Plant Breeding in the 21st Century

P. Stephen Baenziger and Soleman Al-Otayk
University of Nebraska & Al-Qassim University

P. Stephen Baenziger

- B. A. from Harvard University
- M.S. and Ph.D. from Purdue University
- Employment
  - USDA-ARS: 1976-1983
  - Monsanto: 1983-1986 (continue to own stock)
  - University of Nebraska: 1986 to present

The opinions given in this talk represent my views and not those of any institution, organization, or committee upon which I serve.

Small Grains Improvement Team

Genetics:
Bob Graybosch, USDA-ARS
Ismail Dweikat
Guihua Bai, USDA-ARS
Kulvinder Gill, WSU

Plant Pathology:
Stephen Wegulo
Roy French, USDA-ARS
Yue Jin, USDA-ARS

Variety Testing:
Len Nelson

Transformation:
Tom Clemente

Entomology:
Gary Hein
Ming Chen, USDA-ARS

Cropping Systems:
Drew Lyon
Bob Klein, Charles Shapiro

End-use Quality:
Lan Xu
Brad Seabourn, USDA-ARS

Biometry:
Kent Eskridge
Walt Stroup
Ken Russell

Small Grains Improvement Team

Modeling:
Al Weiss
Wally Wilhelm
Greg McMaster (USDA-ARS)

Triticale:
Lance Gibson (ISU)
Ken Vogel (USDA-ARS)

Barley:
My graduate students

Topics:

- The need for plant breeding and crop management.
- The phases of plant breeding.
- Who will be the 21st century plant breeders?
- Critical needs for future plant breeding and understanding how to use your resources (competitive advantages).

The need for plant breeding and crop management:

- The demands on our food system will increase:
  - Increasing population
  - Increasing prosperity
  - To meet environmental needs

Increasing Prosperity:

- 800,000,000 people undernourished--will change with income growth.
- For each 1% increase in real income, the demand for wheat will increase 0.5%.
- Increased wheat utilization is due 2/3 to population and 1/3 to income growth.
- Greater demand for meat--Already 35% of world grain supplies are used for livestock production

Having the Tools vs. Having the Will:

Meeting Environmental Needs:

- Agriculture is often viewed as an enemy of the environment--relies on pesticides, fertilizer, irrigation. Yet intensive agriculture preserves land from being used for farming.
- Agriculture is the largest and most flexible managed ecosystem. It will be asked to remediate the detrimental effects of human activities.
- Future agriculture will rely more on genetics and less on chemical inputs.

Revolutions in Agriculture

- Fertilizer
- Pesticides (herbicides, insecticides, fungicides)
- Irrigation
- Genetics
  - Hybrids (better in diploids than polyploids)
  - Semi-dwarf cultivars for intensive management

Which of these revolutions will be available in the future?

$P = G + E + GxE$

$$P = G + E + M + GxM + GxE + GxMxE$$

- Environment: Weather, tillage, pesticides, irrigation, fertilizer, and prior history. It has both a fixed and a random component.
- Genotype: What Plant breeders are modify.
- Genotype x environment Interaction: How the genotypes respond to different environments.

How will the next production gains be obtained? Have we reached the upper genetic limit (can genetic Improvement continue)?

Phases of Plant Breeding:

- Introduction of genetic variation
- Genetic segregation and selection (may or may not be accompanied by inbreeding)
- Evaluation and release

Plant breeders will change their programs to do something which they could not previously do or to do something they could previously do in a better way. Everything must be tempered by finding your competitive advantage, your niche—which will differ.

Traditional Plant Breeding

Introduce Variation

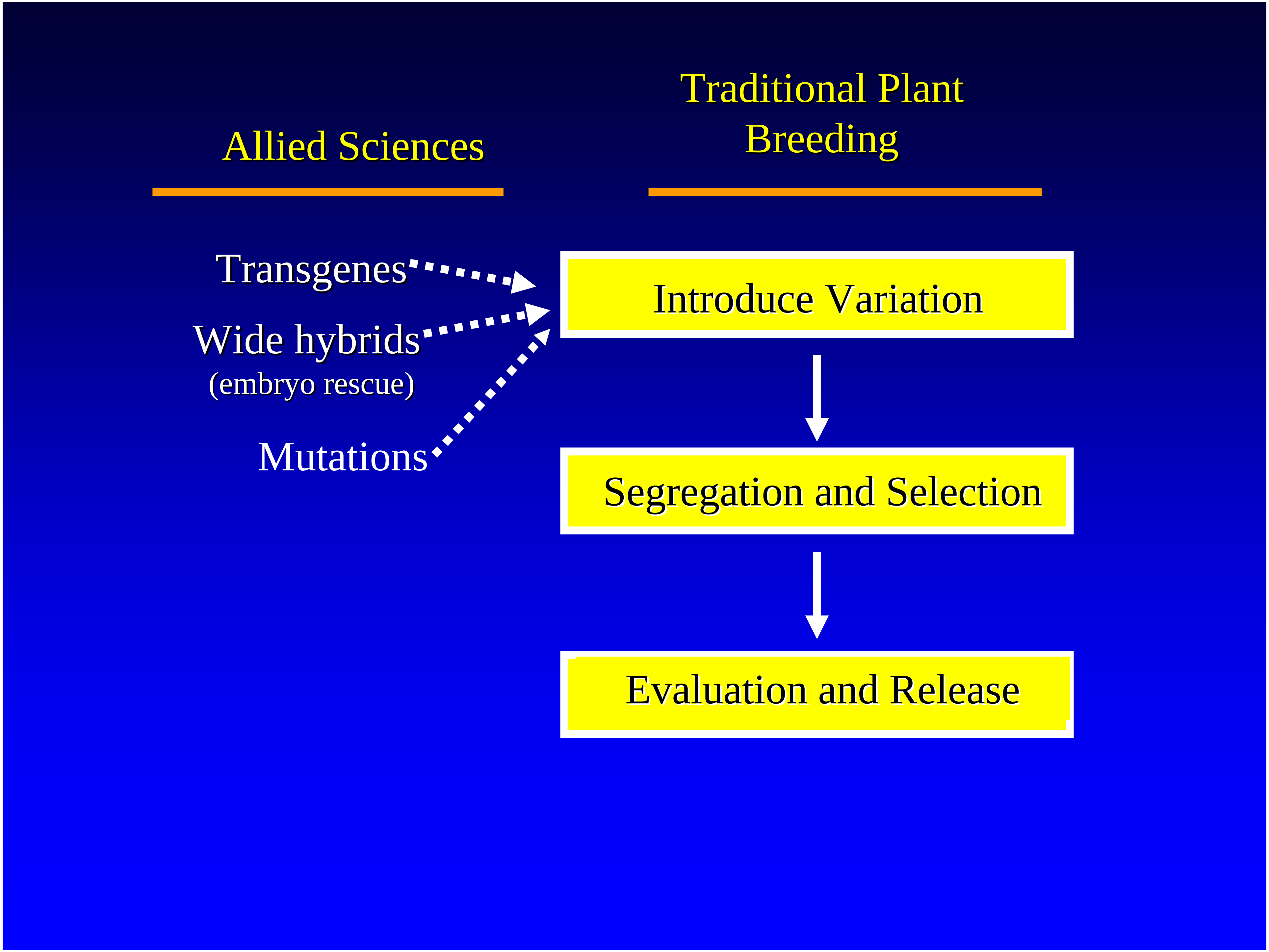
↓

Segregation and Selection

↓

Evaluation and Release

Introducing Variation:

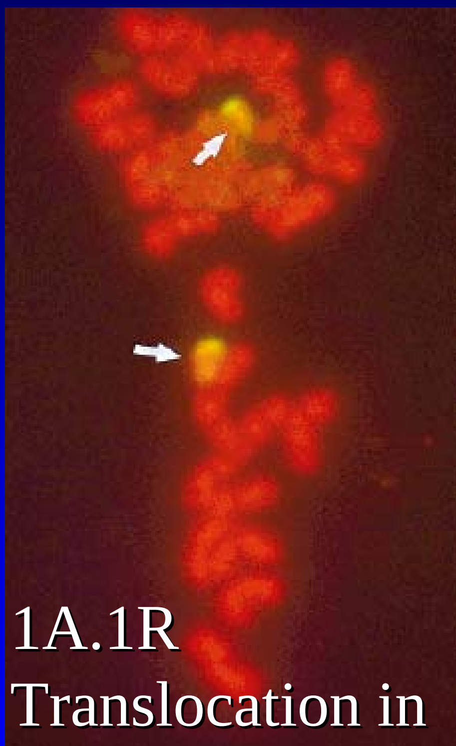

Allied Sciences
Traditional Plant Breeding
Transgenes
Wide hybrids
(embryo rescue)
Mutations
Introduce Variation
Segregation and Selection
Evaluation and Release

Crop Transformation:

- Fundamental question is does a plant breeder have enough genetic diversity (variation) within those species and genera that can be hybridized with the crop of interest?
- According to James (2006), 100 million hectares were planted to transgenic crops of which 54.6 million hectares were in the US. On a global basis, 57% of soybeans, 25% of maize, 13% of cotton, 5% of canola, and 0% of wheat and 0% of rice are transgenic.
- Are wheat and rice destined to become “orphaned” crops due to limited technology?

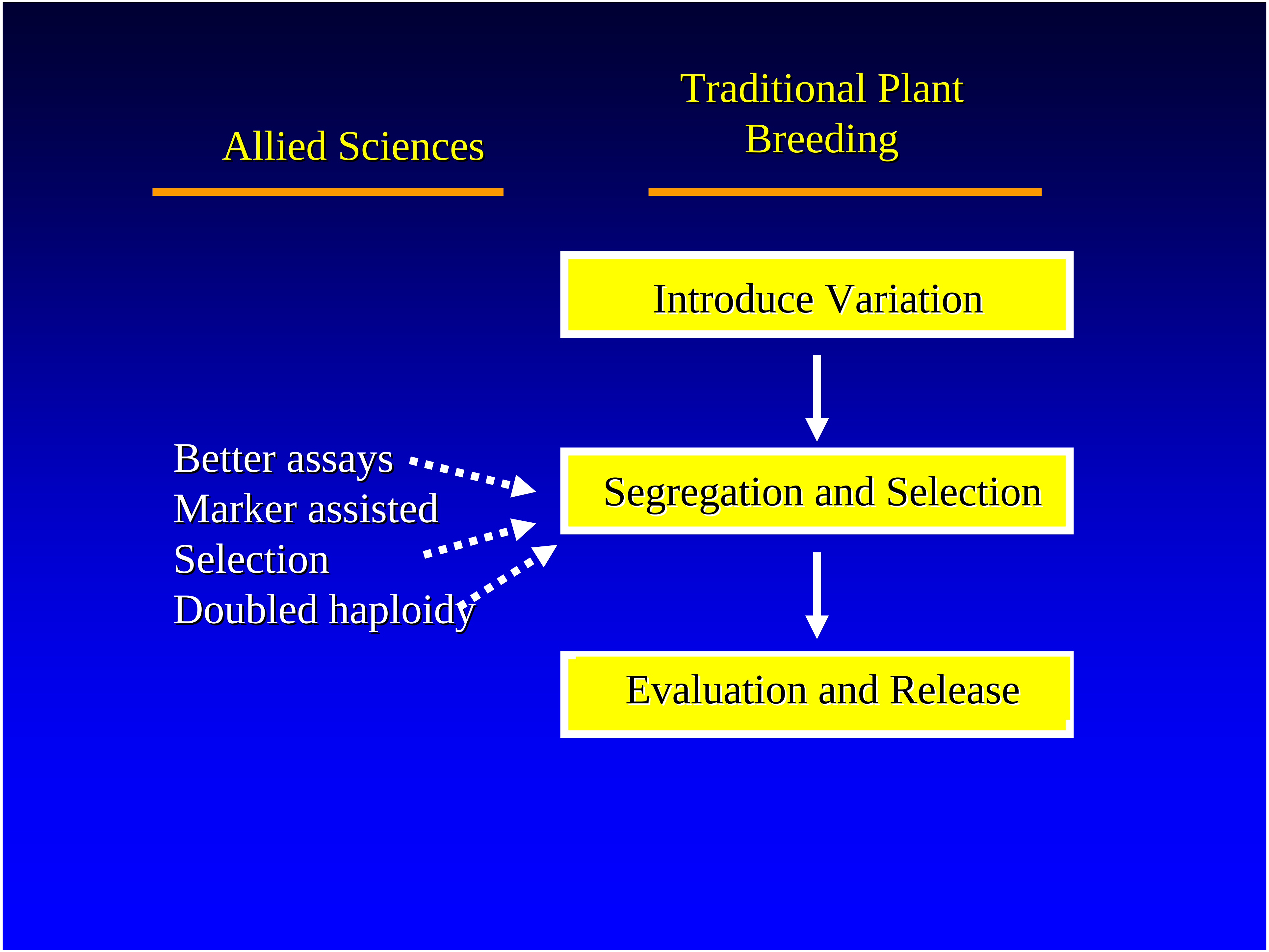
http://www.isaaa.org/resources/publications/briefs/35/executivesummary/default.html

Variation Through Mutations:



1A.1R Translocation in 'Century' Wheat
X-ray chromosome Breakage.
Wenzel and Rayburn (2000)

Imidazolinone-tolerance and wild type susceptibility in wheat. Sodium azide mutagenesis.


Allied Sciences
Traditional Plant Breeding
Introduce Variation
Segregation and Selection
Evaluation and Release
Better assays
Marker assisted Selection
Doubled haploidy

Segregation and Selection:

- Nothing is more efficient than visual selection when it can be used.
- With the size of modern breeding programs, nothing is more necessary than visual selection.
- There is a hierarchy of assays where you use the easier, less expensive assays first, so fewer lines have to be evaluated with expensive assays.

Marker Assisted Selection:

- Best use of technology: on-site or cooperative
- Recommendation:
  - Small local effort for specific projects, especially for training.
  - Centralized labs for the large jobs. Needed for skilled personnel, and for higher quality and modern equipment. Also, the equipment is becoming so fast that a few machines have enormous capacity. Also, it is difficult for many individual programs to have the latest equipment.

Fusarium head blight:

- The disease assay is difficult and time consuming, usually done on flowering wheat plants.
- There are major resistance genes, but they often have to be pyramided to give useful levels of resistance.
- Natural infections are not uniform—maturity dependent
- The major genes are tagged with molecular markers.

Fusarium head blight: Breeding Strategy

- Cross HRS/SRW//HRW
- Two doses of hard texture
- Two doses of winter growth habit
- Can fix the FHB QTL or at least allow it to more frequent in the 3 way cross.
- Need to remove the spring growth habit lines that are soft or low protein. Can be done in the F_2 or F_3 generation using selection.

Stem Rust:

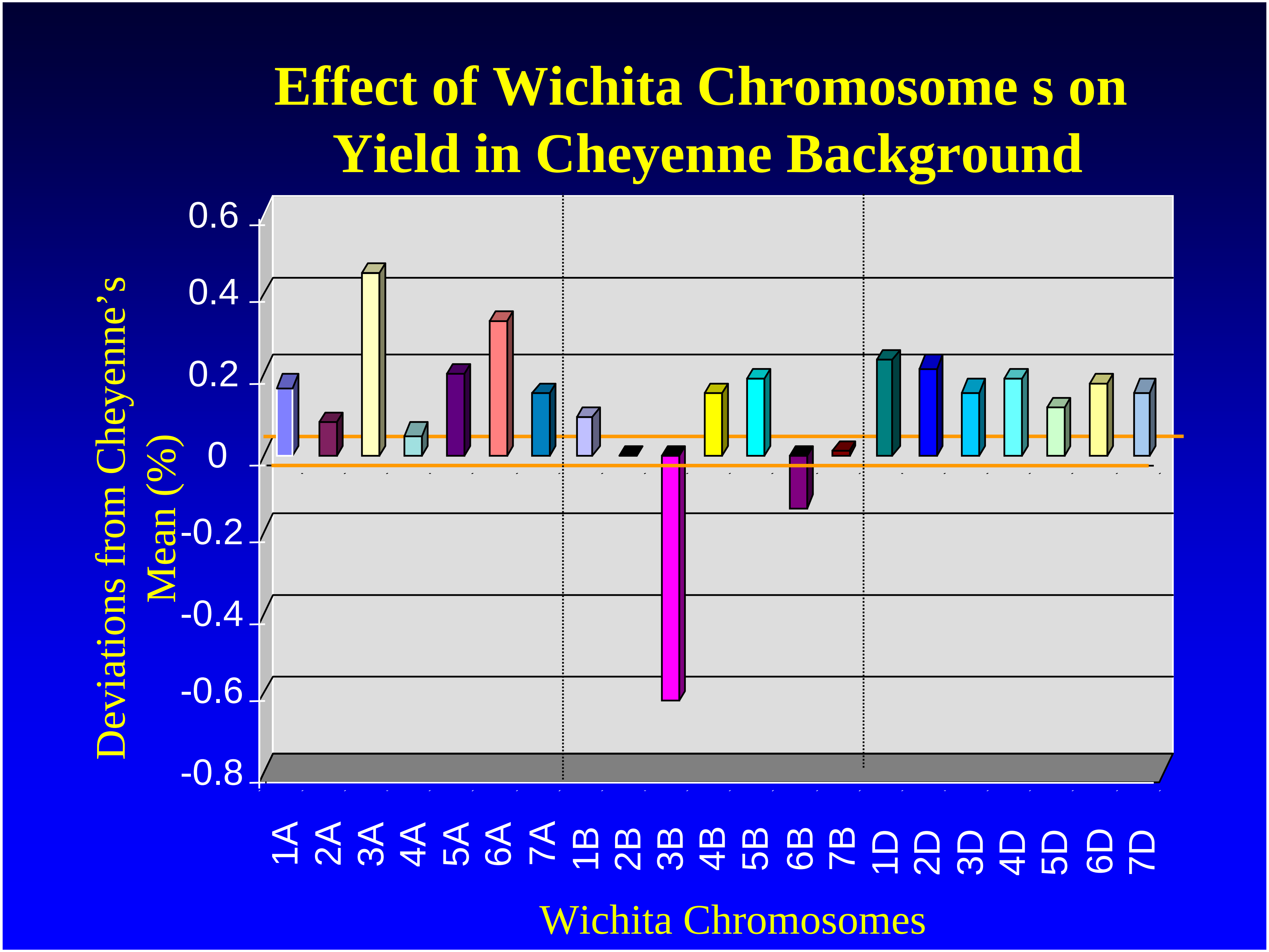
- The disease assay is simple and quick, usually done on seedlings.
- There are major resistance genes, and are effective when used singly.   Races change slowly or quickly (e.g. Ug99).
- Natural and artificial infections can be induced in the field.
- Many major genes are tagged with molecular markers.

Stem Rust: Breeding Strategy

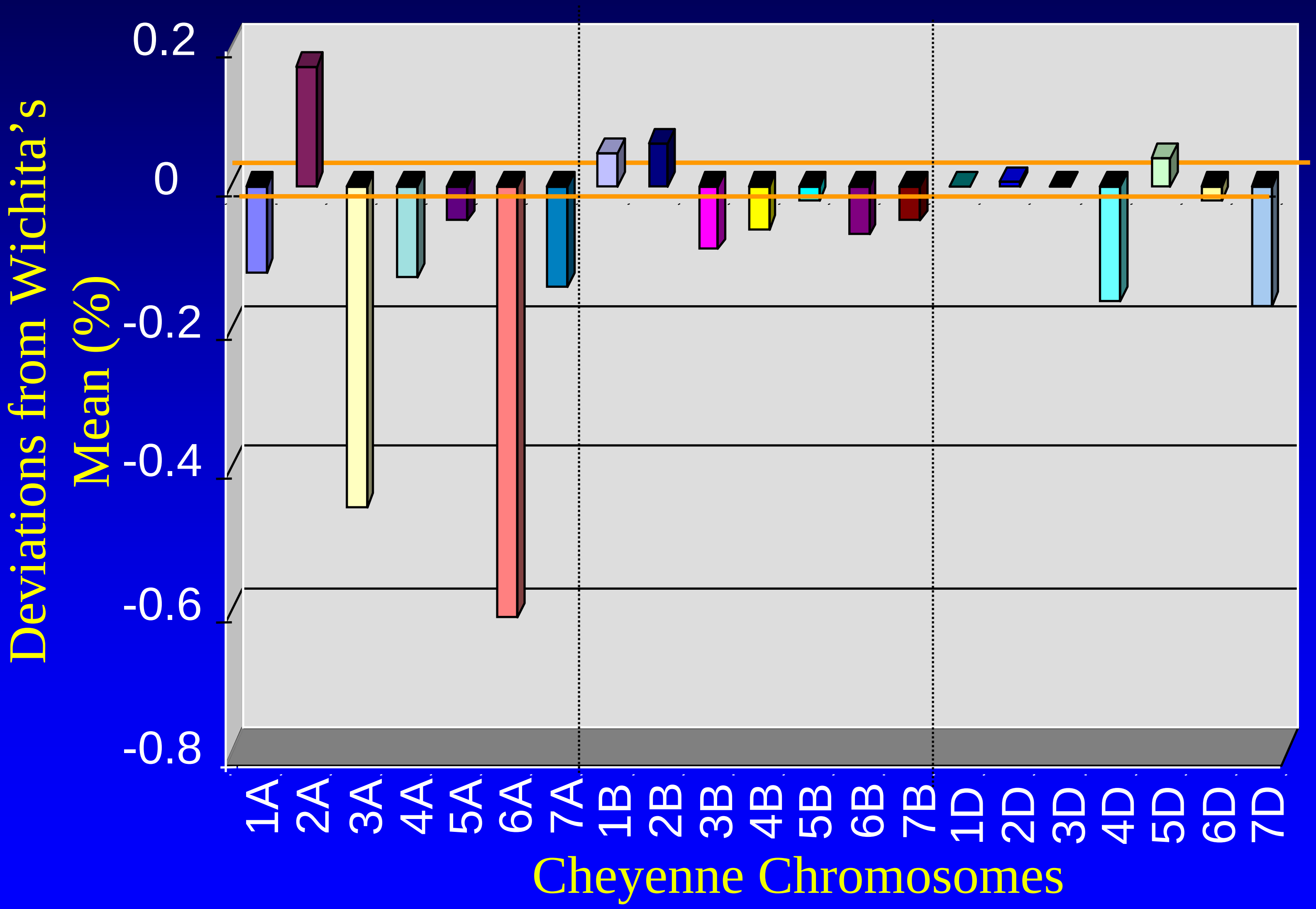
- Resistance is a critical trait. Excellent germplasm is available.
- Cross Resistant by Resistant or R/S//R and select in the F_5 and thereafter seedling stage.
- Use race differentials or molecular markers to identify pyramided gene combinations.

Understanding Grain Yield

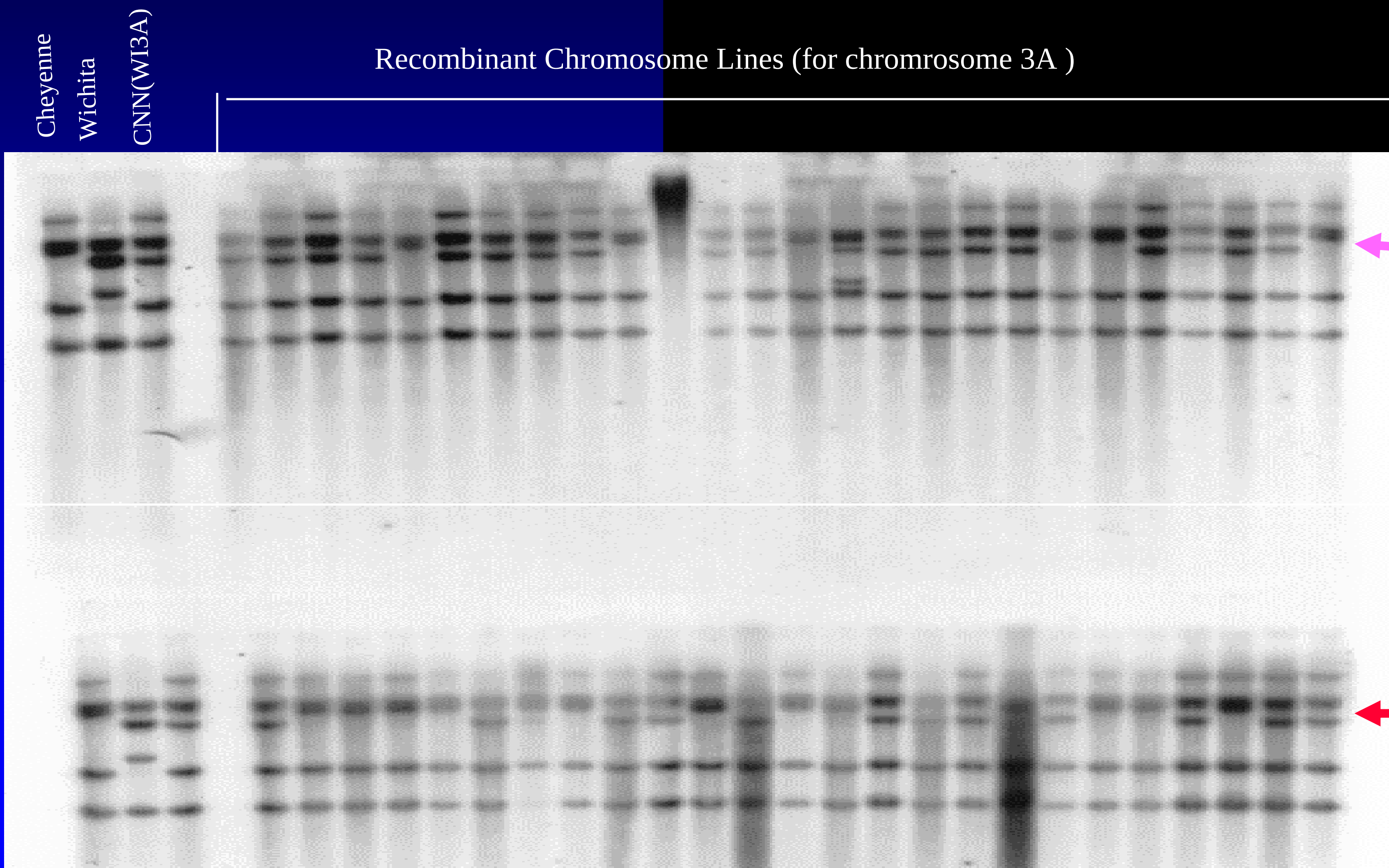
- Complex trait controlled by many genes.
- Can be difficult to identify differences, especially in relatively low yielding environments. Average grain yield for wheat in Nebraska is 2.5 t/ha.
- Very large environmental effects.
- Need very effective tools.


Effect of Wichita Chromosome s on Yield in Cheyenne Background
Deviations from Cheyenne's Mean (%)
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
1A 2A 3A 4A 5A 6A 7A 1B 2B 3B 4B 5B 6B 7B 1D 2D 3D 4D 5D 6D 7D
Wichita Chromosomes

Effect of Cheyenne Chromosome s on Yield in Wichita Background

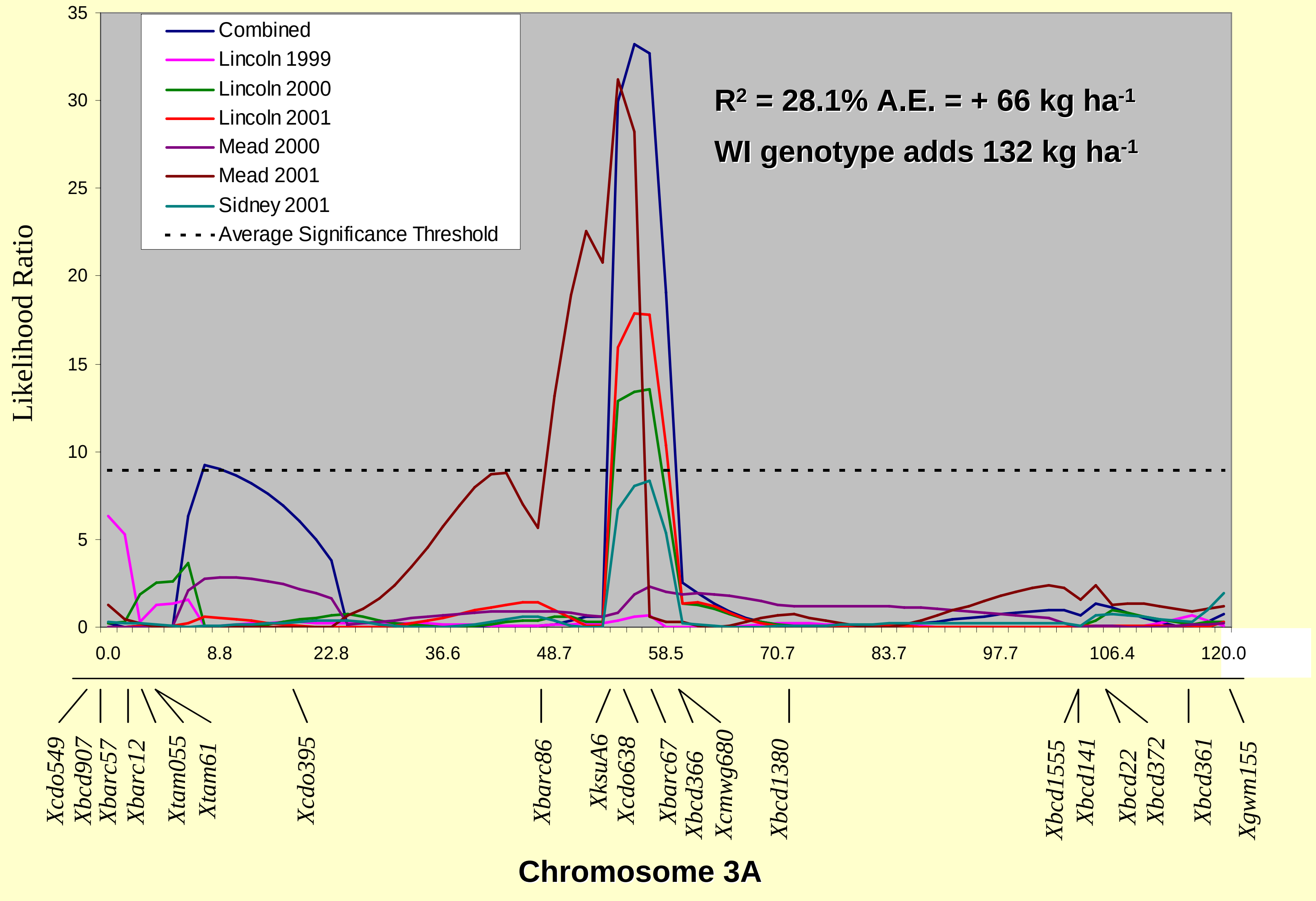


Segregation of RFLP probe *BCD907*, in the RICL*s*-3A population of Wheat



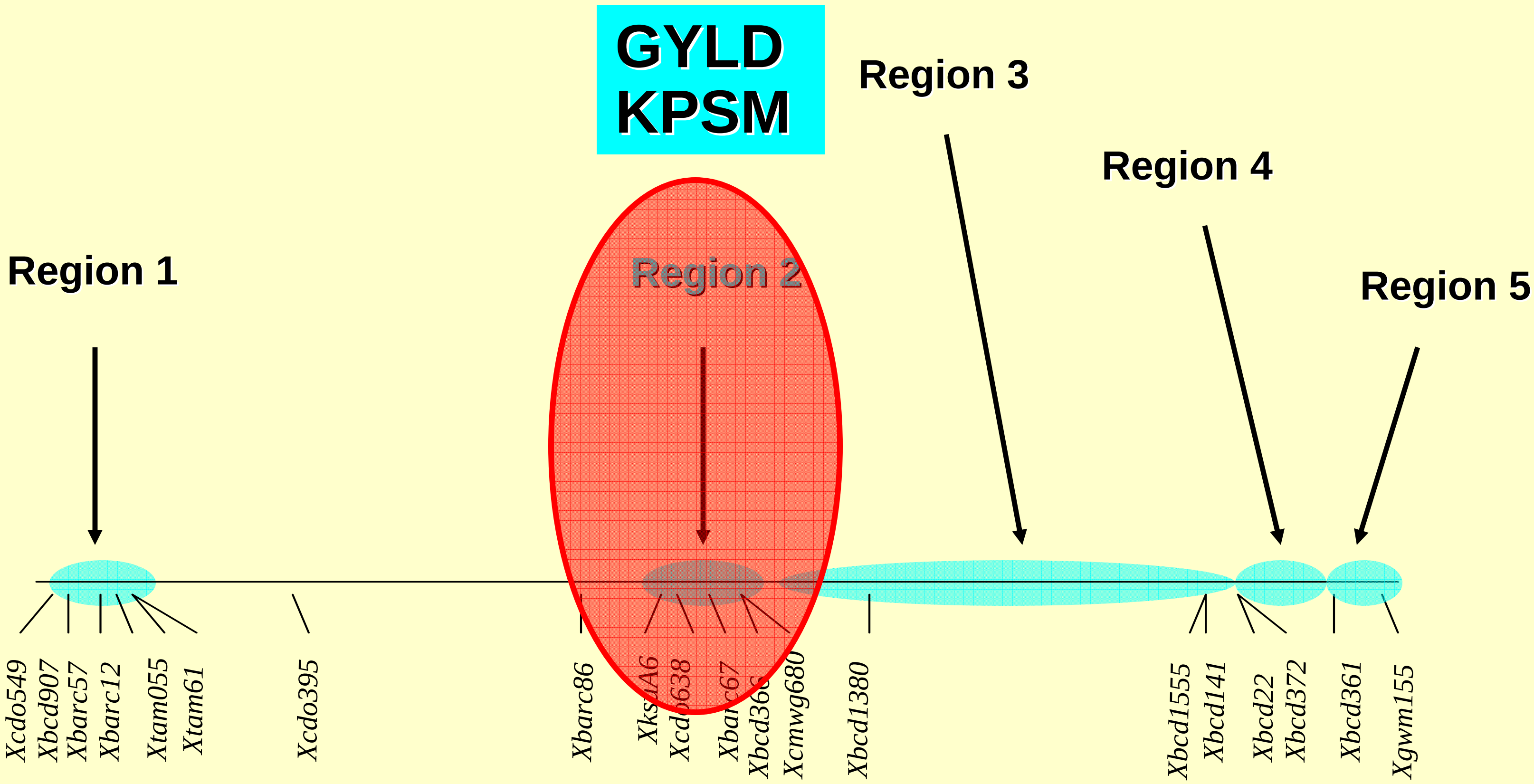
= Polymorphic band

Grain Yield

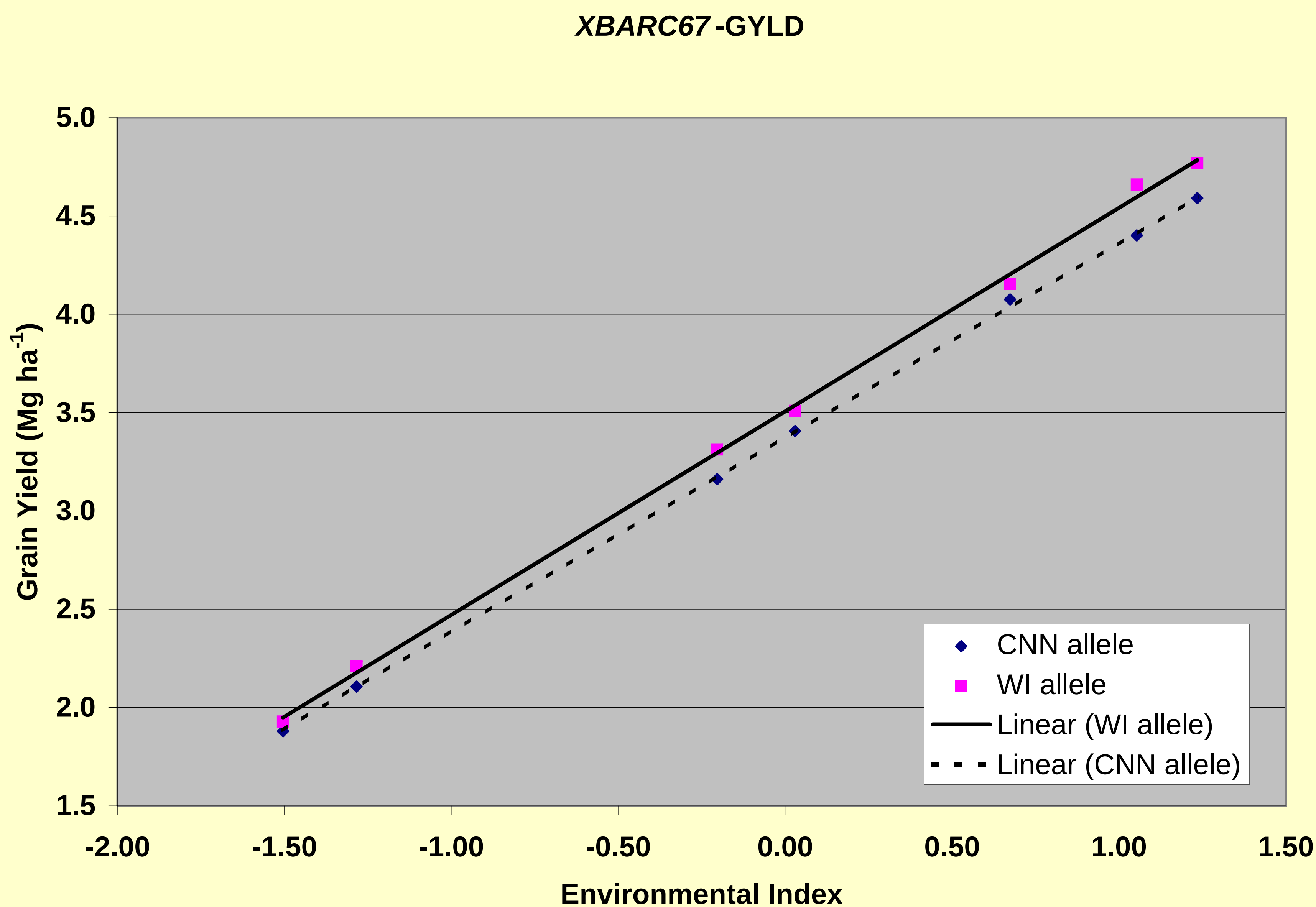


Combined
Lincoln 1999
Lincoln 2000
Lincoln 2001
Mead 2000
Mead 2001
Sidney 2001
Average Significance Threshold
R² = 28.1% A.E. = + 66 kg ha⁻¹
WI genotype adds 132 kg ha⁻¹
Likelihood Ratio
0
5
10
15
20
25
30
35
0.0
8.8
22.8
36.6
48.7
58.5
70.7
83.7
97.7
106.4
120.0
Xcdo549
Xbcd907
Xbarc57
Xbarc12
Xtam055
Xtam61
Xcdo395
Xbarc86
XksuA6
Xcdo638
Xbarc67
Xbcd366
Xcmwg680
Xbcd1380
Xbcd1555
Xbcd141
Xbcd22
Xbcd372
Xbcd361
Xgwm155
Chromosome 3A

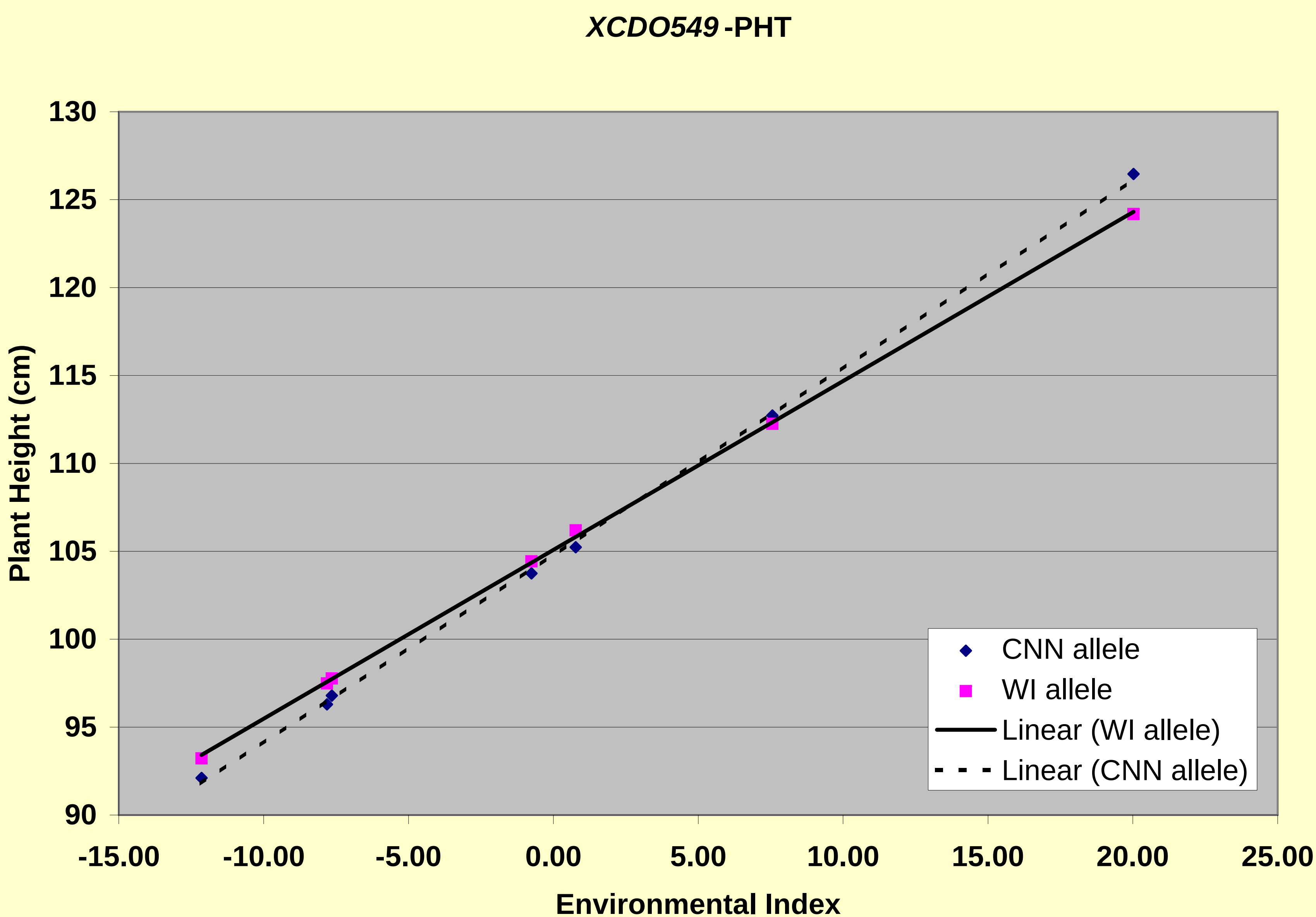
QTL Regions

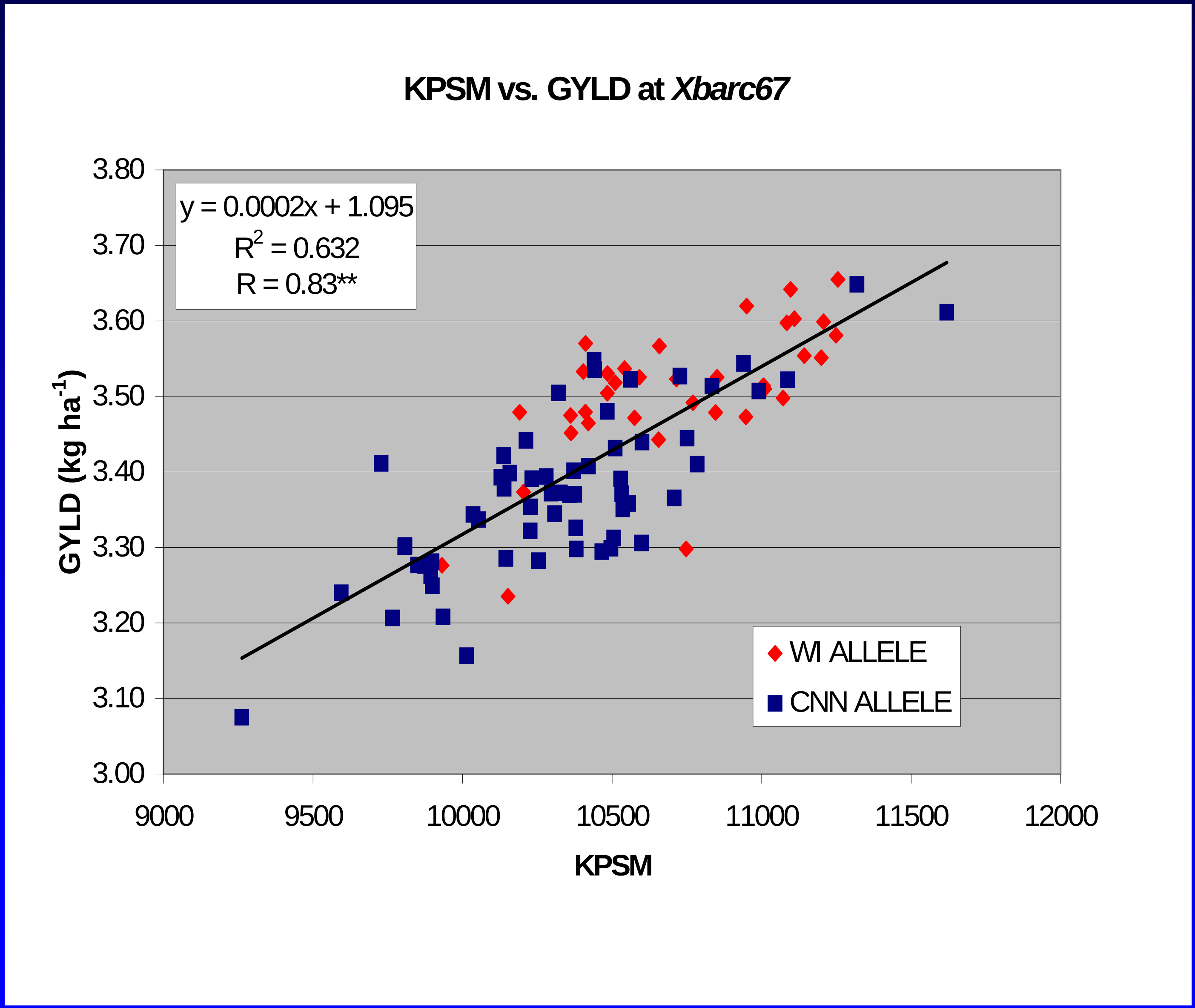

GYLD
KPSM
Region 1
Region 2
Region 3
Region 4
Region 5
Xcdo549
Xbcd907
Xbarc57
Xbarc12
Xtam055
Xtam61
Xcdo395
Xbarc86
XksuA6
Xcdo638
Xbarc67
Xbcd366
Xcmwg680
Xbcd1380
Xbcd1555
Xbcd141
Xbcd22
Xbcd372
Xbcd361
Xgwm155

Change in Magnitude



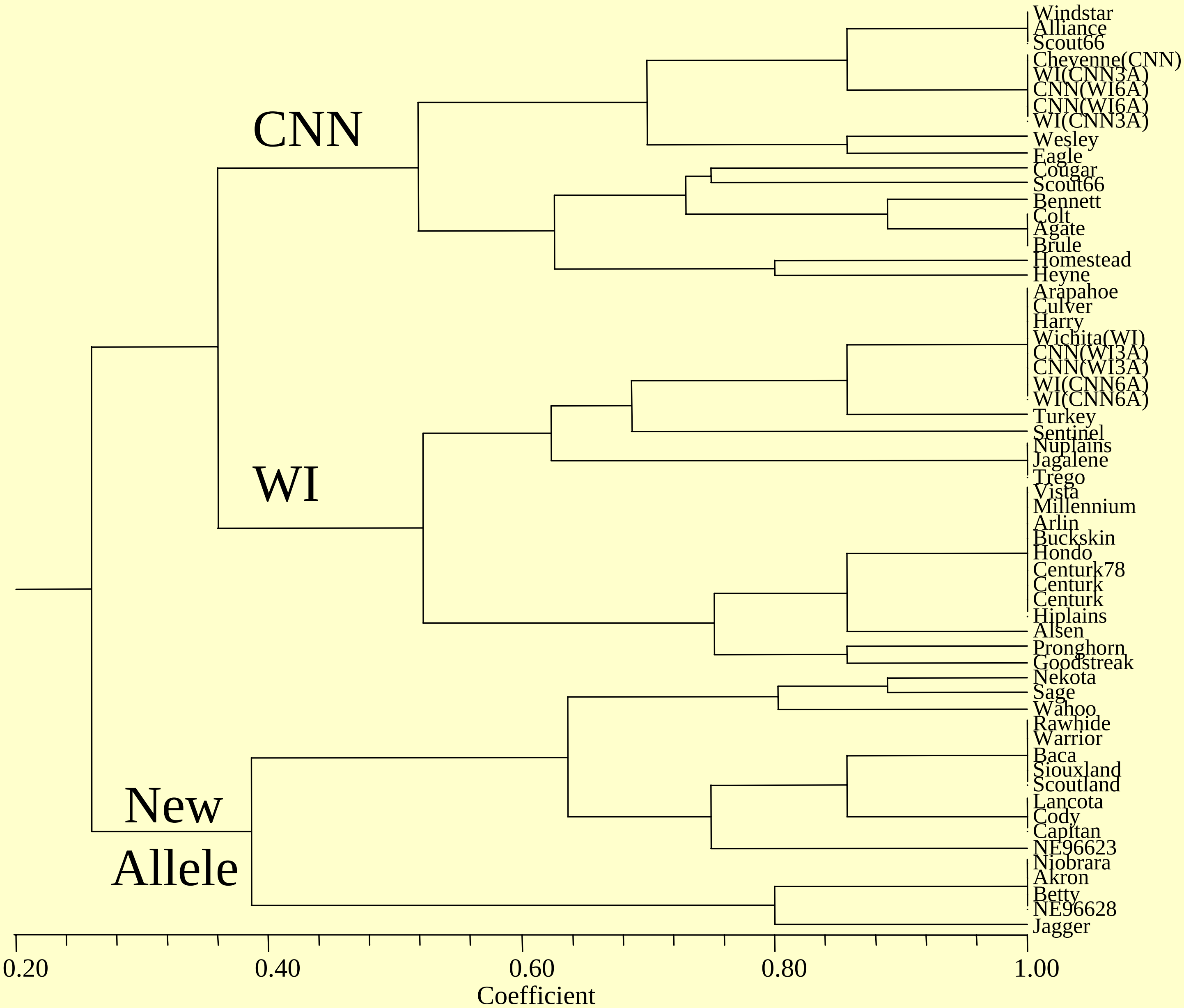
Crossover Interaction





KPSM vs. GYLD at Xbarc67
y = 0.0002x + 1.095
R2 = 0.632
R = 0.83**
3.80
3.70
3.60
3.50
3.40
3.30
3.20
3.10
3.00
GYLD (kg ha-1)
9000
9500
10000
10500
11000
11500
12000
KPSM
WI ALLELE
CNN ALLELE

Fig 5

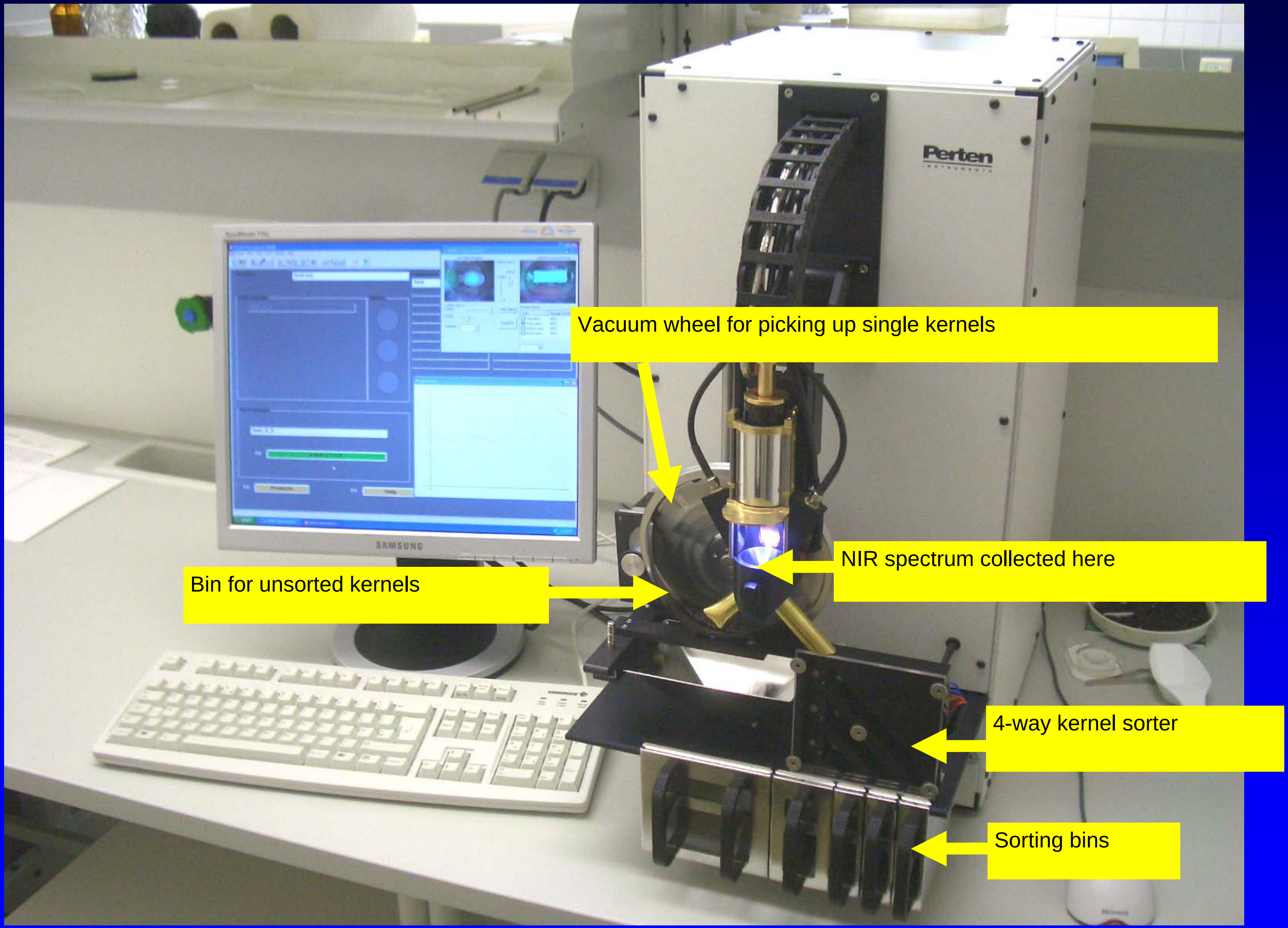

CNN
WI
New
Allele
Windstar
Alliance
Scout66
Cheyenne(CNN)
WI(CNN3A)
CNN(WI6A)
CNN(WI6A)
WI(CNN3A)
Wesley
Eagle
Cougar
Scout66
Bennett
Colt
Agate
Brule
Homestead
Heyne
Arapahoe
Culver
Harry
Wichita(WI)
CNN(WI3A)
CNN(WI3A)
WI(CNN6A)
WI(CNN6A)
Turkey
Sentinel
Nuplains
Jagalene
Trego
Vista
Millennium
Arlin
Buckskin
Hondo
Centurk78
Centurk
Centurk
Hiplains
Alsen
Pronghorn
Goodstreak
Nekota
Sage
Wahoo
Rawhide
Warrior
Baca
Siouxland
Scoutland
Lancota
Cody
Capitan
NE96623
Niobrara
Akron
Betty
NE96628
Jagger
0.20
0.40
0.60
0.80
1.00
Coefficient

Selection Techniques:

- The importance of selection seems to becoming less researched and less understood.
- Natural Selection and selection nurseries
- Cropping systems and optical sorting.

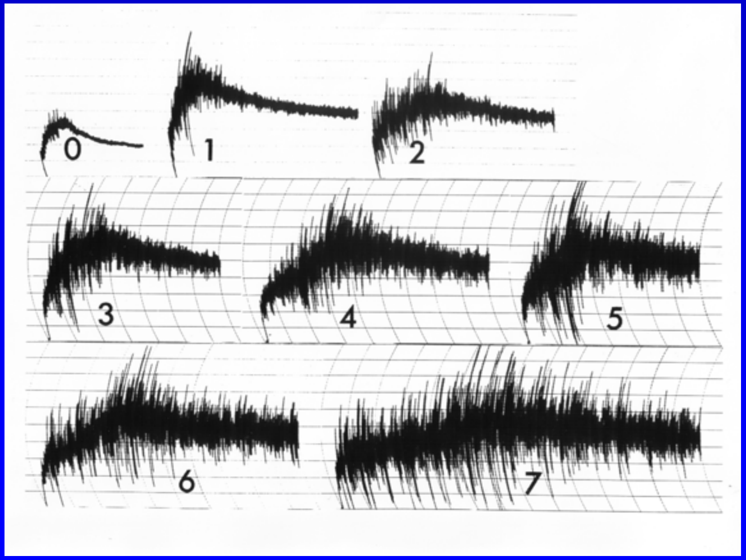
- The question is one of opportunity costs- What technologies are we giving up for those we are accepting? Also, one technology is not right for everyone.

Optical Kernel Sorting:



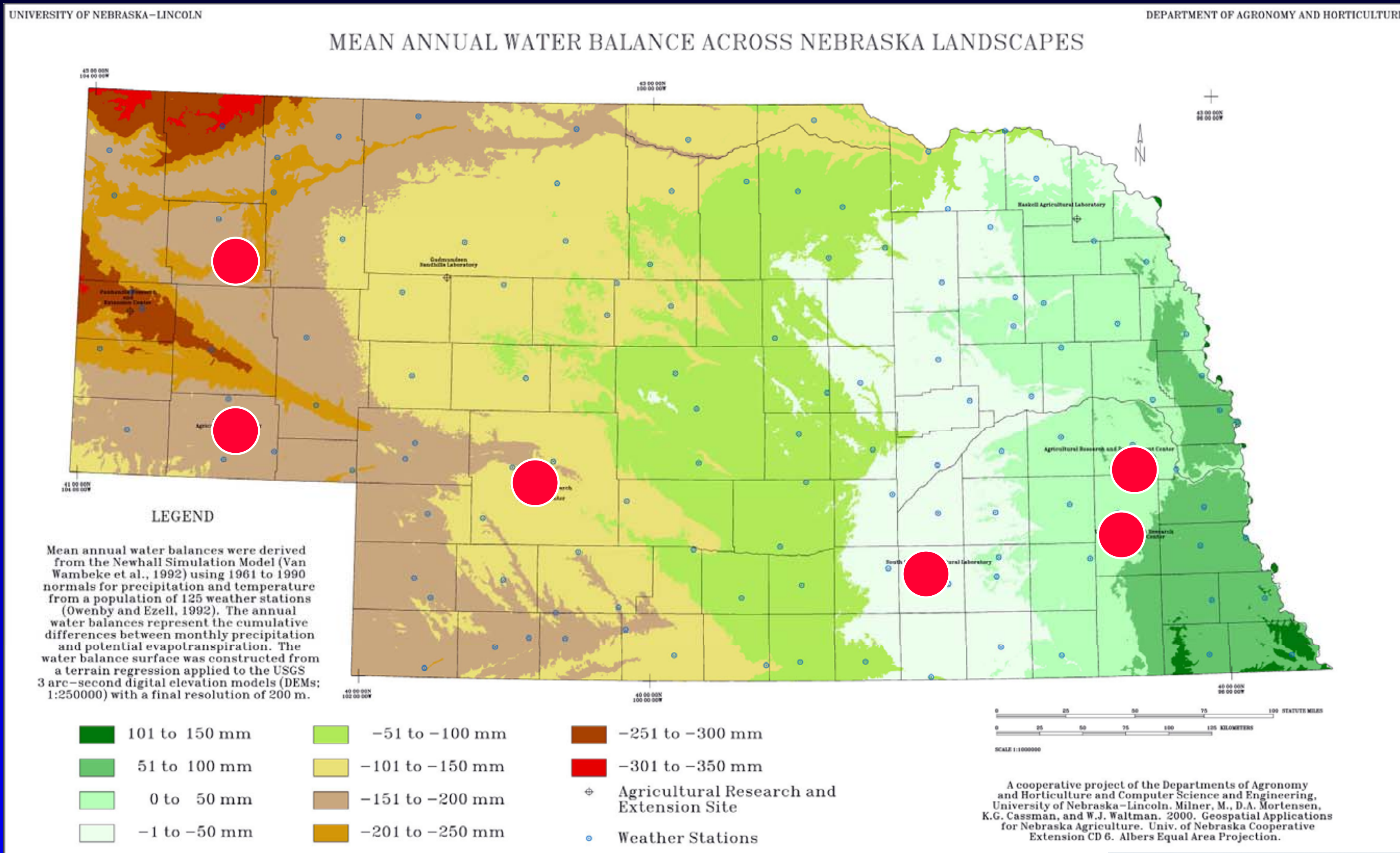
Segregation and Selection:



Evaluation and Release:

- Cropping systems: Crops have to evaluated in the manner to which they are to be grown.
- Biometry: Statistical approaches to identify differences. More efficient designs allow better evaluation (nearest neighbors, alpha lattices, etc.)
- Modeling: Will allow the trial data from a limited number of tests to be extrapolated to other environments.


UNIVERSITY OF NEBRASKA–LINCOLN
DEPARTMENT OF AGRONOMY AND HORTICULTURE
MEAN ANNUAL WATER BALANCE ACROSS NEBRASKA LANDSCAPES
LEGEND
Mean annual water balances were derived from the Newhall Simulation Model (Van Wambeke et al., 1992) using 1961 to 1990 normals for precipitation and temperature from a population of 125 weather stations (Owenby and Ezell, 1992). The annual water balances represent the cumulative differences between monthly precipitation and potential evapotranspiration. The water balance surface was constructed from a terrain regression applied to the USGS 3 arc–second digital elevation models (DEMs; 1:250000) with a final resolution of 200 m.
101 to 150 mm
51 to 100 mm
0 to 50 mm
−1 to −50 mm
−51 to −100 mm
−101 to −150 mm
−151 to −200 mm
−201 to −250 mm
−251 to −300 mm
−301 to −350 mm
Agricultural Research and Extension Site
Weather Stations
A cooperative project of the Departments of Agronomy and Horticulture and Computer Science and Engineering, University of Nebraska–Lincoln. Milner, M., D.A. Mortensen, K.G. Cassman, and W.J. Waltman. 2000. Geospatial Applications for Nebraska Agriculture. Univ. of Nebraska Cooperative Extension CD 6. Albers Equal Area Projection.




The effect of drought: Field Variation

The effect of snow cover: Field Variation

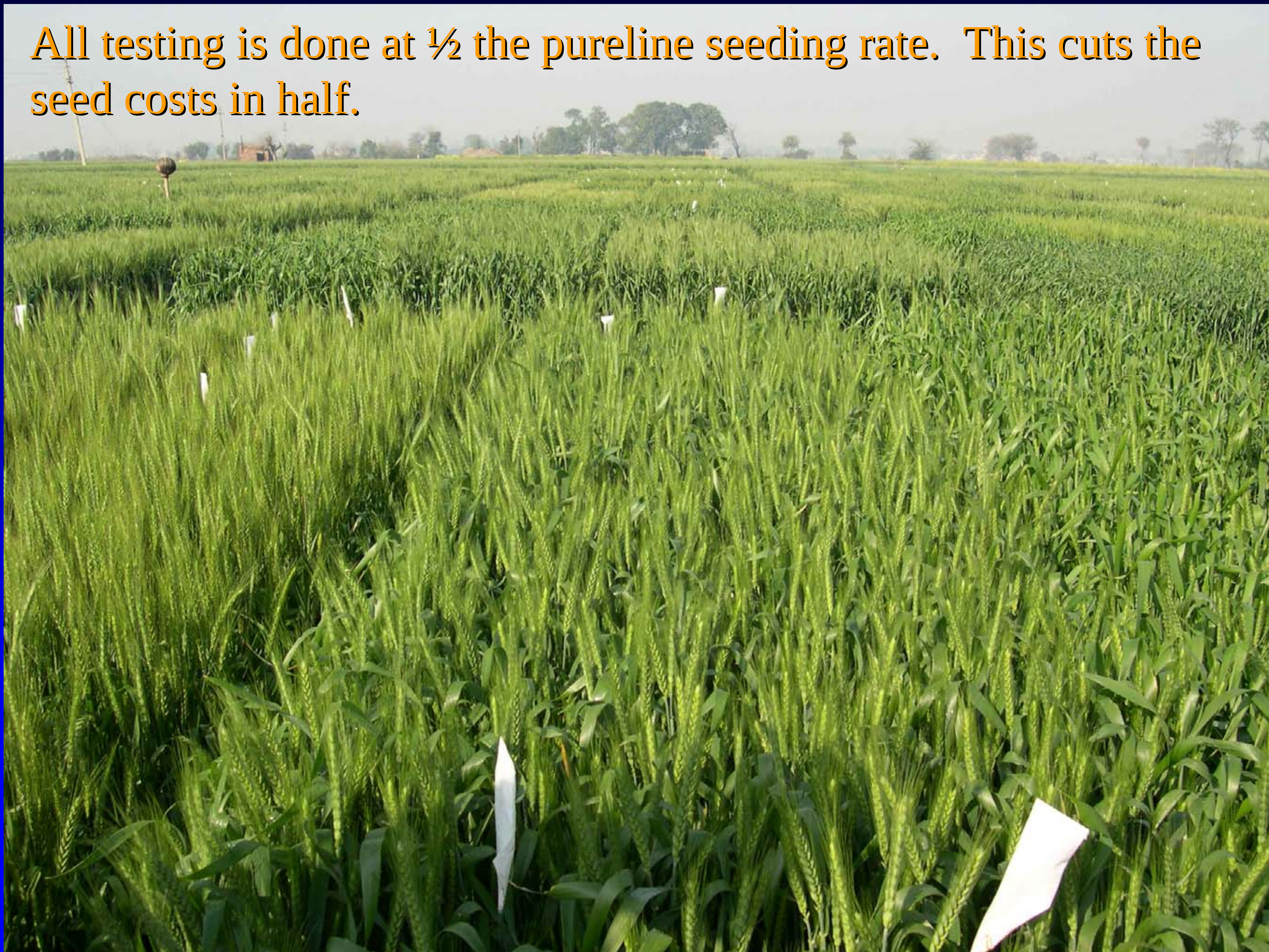
Hybrid Crops: Wheat

Hybrid wheat is grown in India, South Africa, and Australia.

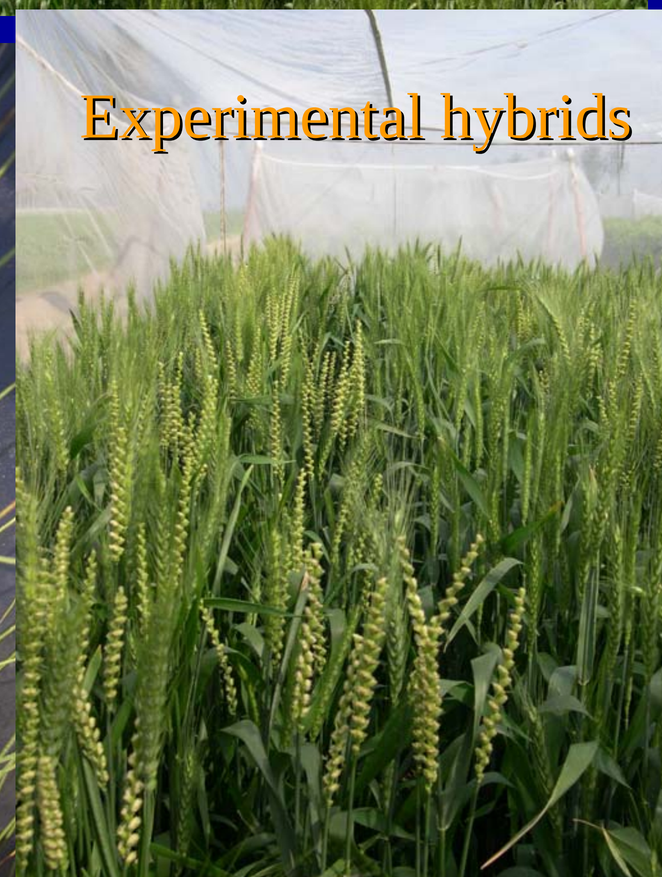
Seed costs and the lower levels of heterosis are major limitations to hybrid wheat adoption.

Though considerable effort has been made on CHA, CMS systems appear to be the most efficacious and reliable. Restoration has been a problem.

All testing is done at ½ the pureline seeding rate. This cuts the seed costs in half.



Hybrid Crops: Wheat



Critical Needs for 21st Century Plant Breeding: Fearless Predictions

Critical Needs for 21st Century Plant Breeding

- Have we reached our upper genetic limit? Have we reliable cropping systems to allow breeders to select for higher yield?
- Can we better identify the world’s agroecological zones to foster germplasm exchange among similar zones?
- Need a global consensus on the appropriate use of technology.
- Need public-private partnerships to benefit all in plant breeding. The public sector need to re-evaluate how it deploys its resources so as not to duplicate the private sector research and to address the great problems affecting our crop productivity (e.g hybrid wheat or non-hybrid maize).

... a good past is positively dangerous if it makes us content with the present and unprepared for the future.

Charles Eliot

Thank You