Breeding for a Variable Climate: Strategies for Improving Drought Tolerance of Crops

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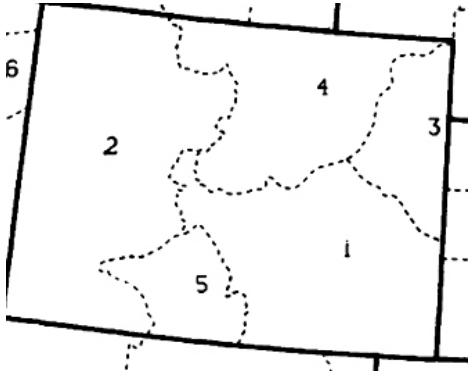
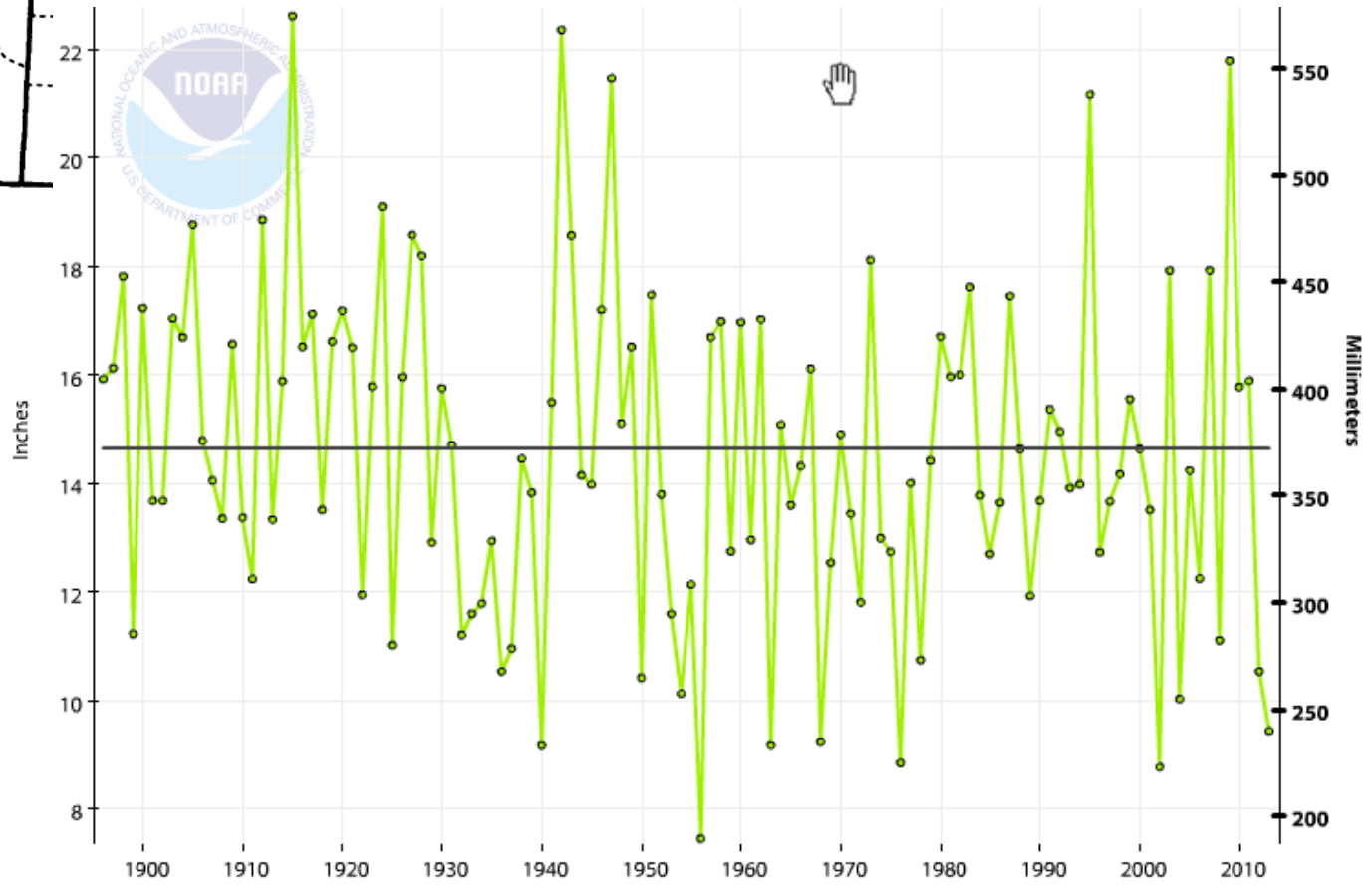
Soil & Crop Sciences

Outline

- Analysis of historical climate and yield data
- Strategies that plants use to tolerate drought
- Evaluation of wheat roots and yield-related traits
- GMO and gene editing approaches
- Deficit irrigation for water saving
- Root-associated microbiome

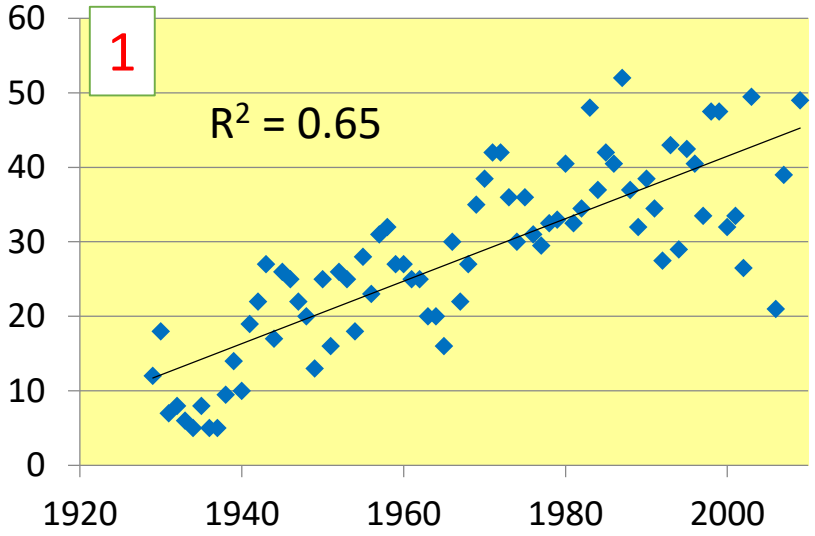


Colorado Climate Division 3, Precipitation, Aug.-June, 1896-2012



Predictions for our part of the country are warmer, drier, and more variable.

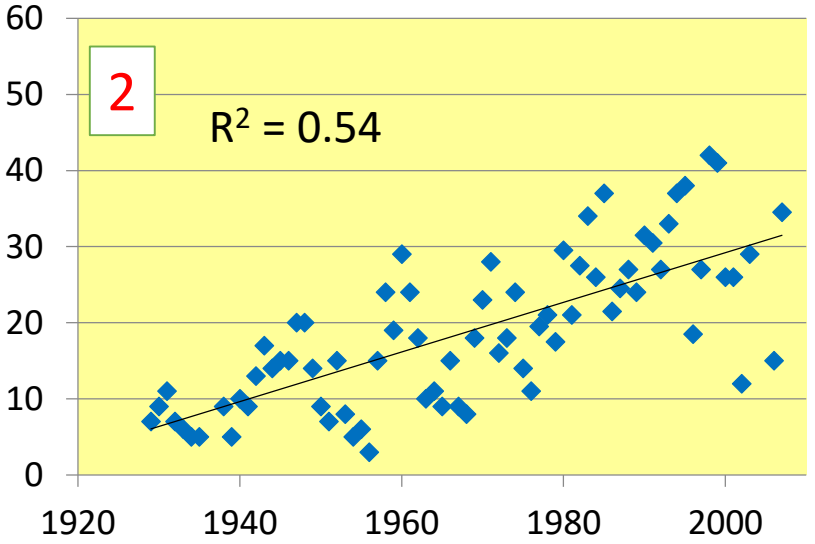
Mean estimated dryland winter wheat yields, bu/ac

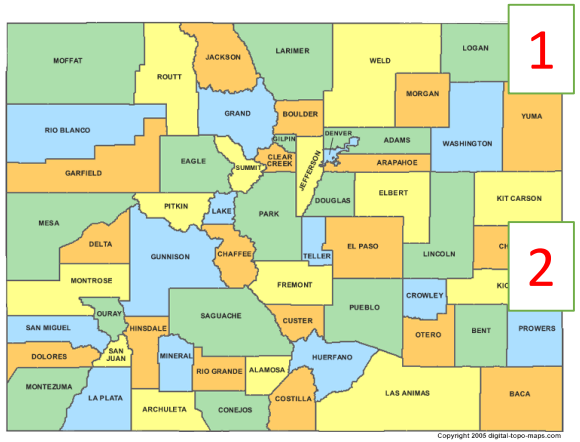


Sedgwick County, Colorado

Mean yield: 27.9 bu/ac

Slope: 0.42 bu/ac per year





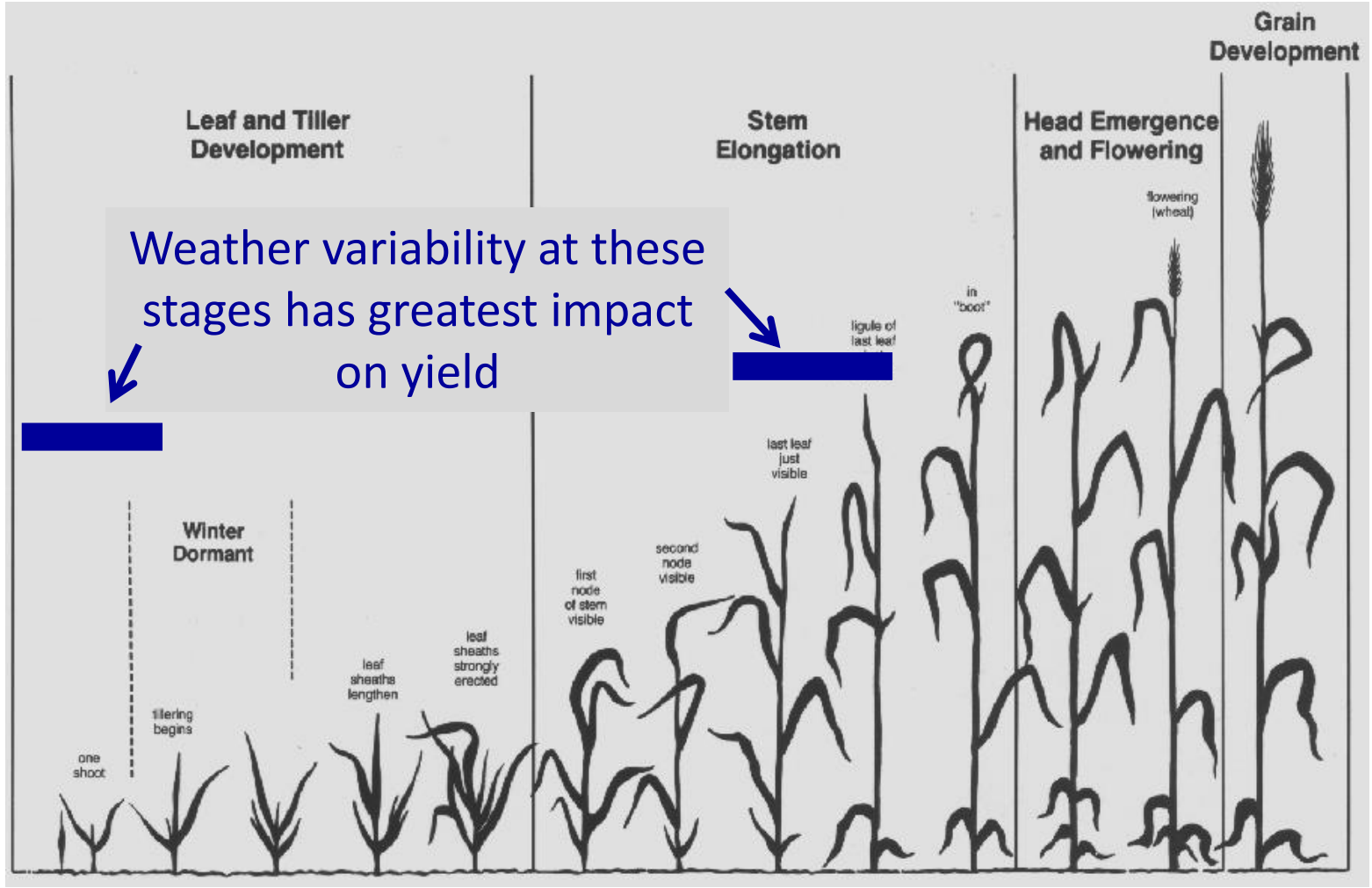
Cheyenne County, Colorado

Mean yield: 18.7 bu/ac

Slope: 0.33 bu/ac per year

Data source: USDA-NASS

Winter Wheat Development in Colorado



October ⟵ March - April ⟶ May-June

Three Categories of Drought Tolerance Mechanisms

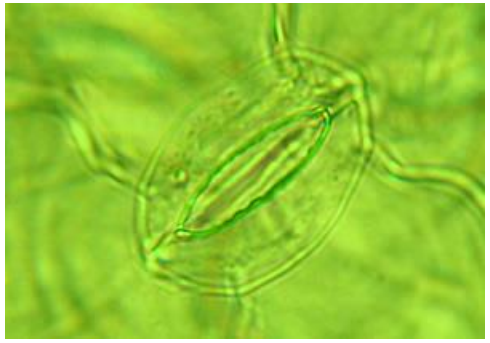
1. Drought escape refers to early flowering and maturity to escape drought stress at the later stages of the crop cycle.

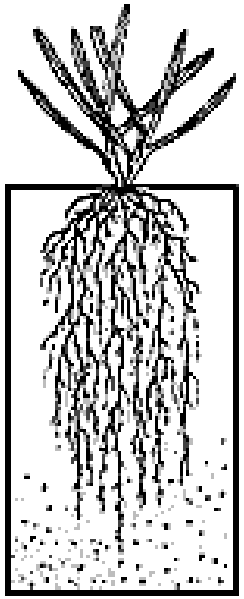
Flowering (heading) time for wheat in Colorado

2. Dehydration tolerance is a plant's ability to function or remain alive while desiccated, as in the resurrection plant.

Three Categories of Drought Tolerance Mechanisms

3. Dehydration avoidance or postponement means that a plant is able to maintain tissue hydration under conditions of soil moisture stress. Examples are quick closure of stomates, deep root growth, and waxy cuticle layers.



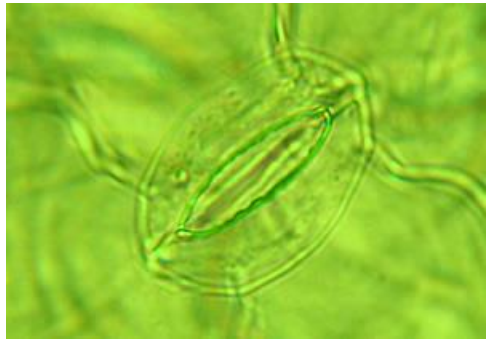


Dehydration avoidance

Two types of dehydration avoiding plants (Levitt, 1980):

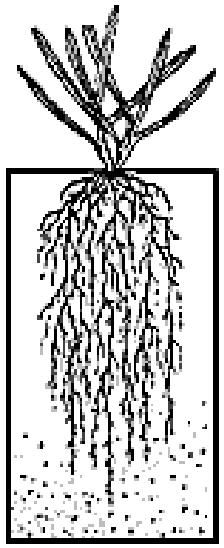
- Water savers maintain tissue hydration by reduced transpiration and therefore reduced water use, e.g., by quick closure of stomates. They use water conservatively, preserving soil moisture for later in the life cycle.

Closed stomate,
www.plantsci.cam.ac.uk

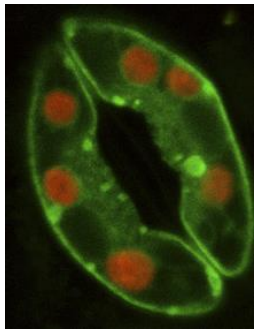


- Water spenders use mechanisms other than reduced transpiration to avoid dehydration, e.g., deeper root systems. They often use large amounts of water.

  Through these mechanisms, the vegetation of water spenders stays more hydrated, stomates stay open, photosynthesis continues, and yields are higher.



Univ. of Minn. Extension

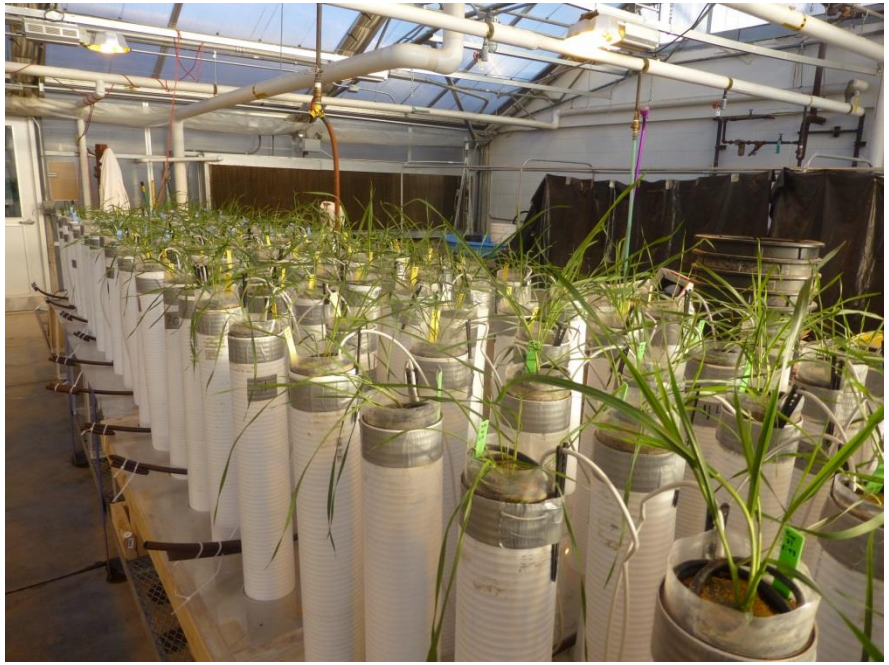


Open stomate
(red=fluorescing chlorophyll)
Wikipedia.org

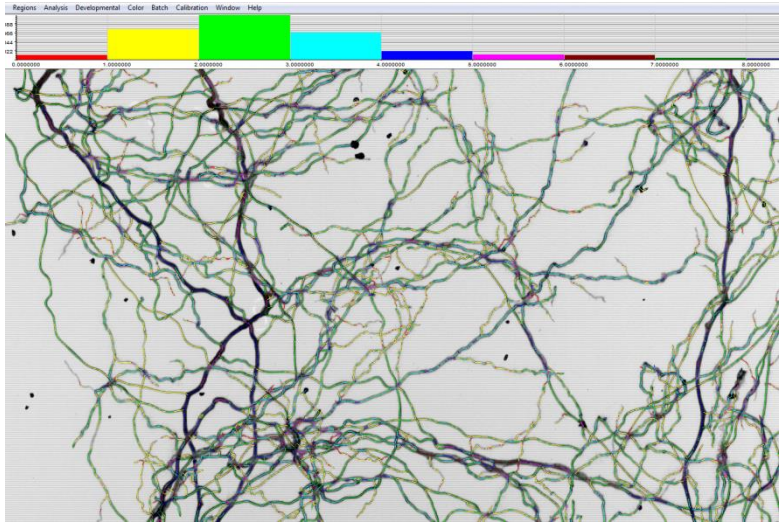
- These are “optimistic” plants that are betting that rains will resume and therefore do not need to be so stingy with their water use.

Root evaluation in 1-m root tubes

Plants are grown in Greens Grade (a fritted clay medium) allowing clean separation of the root mass.



WinRhizo analysis



Diameter (mm)

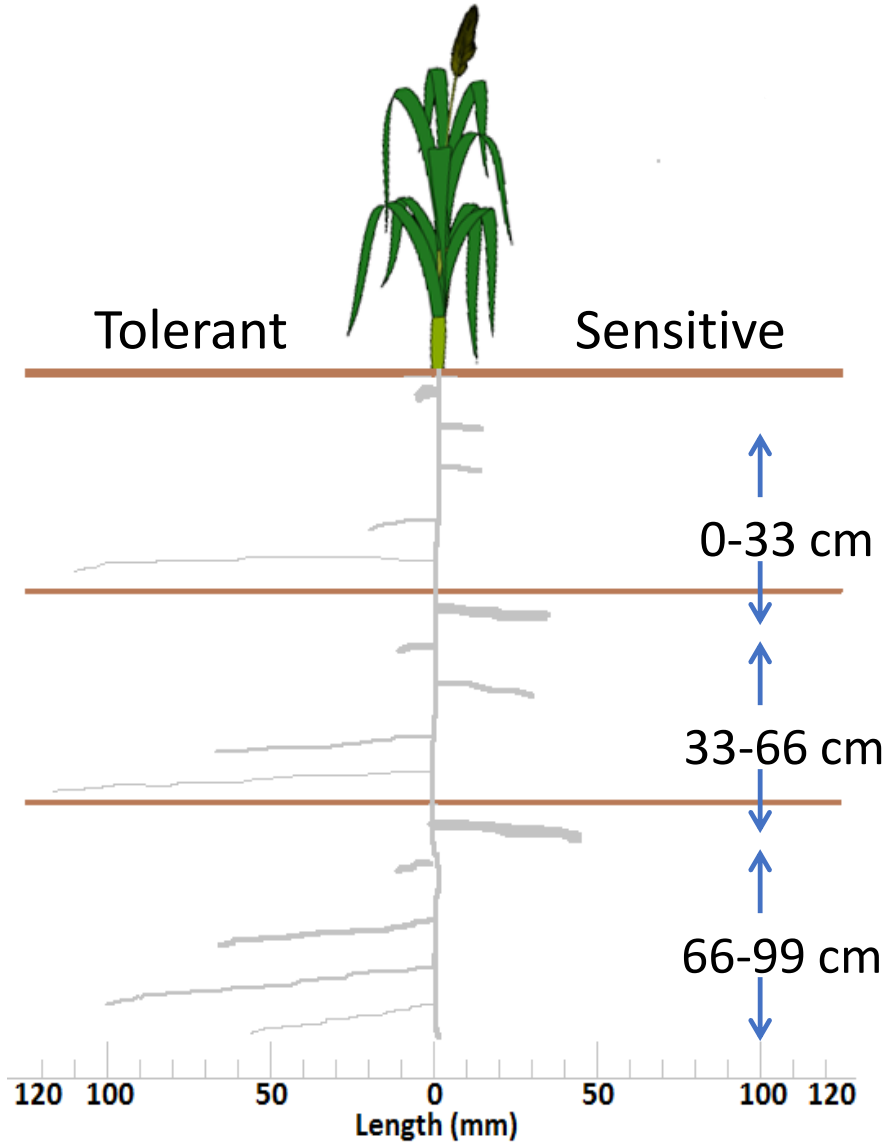
1.0+

0.75 – 1.0

0.50 – 0.75

0.25 – 0.50

0.0 – 0.25



Root diameter analysis, drought-stressed treatment

Agronomy Journal, 2018

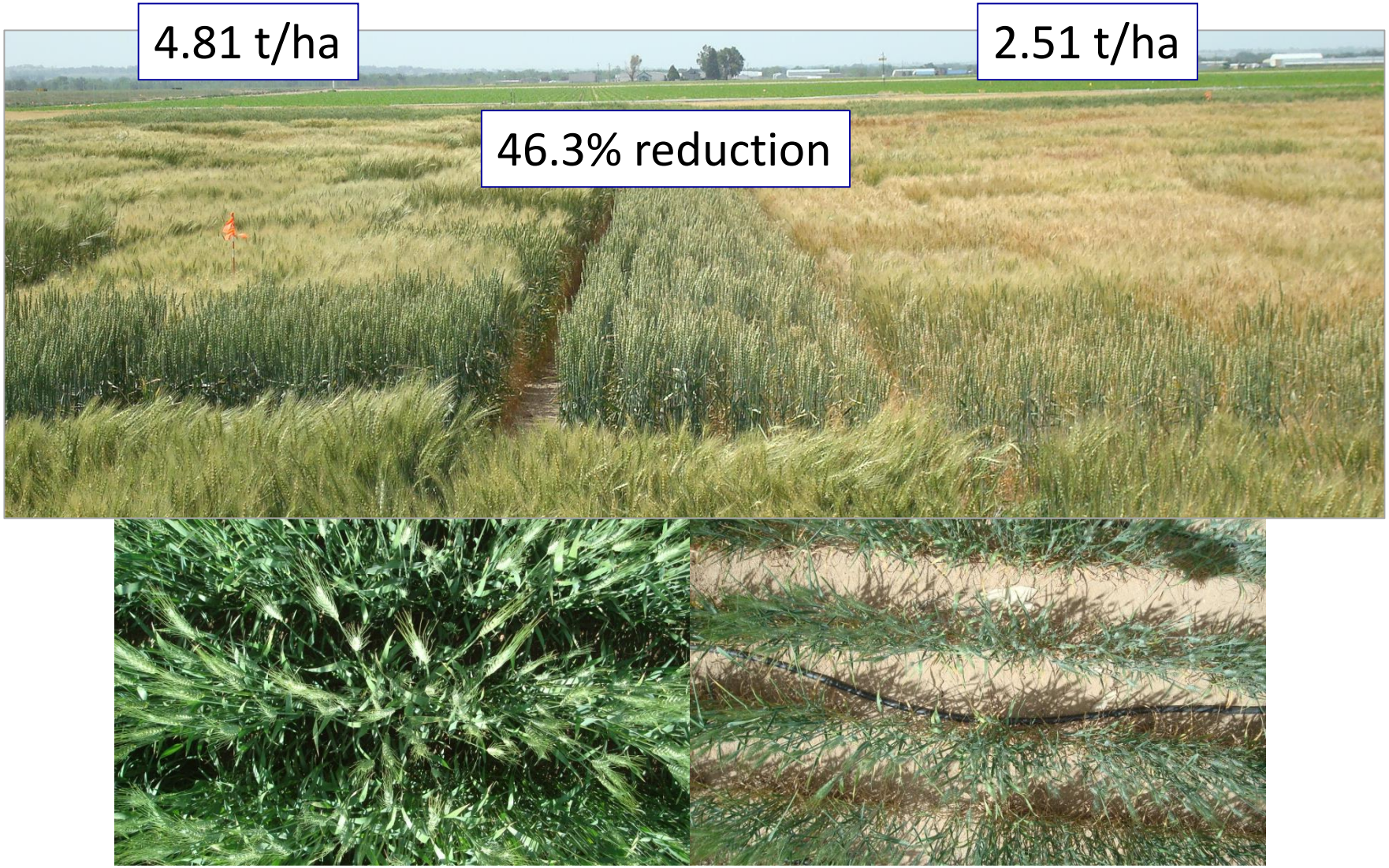
Great Plains Winter Wheat Varies for Root Length and Diameter under Drought Stress

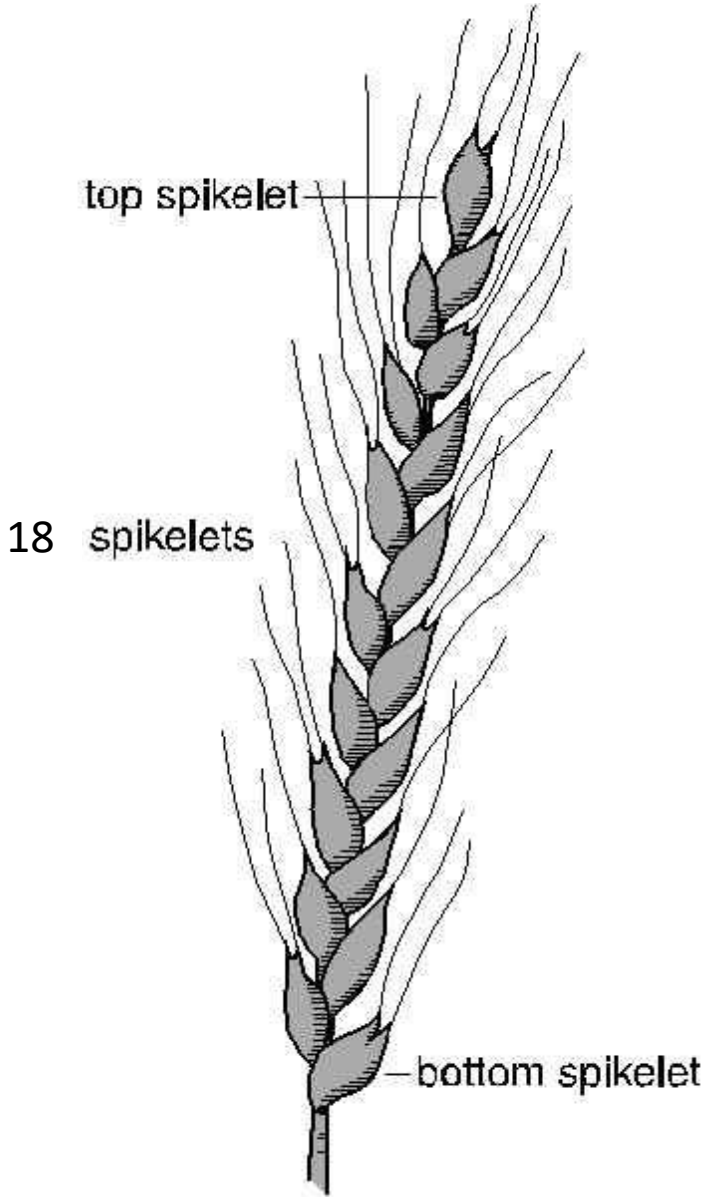
Wahid Awad, Patrick F. Byrne,* Scott D. Reid, Louise H. Comas, and Scott D. Haley

Currently evaluating root angle and growth rate of Great Plains wheat.

USDA Limited Irrigation Research Farm, Greeley, CO

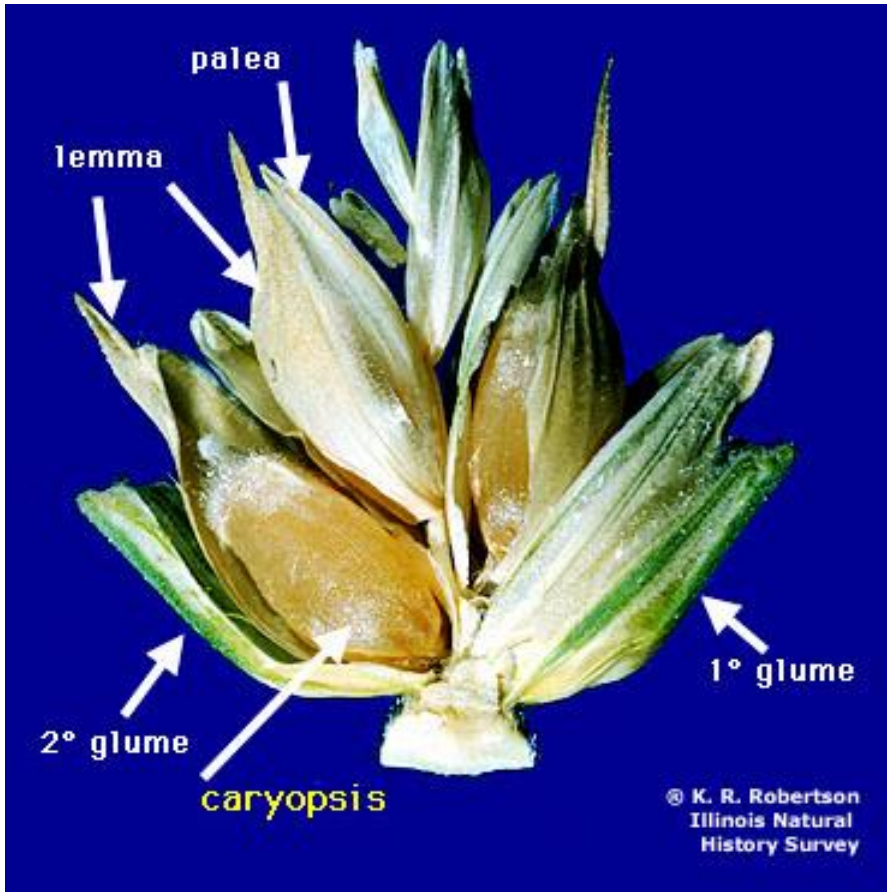
USDA Limited Irrigation Research Farm, Greeley, CO 2012





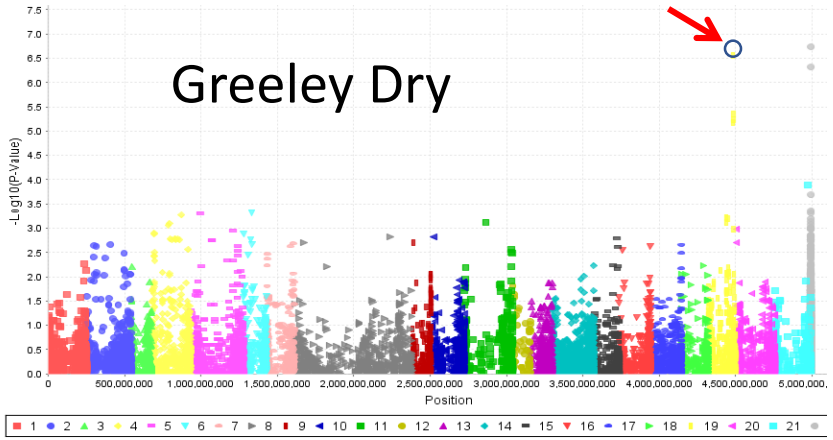
North Dakota State Univ.

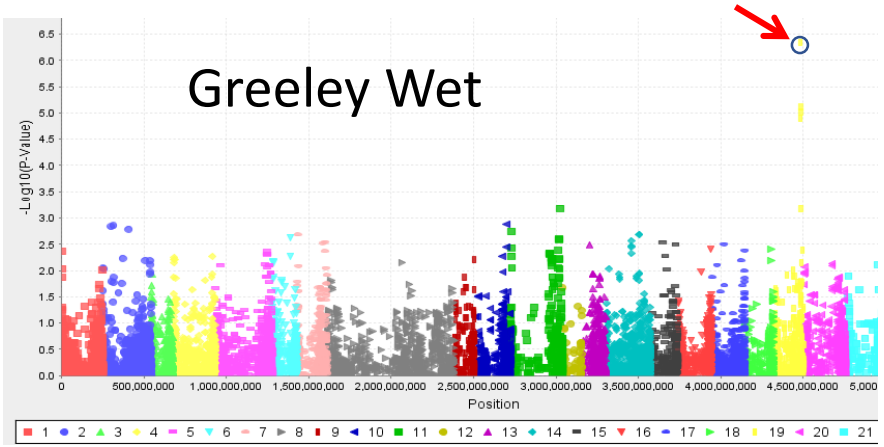
Spikelet of wheat

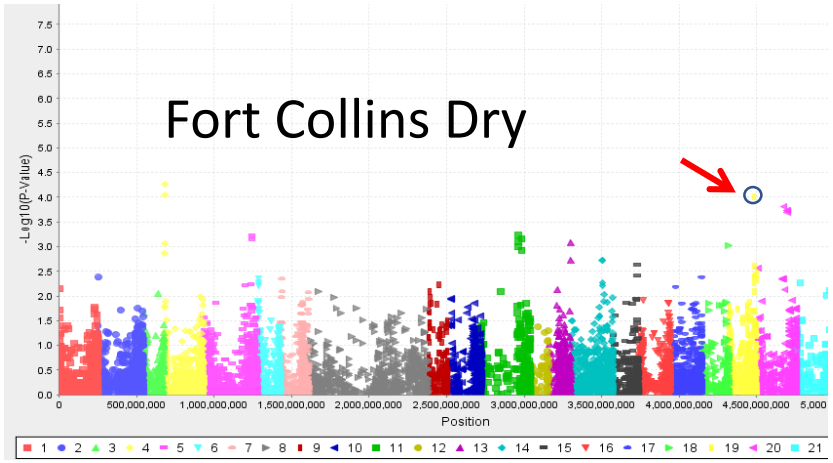


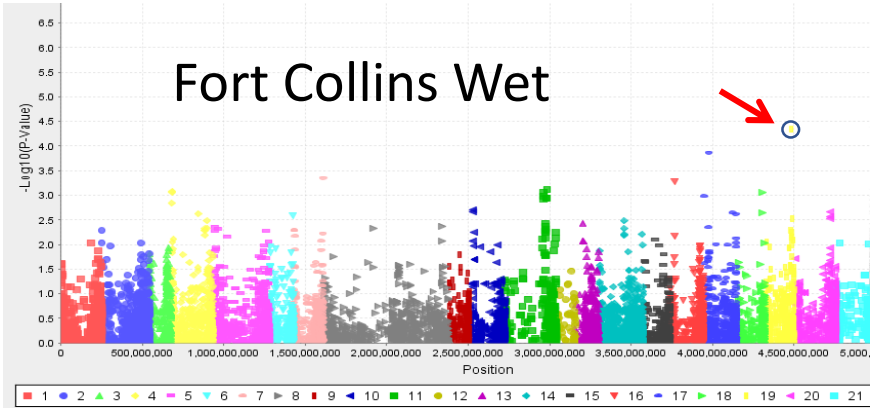
Univ. of Illinois

Genome-wide association study (GWAS) for spikelets per spike in wheat in four environments – consistent effect on chromosome 7A









The first GM drought tolerant crop was released in 2013

- MON 87460 (‘DroughtGard’), GM drought tolerant corn jointly developed by Monsanto and BASF, was released in the U.S. in 2013.
- Transgene is *CspB*, encoding a cold shock protein from the bacterium *Bacillus subtilis*.
- The gene produces an RNA binding protein with chaperone activity that maintains gene expression under stress conditions.
- Expected to improve yields 5-10% under moderate drought stress, with no yield penalty under well watered conditions (Chang et al., 2014).

Argentina approves first drought-resistant, herbicide-tolerant GMO soybean

ChileBio | October 22, 2018

Argentina could be first country to plant GMO wheat, engineered for drought resistance—if regulators approve

Javier Patiño | eFarmNews | November 20, 2018

Image Credit: GMO Awareness

Transgene in both cases is a transcription factor (regulator of gene expression) from sunflower

Gene editing technology, e.g., CRISPR/Cas9

- Enables precise changes in DNA genetic code, sometimes changing just a single base in the sequence
- Efficient; low cost
- Are gene-edited products GMOs or not?
- How will they be regulated (in the US and globally)?

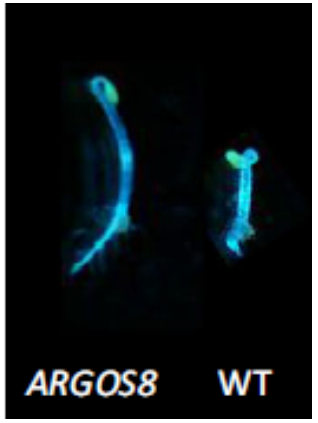
Corteva (Dupont Pioneer) has developed a drought-tolerant maize based on CRISPR technology.

Plant Biotechnology Journal

Plant Biotechnology Journal (2017) **15**, pp. 207–216 doi: 10.1111/pbi.12603

ARGOS8 variants generated by CRISPR-Cas9 improve maize grain yield under field drought stress conditions

Jinrui Shi*, Huirong Gao, Hongyu Wang, H. Renee Lafitte, Rayeann L. Archibald, Meizhu Yang, Salim M. Hakimi, Hua Mo and Jeffrey E. Habben



ARGOS8 is a gene that reduces sensitivity to the stress hormone ethylene, thus allowing growth to continue.

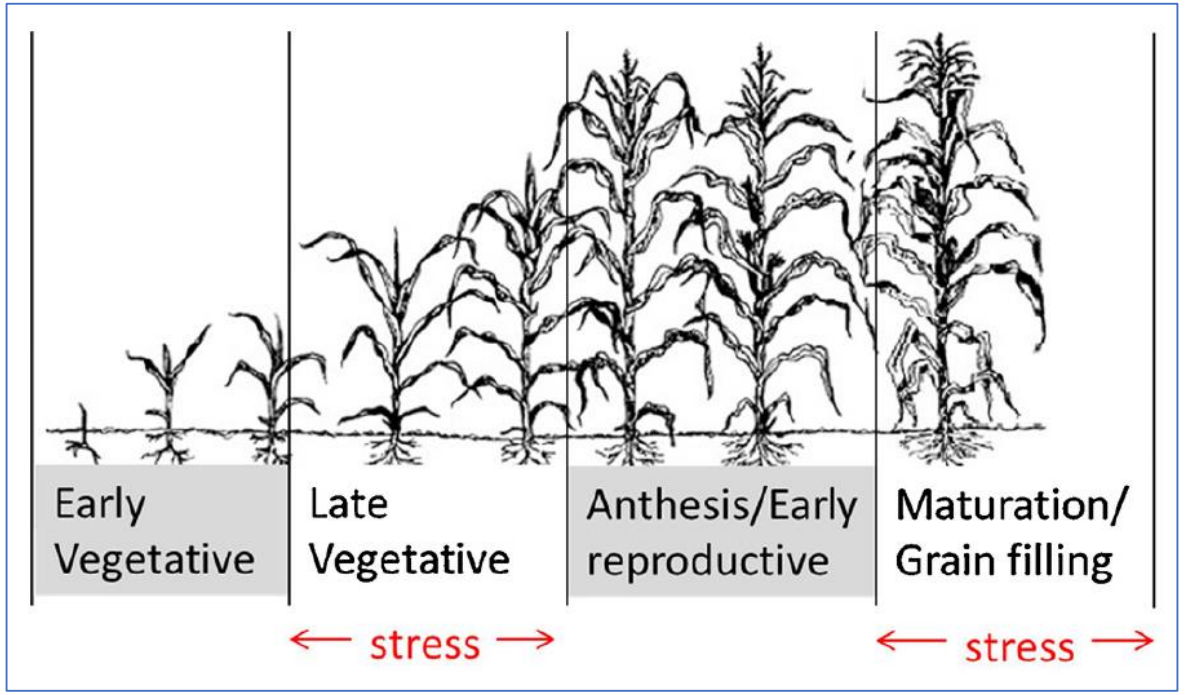
Growth of ARGOS8 and wild type (WT) maize seedlings exposed to ethylene.

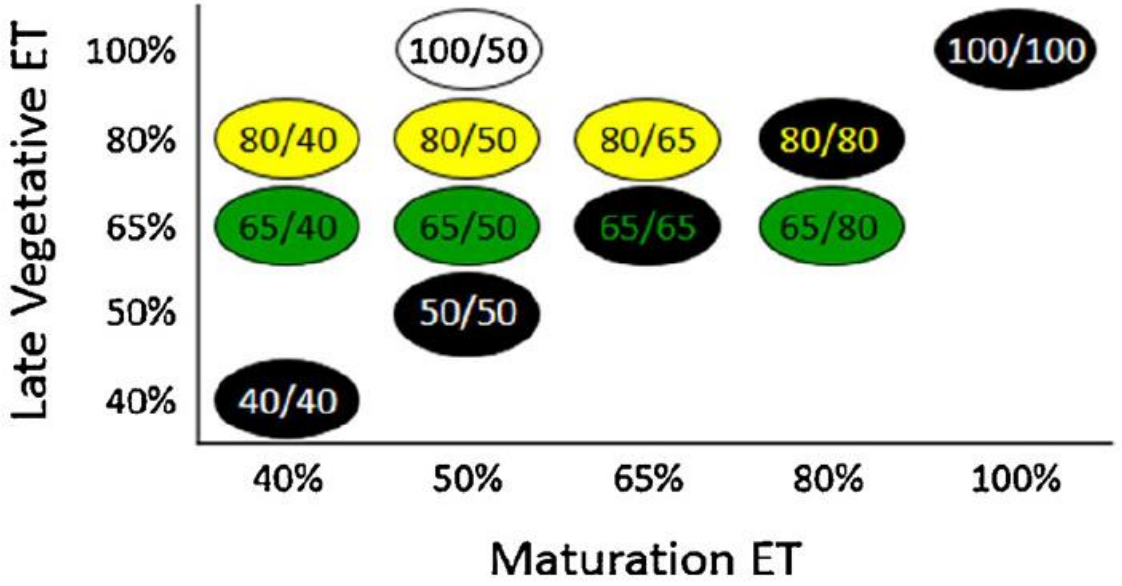
Deficit irrigation for water saving

Water productivity under strategic growth stage-based deficit irrigation in maize

(Comas et al., Agricultural Water Management, 2018)

Research was carried out by USDA scientists in Greeley, CO





Grain yield of corn under 12 deficit irrigation treatments (Comas et al., 2018)

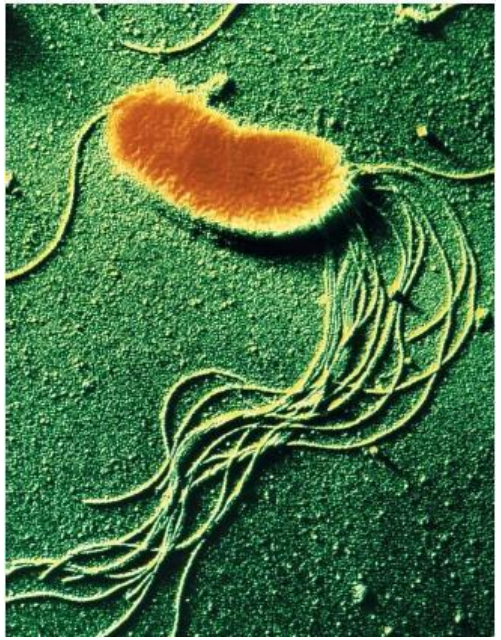
Year	Target ET, %	Yield, kg/ha	Year	Target ET, %	Yield, kg/ha
2012	100/100	15,734	2013	100/100	15,699
	80/80	14,946		80/80	15,301
	65/65	12,615		65/65	13,903
	50/50	11,376		50/50	12,064
	40/40	10,686		40/40	8,567
	100/50	12,674		100/50	13,076
	80/65	13,332		80/65	14,848
	80/50	11,275		80/50	13,066
	80/40	12,807		80/40	10,600
	65/80	14,712		65/80	15,099
	65/50	12,039		65/50	12,120
	65/40	11,643		65/40	10,898

Collaboration with USDA-ARS colleagues to obtain high-throughput UAV data to better identify drought-tolerant breeding lines

… and compare with Crop Circle and Canopeo data

Root-associated microbes

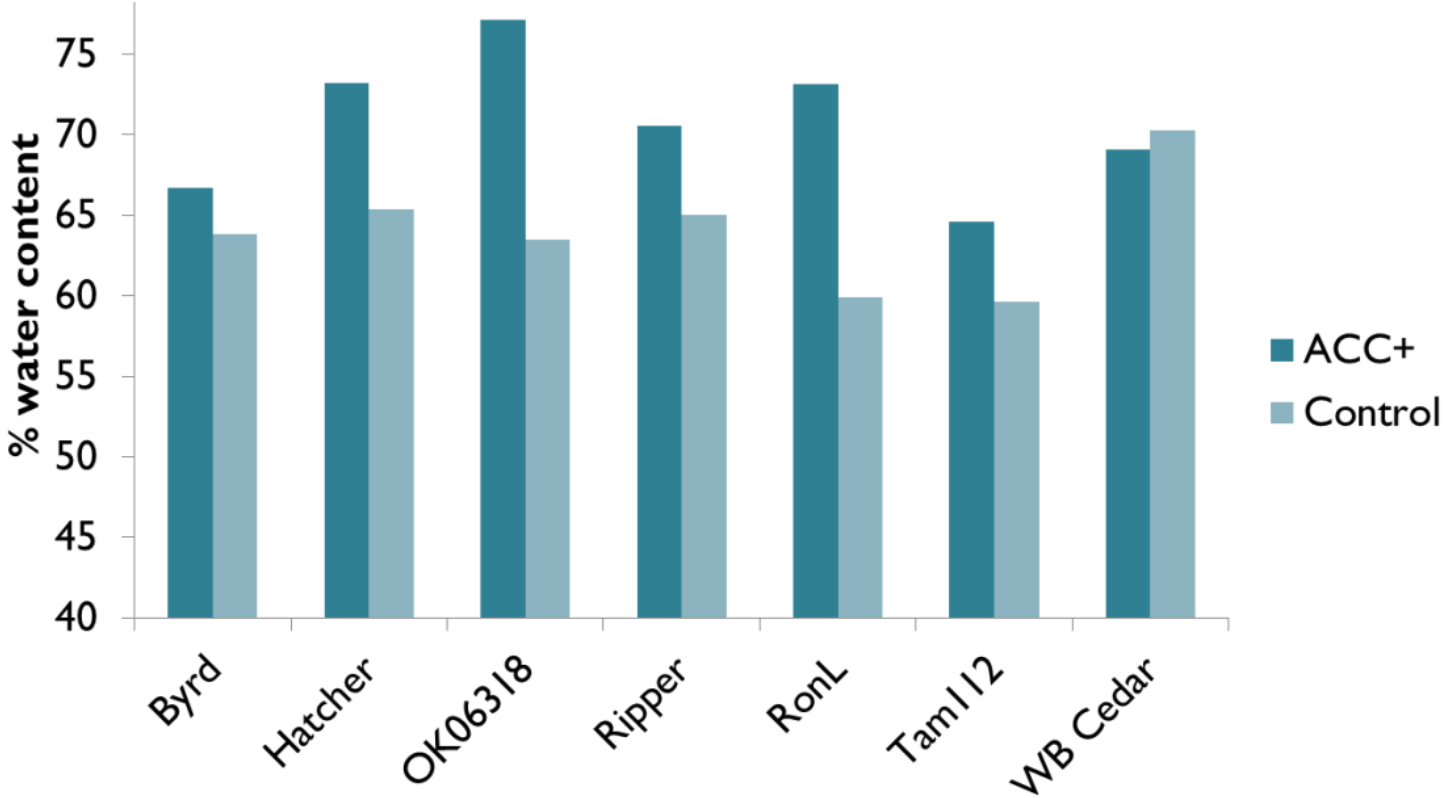
- There is growing evidence that soil microbial communities can influence a plant's tolerance to stress.
- ACC deaminase positive bacteria degrade the plant-produced precursor to ethylene, leading to continued root growth and delayed senescence.



- Mary Stromberger and Dan Manter, soil microbiologists at Colorado State and USDA, are collaborating to study the effects of root exudates on microbial populations and drought tolerance.

Do Great Plains wheat cultivars respond differently to inoculation with ACC+ bacteria?

Leaf relative water content in drought-stressed wheat plants inoculated with or without ACC+ bacteria (4 reps). The main effect of inoculation was significant (*P*=0.03).



In conclusion,

- Drought stress is predicted to increase in the western Great Plains due to more variable rainfall and greater evaporation due to higher temperatures.
- Promising areas for future research include optimizing root systems, editing of key genes, high throughput field evaluation, deficit irrigation, and root-associated microbial populations.
- Improvements in drought tolerance of wheat may not free up water for other uses, but will contribute to the economic sustainability of agriculture in our semi-arid region.

USDA
National Institute of Food and Agriculture

Colorado Wheat Research Foundation

Collaborators

Stephen Baenziger
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Shuyu Liu
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Greg McMaster
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