Drought Tolerance and Drought Timing in Corn

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Corn stage	Evapotranspiration (inches/day)[1]	Yield reduction (%) from 4 consecutive days of wilting[2]	Yield reduction (%) from 1 day of wilting[3]
Early vegetative	0.06 – 0.10	5 – 10	.
Mid-vegetative	0.18	.	.
V12 – V15	0.21	.	2.1 – 3.7
V16 – Vn	0.33	.	2.5 – 4.3
Tasseling (VT)	0.33	10 – 25	2.7 – 5.0
Silking (R1)	0.33	40 – 50	3.0 – 8.0
Blister (R2)	0.33	30 – 40	3.0 – 6.0
Milk (R3)	0.26	.	3.0 – 5.8
Dough (R4)	0.26	20 – 30	3.0 – 5.0
Dent (R5)	0.26	.	2.5 – 4.0

[1] Rhoads & Bennet, 1990 (Corn. *In* Irrigation of Agric. Crops, ASA-CSSA-SSSA)
[2] Classen & Shaw, 1970 (*Agronomy Journal* 62:652–655)
[3] Shaw, 1988 (Climate requirement. *In* Corn & Corn Improvement, ASA)

Drought stress during vegetative development

- Can reduce plant size & nutrient uptake

- Before V12 = has small effect on yield, but **severe** early-season stress that lasts through the late vegetative stages can lead to short plants & large yield reductions

- Around V7 = can reduce rows per ear

- At V8–V15 = can reduce potential kernels per row

- Drought stress just before pollination can delay silk emergence until pollen shed is well underway
  - Increases the likelihood that some silks will not receive pollen
- Drought stress during & just after pollination causes loss of kernels, especially for late-fertilized kernels near the tip of the ear

Photo: S. Ao (Univ. of MN)

Drought stress during the grain-filling period

- Causes early senescence
  - Less photosynthesis & shortened grain-filling period = smaller kernels

Photos: S. Ao (Univ. of MN)

Drought stress & stalk quality

- Potassium (K) is important for stalk strength
- 63% of total K uptake occurs between V6 & V18 Abendroth & others, 2011 (*Corn Growth & Development*)
  - Drought stress at this time can reduce K uptake & lead to weak stalks
- Drought stress during grain filling favors translocation of carbohydrates from the stalk to the ear, especially when ears have high kernel number
  - This can lead to hollow stalks & lodging

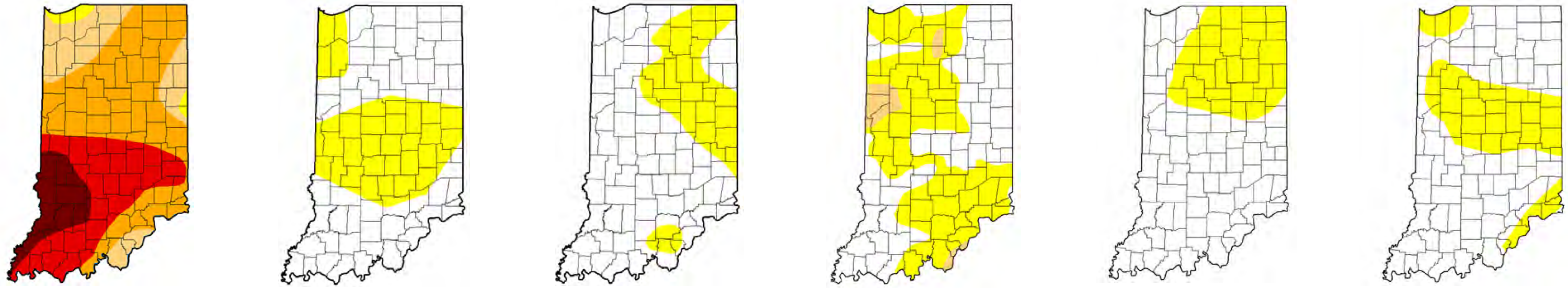
Typical scenario in the Corn Belt

- Water surplus in the spring
- Water deficit during grain filling

Abnormally dry or drought conditions have impacted at least 25% of Indiana during grain filling in 6 of the past 10 years

Drought maps from ~August 20

2012 | 2013 | 2014 | 2019 | 2020 | 2021



Intensity:

- None
- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

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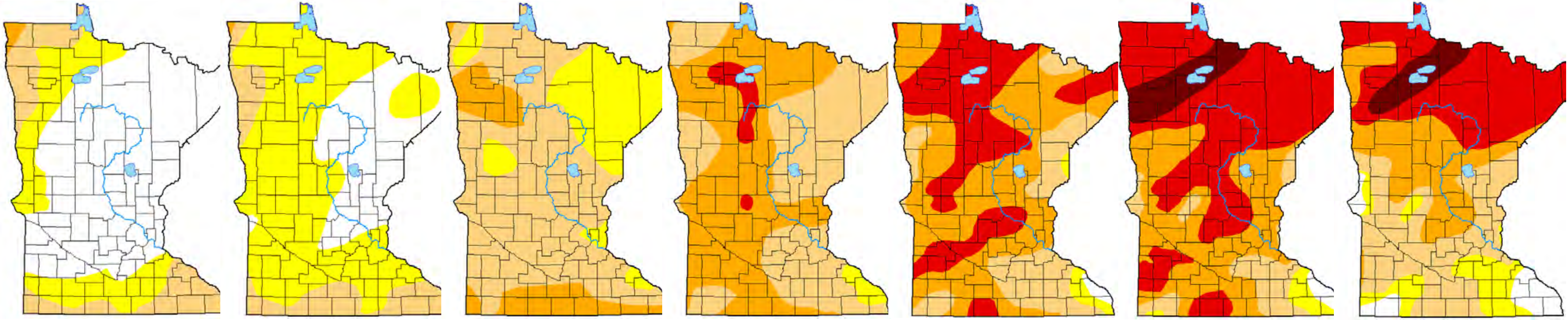
Drought progression in 2021

May 11 | June 1 | June 22 | July 13 | Aug. 3 | Aug. 24 | Sept. 14



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USDA NDMC NOAA

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2021 growing season	Lamberton, MN (southwest)	Waseca, MN (south-central)	Rochester, MN (southeast)
	-------------------- rainfall (inches) --------------------		
May 1–31	2.7	2.7	5.7
June 1–30	0.5	2.0	1.9
July 1–15	0.9	2.0	1.6
July 16–31	0.3	0.7	0.4
Aug. 1–15	0.1	0.7	4.3
Aug. 16–31	4.6	4.1	7.7
Sept. 1–15	1.5	1.1	1.9
Total	10.6	13.3	23.5

Soil texture:	loam	clay loam	silt loam
Soil OM:	4.6%	5.3%	4.8%

2021 growing season

	Lamberton, MN (southwest)	Waseca, MN (south-central)	Rochester, MN (southeast)
Yield, average of 71 entries	167 bu/acre	254 bu/acre	280 bu/acre
Rainfall, May 1 to Sept. 15	10.6"	13.3"	23.5"
Rainfall productivity	16 bu/acre per inch	19 bu/acre per inch	12 bu/acre per inch

Strategies to reduce the risk of drought stress

1. **Maintain residue on the soil** to reduce evaporation & promote water infiltration

2. **Adequate fertilization** to promote crop growth & efficient water use

3. **Plant early** to build root system before the soil dries out & complete pollination & kernel set before drought sets in

(Hesterman & Carter, 1990, NCH-58, *In* National Corn Handbook)

Strategies to reduce the risk of drought stress

3. **Plant hybrids of varying maturity** to spread risk of moisture stress during pollination

4. **Plant hybrids with high ratings for drought tolerance**

5. **Avoid excessive plant populations** to avoid excessive water use

6. **Control weeds** to conserve moisture

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(Hesterman & Carter, 1990, NCH-58, *In* National Corn Handbook)

Characteristics of drought-tolerant hybrids under drought

- Efficient use of water
- Resistance to dehydration
  - Closing of stomata (pores in leaves) to reduce transpiration
- High rate of photosynthesis
- High growth rate around flowering

Araus & others, 2012 (*Frontiers in Physiology* 3:305)

Lopes & others, 2011 (*Journal of Experimental Botany* 62:3135–3153)

Characteristics of drought-tolerant hybrids under drought

- Adequate pollen supply
- Narrow interval between the start of pollen shed & silking
- Resistance to kernel loss after pollination
- Greater stay green

Araus & others, 2012 (*Frontiers in Physiology* 3:305)

Lopes & others, 2011 (*Journal of Experimental Botany* 62:3135–3153)

Characteristics of drought-tolerant hybrids

- Greater water uptake capacity
  - Deep rooting before the onset of drought
  - Vigorous root growth where soil moisture is available

Araus & others, 2012 (*Frontiers in Physiology* 3:305)

Lopes & others, 2011 (*Journal of Experimental Botany* 62:3135–3153)

The role of nitrogen (N) in drought stress

- The development of drought stress & the response of corn yield to drought stress are mediated by N supply & corn N uptake

- Uptake of water & N by corn are positively correlated
  - Adequate N supply increases corn water use efficiency
  - Adequate water supply increases corn N use efficiency

Photo: E. Ristau (Univ. of MN)

Drought-tolerant hybrids

- Compared to standard hybrids, drought-tolerant hybrids have generally produced:
  - Similar yield in the absence of drought stress
  - Greater yield under drought stress, especially as the duration of drought stress increases

Drought-tolerant (DT) vs. non-DT hybrids in small-plot trials across the U.S. in 2008–2010

Environment	Locations	6 DT hybrids	10 non-DT hybrids	Difference	Statistically significant at 5% level
	#	------- bu/ac -------		%	
Water-limited	53	127	121	5	No
Favorable	502	207	202	3	Yes

Gaffney & others, 2015 (*Crop Science* 55:1608–1618)

Drought-tolerant (DT) vs. non-DT hybrids in on-farm strip trials across the U.S.

Year	Environment	Locations	6 DT hybrids	10 non-DT hybrids	Difference	Statistically significant at 5% level
		#	------- bu/ac -------		%	
2011	Water-limited	271	84	78	7	Yes
	Favorable	1960	211	203	4	Yes
2012	Water-limited	1380	97	88	10	Yes
	Favorable	2779	219	213	3	Yes
2013	Water-limited	355	111	107	3	Yes
	Favorable	3986	217	216	0	No

Gaffney & others, 2015 (*Crop Science* 55:1608–1618)

- **Previous research comparing drought-tolerant & standard corn hybrids has evaluated the effect of:**
  - Growing environment
  - Seasonal irrigation amount
  - Watering regime initiated at early to mid-vegetative development

- **No published research had directly compared drought-tolerant & standard corn hybrids:**
  - under sustained drought stress beginning at late vegetative or early reproductive stages
  - and with no confounding effect of heat stress due to high air temperature

- **We compared a drought-tolerant hybrid & a standard hybrid under:**
  - Well-watered conditions
  - Sustained moderate drought stress beginning at late vegetative (V14) or early reproductive (kernel blister) stages
  - Each combination of hybrid & water regime was evaluated with 3 N fertilizer rates

Ao & others, 2020 (*Crop Science* 60:1591–1606)
Ao & others, 2020 (*Agronomy* 10:1374)

Objectives

- Compare grain & silage yields, grain yield components, & N uptake between drought-tolerant & standard corn hybrids subjected to different durations of drought stress & N fertilization

- Better understand the effect of timing of drought stress on yield characteristics of corn hybrids

Ao & others, 2020 (*Crop Science* 60:1591–1606)

Ao & others, 2020 (*Agronomy* 10:1374)

Drought stress study at Becker, MN in 2013

- Conducted using drip irrigation
- Soil texture by depth:

    0- to 18-inch depth = loamy sand

    18- to 42-inch depth = sand

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Photo: T. Varga (Univ. of MN)

Drought stress study at Becker, MN in 2013

- 3 experiments located within 0.3 miles of each other
- Each experiment evaluated 18 treatments that were replicated 4 times:

  2 hybrids × 3 drought-stress treatments × 3 N rates

Drought stress study at Becker, MN in 2013

- 2 hybrids
  - Drought tolerant = NK Brand N42Z-3011A (99 RM)
    - Non-transgenic drought tolerance (Agrisure Artesian® technology) & reported to have top-end yield potential in all yield environments
  - Standard = NK Brand N36A-3000GT (96 RM)
    - Reported to produce maximum yields on highly productive soils
- Final stand = 33,000 plants/acre for both hybrids

Drought stress study at Becker, MN in 2013

- 3 durations of sustained moderate drought stress:
  - None
  - Stress from R2 (kernel blister) to R6 (maturity)
  - Stress from V14 to R6
- 3 N fertilizer rates:
  - 50, 100, & 150% of the expected economically optimum N rate

Photos: S. Ao (Univ. of MN)

	Time of drought stress		
Month	**None**	**R2-R6**	**V14-R6**
	-- rainfall + irrigation (inches) --		
May	2.2	2.2	2.2
June	5.4	5.4	5.4
July	7.5	6.6	4.9
August	7.7	3.4	3.8
September	5.0	3.8	3.8
Total	27.8	21.4	20.1

This study was conducted in the absence of significant heat stress

- From emergence to R6:

  79°F = average daily max. air temperature

  54°F = average daily min. air temperature

  5 days with max. air temperature of 96–97 °F

- 95°F = above this, corn can experience heat stress in the absence of drought stress (Shaw & Newman, 1985, NCH-18, *In* National Corn Handbook)


Photo: M. Russelle (Univ. of MN)

No drought stress

Drought stress

No drought stress

Drought stress

Photos: S. Ao (Univ. of MN)

No drought stress

Drought stress

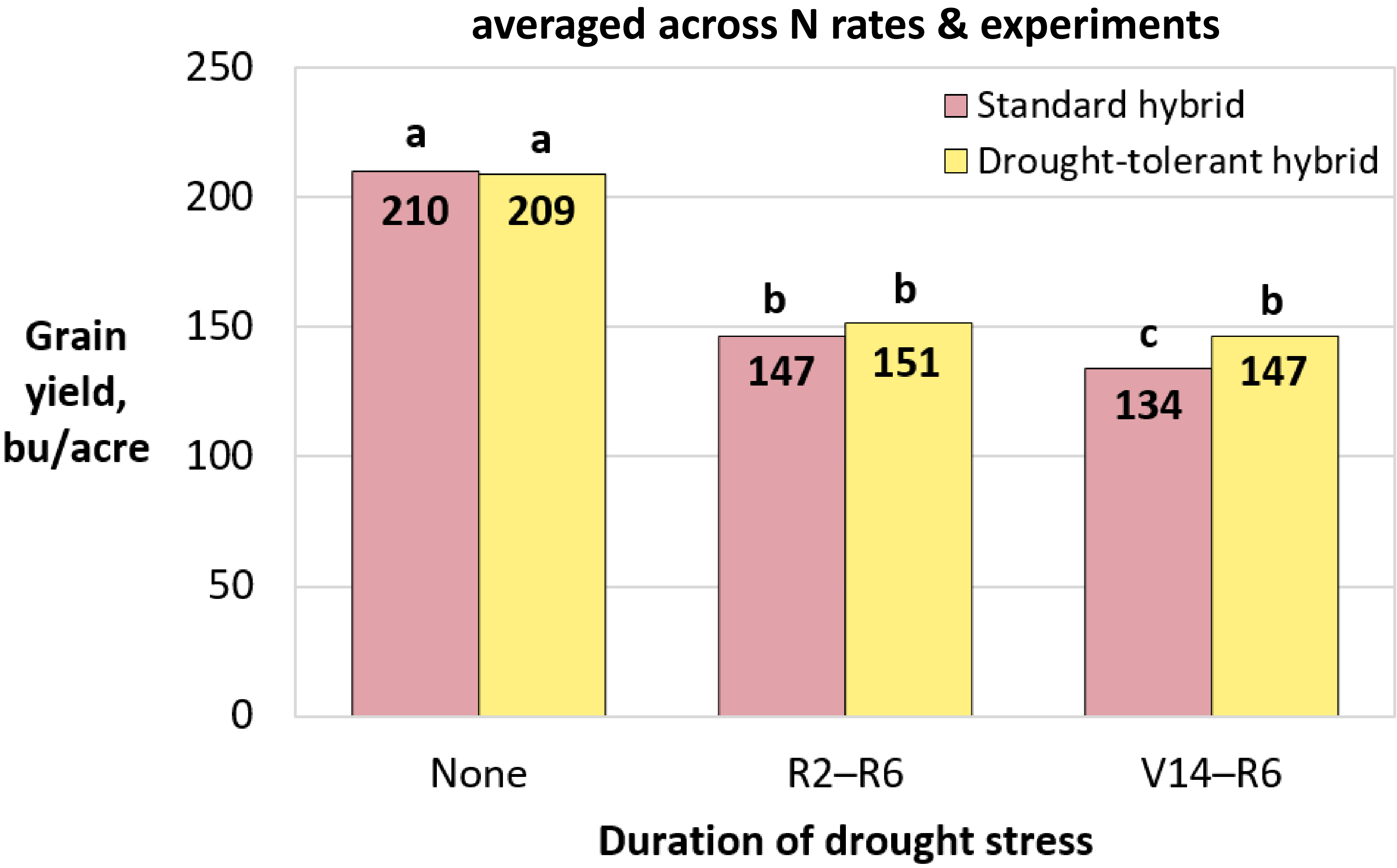
Photos: S. Ao (Univ. of MN)

No drought stress or N deficiency (150% N rate)

Drought stress (V14–R6) & N deficiency (50% N rate)

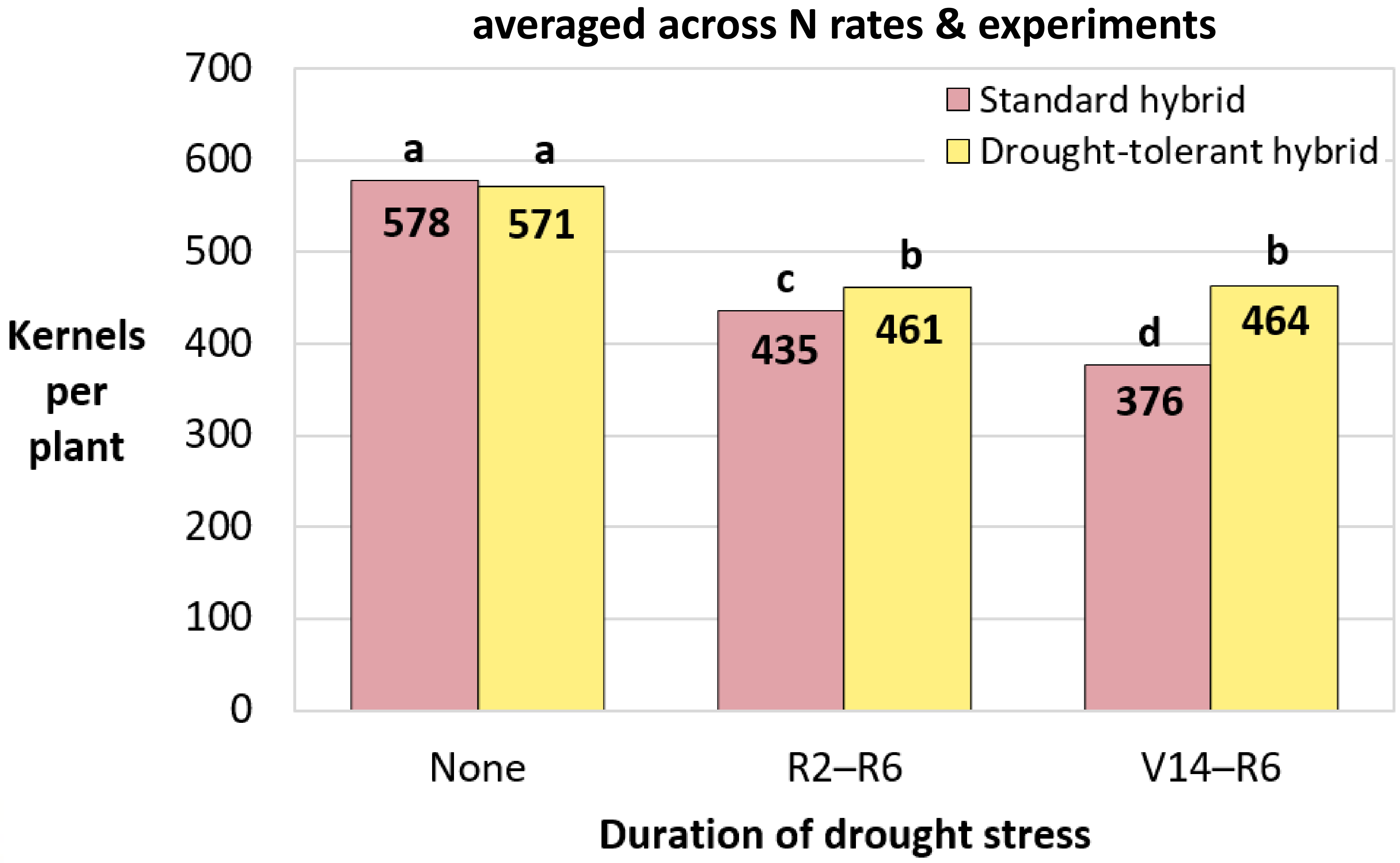
Photos: S. Ao (Univ. of MN)

Greater grain yield for the drought-tolerant hybrid when drought stress from V14–R6



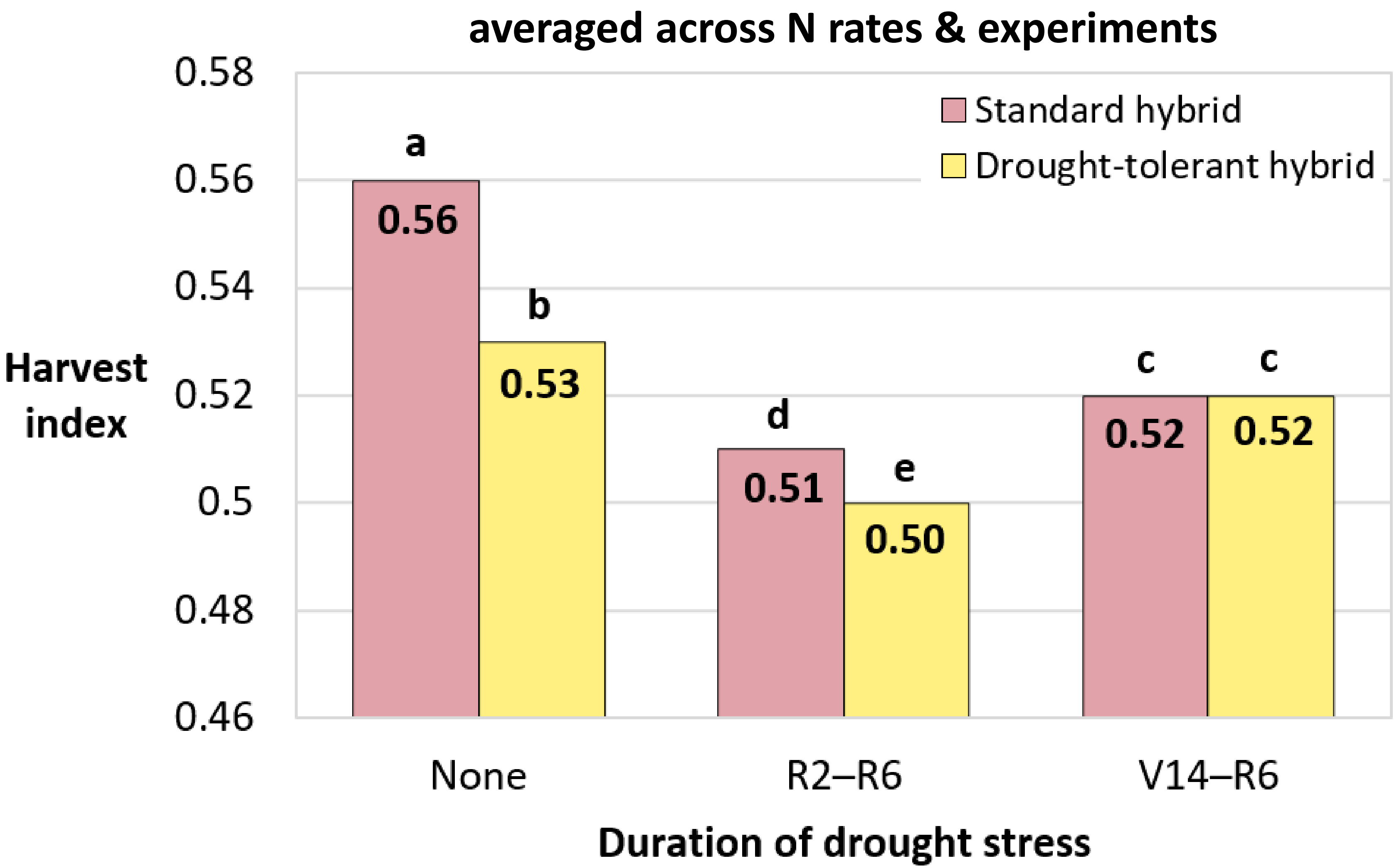
LSD (0.05)

Kernels/plant of the drought-tolerant hybrid was not reduced when drought stress was extended from R2–R6 to V14–R6



LSD (0.05)

The increase in harvest index when drought stress was extended from R2–R6 to V14–R6 was greater for the drought-tolerant hybrid



LSD (0.05)

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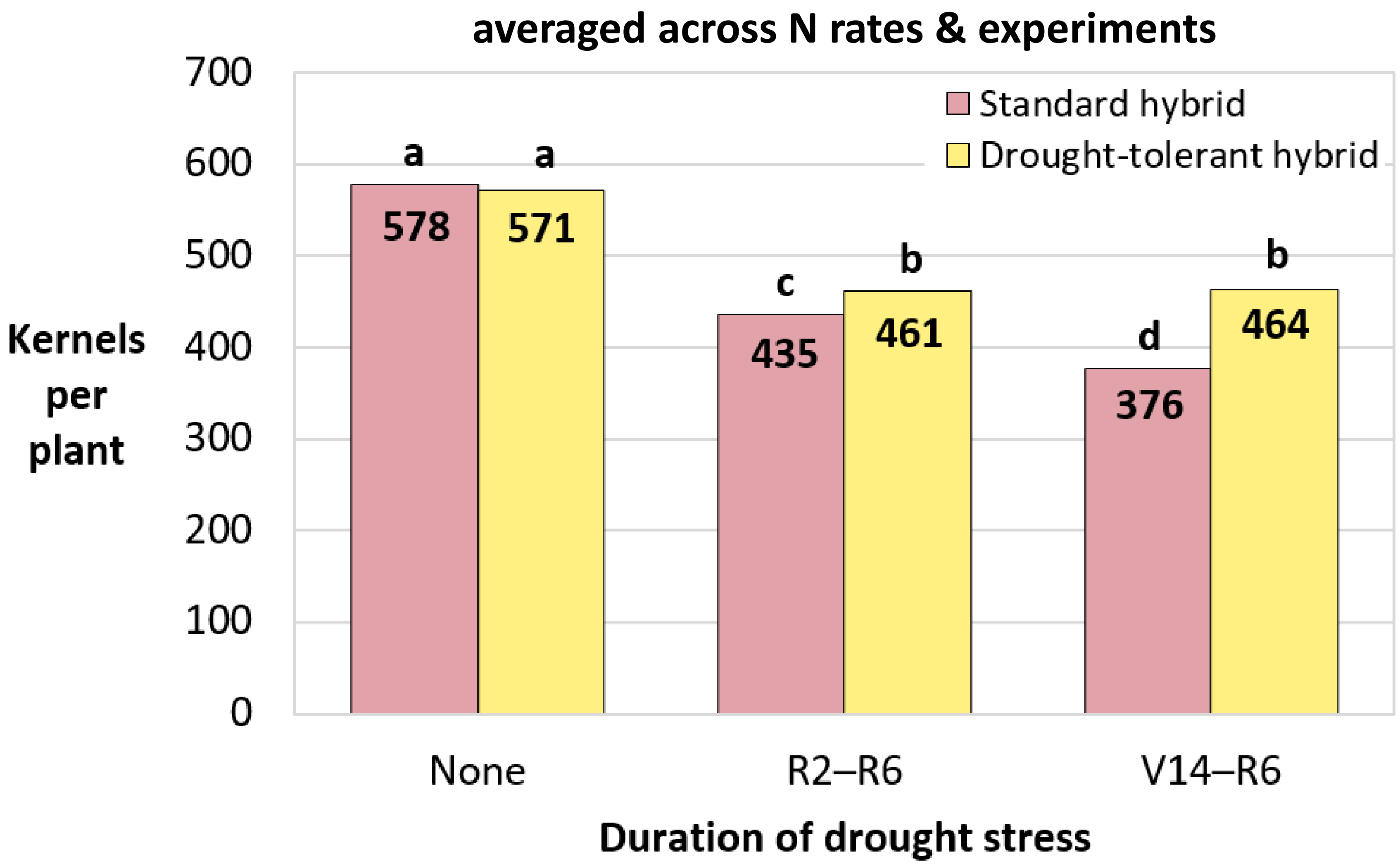


LSD (0.05)

Additional findings

- On average, the interval between the start of pollen shed and silking was narrower for the drought-tolerant hybrid (0.9 days) than the standard hybrid (1.4 days)
  - This may have helped to increase kernel number & grain yield of the drought-tolerant hybrid when drought stress occurred from V14–R6

Photo: S. Ao (Univ. of MN)

Additional findings

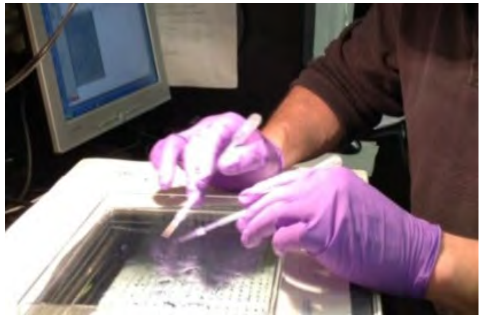
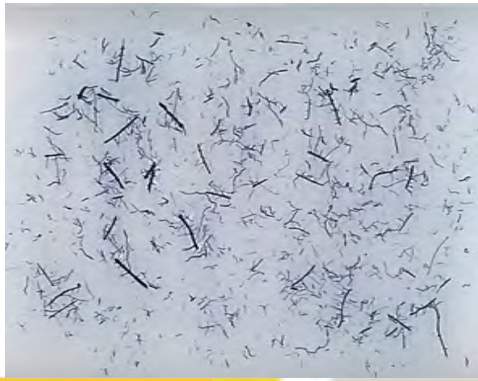
- Root length density = root length per unit volume of soil
- On average, root length density for the 0- to 6-inch depth was greater for the drought-tolerant hybrid by:

  19% for fine roots with a diameter of 0.41–0.70 mm

  43% for fine roots with a diameter of 0.71–1.50 mm

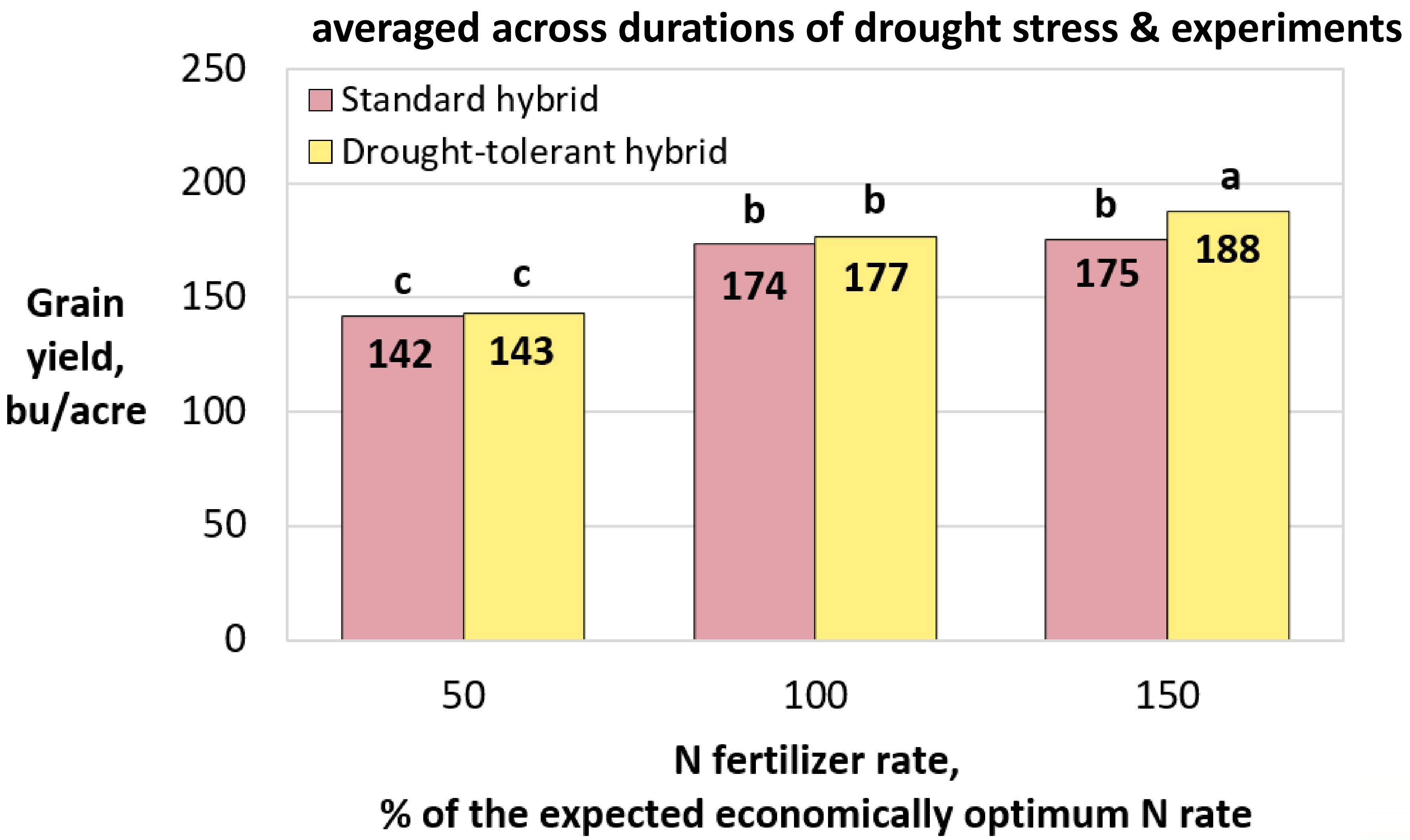
  – This likely led to greater uptake of water & nutrients



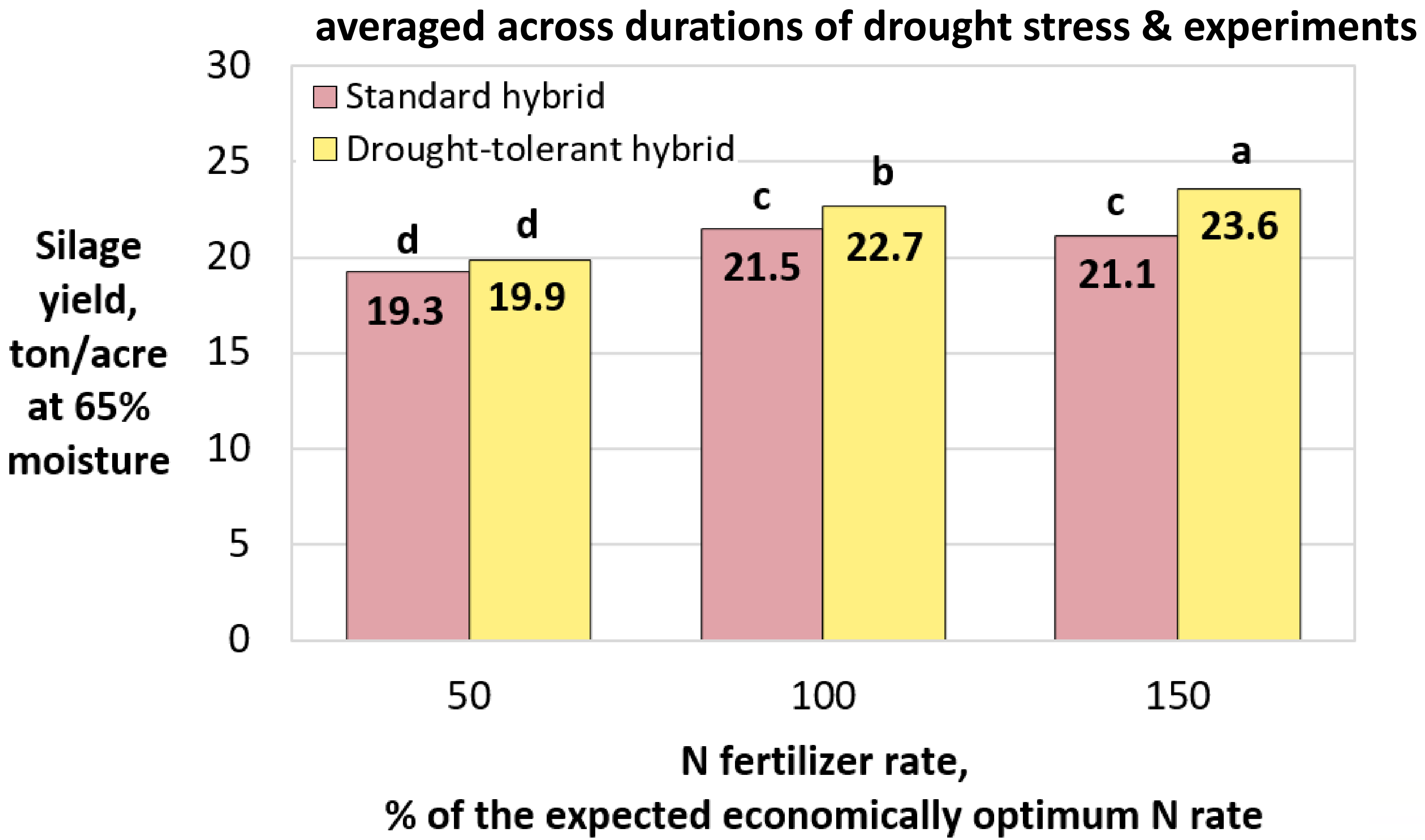
Photos: S. Ao (Univ. of MN)

Greater grain yield at 150% N rate than 100% N rate for the drought-tolerant hybrid



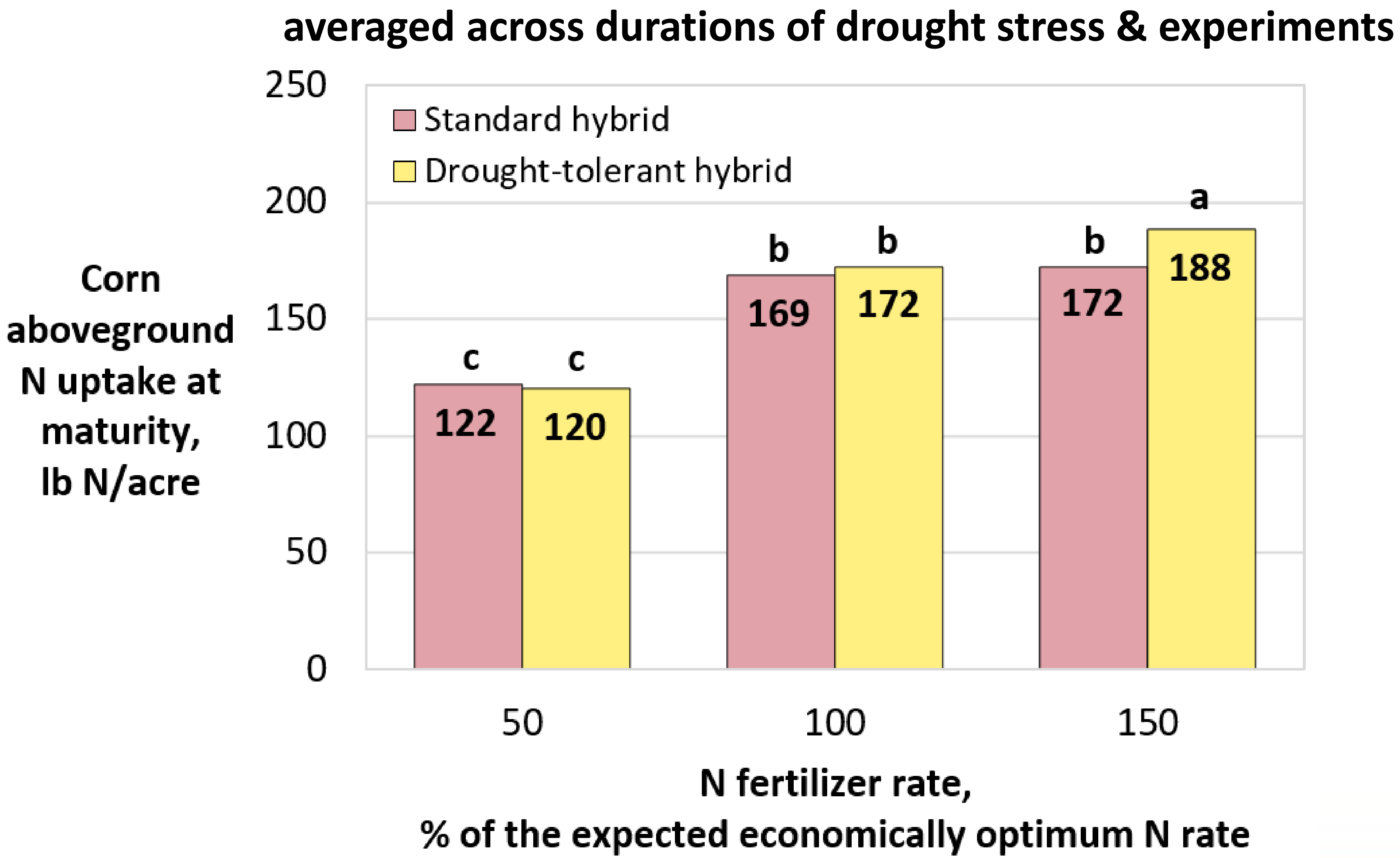
LSD (0.05)

Greater silage yield at 150% N rate than 100% N rate for the drought-tolerant hybrid



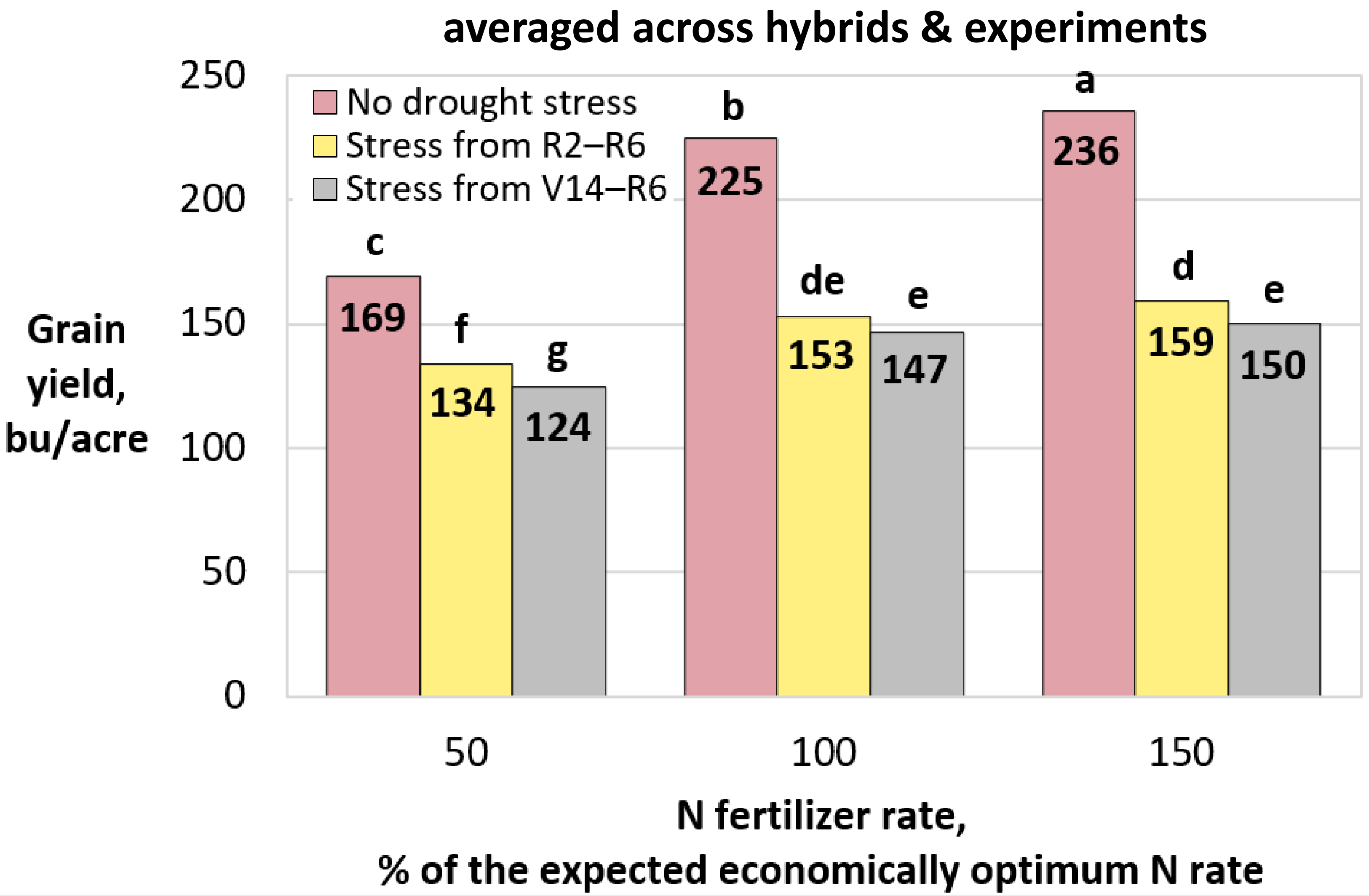
LSD (0.05)

Greater N uptake at 150% N rate than 100% N rate for the drought-tolerant hybrid

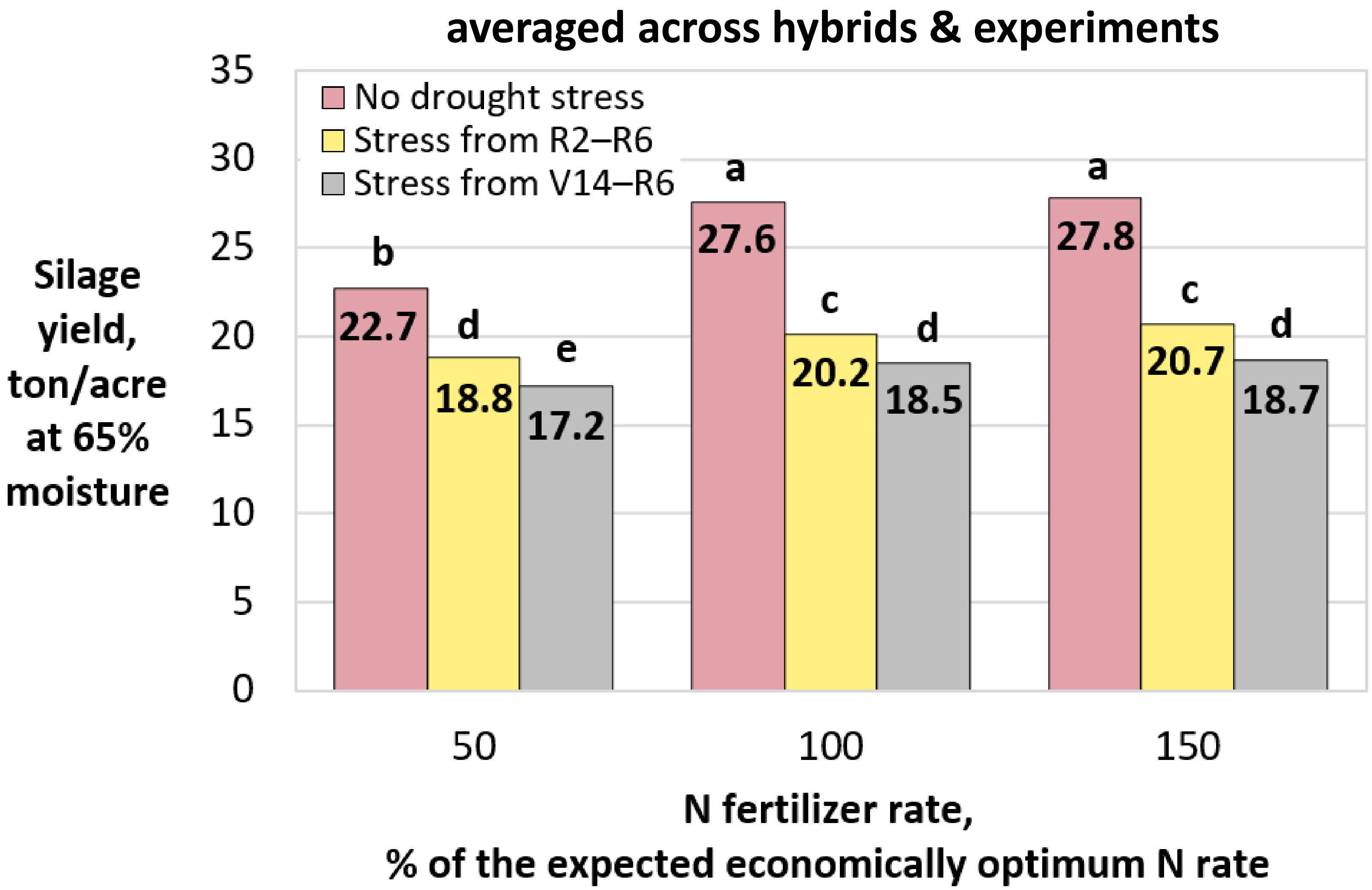


LSD (0.05)

Greater grain yield at 150% N rate than 100% N rate when no drought stress

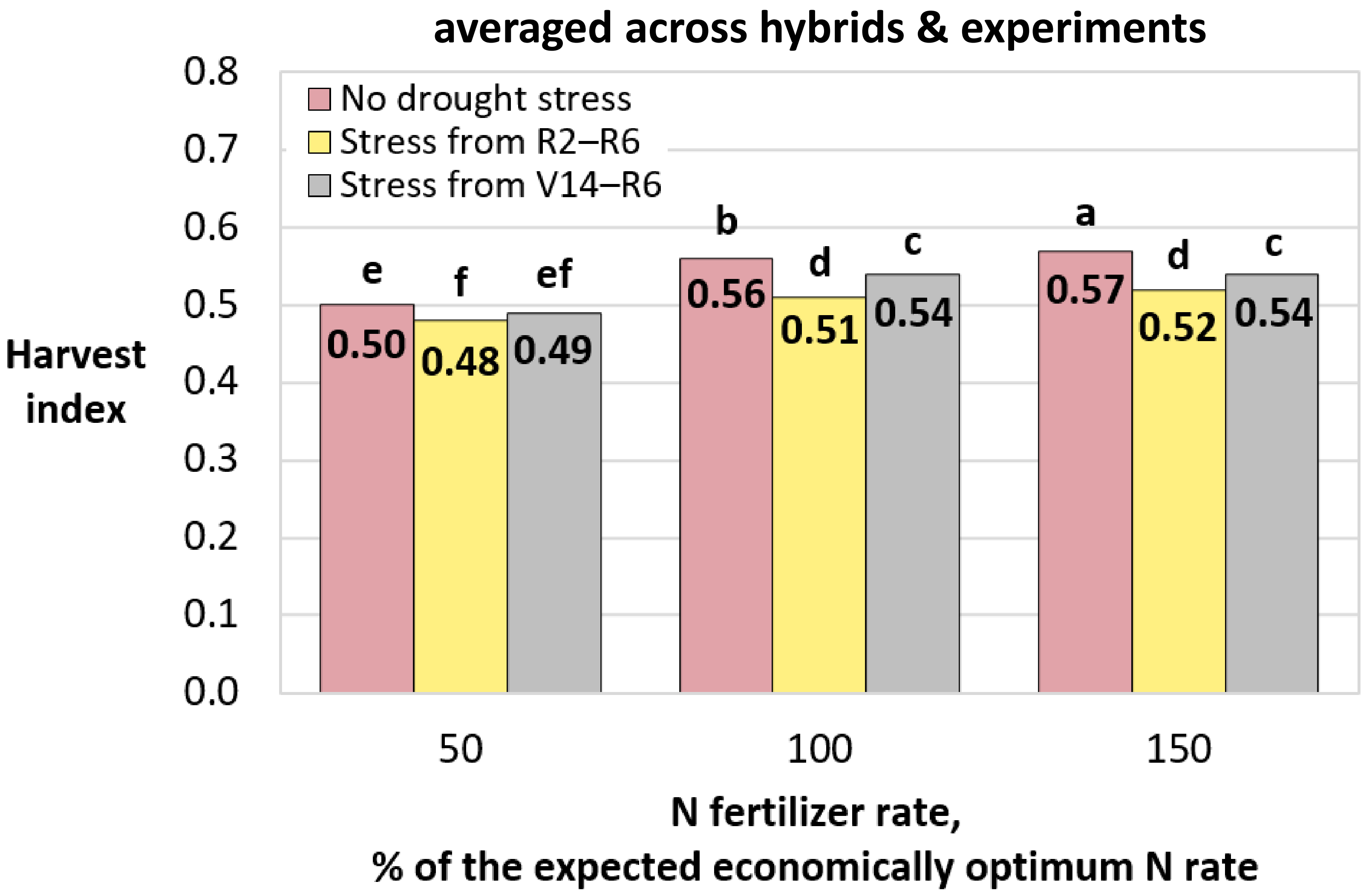


No difference in silage yield between 150% N rate & 100% N rate, regardless of the level of drought stress



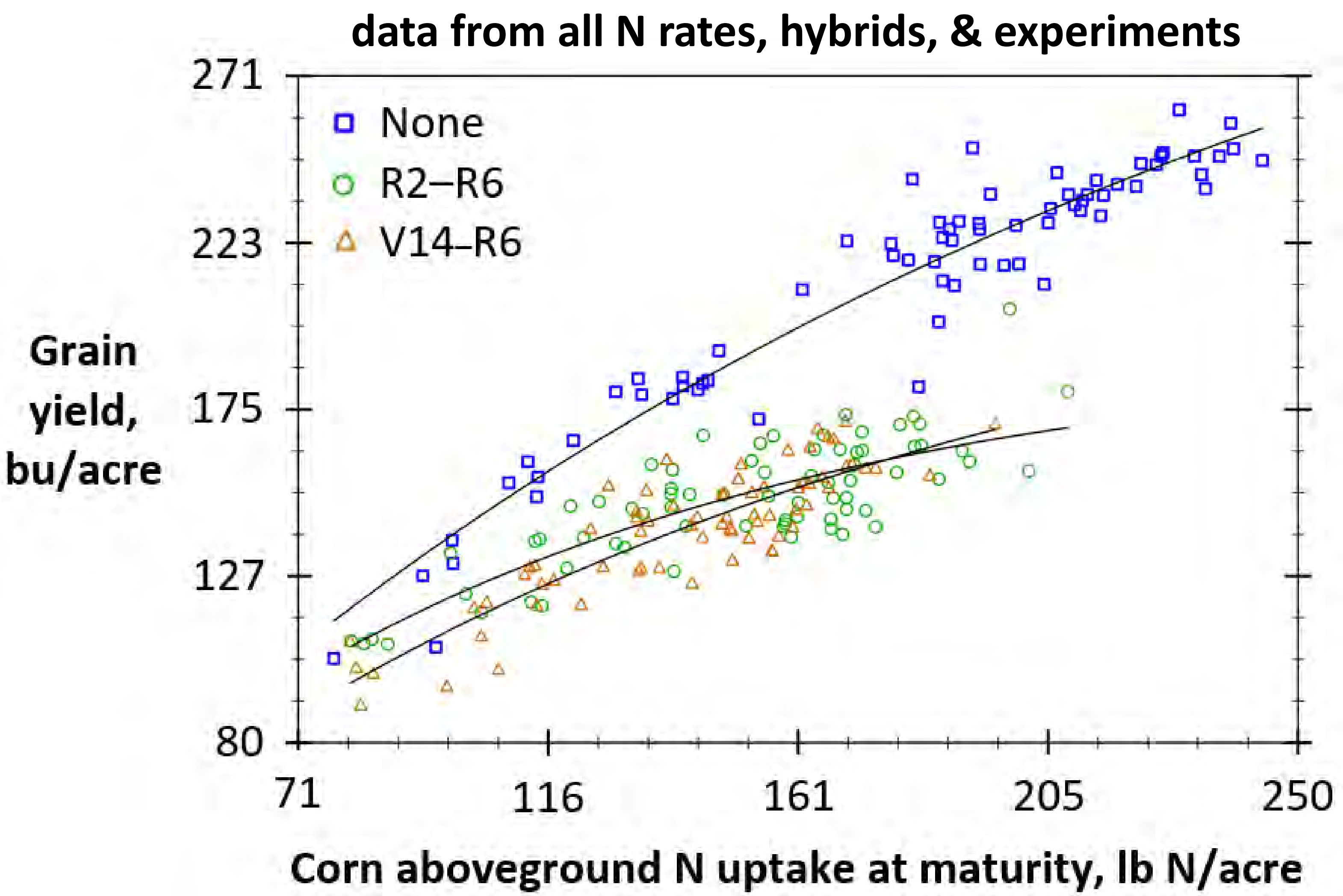
LSD (0.05)

Harvest index was lower when drought stress from R2–R6 than V14–R6 at 100% N rate & 150% N rate



LSD (0.05)

Grain yield increased with greater N uptake, & the rate of increase was greater in the absence of drought stress



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Conclusions

- Drought in the Midwest:
  - Often during the grain-filling stages of corn
  - Sometimes during pollination of corn
- Drought-tolerant hybrids have generally produced greater yield under drought stress

- **No published research had directly compared drought-tolerant & standard corn hybrids:**
  - under sustained drought stress beginning at late vegetative or early reproductive stages
  - and with no confounding effect of heat stress due to high air temperature

Conclusions

- This study simulated drought conditions that could become more common, based on research involving:
  - A farm with sandy soil
  - Drip irrigation
  - A year with low rainfall & without extreme high air temperatures

Photo: S. Ao (Univ. of MN)

Conclusions

- The increase in grain & silage yields, & aboveground N uptake with increased N rate was greater in the absence of drought stress
- Greater grain & silage yields, & N uptake at 150% N rate than 100% N rate for the drought-tolerant hybrid
  - This indicates a greater N requirement for the drought-tolerant hybrid
- Further research is needed to improve knowledge on N management for drought-tolerant hybrids

Conclusions

- The drought-tolerant hybrid had greater grain yield than the standard hybrid when drought stress occurred from V14–R6, but not in the absence of drought stress or when drought stress occurred from R2–R6
  - This was associated with greater kernels per plant & aboveground N uptake for the drought-tolerant hybrid

Conclusions

- The drought-tolerant hybrid also had:
  - A narrower interval between the start of pollen shed and silking
  - More fine roots in the 0- to 6-inch depth

Conclusions

- Drought-tolerant hybrids can reduce yield loss if there is sustained moderate drought stress beginning before pollination, while allowing yield to be maximized in more favorable growing environments

Thank you!

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Photo: T. Varga (Univ. of MN)