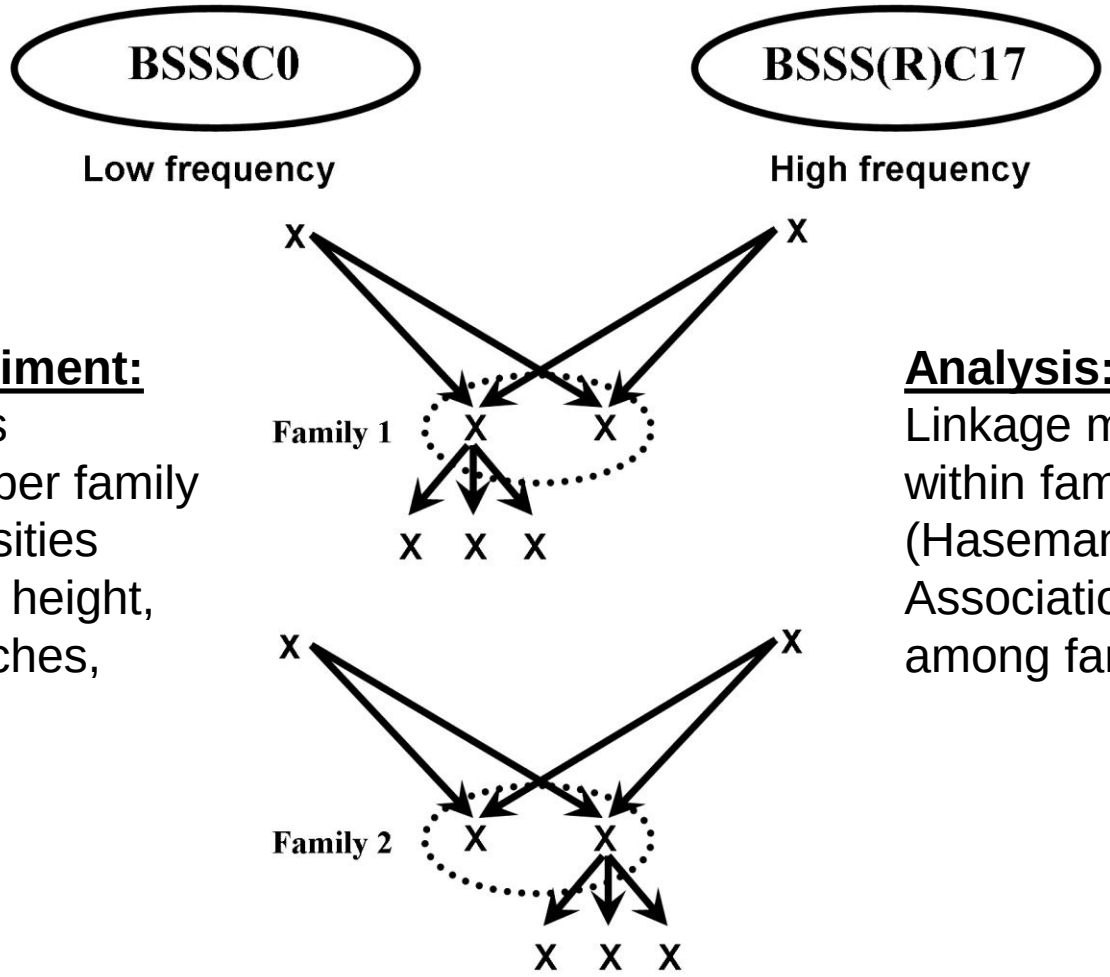
Inbred Progeny Selection

- Inbred progeny selection has not been effective for grain yield (Wardyn et al., 2009; Edwards, 2010)
- inbred progeny selection for adaptive phenotypes is a good idea (Troyer, 2009)
  - Adaptation was often additive or recessive
  - In contrast to grain yield, all crosses were intermediate to parents in this study
  - Caveat: make sure we know the ideotype

Use of Germplasm

- It has taken 70 years of maize breeding to derive BSSS(R)C17 from BSSS
- How do we do it faster?
  - Select directly for adaptation to high plant density
  - Genomics: Identify alleles that confer adaptation to high plant density and use markers to stack adaptation alleles in unadapted populations
- If 70 years could be reduced to 20 years or 10 years, an enormous pool of diverse germplasm could be evaluated much more effectively

Mapping Adaptation



2010 experiment:
100 families
8 $F_{2:3}$ lines per family
4 plant densities
Traits: ASI, height, tassel branches, leaf angle

Analysis:
Linkage mapping within families (Haseman-Elston)
Association testing among families (?)

Acknowledgements

- Yoon-Sup So
- Brent Brekke
- Steve Eichenberger
- Allen Knapp
- All who contributed to 75 years of recurrent selection in BSSS