Strategies in the Application of Biotech to Drought Tolerance

Marc C. Albertsen
Director, Agronomic Traits
Pioneer Hi-Bred Intl., Inc.

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Drought Tolerance: Many Definitions

Broad – A recovery of yield normally lost under all levels of stress

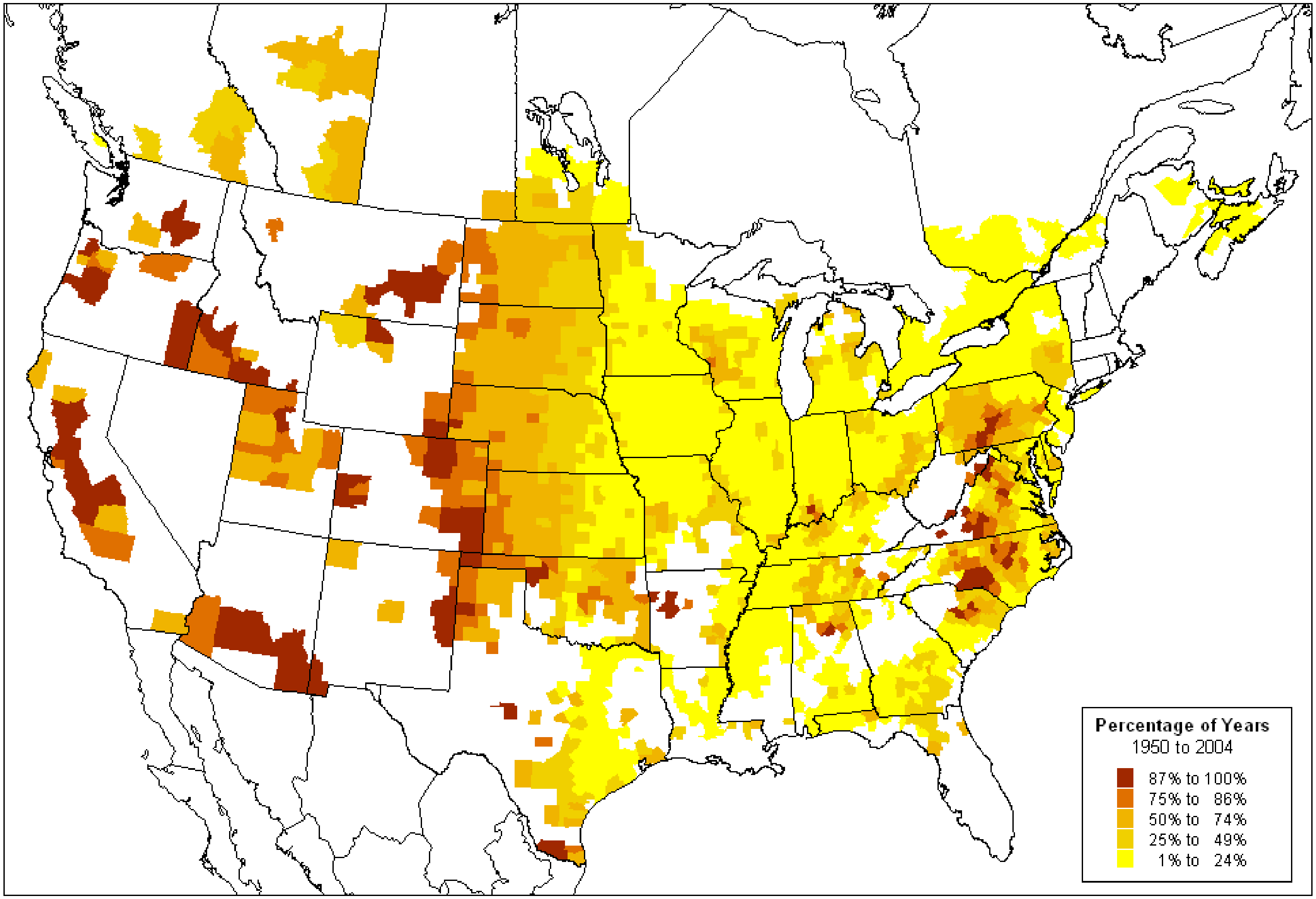
Moderate – A recovery of yield normally lost under a limited range of drought stress

Stage-Specific – Greater tolerance for drought stress during specific development stages

- During pollination (Flowering Stress)
- During grain fill (Grain Fill Stress)
- At emergence and during early season growth

Flowering Stress – Dryland

M* and *H*



Source: Pioneer Hi-Bred International Inc.

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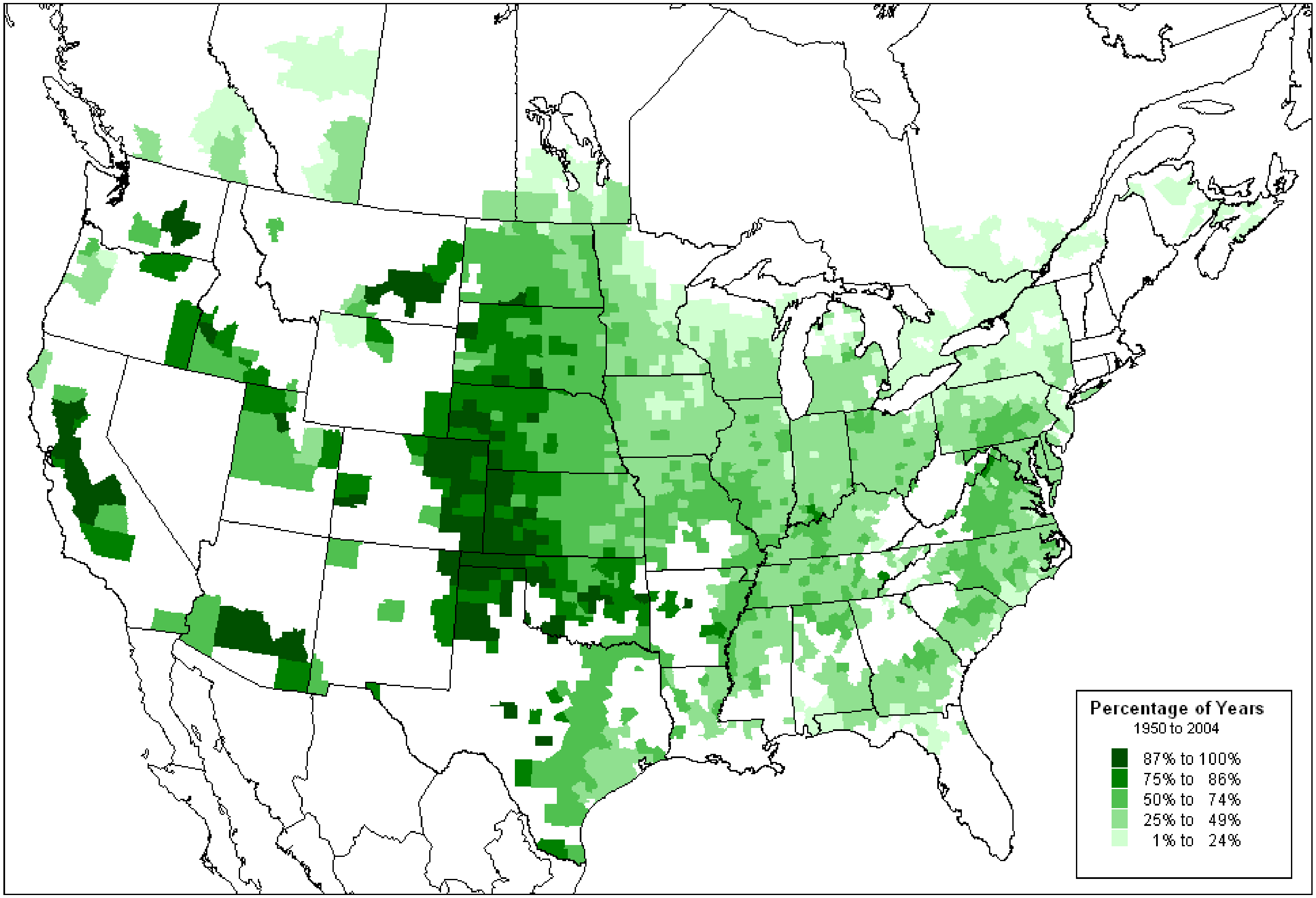
Grain Filling Stress – Dryland

*****M and **H***



Source: Pioneer Hi-Bred International Inc.

Drought Tolerance—Why Be Concerned?

- **Drought is a primary limiting factor in U.S. soils (Boyer, Science, 1982) and is a key limitation for 50% of the global corn market.**
- **Transient water deficits are common in the Corn Belt around pollination and during grain-fill. One year in five water acts as a significant limitation to yield. In the 90's, FEMA estimated US drought losses at $6-8 billion/yr.**

Source: Pioneer Hi-Bred International Inc.

Estimated Yield Losses

- Est. average annual loss from FT stress = 41 bu/A (21%) on 11.8 million affected acres (16% of the acres).
- Est. average annual loss from GF stress = 29 bu/A (15%) on 25.2 million acres (34% of the acres).
- Est. average annual yield loss from drought stresses for all corn acres is 25 bu/A (13%).

Corn Yield Winners

2005 Corn Yield Winners | **2004 Corn Yield Winners**

Non-Irrigated Class A

Name	State	Yield Bu/A		Name	State	Yield Bu/A
B. Woodall	TN	280		S. Santini, Jr.	NJ	272
H.G. Everman	NY	268		T.L. Snodgrass	NE	272
M.A. Kennedy Farms	NY	266		Seven Springs Farms	KY	270

Non-Irrigated AA

Name	State	Yield Bu/A		Name	State	Yield Bu/A
Mezera Farms	WI	323		F.R. Childs	IA	331
F.R. Childs	IA	320		M. Dempsey	IL	320
Mez-Farm	WI	306		Mezera Farms	WI	296

No Till/Strip Till Non-Irrigated A

Name	State	Yield Bu/A		Name	State	Yield Bu/A
D.K. Hula	VA	334		D.K. Hula	VA	339
G. Swede Farms	NY	265		Schwenke Bros.	KY	291
H.D. Everman	NY	264		T. Bishop	MD	286

Source: National Corn Growers Association, The World of Corn 2005/2004.

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Corn Yield Winners

2005 Corn Yield Winners | **2004 Corn Yield Winners**

No Till/Strip Till Non-Irrigated AA

Name	State	Yield Bu/A		Name	State	Yield Bu/A
J. Mezera	WI	302		D. Hadden	IL	280
J. Mezera	WI	292		S. Williams	IN	273
K. Klahn	WI	280		R. Little	IN	270

Ridge Till Non-Irrigated A

Name	State	Yield Bu/A		Name	State	Yield Bu/A
M. Gorder	ND	237		B. Anthony.	NE	287
M. Moody	NE	235		C. Santini	NJ	258
B. Tanner	TN	232		S. Santini	NJ	248

Ridge Till Non-Irrigated AA

Name	State	Yield Bu/A		Name	State	Yield Bu/A
G.N. Porter	IA	276		G.N. Porter	IA	279
Cox Farms	MO	267		W. Tomhave	IL	263
L. Porter	MO	259		J. Cox	MO	261

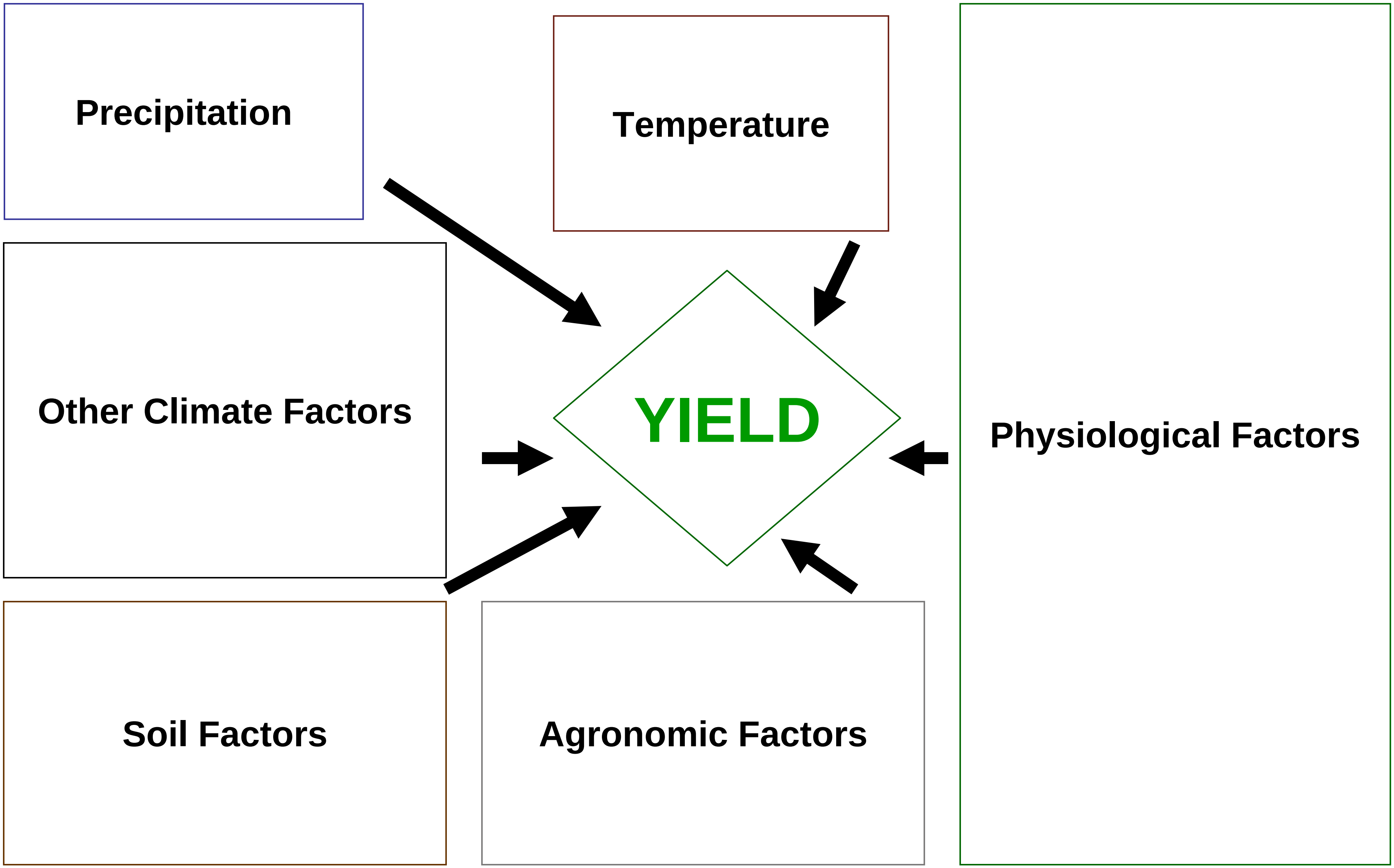
Source: National Corn Growers Association, The World of Corn 2005/2004.

Drought Tolerance is a Shifting Target

Corn hybrids today are substantially more drought tolerant than those of the past

- Pollination during drought stress has been greatly improved
  - Improved synchronization of pollen shed and silk exertion
  - Improved duration of pollen shed
  - Improved pollen heat tolerance
- Incremental improvement in drought tolerance has been an important part of increasing genetic yield gain
- But, there is still room for risk reduction
  - Can we achieve step-changes in the future?

Drought Complexity: Mechanistic factors



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Well Watered

Severe Stress

Drought

↓

↓ Photosynthesis

↓

↓ CHO Flux

↓

Decreased Yield

Drought Tolerance: How to approach?

- **Yield and productivity** remain the keys to successful drought tolerance
- ”Cactus-corn” might be an interesting novelty but unlikely to generate much farmer interest!

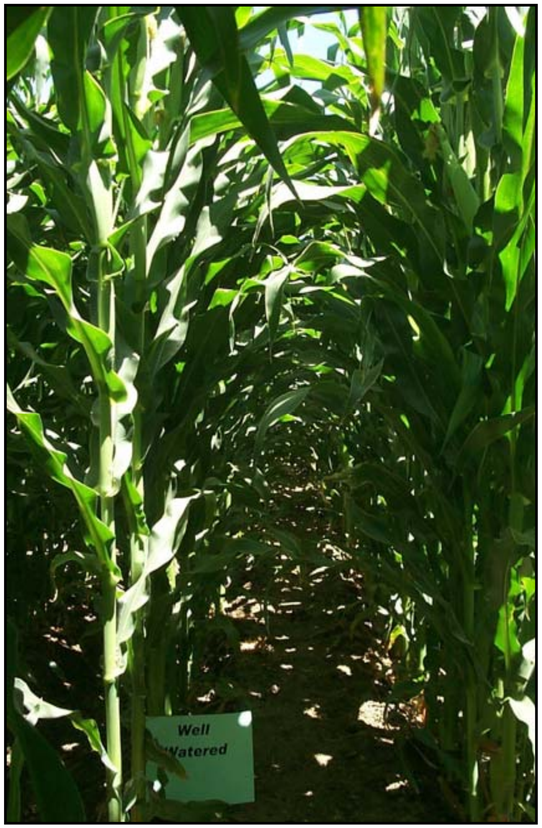
Additional Strategies for Drought Tolerance Research:

- Association Mapping
- Molecular Breeding
- Map-Based Cloning
- Transgenics

- **BUT, without a repeatable, reliable testing regime in the specific crop of interest, success will be a random event…**

Managed Environment Research Site

Managed Environment – Enables precise manipulation of flowering stress and/or grain-filling stress



Well-Watered

400 GDU Pre-Flowering Stress

700 GDU Pre-Flowering Stress

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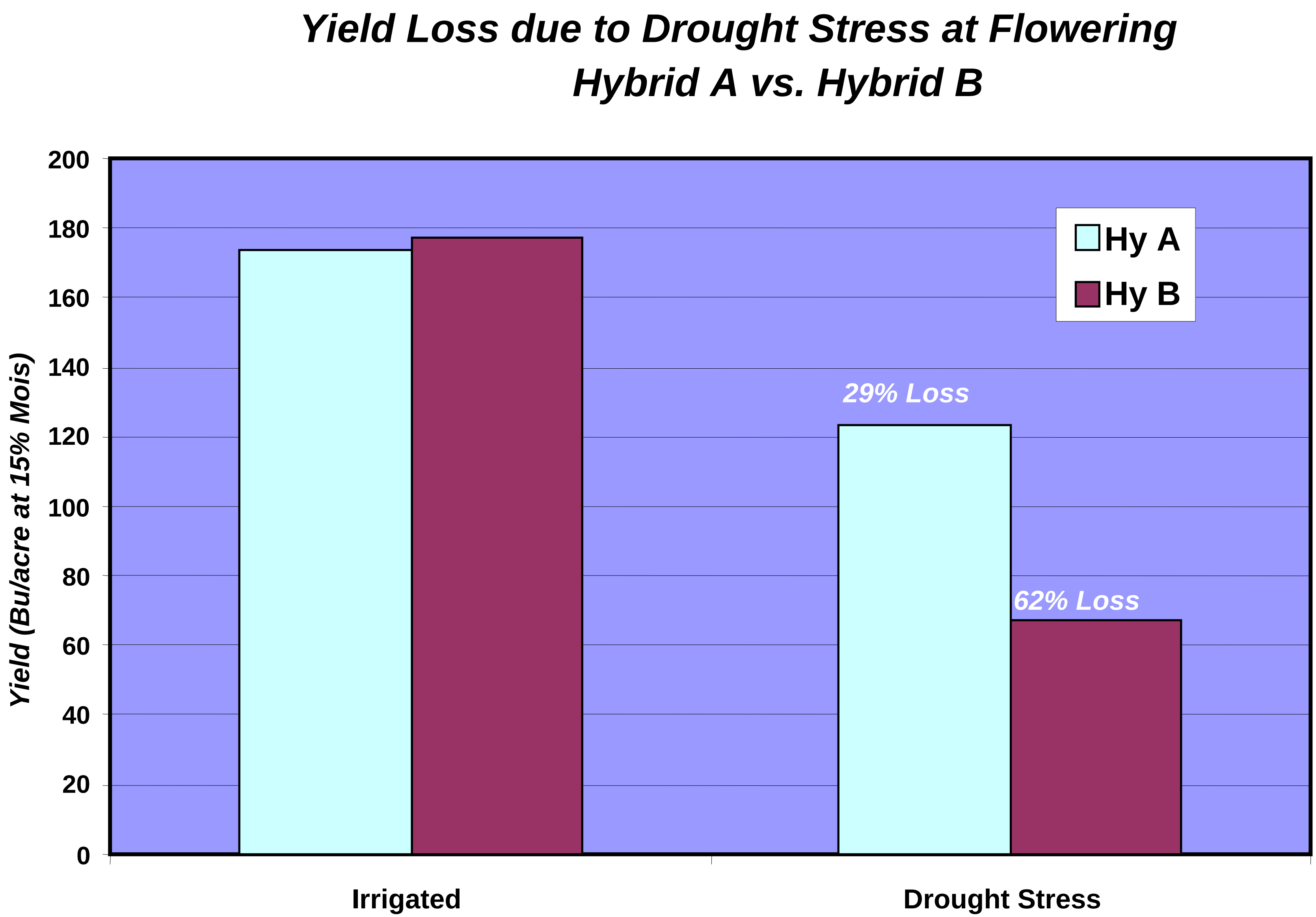
Managed Environment – Techniques

Plant Height **Ear Size at 10 DAS** **Kernel no. at 35 DAS**

Managed Environment – Techniques

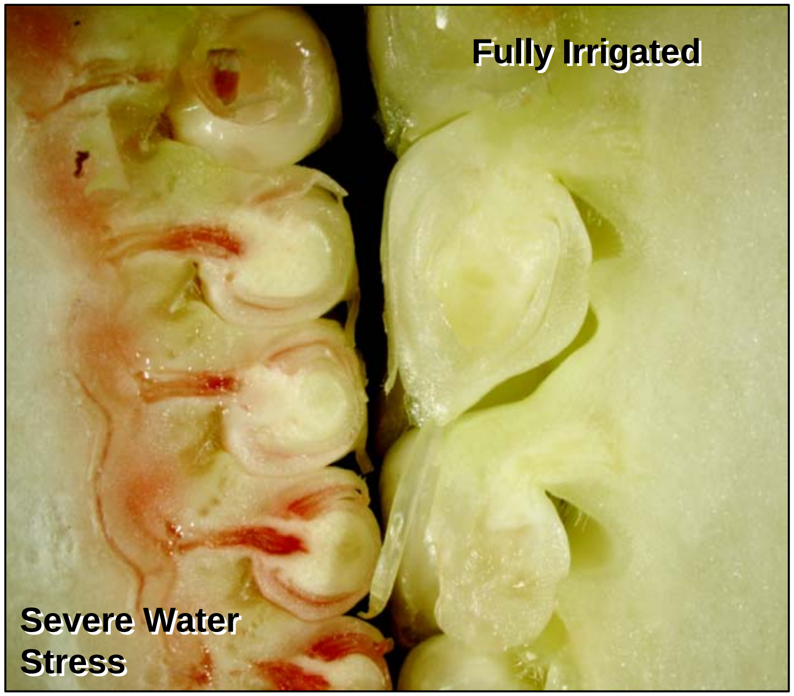
Reproducible evaluation of performance under stress, using precision drip tape irrigation, carries through to harvest

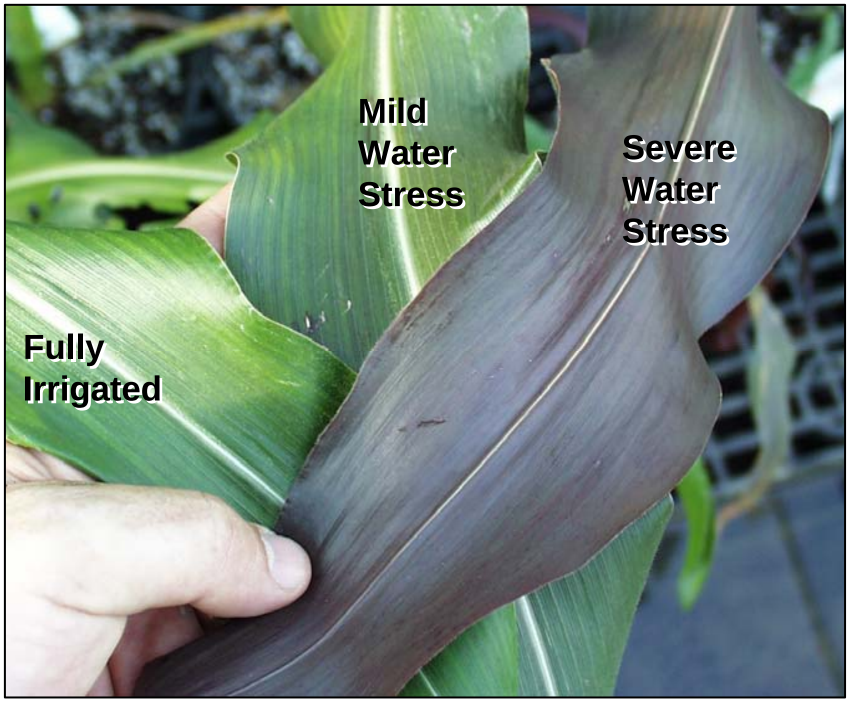
Managed Environment – Results



Lessons Learned from Field-based Discovery Efforts

- Used a stress-induced color-producing construct to visually monitor response to drought stress.





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A repeatable, controllable testing regime enables both conventional and molecular-based approaches to drought tolerance

Genetic Diversity

Genetic mapping
Map-based cloning

A	A	T	A	C	G	A		T
A	A	T	A	C	G	A		T
A	A	T	A	C	G	A		T
A	A	T	A	C	G	A		T
A	A	T	A	C	G	A		T
A	A	T	A	C	G	A		T
A	A	T	A	C	G	A		T
A	A	T	A	C	G	A		T
G	A	T	A	C	A	A	I/D	C
G	A	T	A	C	A	A	I/D	C
G	A	T	A	C	A	A	I/D	C
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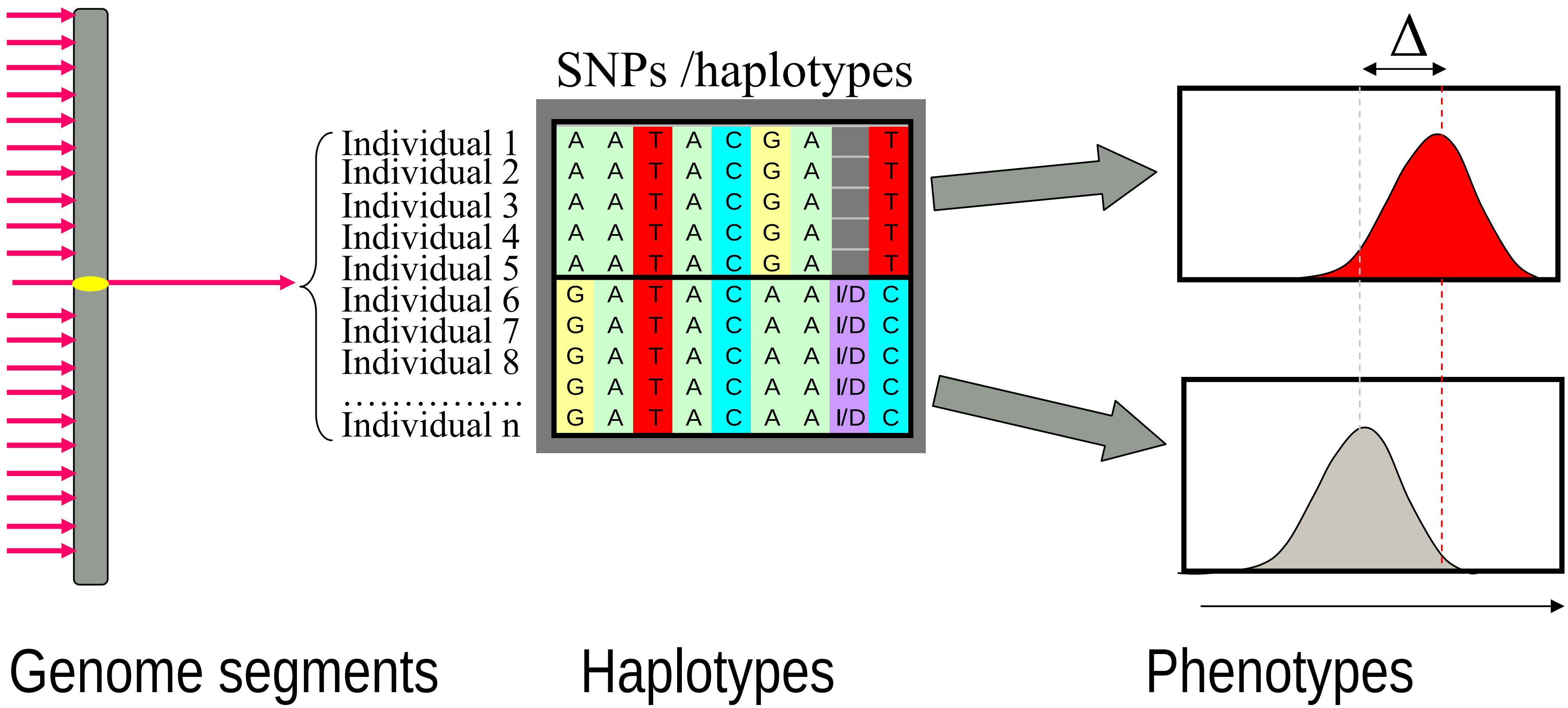
G	C	A	T	T	A	C		T
G	C	A	T	T	A	C		T
G	C	A	T	T	A	C		T
G	C	A	T	T	A	C		T

Association Mapping

Whole genome scan

- Scan haplotype diversity at frequent intervals across the whole genome



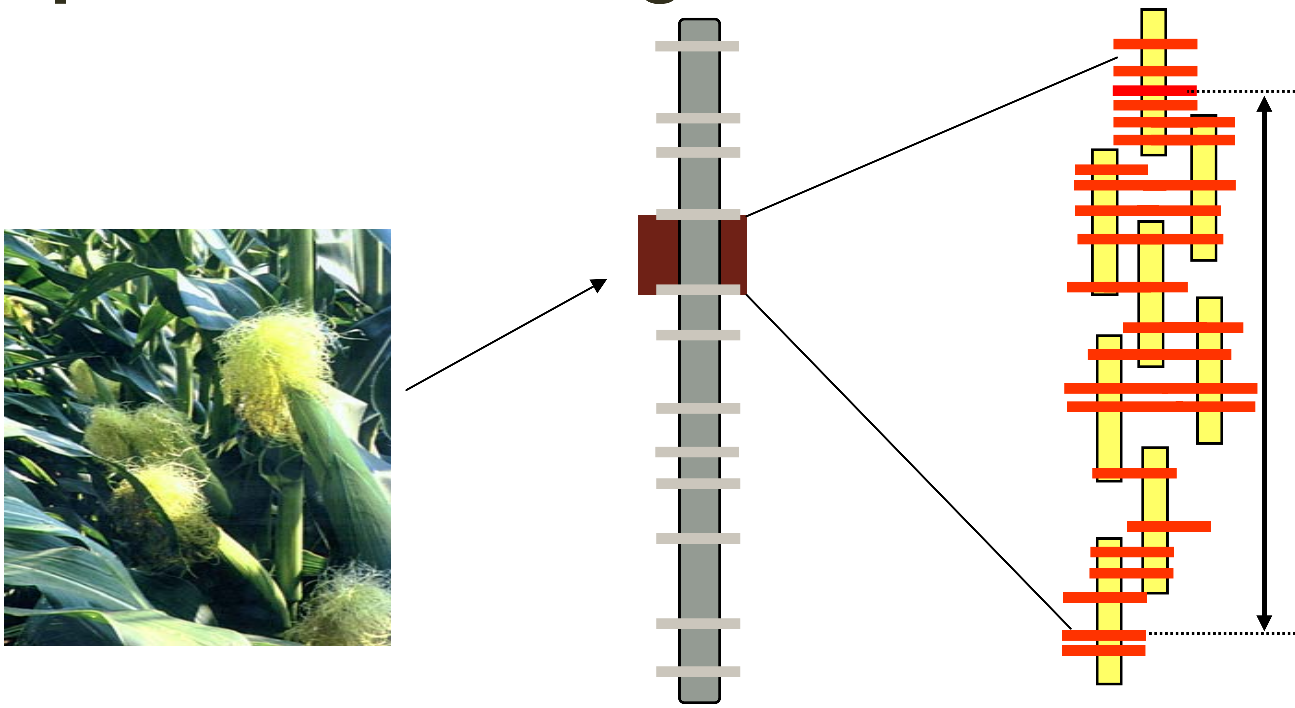
With This Information We Have Two Choices

Molecular breeding to move the identified chromosome segment into elite breeding lines

OR

Clone the gene in the segment that is actually responsible for the desired phenotype and manipulate through genetic engineering

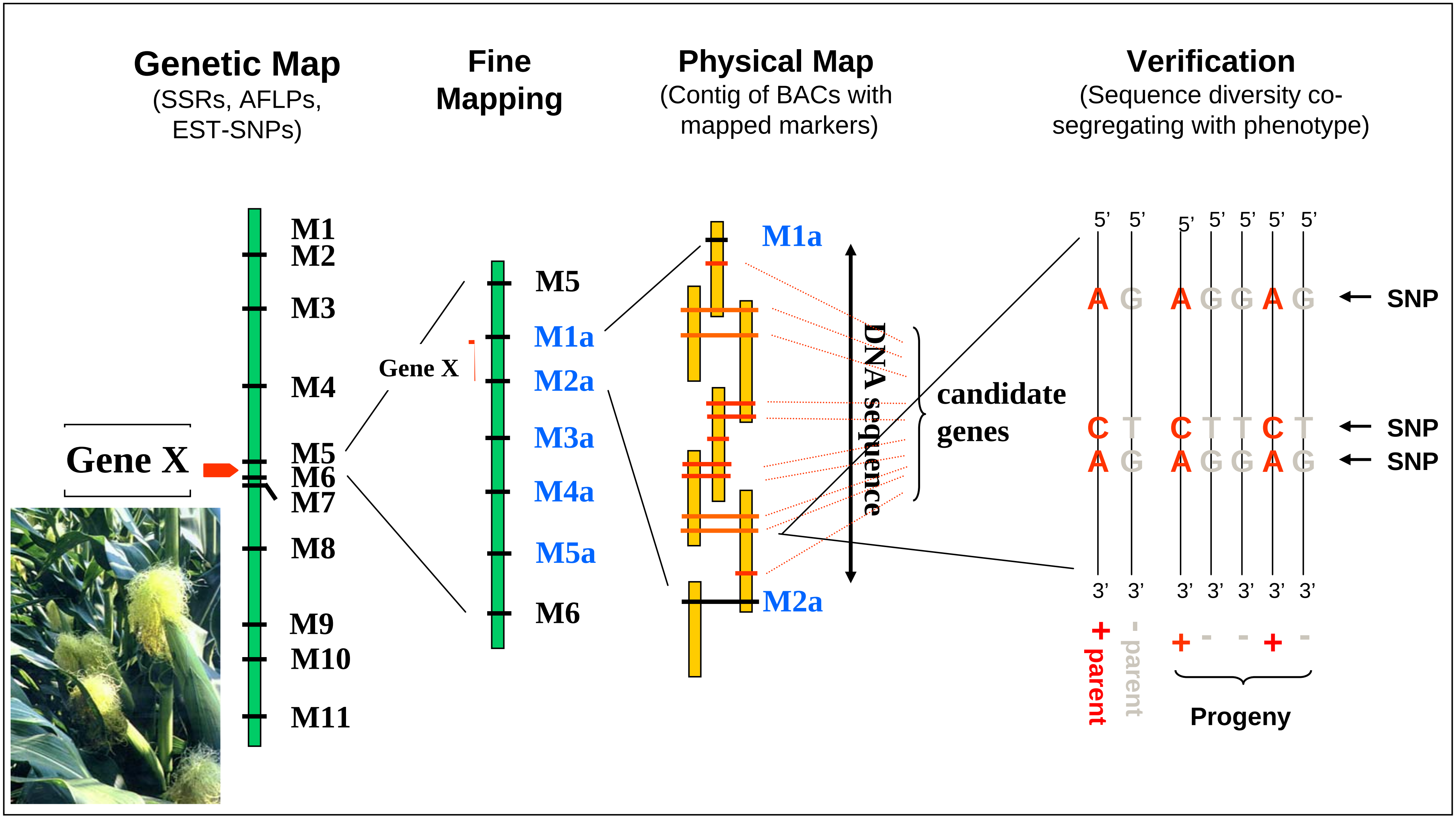
Map-Based Cloning



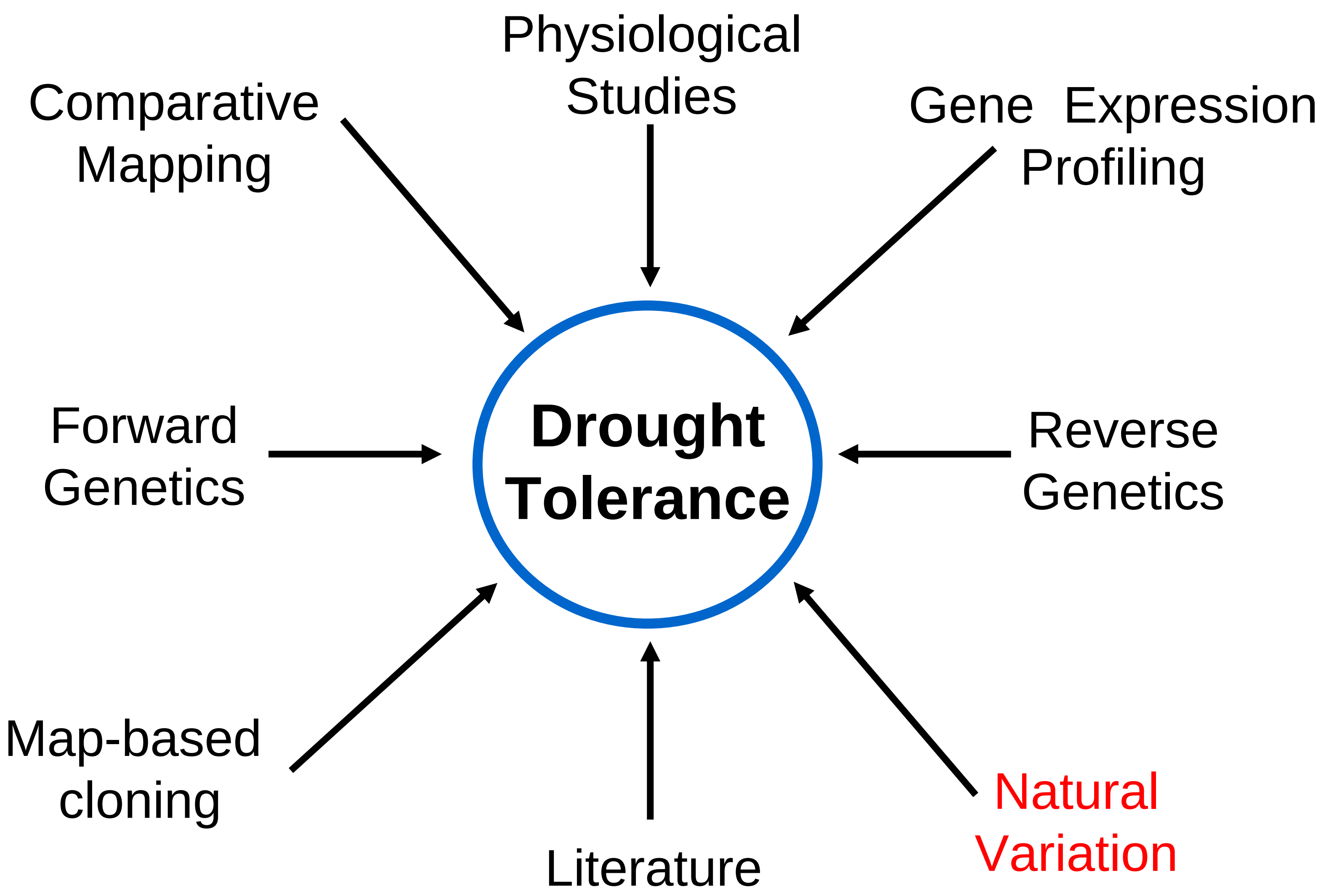
Phenotype Genetic Map Physical Map

- Genetic mapping defines and delimits the trait locus to a small interval
- Physical mapping provides genomic clones spanning the trait locus so that all the genes in that segment can be separated

Map-Based Cloning



Drought Tolerance Improvement – Genes and Pathways



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Initial Evidence for Protection From Drought Stress in T0's

Notice the lack of ear development on the plants on the right

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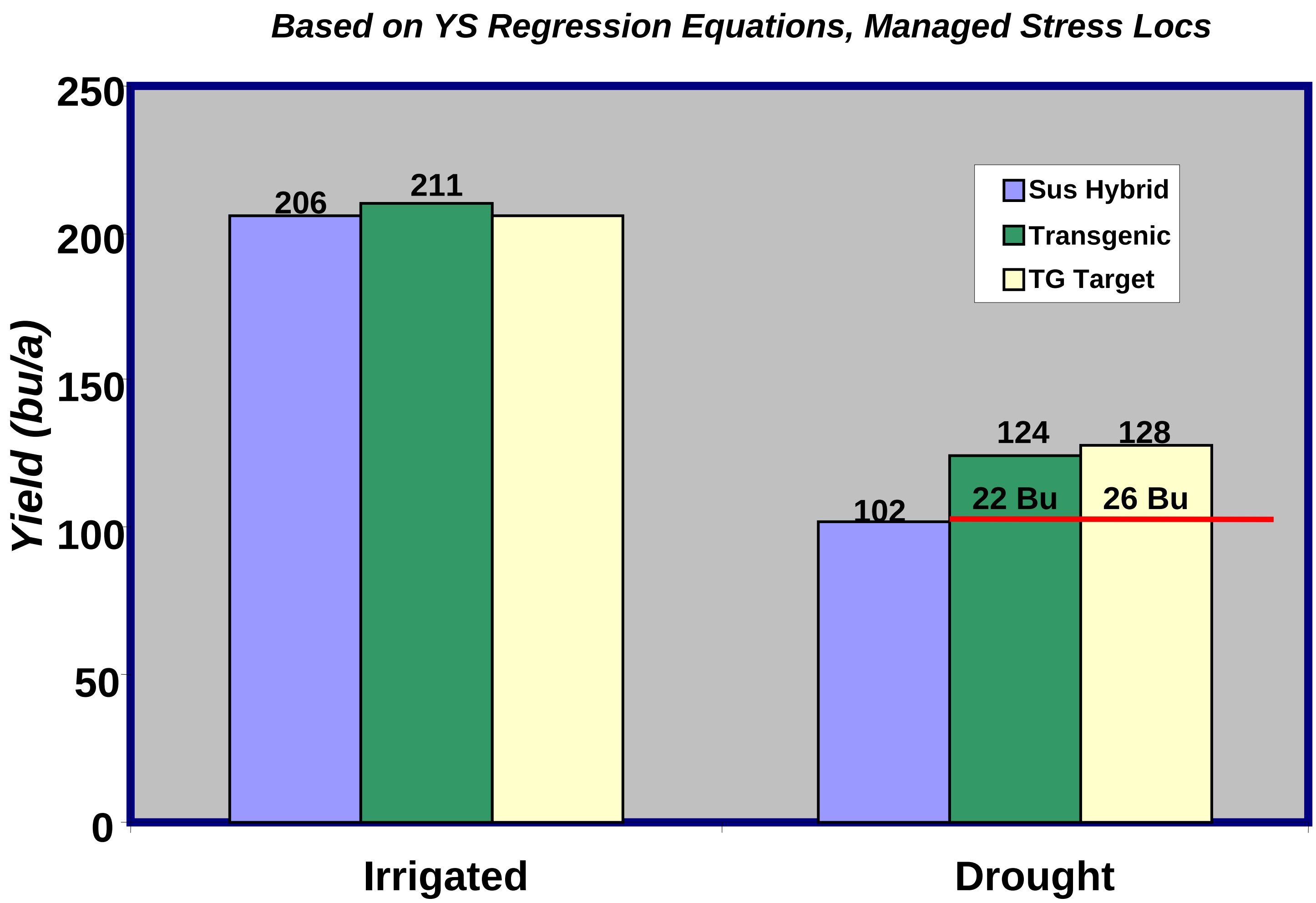
Yield Stability of a Transgenic



Summary: Drought Tolerance—Where Are We Today?

- **Hybrid responses to drought can vary significantly depending upon the timing of the stress and the developmental stage.**
- **Experimental efforts have been aimed at understanding maize yielding ability under drought stress**
- **Starting to gain rudimentary understanding of crop productivity at the whole plant and molecular level**
- **Experiments to validate/refute hypotheses generated from a pathway perspective by testing in a managed environment are underway**
- **Single gene changes to a complex trait such as drought tolerance may result in genotype or environment specificity that can lack adequate robustness as a product**
- **Drought tolerance QTL's can be identified, and individual responsible genes can be cloned**
- **Whether manipulating genes in blocks or one at a time, effective plant breeding will be the key to success**

Summary: Drought Tolerance—Strategies for Success

- Early assessment of the traits associated with drought tolerance—need to choose the relevant response
  - e.g. the drought survival response likely not too relevant for practical application
- Effective phenotyping of the genetic modifications
  - Experiment protocol and testing is critical
- Multi-disciplinary effort likely required
  - Combination of conventional breeding, molecular breeding, genetic engineering
- Long-term research and development commitment
  - Biotechnology and its technology may shorten the total time, but likely still ~10 years

(paraphrased from Sinclair, et al., TIPS 9: 1360. 2004)

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