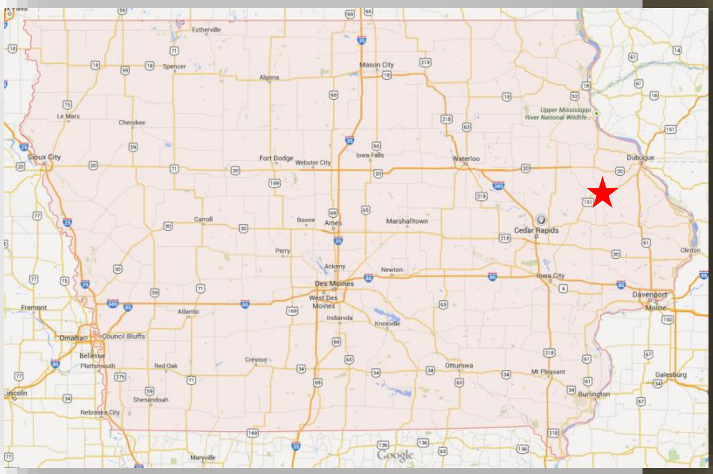
Evaluation of excessively drained yield trial site as a novel environment for screening for drought tolerance in maize

Ryan A Pape

Contents:

Background



- Raised in small town Eastern Iowa.
- Little true exposure to agriculture.

- Attended the University of Northern Iowa
  - B.A. in Biology
    - Biotechnology emphasis
    - Undergraduate research in drought stress in barley.
      - Experience manipulating DNA
      - Embryo excision
      - Agrobacterium transformation
      - Biolistic transformation
      - All treatments applied in growth chamber

Background

- DuPont Pioneer Maize Research, Marion, Iowa.
  - Professional research internship program
  - 2006 and 2007 growing seasons
- DuPont Pioneer Maize Research, Marion, Iowa.
  - Research Associate
  - 2008-2012
- DuPont Pioneer Maize Research, Marion, Iowa.
  - Senior Research Associate
  - 2012-present
- Entire career spent in environmental classification or stress screening with Maize Stress Product Development
- Began M.S. in Agronomy in Spring 2011

(map data © 2015 Google)

Introduction

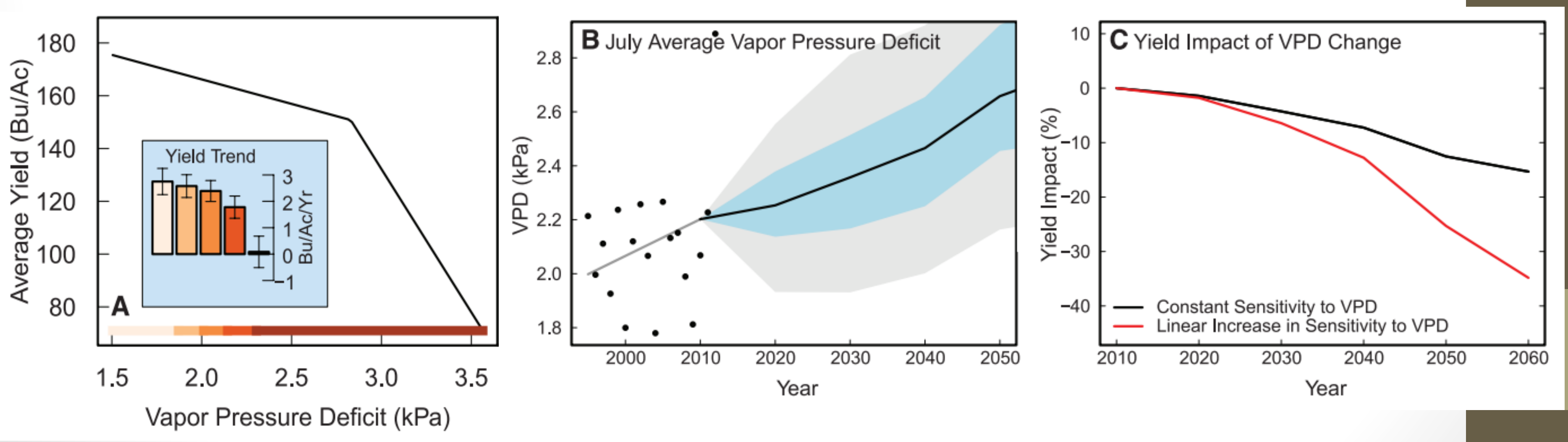
- Drought stress globally is one of the largest causes of maize yield reduction from potential.

- Long term drought conditions:
- Seasonal or longer
- 2012 North American drought reduced grain yields by 21%.
- Global food supply is more vulnerable to these single drought events now than any time in history.
- Single event increased global maize commodity prices by 53% as compared with 17-24% following extreme droughts in the 80's.[1]

[1](Boyer et al., 2013)

Introduction

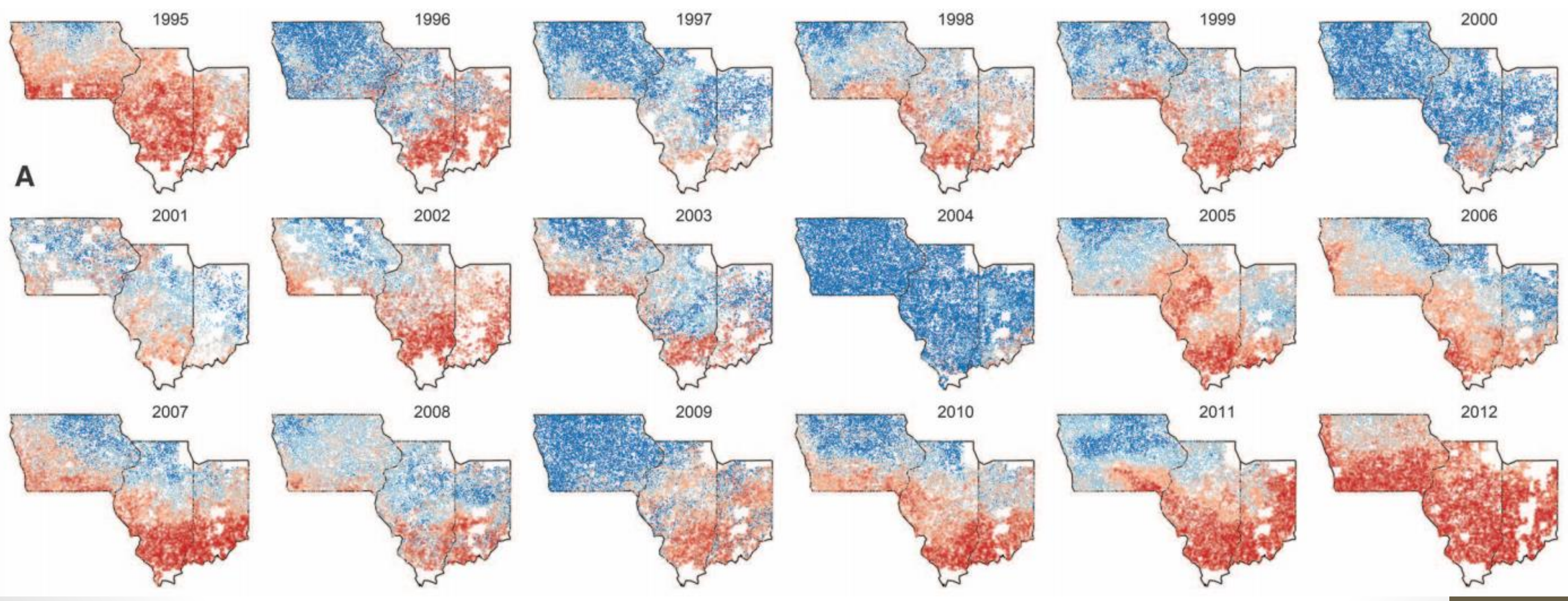
- ‘Transient’ drought stress:
- Brief period of vapor pressure deficit (VPD) during a growing season
- Causes increases in moisture losses, high VPD is known to cause yield reductions
- Common across central corn belt, not solely in the west.



(Lobell et al., 2014)

Introduction

- Potential markets for drought screened hybrids.
- Areas of each modeled yield environment, of which rainfall, temperature, and VPD are the largest factors:



(Lobell et al., 2014)

Introduction

- Seed company response:

Agrisure® Artesian® Hybrids	**Genuity® DroughtGard® Hybrids**	**AQUAmax® Hybrids**
Water use efficiency	Water use efficiency (Hydro-efficiency)	Water use efficiency
(Converting water to grain more efficiently.)	More kernels per ear	More vigorous silking
	Soil water conservation	Deeper kernels
		Efficient rooting
		Stomatal control

(DuPont Pioneer, 2014) (Monsanto Company, 2014) (Syngenta, 2014)

Introduction

- Limitations to testing:
  - Generally accepted that field testing is only true way to screen for drought tolerance.[1]
  - Pipeline of traits and hybrids outpaces field screening space.[1]
  - Drought tolerance is not a qualitative trait, environmental interaction factor is very large.
  - Many discrete testing environments are necessary for a statistically robust screen as well as one that creates confidence in a product release across many, extreme environments.

[1](Campos et al., 2004)

Introduction

- Drought tolerance versus drought avoidance
- Drought avoidance
  - Often a temporal advantage, placing key growth stages outside of periods of drought.
    - Ex. A 108 day relative maturity hybrid that flowers early, before other 108 crm hybrids, before periods of stress.
    - Ex. Less soil water usage during vegetative growth, banking it in the soil for availability during periods of high demand.
- Drought tolerance
  - Non-temporal, true drought tolerance mechanism.
    - Ex. Anthesis silking interval that stays short even under periods of stress.

Introduction

- Hypothetical screening for true drought tolerance
  - Using sites with little soil moisture holding capability.
    - Allows researchers to control soil moisture, despite rainfall events.
      - Much of current research pipeline attempts control of soil moisture by controlling rainfall or simulated rainfall, not through maximum soil moisture capacity limitations.
    - Allow for acute periods of stress exactly when needed to adequately screen for stress at any point in development
    - Simulate short periods of moisture stress, common to Midwest fields, especially those with no irrigation available.

Introduction

- A “common” Western corn belt drought testing location, is limited by rainfall or irrigation, not soil type.
- Monsanto’s Gothenburg, NE Water Utilization Learning Center
  - Generally a Hord silt loam.
  - Water holding capacity 0.16 cm/cm.
  - Entire profile to 1.5 m capable of holding 24 cm of soil moisture.
  - **A full profile is good for 27 days in best case root extraction scenario, assuming 7mm/day mid-season ET and a 20% PWP level.**

(Monsanto, 2015)

Introduction

- Fruitland, IA. Field trial site.

Introduction

- 25 hectares (60 Acres)
- Pivot irrigated
- Uniform
  - Entirely composed of NRCS soil unit 759
  - Fruitfield sand
  - Alluvial, deposited by the Mississippi
  - Consistent to 1.5m in depth
  - Low organic matter 1-1.5%
  - Excessively drained, permeability > 50cm/hr
- Water holding capacity
  - 0.04 cm/cm
  - **Total 1.5m profile holds only 6 total cm of water when at field capacity.**
  - **A full profile is only good for roughly five days in best case root extraction scenario, assuming 7mm/day mid-season ET and a 12% PWP level.**

(USDA, 1988)

Introduction

- Due to extremely low water holding capacity the site behaves like a restricted root zone growth medium.
- The flexibility of the imposition of the drought offers a different screening pressure.

Introduction

Questions for the trial to answer:

- Is it possible to manage the extreme environment and get drought stress at the site?
  - Do grain yields reduce about 50% under drought stress when compared to fully irrigated yields at the site?

- Do sub-soil characteristics minimize soil moisture interactions between entries?

- Does the site offer a novel managed environment for hybrid selection?

Materials and Methods

Experiment design:

- 10 hybrid entries
  - All between 108-113 CRM
  - Varying levels of drought tolerance
- 4 Replicates
  - Entries completely randomized within each replicate.
- 3 “locations”
  - 2 limited irrigation
  - 1 fully irrigated
  - All at same geographical site

Materials and Methods

Irrigation

- Valley 8000 series center pivot system.
  - 3400 L/min
- Nelson R3000 rotating sprinklers
  - Positioned high on water supply pipe.
- Variable rate control
- Remote control from smartphones

Environmental monitoring

- HOBO data logging/transmitting weather station
- Records and transmits the following data every 15 minutes.
  - Temperature
  - Wind speed
  - Rainfall
  - Relative humidity
  - PAR

Materials and Methods

Irrigation management

- Fully irrigated treatment
  - VE-V10
    - Approximately 4 cm/week in irrigation, barring rainfall.
  - V10-PM
    - Approximately 6 cm/week in irrigation, barring rainfall.
      - Irrigation or rain needs to fully offset ET in a given period.
- Limited irrigation treatment
  - VE-V14
    - Approximately 4 cm/week in irrigation, barring rainfall.
      - No stress induced during this period.
  - V14-PM
    - Approximately 1.5 cm/week, around 1/3rd typical ET.
      - Stress was reviewed nearly daily and adjustments made empirically.
      - Soil too coarse for most modeling.

Materials and Methods

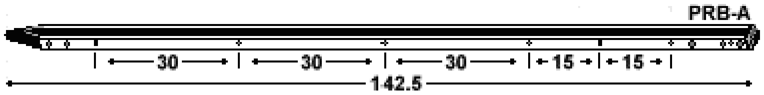
Planting and stand establishment

- Planted May 3rd
  - 4 row plots
  - 5 m in length
  - 76.2cm (30”) row spacing
  - Density target 88,920 plants per hectare

- Kinze/Almaco 360 planter
  - 8 row vacuum/air controlled
  - Applied 4.82 kg/ha Force 3G in furrow

- Emergence was uniform and counted to ensure adequate plant stand of each plot.

Materials and Methods



Soil moisture monitoring

- Time Domain Reflectometer (TDR)
- 1.2 m effective measurement depth
- 5 segments, 5 averaged values
  - Top two: 15 cm each
  - Bottom three: cm each

- Inserted in line with corn row
  - Away from edges of the plots
  - Surrounded by typical stands
  - In small gap in row

Materials and Methods

Data collection

- Soil moisture
  - V6 (no visible stress)
  - VT (evident stress)
  - R2 (evident stress)

- Flowering data
  - Record date of 50% plot shedding and 50% plot silking
  - Anthesis silking interval (ASI)

- Leaf rolling
  - 1-9 scale (1 extreme rolling – 9 no rolling)
  - Taken same afternoon as VT soil moisture reading

- Mechanical harvest
  - Moisture
  - Plot weight

Materials and Methods

Data analysis

- One way ANOVA with SAS Enterprise version 4.3
  - Indications of significance set at 95% confidence interval, $P<0.05$
- Tukey's honest significant difference (HSD) post-hoc test.

Data concerns

- Fully irrigated reps had mid-season soil moisture interaction
  - Large range in yield values, SDs and SE.
- One probe was inoperable at VT
- Four reps of limited irrigation chosen for better descriptive stats
  - Lower SD and CV

Results and Discussion

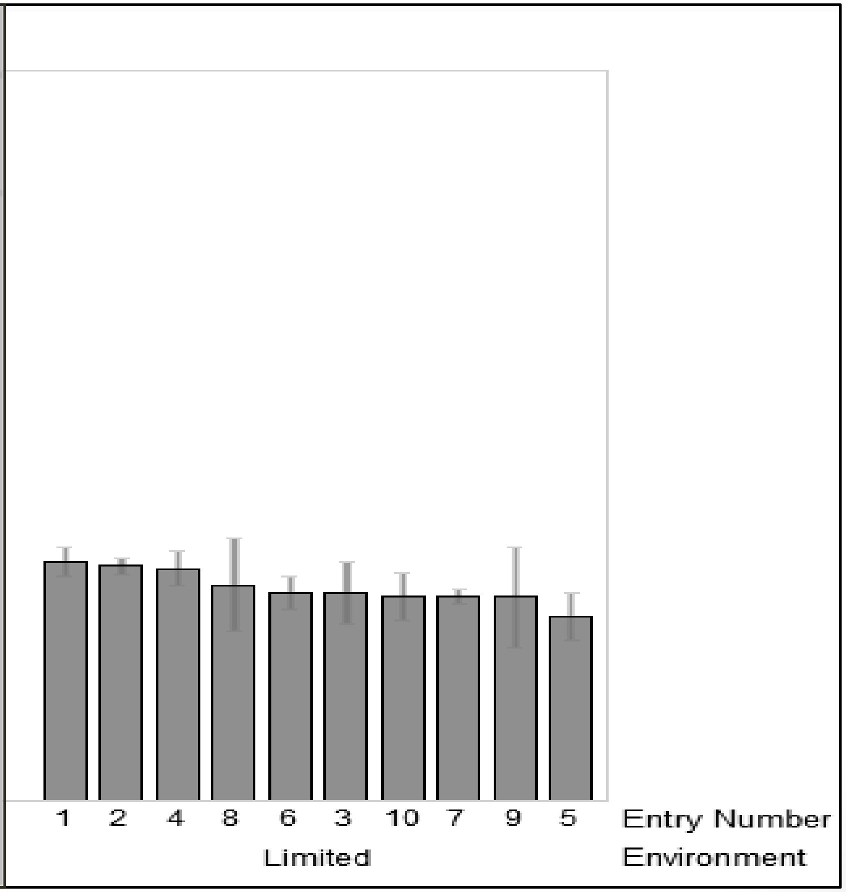
- Drought stress was achieved.
- Overall yield reduction 42%

Environment	Yield (kg/ha)	Yield reduction (%)	P- Value
Fully irrigated	12,871.6	0.0	N/A
Limited irrigation	7,477.4	41.9	<0.0001

Results and Discussion

- Screening pressure was sufficient to reorder the entries due to drought stress.

Yields by entry in kg/ha				
Tukey Grouping		Mean	N	Entry Number
	A	8369.9	4	1
	A	8218.4	4	2
	A	8148	4	4
B	A	7563.1	4	8
B	A	7297.2	4	6
B	A	7291.8	4	3
B	A	7166.7	4	10
B	A	7142	4	7
B	A	7137.4	4	9
B		6439.4	4	5



Results and Discussion

- Drought yield by top performers manufactured stability.

Entry #	1	2	4	8	6	3	10	7	9	5	Treatment Mean
Full Irrigation	12478.1	12941.4	12031.7	14926.1	12384.0	13822.4	13358.5	12958.3	Not Available	11993.8	12871.6
Limited	8369.9	8218.4	8148.0	7563.1	7297.2	7291.8	7166.7	7142.0	7137.4	6439.4	7477.4
Yield Reduction (kg/ha)	4108.3	4723.0	3883.7	7363.0	5086.8	6530.6	6191.7	5816.3	N/A	5554.4	5394.2
Percent Yield	-32.9%	-36.5%	-32.3%	-49.3%	-41.1%	-47.2%	-46.4%	-44.9%	N/A	-46.3%	-41.9%

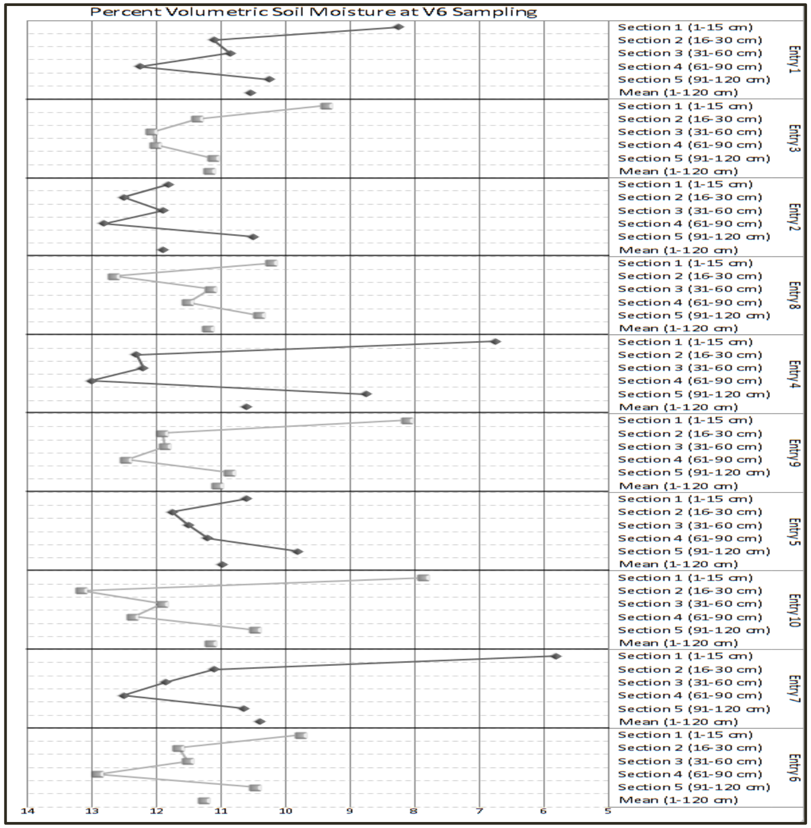
Results and Discussion

Soil moisture interaction between entries.

- Many significant interactions between soil moisture beneath entries makes screening complex. Difficult to screen and compare responses to drought when certain entries are in their own micro-climate.
- Sampling times
  - V6 (no stress)
  - VT (visible stress)
  - R2 (visible stress)

Results and Discussion

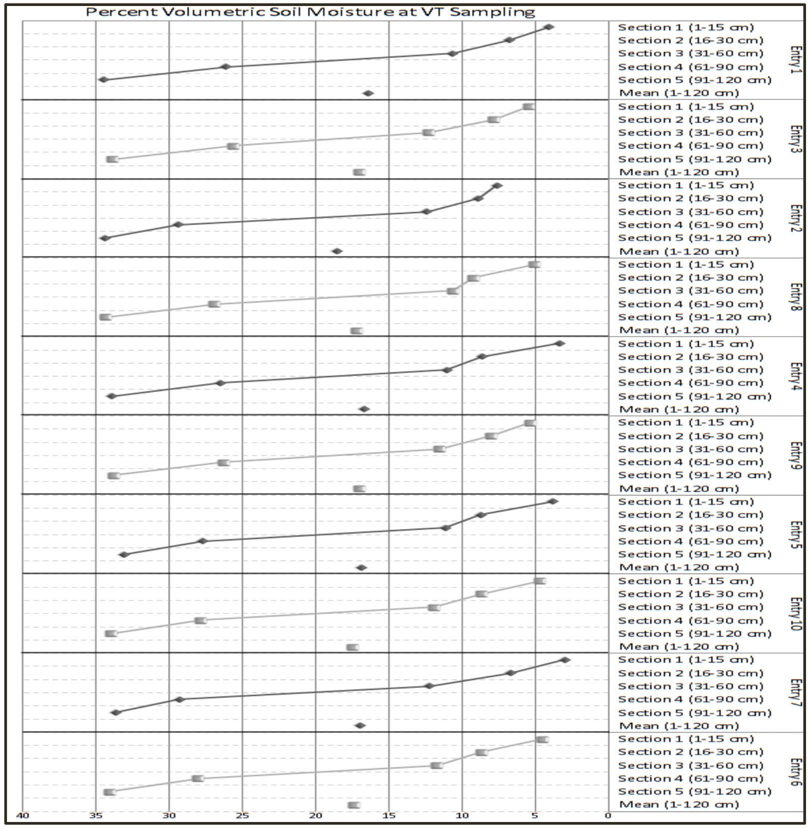
- V6 sampling period



Tukey's HSD significance analysis V6 sampling																	
Section One (1-15 cm)			Section Two (16-30 cm)			Section Three (31-60 cm)			Section Four (61-90 cm)			Section Five (91-120 cm)			Mean of all sections (1-120 cm)		
Tukey's HSD Grouping	Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order
A	11.8	2	A	13.15	10	A	12.2	4	A	13	4	A	11.1	3	A	11.9	2
A	10.6	5	A	12.65	8	A	12.05	3	A	12.9	6	A	10.85	9	A	11.25	6
A	10.2	8	A	12.5	2	A	11.9	2	A	12.8	2	A	10.65	7	A	11.18	8
A	9.75	6	A	12.3	4	A	11.9	10	A	12.5	7	A	10.5	2	A	11.17	3
A	9.35	3	A	11.9	9	A	11.85	7	A	12.45	9	A	10.45	6	A	11.14	10
A	8.25	1	A	11.75	5	A	11.85	9	A	12.35	10	A	10.45	10	A	11.03	9
A	8.1	9	A	11.65	6	A	11.5	5	A	12.25	1	A	10.4	8	A	10.97	5
A	7.85	10	A	11.35	3	A	11.5	6	A	12	3	A	10.25	1	A	10.6	4
A	6.75	4	A	11.1	7	A	11.15	8	A	11.5	8	A	9.8	5	A	10.54	1
A	5.8	7	A	11.1	1	A	10.85	1	A	11.2	5	A	8.75	4	A	10.38	7

Results and Discussion

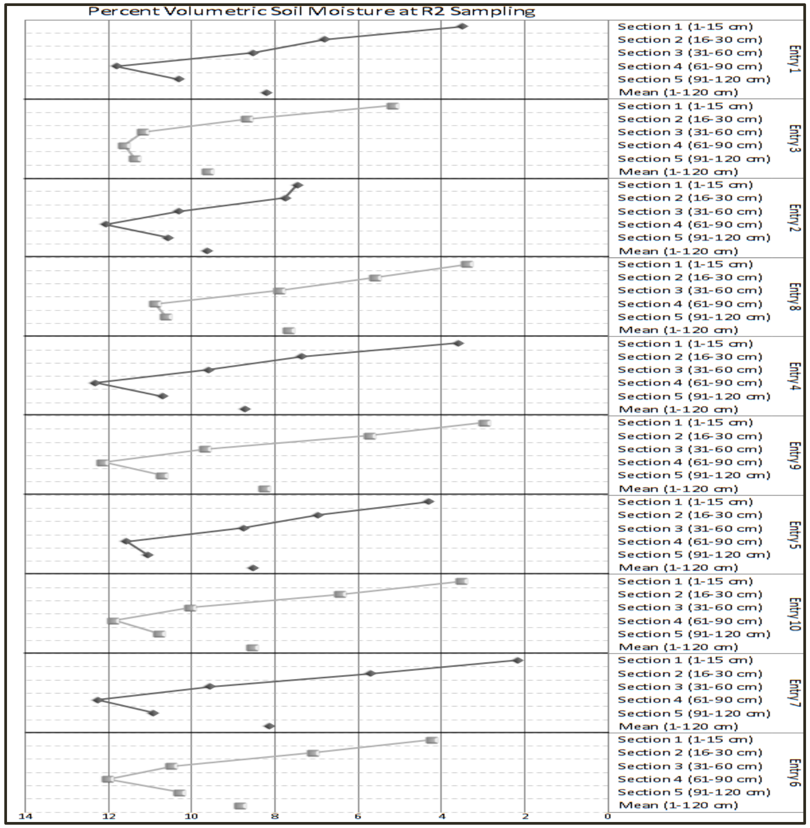
- VT Sampling period



Tukey's HSD significance analysis VT sampling																		
Section One (1-15 cm)				Section Two (16-30 cm)			Section Three (31-60 cm)			Section Four (61-90 cm)			Section Five (91-120 cm)			Mean of all sections (1-120 cm)		
Tukey's HSD Grouping		Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order
	A	7.6	2	A	9.15	8	A	12.35	2	A	29.35	2	A	34.4	1	A	18.49	2
B	A	5.3	3	A	8.85	2	A	12.2	3	A	29.25	7	A	34.3	2	A	17.34	10
B	A	5.25	9	A	8.7	5	A	12.15	7	A	27.9	6	A	34.2	8	A	17.32	6
B	A	5	8	A	8.6	6	A	11.85	10	A	27.75	10	A	34	6	A	17.14	8
B		4.6	10	A	8.6	4	A	11.65	6	A	27.7	5	A	33.9	4	A	16.91	7
B		4.45	6	A	8.6	10	A	11.45	9	A	26.8	8	A	33.9	10	A	16.9	9
B		4.05	1	A	7.9	9	A	11.1	5	A	26.45	4	A	33.75	3	A	16.9	3
B		3.8	5	A	7.75	3	A	11	4	A	26.2	9	A	33.7	9	A	16.86	5
B		3.25	4	A	6.75	1	A	10.6	1	A	26.05	1	A	33.55	7	A	16.64	4
B		2.95	7	A	6.65	7	A	10.55	8	A	25.5	3	A	33	5	A	16.37	1

Results and Discussion

- R2 Sampling period



Tukey's HSD significance analysis R2 sampling																		
Section One (1-15 cm)				Section Two (16-30 cm)			Section Three (31-60 cm)			Section Four (61-90 cm)			Section Five (91-120 cm)			Mean of all sections (1-120 cm)		
Tukey's HSD Grouping		Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order	Tukey's HSD Grouping	Mean	Entry Order
	A	7.45	2	A	8.65	3	A	11.15	3	A	12.3	4	A	11.35	3	A	9.62	2
B	A	5.15	3	A	7.75	2	A	10.45	6	A	12.25	7	A	11.05	5	A	9.58	3
B	A	4.3	5	A	7.35	4	A	10.3	2	A	12.1	9	A	10.9	7	A	8.79	6
B	A	4.2	6	A	7.05	6	A	10	10	A	12.05	2	A	10.75	10	A	8.71	4
B	A	3.6	4	A	6.95	5	A	9.65	9	A	12	6	A	10.7	4	A	8.52	5
B	A	3.5	1	A	6.8	1	A	9.6	4	A	11.85	10	A	10.7	9	A	8.5	10
B	A	3.5	10	A	6.4	10	A	9.55	7	A	11.8	1	A	10.6	8	A	8.22	9
B	A	3.35	8	A	5.7	7	A	8.75	5	A	11.6	3	A	10.55	2	A	8.18	1
B		2.95	9	A	5.7	9	A	8.5	1	A	11.55	5	A	10.3	1	A	8.11	7
B		2.15	7	A	5.55	8	A	7.85	8	A	10.85	8	A	10.25	6	A	7.64	8

Results and Discussion

Soil moisture results

- Little soil moisture variability at this site.
  - Two section readings out of the entire data set register significantly different at the 95% level.
  - These sections measured were always the shallowest in the profile, most likely to show variance due to interaction with the atmosphere.
  - Sections that show variance all have soil moistures below estimated permanent wilting point for this soil, so moisture variance is not likely due to plant extraction.

Results and Discussion

Additional traits

- Anthesis silking interval
  - Extended ASI reduces kernel numbers per plant.
  - Moisture stress extends ASI period.[1]
  - Moisture stress produces less receptive silks to pollen grains.[1]
  - Kernel numbers per plant strongly links to grain yield.[2]
  - Poor pollination under stress inhibits ear growth rates. [2]

[1](Bassetti, Westgate, 1993a) [2](Barker et al., 2005) (Campos et al., 2004) (Otegui et al., 1995)

Results and Discussion

- ASI ranked (less is generally better)
- Tukey's HSD grouping significance to 95% level.

ASI Values by entry (GDD)				
Tukey's HSD Grouping		Mean	Entries by ASI	Entries by Yield
	A	-43.5	4	1
C	A	10.5	7	2
C	A	13	10	4
C	A	25.5	2	8
C	B	51	3	6
C	B	51	1	3
C	B	64	9	10
C	B	64	8	7
C	B	98.2	5	9
	B	109	6	5

Results and Discussion

- Leaf Rolling
  - Not as clear cut ties to yield performance, but interesting trends are evident.
  - High score indicative of little rolling, low score, heavy rolling.

Leaf rolling score by entry				
Tukey's HSD Grouping		Mean	Entries by LR Score	Entries by Yield
	A	8	5	1
B	A	7.25	10	2
B	A	5.75	3	4
B	C	4	6	8
B	C	4	1	6
B	C	3.75	2	3
B	C	3.25	4	10
B	C	3	9	7
	C	2.25	8	9
	C	2	7	5

Conclusions

- Main Objective: Assess the potential to characterize true drought tolerance versus drought avoidance using this site as a novel screen.
  - Metrics
    - Reduce yield due to controlled drought stress to be able to change rankings of hybrids and select for drought performance.
    - Do so uniformly to minimize variance within treatments.
    - Measure limited sub-surface moisture interactions between hybrid entries, so as to limit variables and simplify selection for true drought tolerance.
    - **Does the site offer and easily managed environment for hybrid selection in a novel, additional, environment?**

Conclusions

- Yield was significantly reduced.
- Rankings of hybrids was changed from well watered environment indicating GxE interaction.
- Yield reduction was clearly linked to treatment variables, not location variables.
- Sub-soil moisture was largely controlled between entries, the implication being that limited water holding capacity is the reason for this.
- More replicates at locations such as this would likely produce novel, statistically significant yield screens.
- **Definitively declaring this a novel environment that screens for true drought tolerance will require more locations/years/soil moisture probes.**

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Questions and comments