Shallow groundwater and soil texture drive subfield-scale yield patterns

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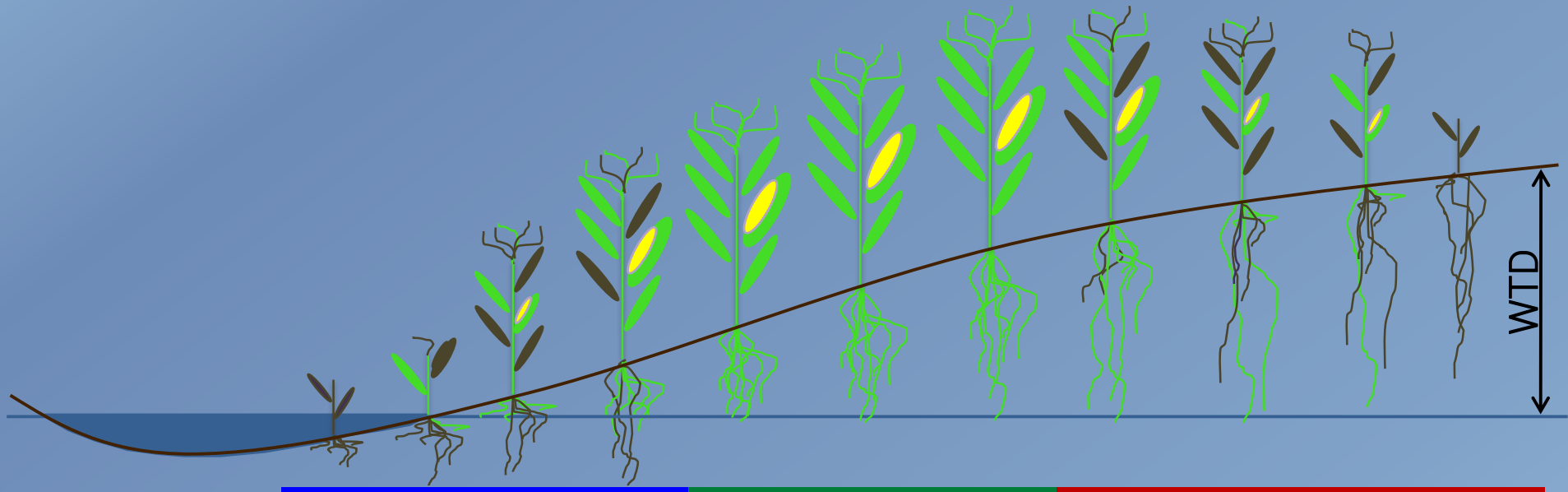
How do GW, soil texture, & weather influence yield?

Oxygen Stress
Roots unable to respire

Optimum WTD
GW available when soil water depleted

Water Stress
Growth limited by water availability



GW Yield Penalty | GW Yield Subsidy | No GW Influence

Increase in yield in presence of shallow GW, relative to free drainage conditions

How do GW, soil texture, & weather influence yield?

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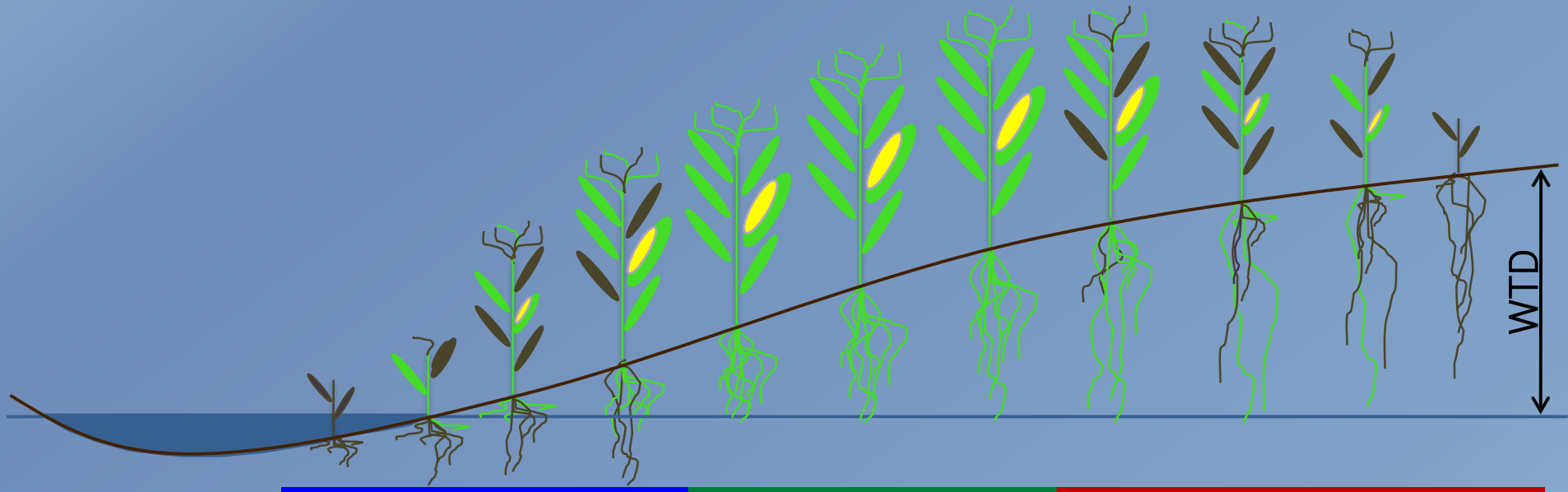
Growth limited by water availability



GW Yield Penalty | GW Yield Subsidy | No GW Influence

Finer Soil/ Wetter Year:

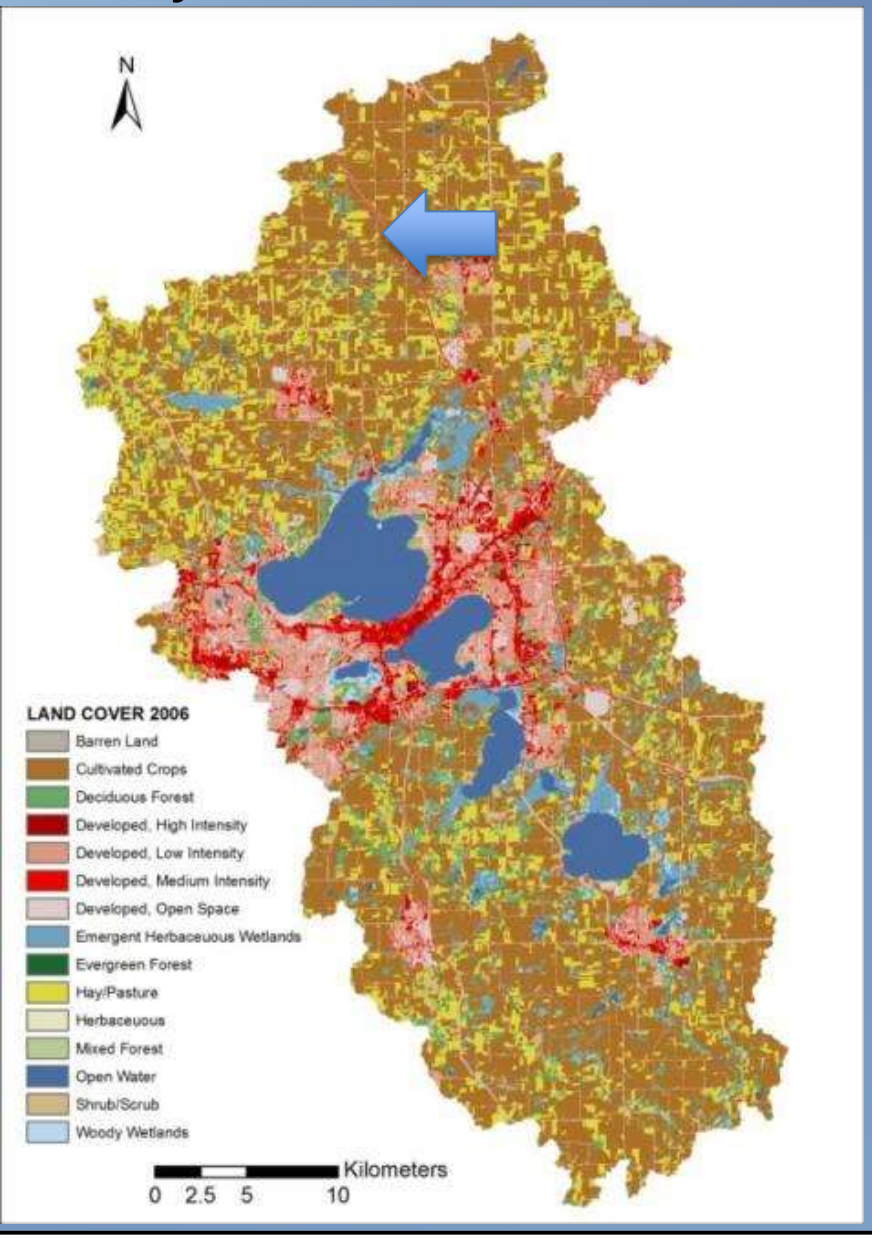
Coarser Soil/ Drier Year:

How do GW, soil texture, & weather influence yield?

(1) Can shallow water tables provide a groundwater yield subsidy and/or penalty to corn production?

(2) How do soil texture and growing season weather conditions influence relationships between groundwater and corn yield?

Study Site


N
LAND COVER 2006
Barren Land
Cultivated Crops
Deciduous Forest
Developed, High Intensity
Developed, Low Intensity
Developed, Medium Intensity
Developed, Open Space
Emergent Herbaceuous Wetlands
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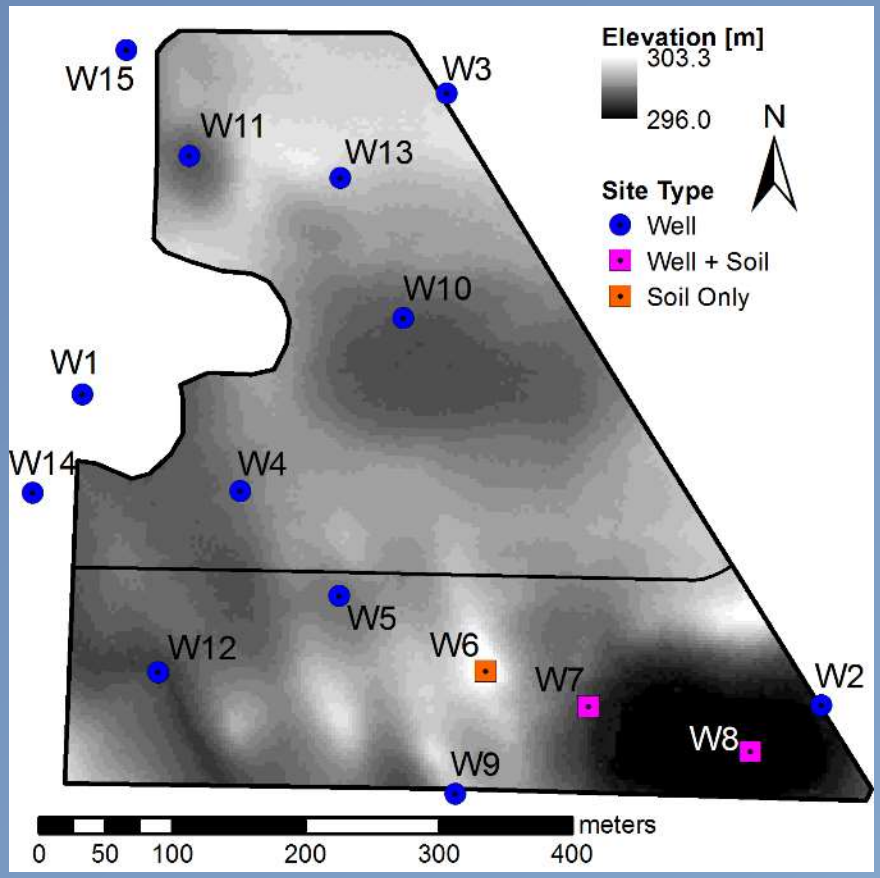
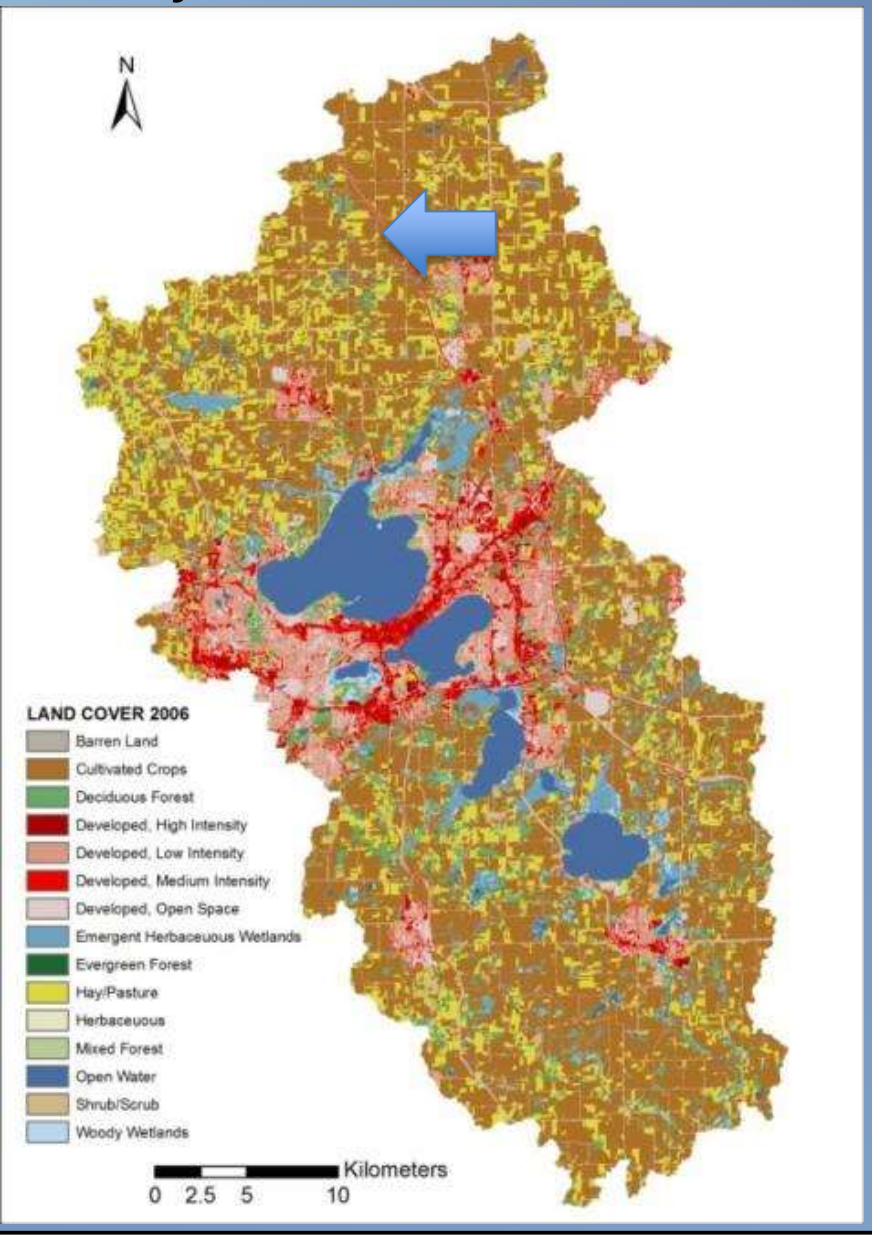
Hay/Pasture
Herbaceuous
Mixed Forest
Open Water
Shrub/Scrub
Woody Wetlands
Kilometers
0 2.5 5 10


Elevation [m]
303.3
296.0
N
Site Type
Well
Well + Soil
Soil Only
W15
W3
W11
W13
W10
W1
W14
W4
W5
W12
W6
W7
W2
W8
W9
meters
0 50 100 200 300 400

Study Site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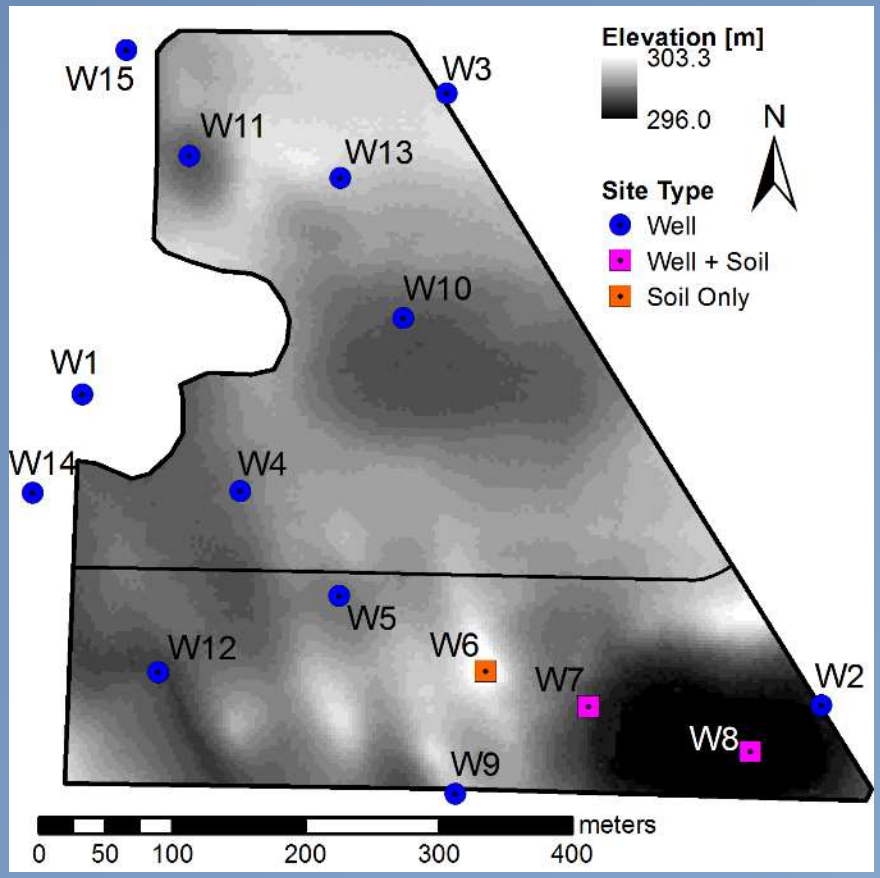
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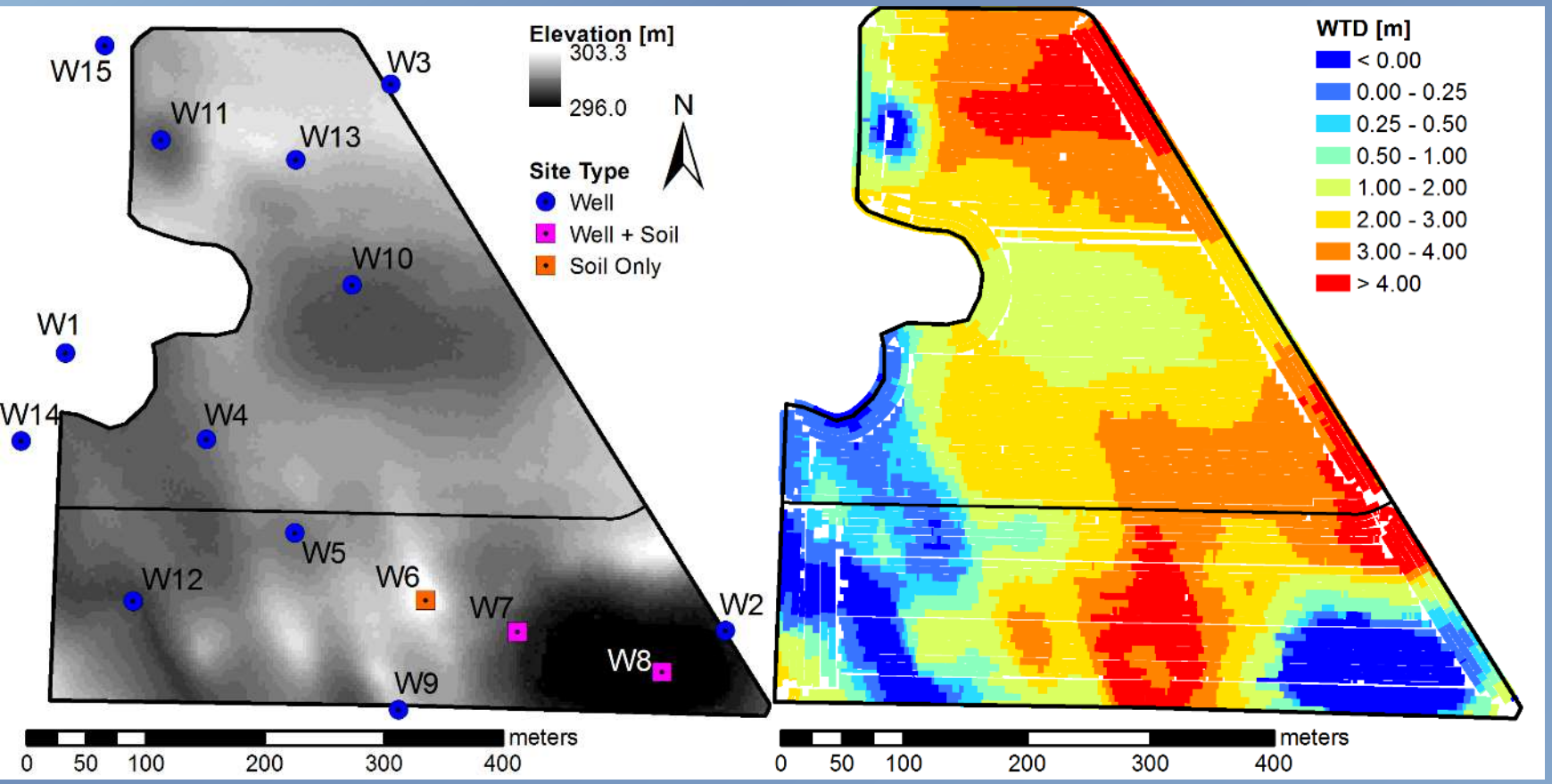
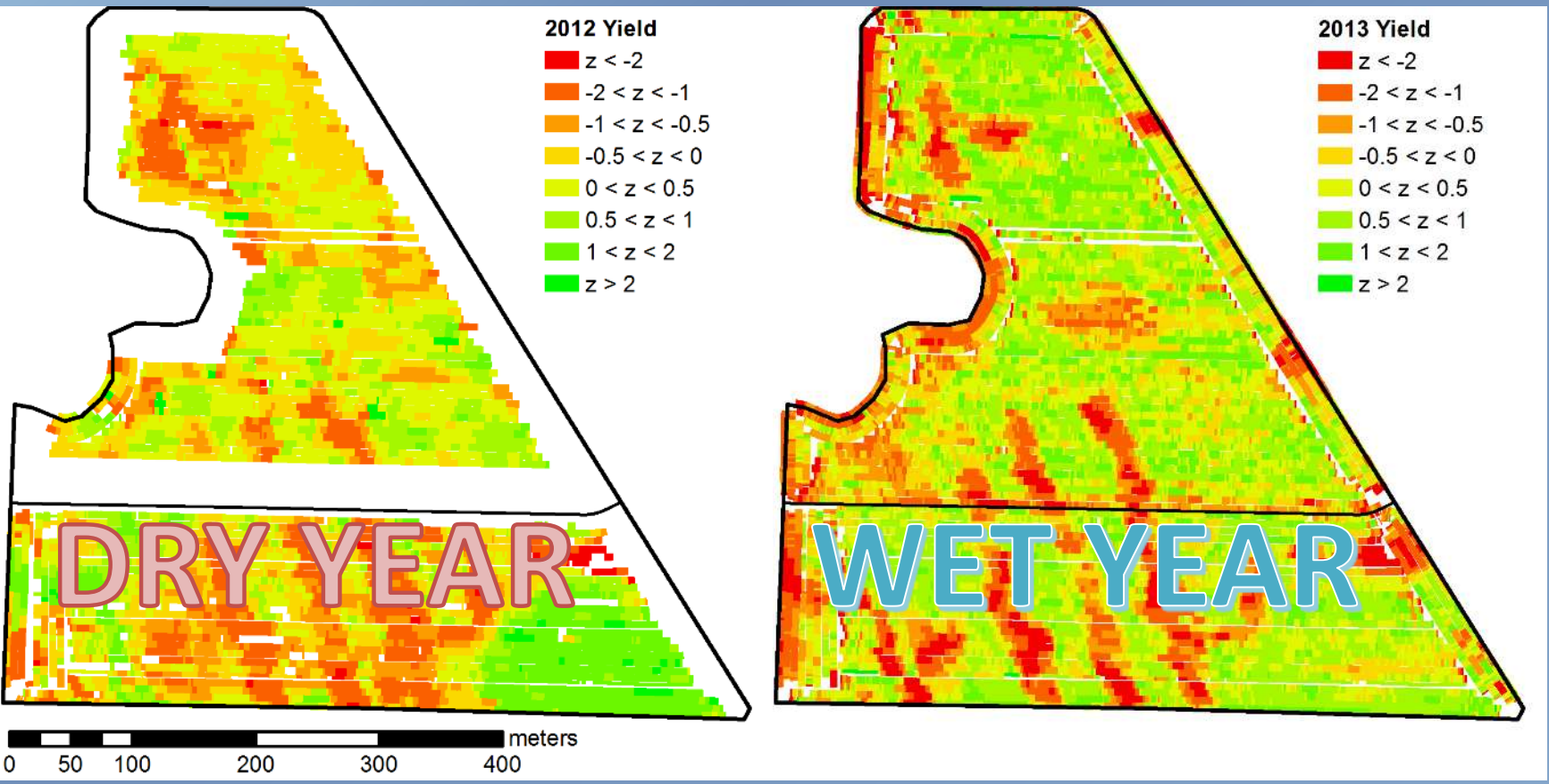
W1
W14
W4
W5
W12
W6
W7
W2
W8
W9
meters
0 50 100 200 300 400

Groundwater Data



- Gap-filled via multiple linear regression
- Water surface linearly interpolated between wells
- Various metrics calculated– Maximum 7-day mean WTD shown

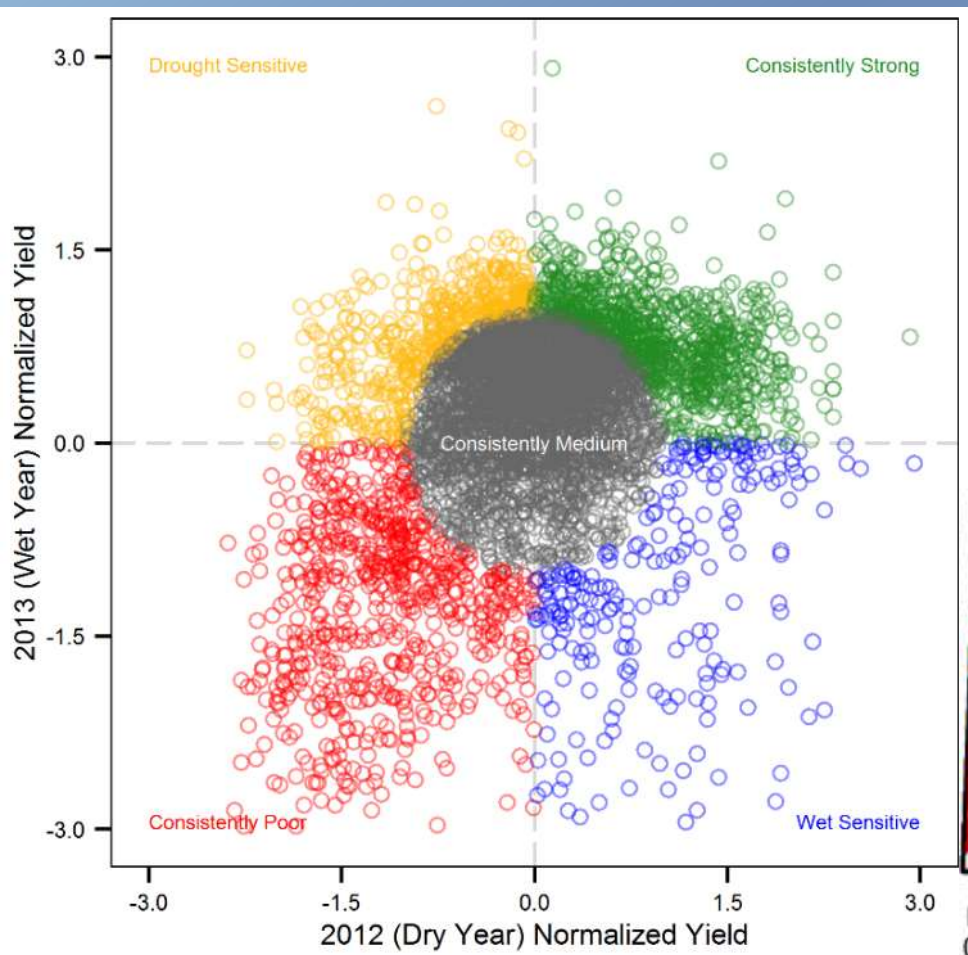
Yield Data

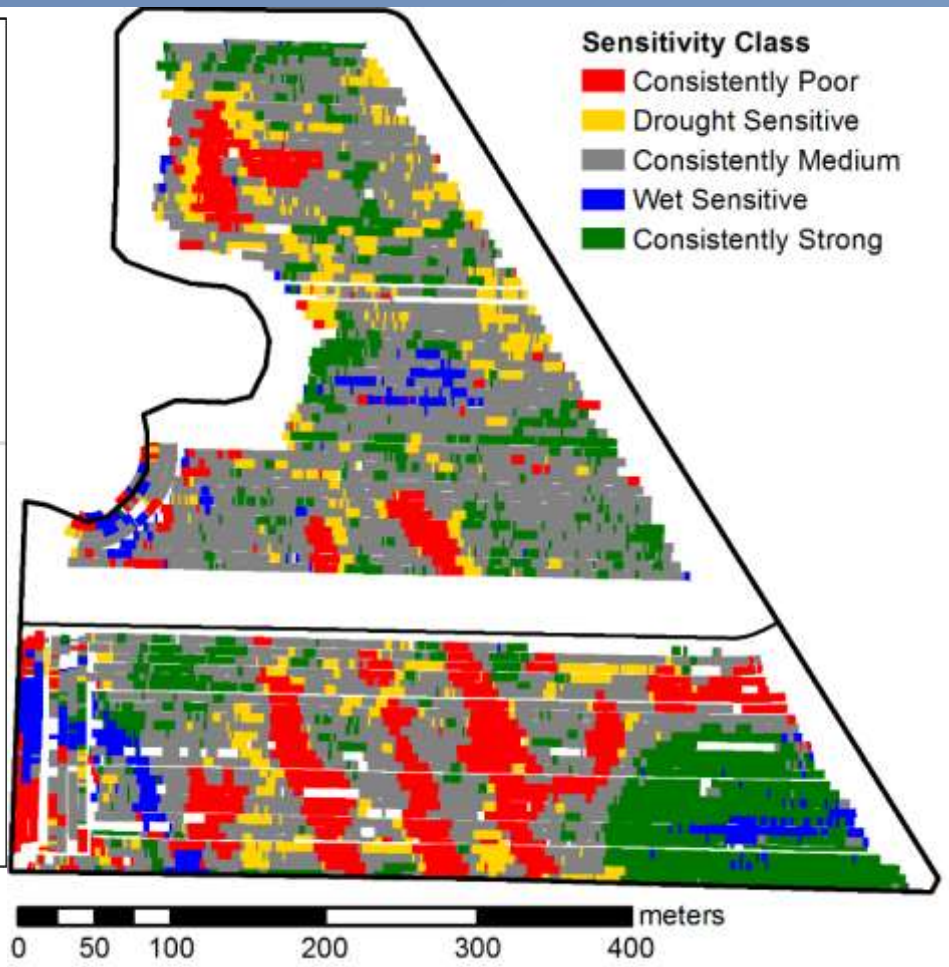


- Data collected by yield monitoring equipment on combine
- Turn-around and anomalous pixels eliminated
- Normalized to z-score to compare between years & products

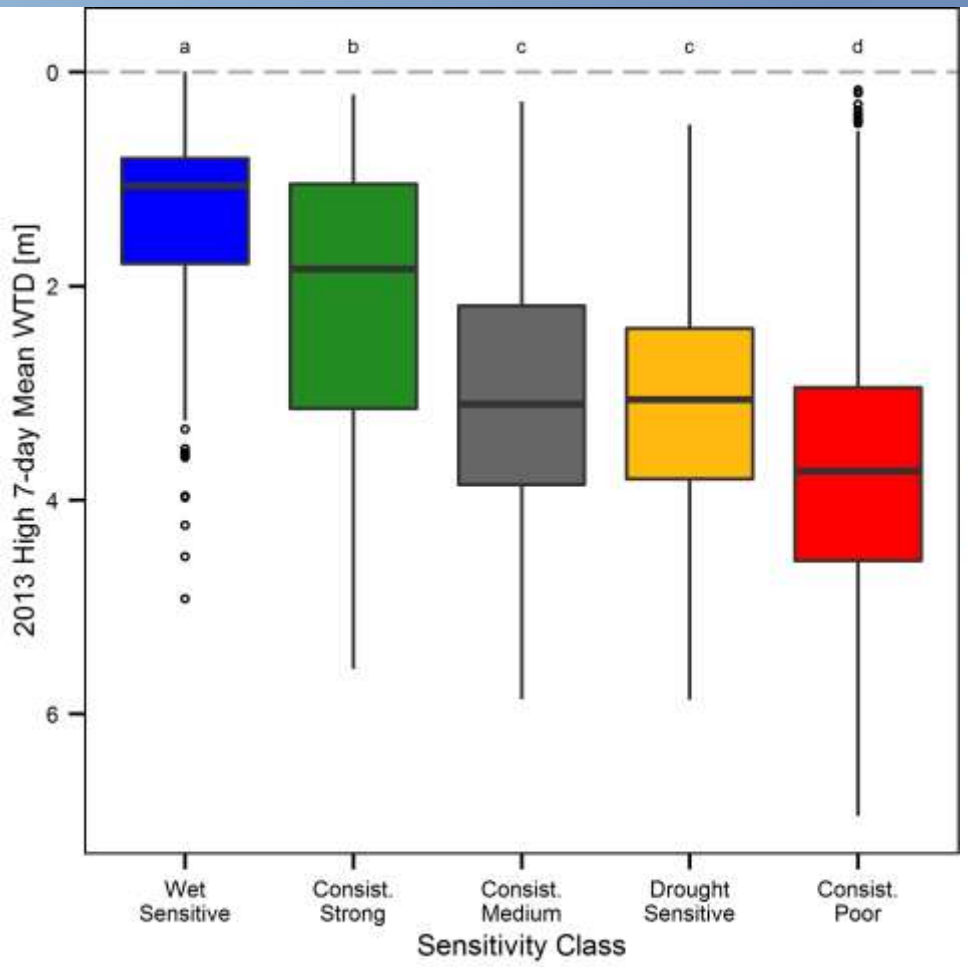
$$z = (y - \bar{y})/\mu$$

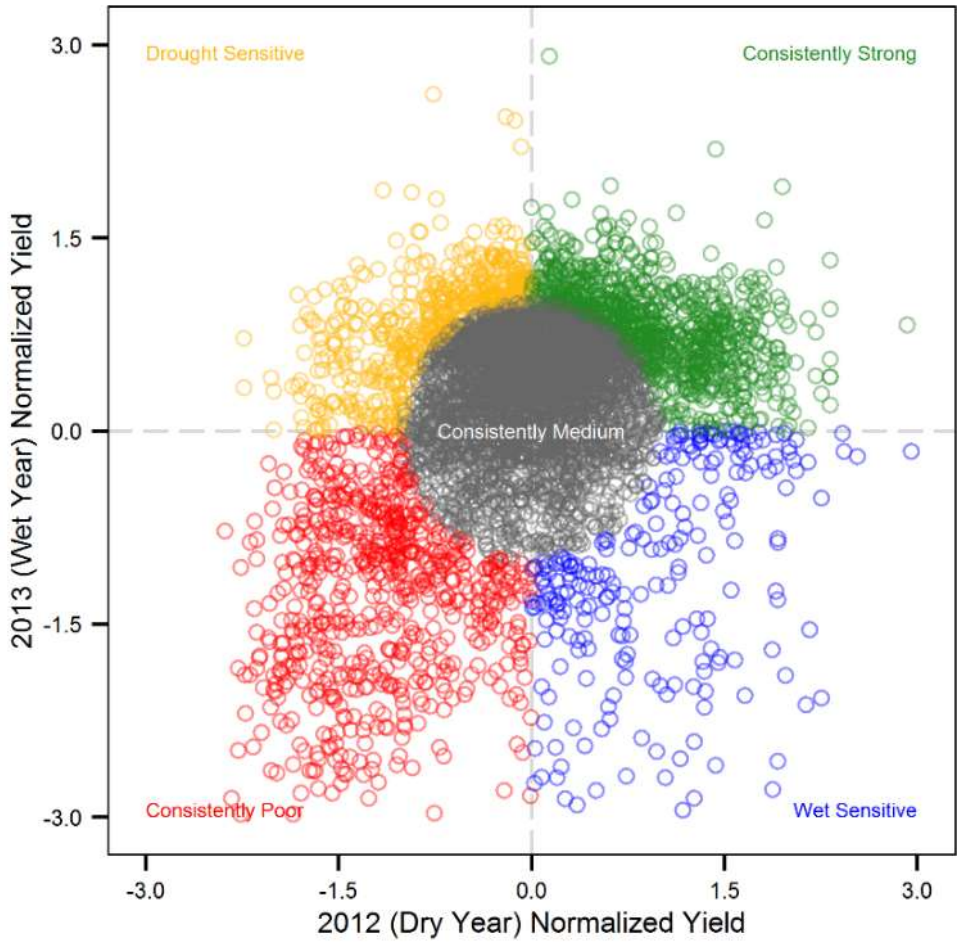
Field-Scale Sensitivity





Field-Scale Sensitivity: Groundwater as a driver





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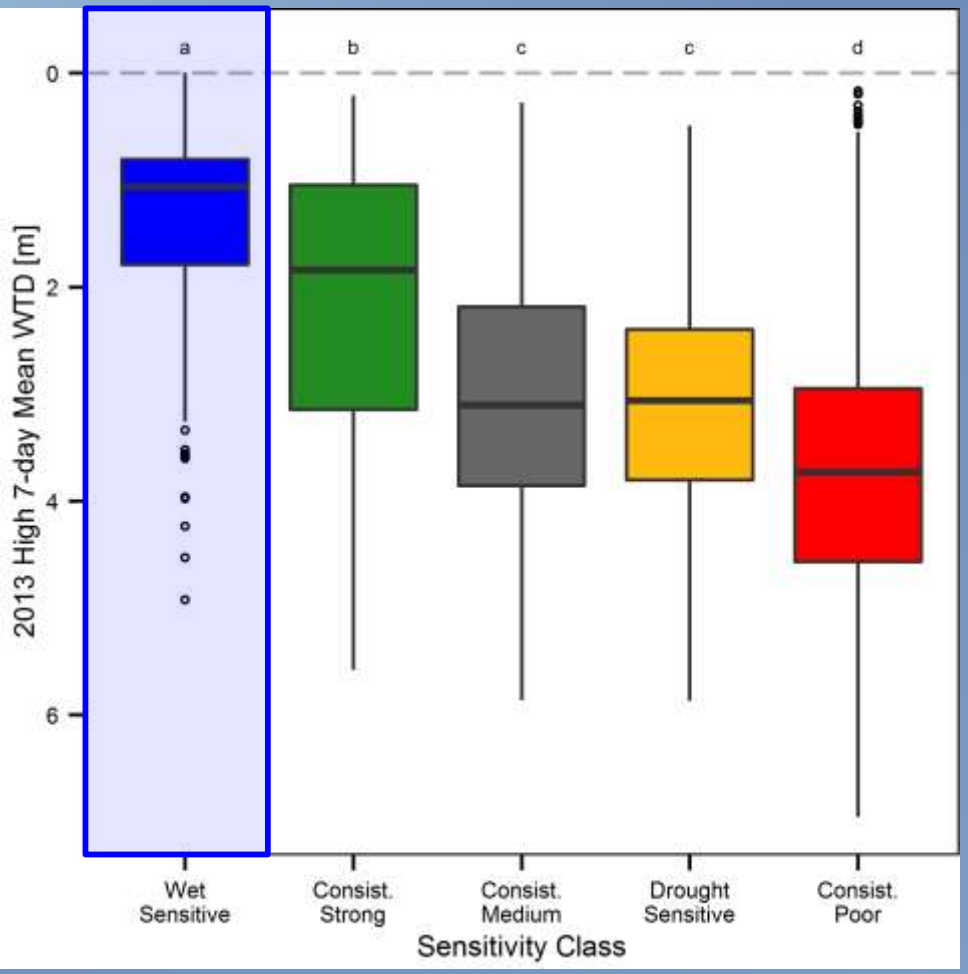
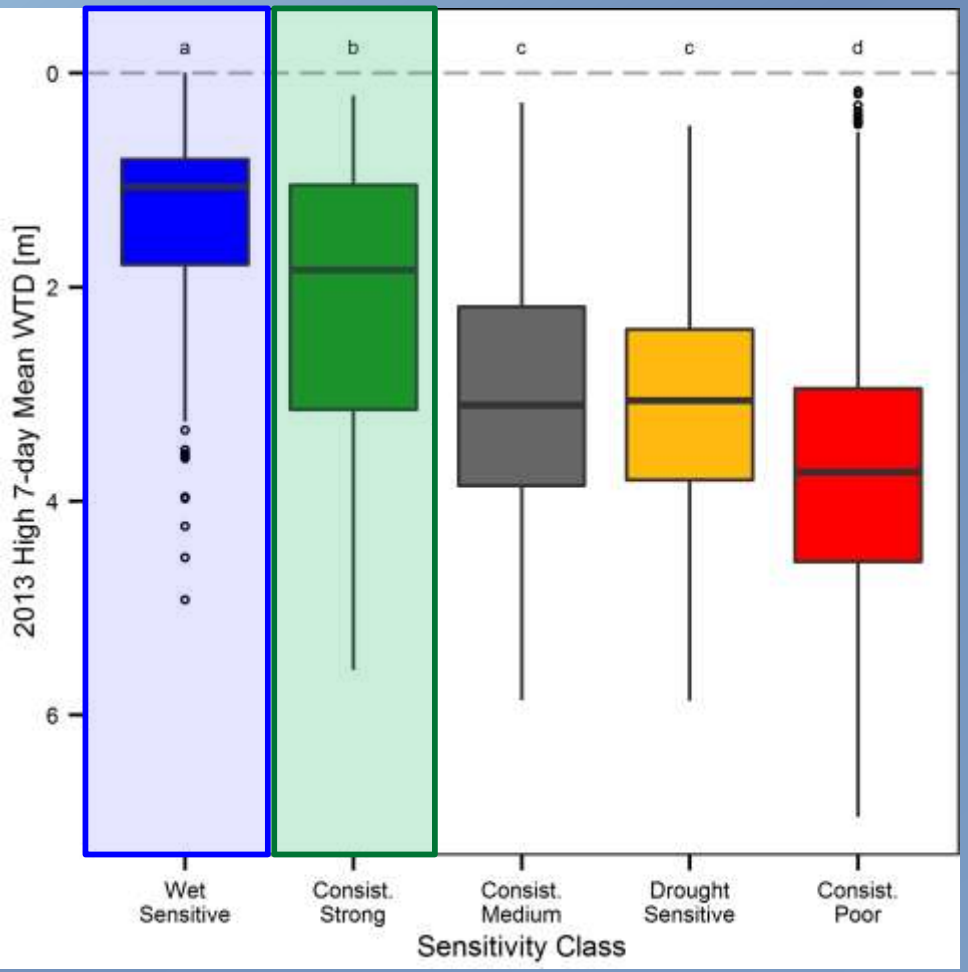


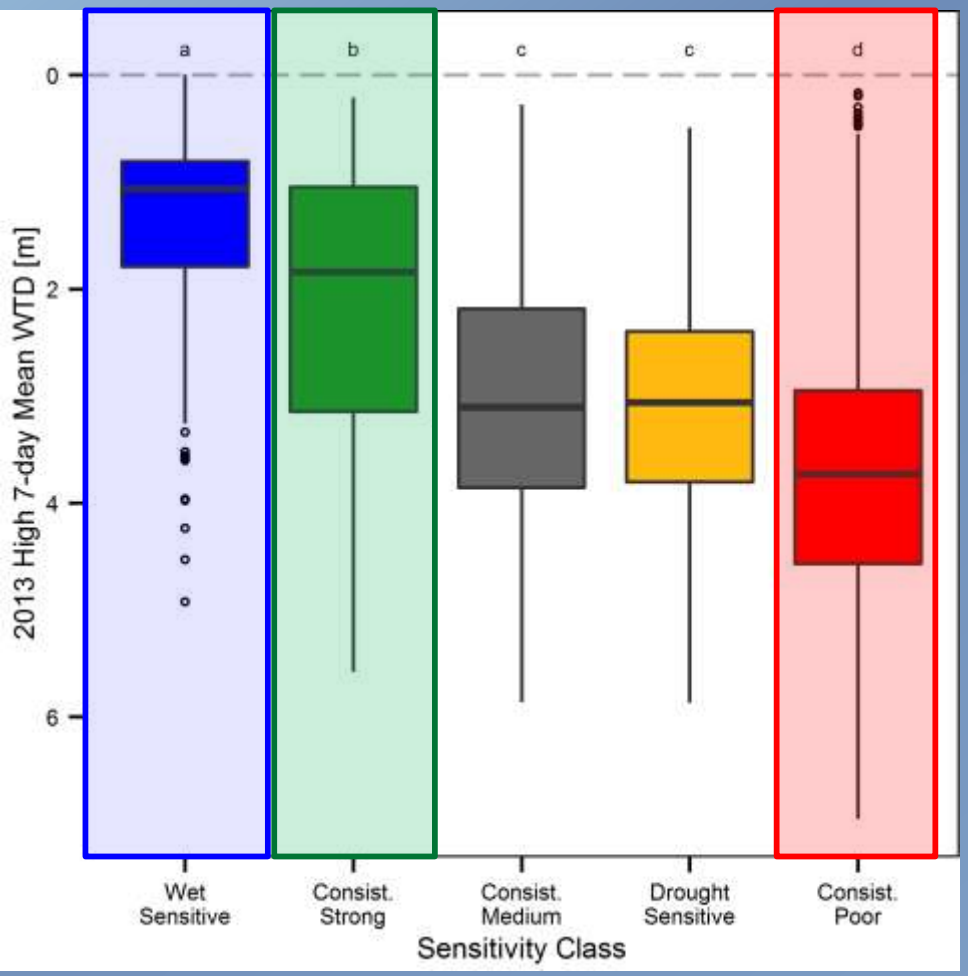
- Shallow GW → Sensitive to wet growing season → Groundwater yield penalty

Field-Scale Sensitivity: Groundwater as a driver



- Shallow GW → Sensitive to wet growing season → Groundwater yield penalty
- Intermediate GW → Resilient to wet & dry growing season → Groundwater yield subsidy

Field-Scale Sensitivity: Groundwater as a driver



- Shallow GW → Sensitive to wet growing season → Groundwater yield penalty
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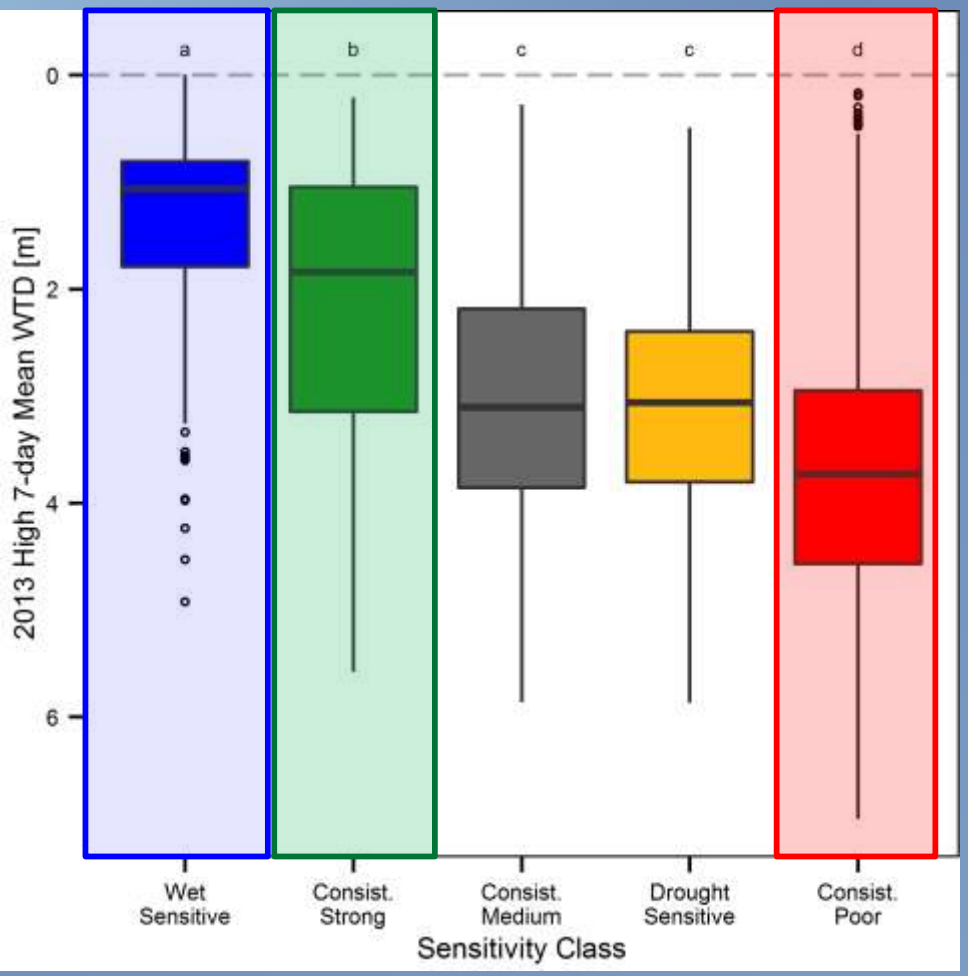
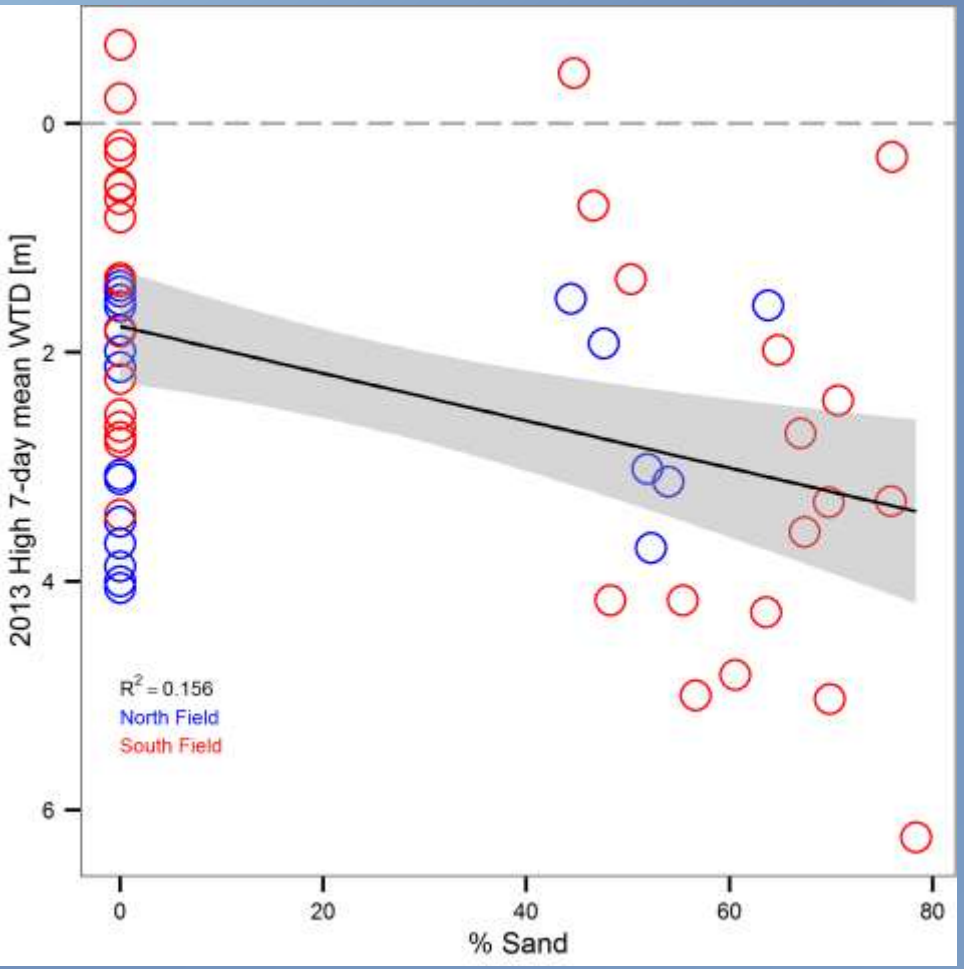
Field-Scale Sensitivity: Groundwater as a driver



- Shallow GW → Sensitive to wet growing season → Groundwater yield penalty
- Intermediate GW → Resilient to wet & dry growing season → Groundwater yield subsidy
- Deep GW → Low yield in both wet & dry growing season → No groundwater influence
- Shallow water table influence moderated by growing season weather conditions

Soil-Groundwater Relationship



WTD & soil texture co-vary

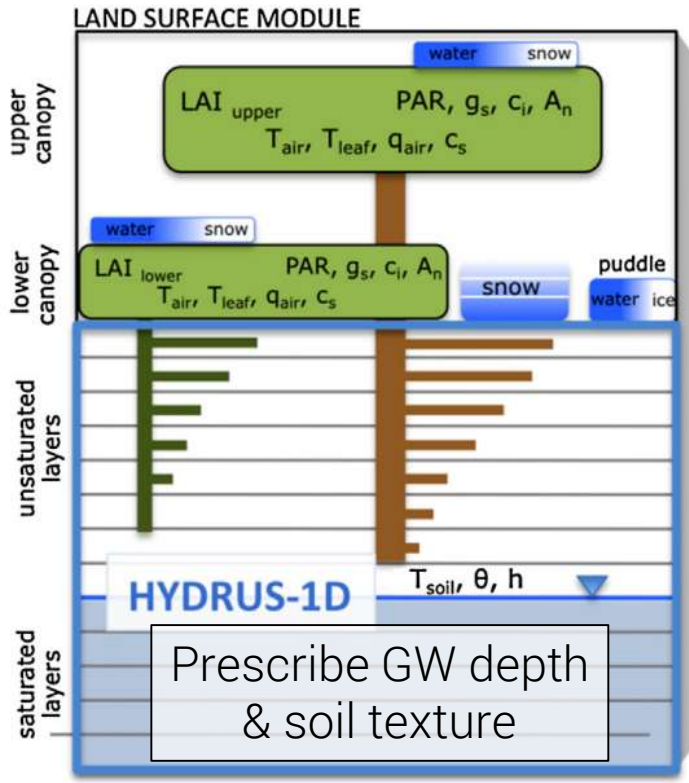
Complementary yield effects:

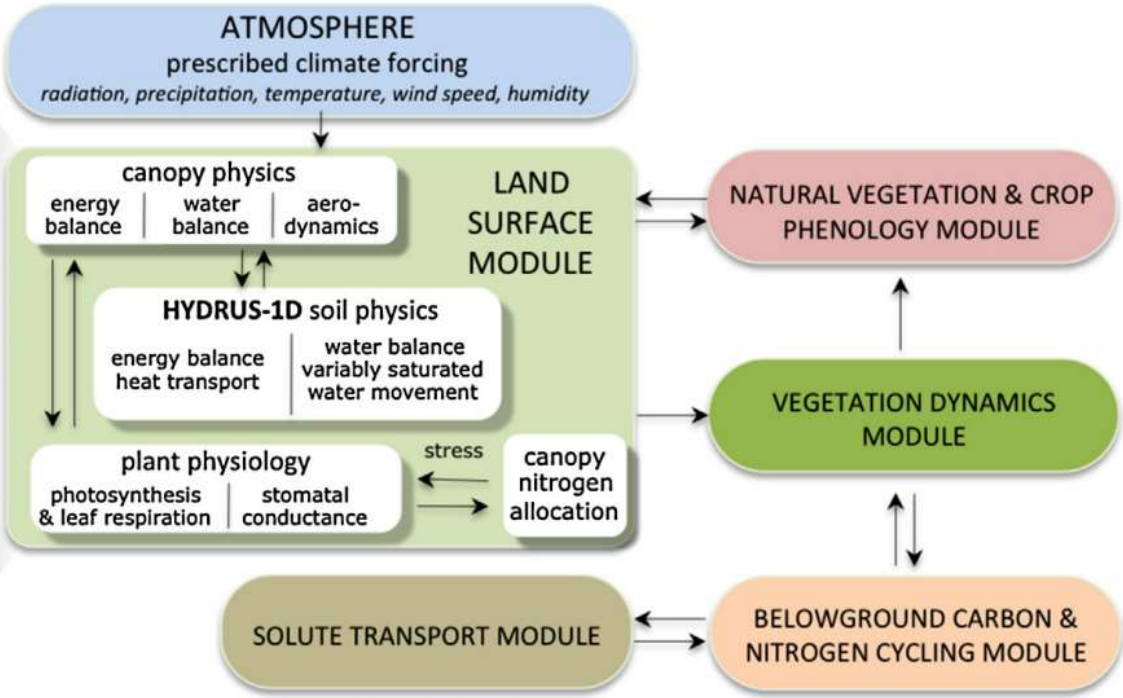
→ Fine soil + shallow GW = increased drought resilience but higher oxygen stress risk

→ Coarse soil + deep GW = more water stress but lower oxygen stress risk

Model Description: AgroIBIS-VSF

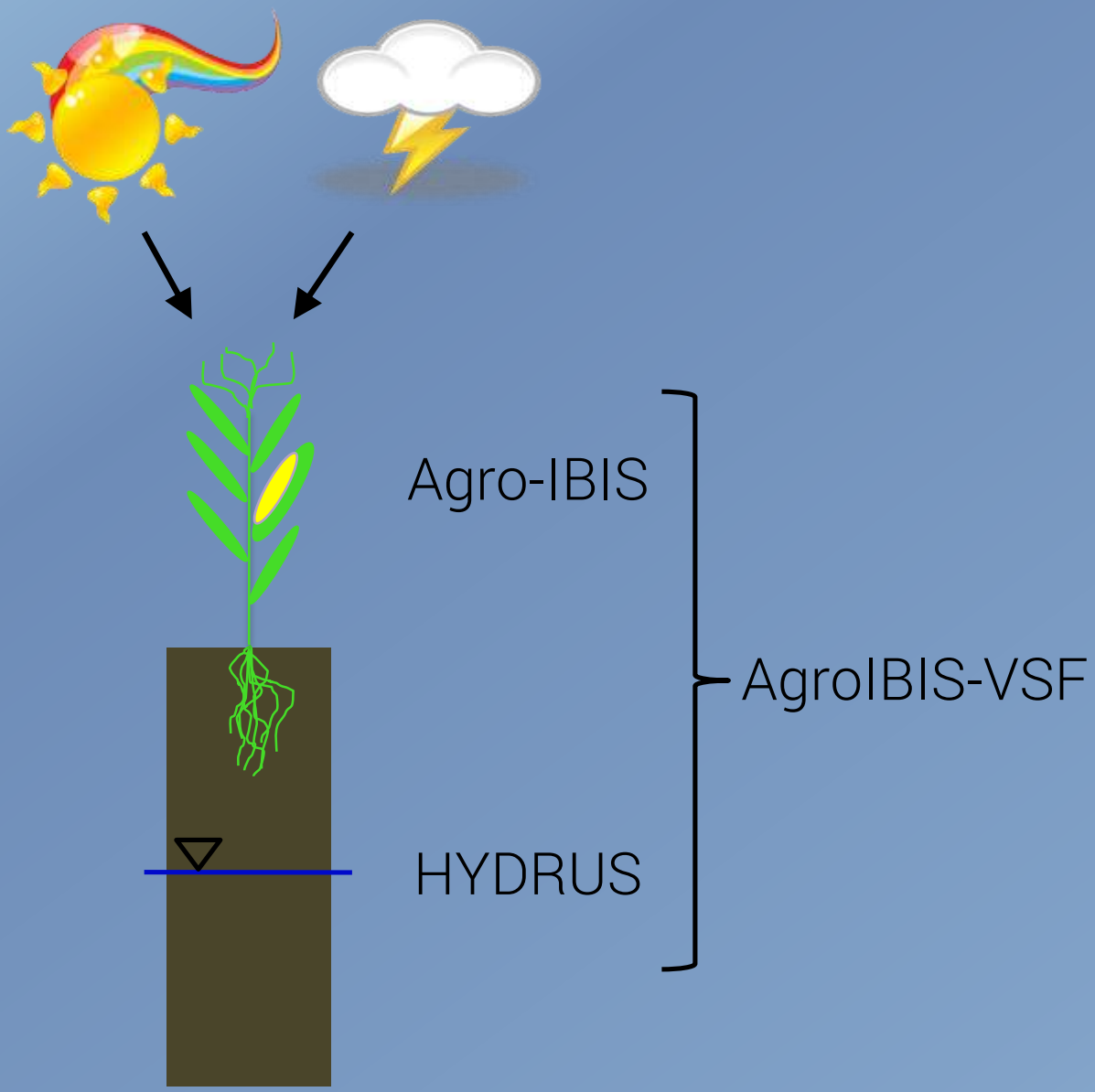
M.E. Soylu et al. / Agricultural and Forest Meteorology 189–190 (2014) 198–210



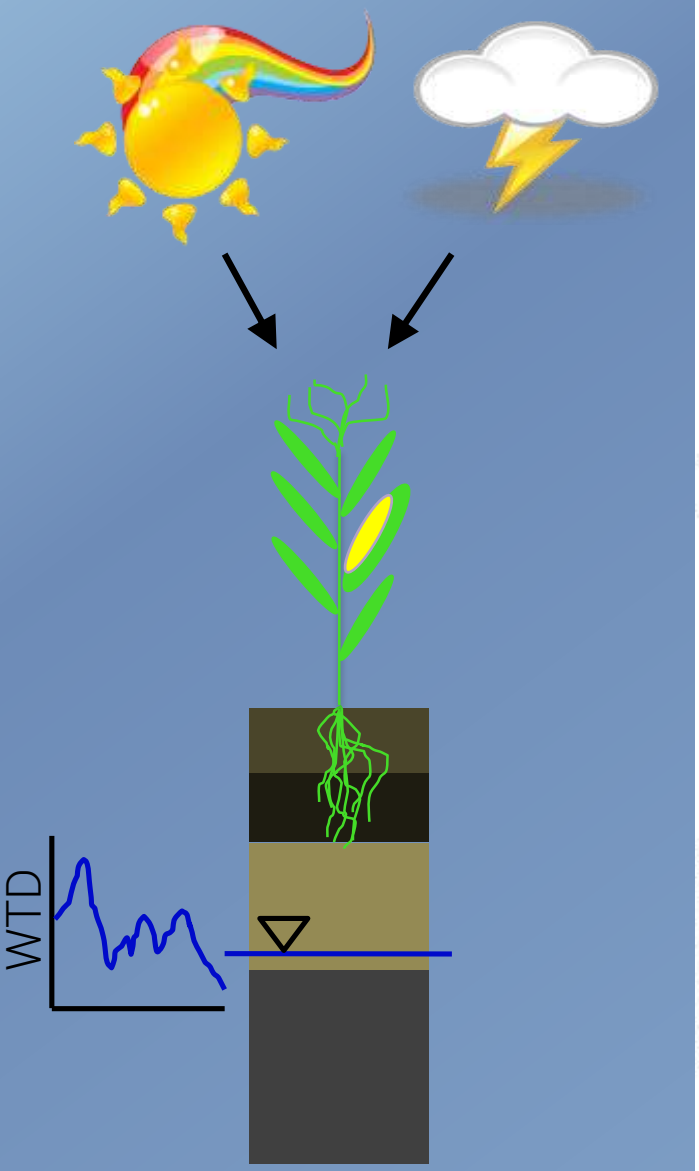


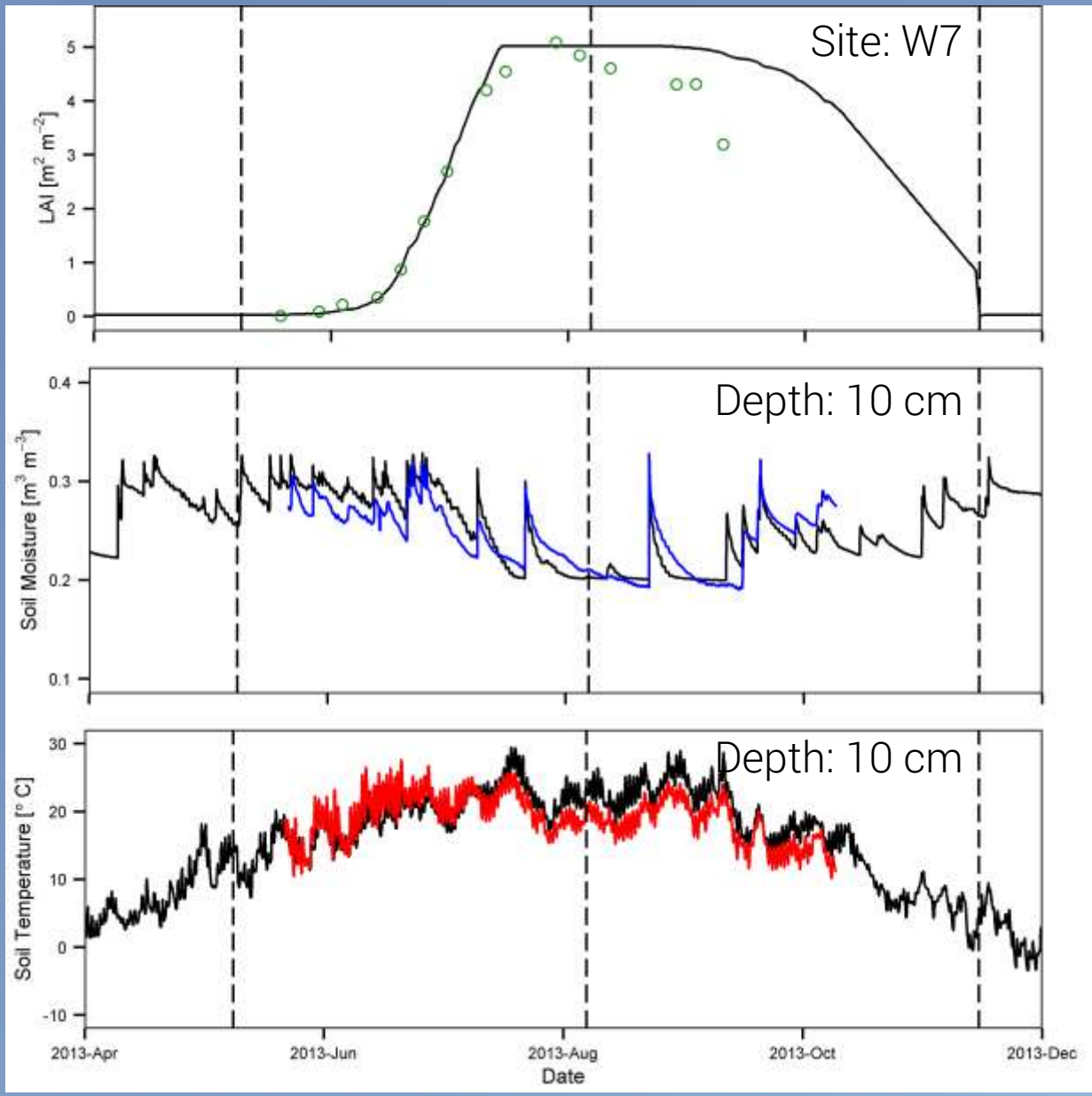
- IBIS: global dynamic vegetation model (Foley et al., 1996)
- Agro-IBIS: U.S.-only version with agroecosystems (Kucharik, 2003)
- AgroIBIS-VSF: couples HYDRUS-1D soil physics (Soylu et al., 2014)

Model Description: AgroIBIS-VSF



Model Validation: AgroIBIS-VSF

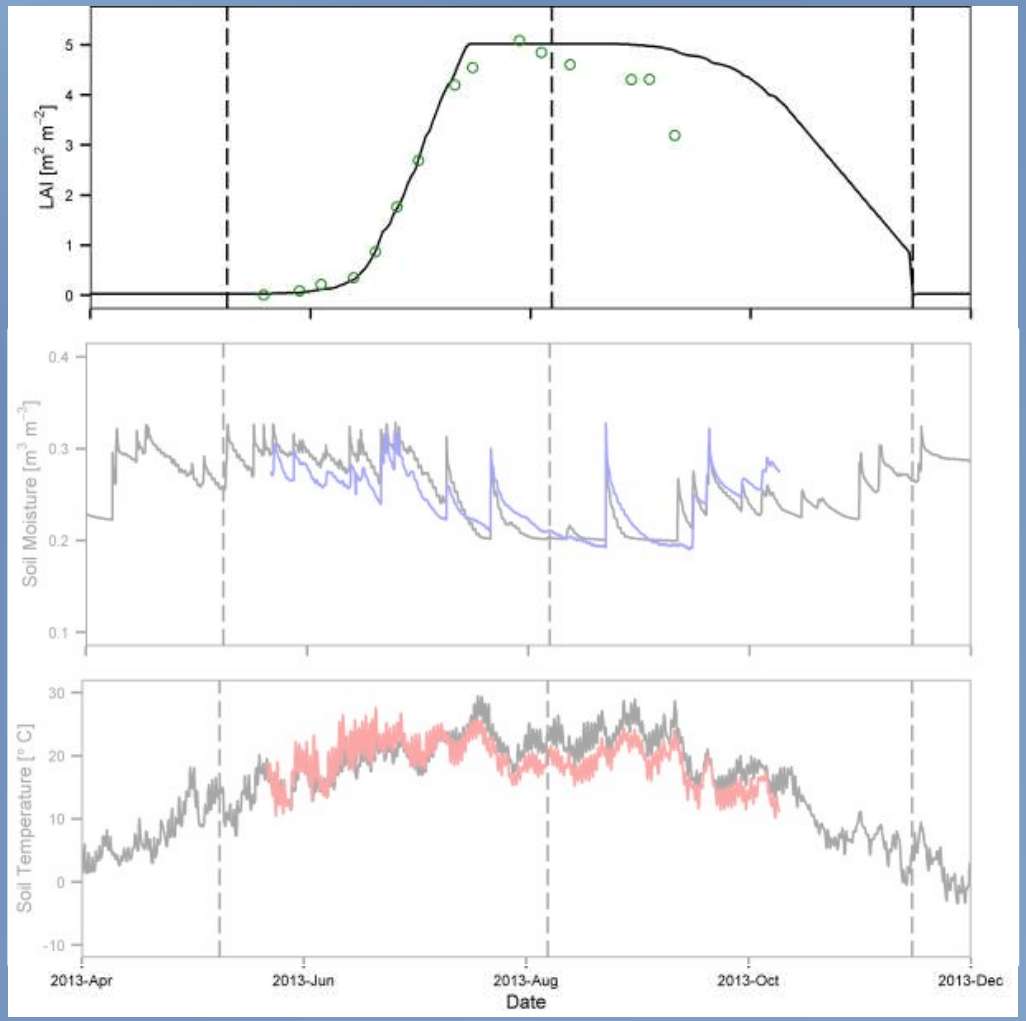




Site: W7

Depth: 10 cm

Depth: 10 cm



Variable:	**LAI**	**Soil Moisture**								**Soil Temperature**			
Metric:	*RMSE*	*RMSE*				*Nash-Sutcliffe Efficiency*				*RMSE*			
Depth:		*10 cm*	*35 cm*	*65 cm*	*Deep*	*10 cm*	*35 cm*	*65 cm*	*Deep*	*10 cm*	*35 cm*	*65 cm*	*Deep*
W6	0.143	0.013	0.019	0.024	0.011	0.817	0.714	0.656	0.313	1.814	1.452	1.674	1.529
W7	0.535	0.020	0.019	0.016	0.008	0.624	0.854	0.769	0.768	2.861	2.480	2.341	2.520
W8	0.545	0.039	0.046	0.025	0.026	0.693	0.448	0.662	0.639	2.252	0.420	2.248	3.045

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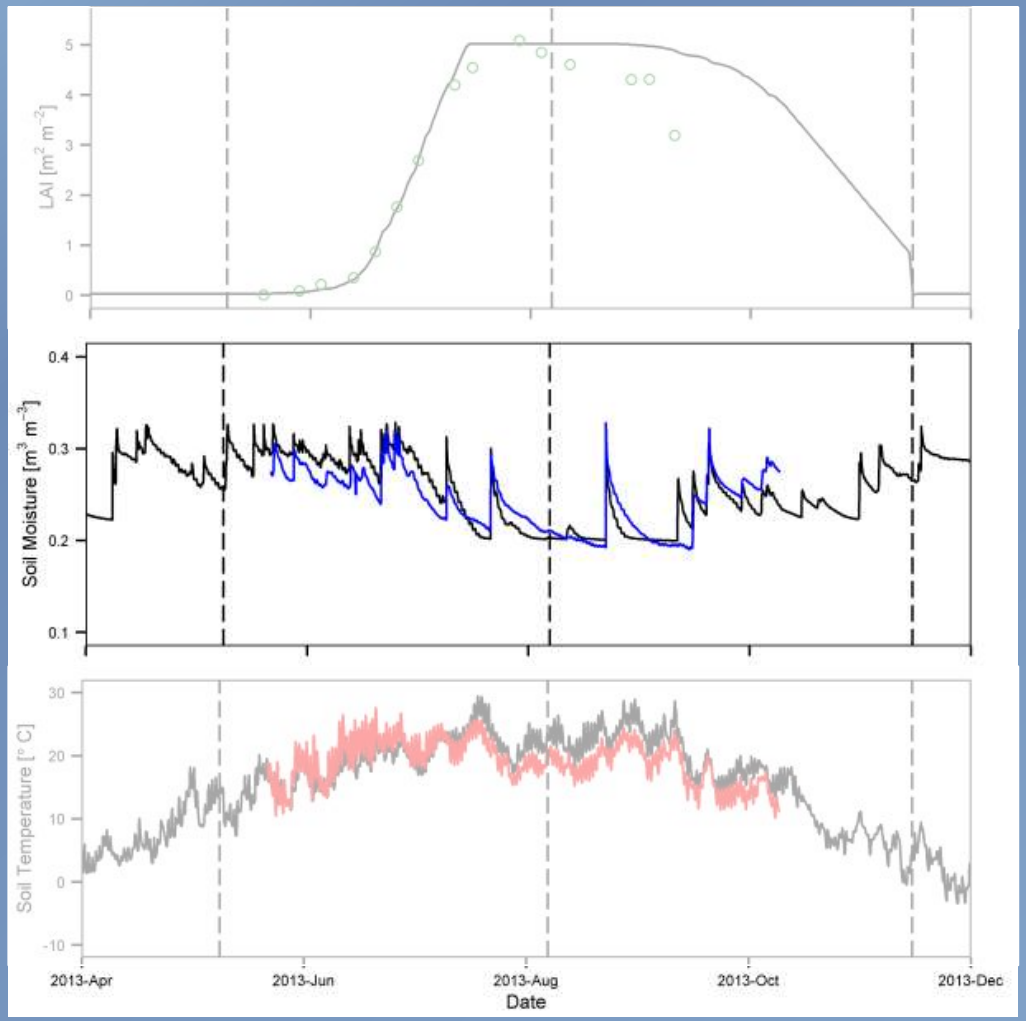

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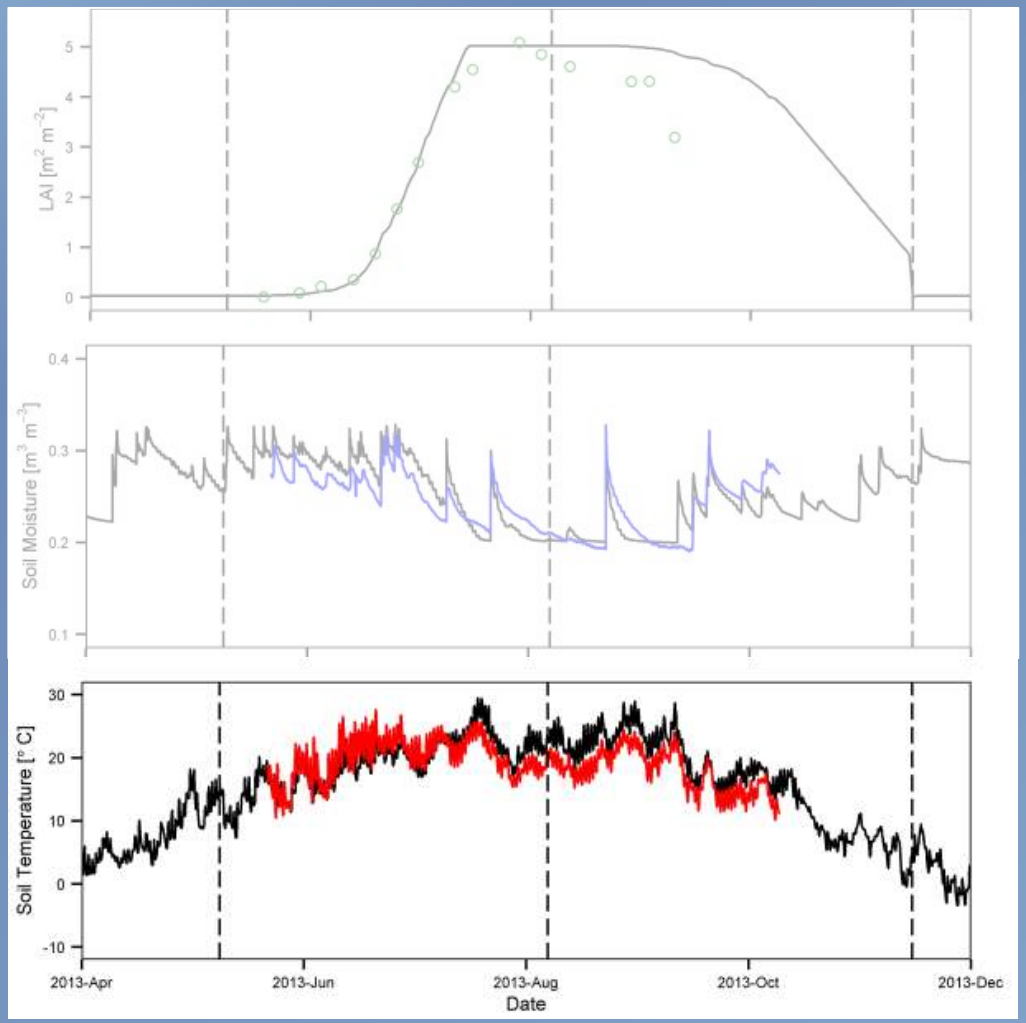

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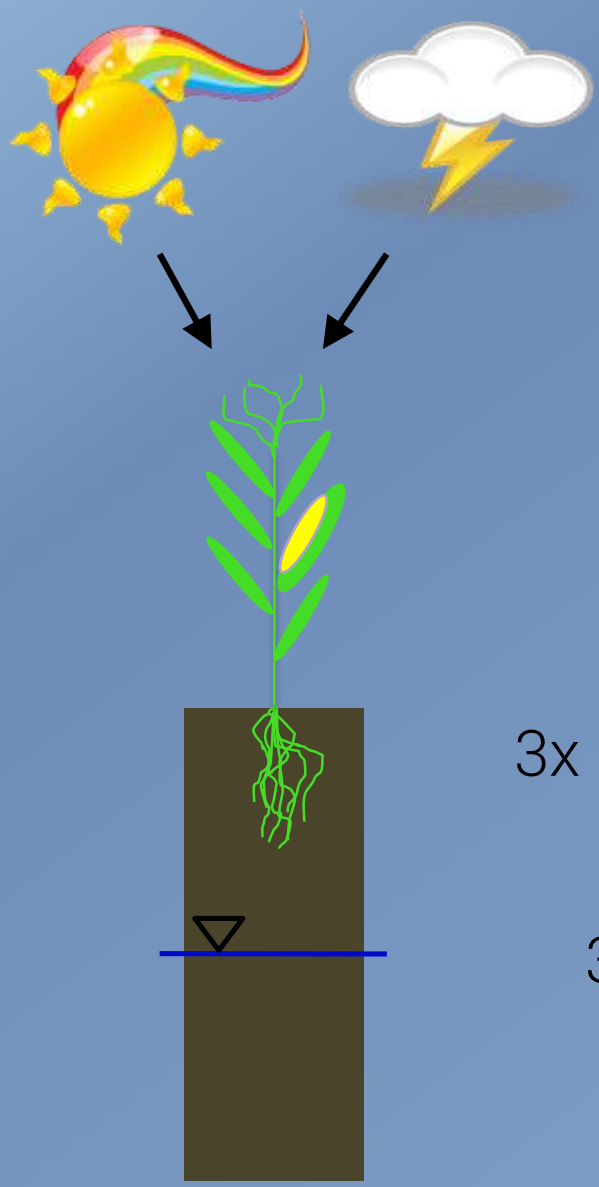
Model Results: Calculating the Optimum WTD

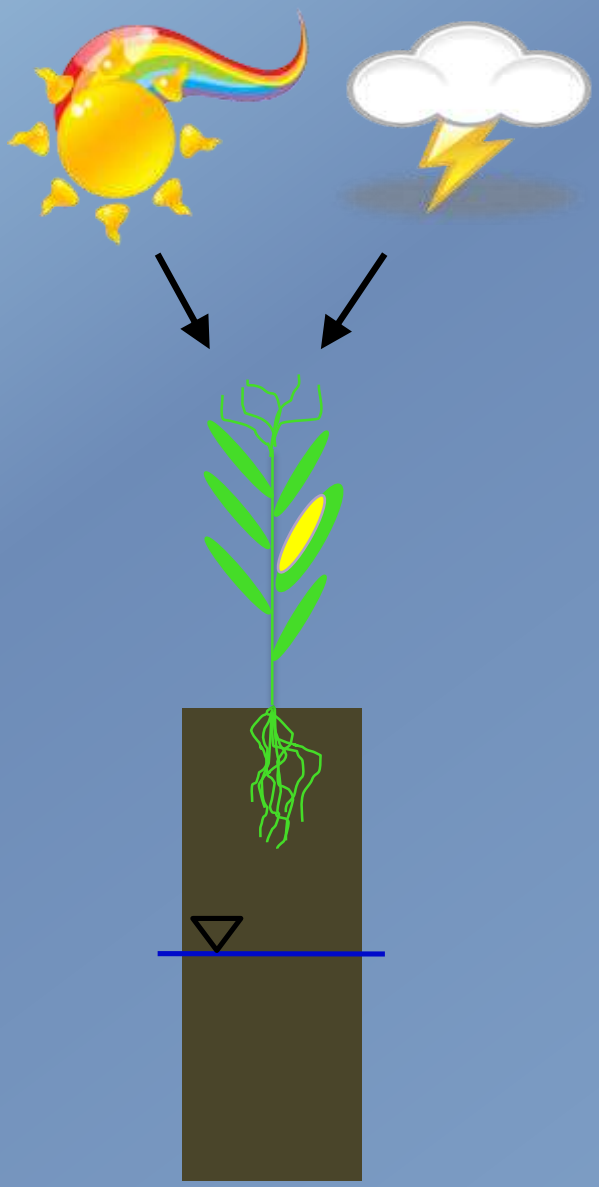


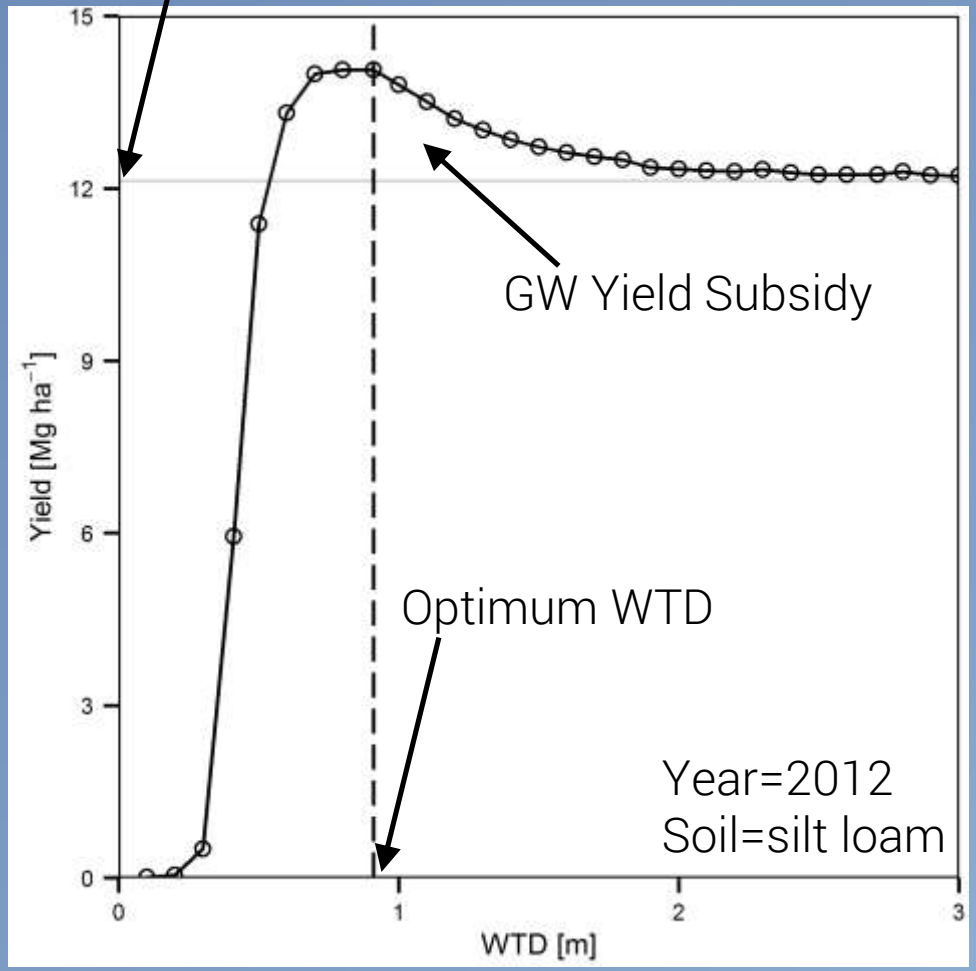
28x growing seasons (1986-2013)

3x soil textures (silt loam, loam, sandy loam)

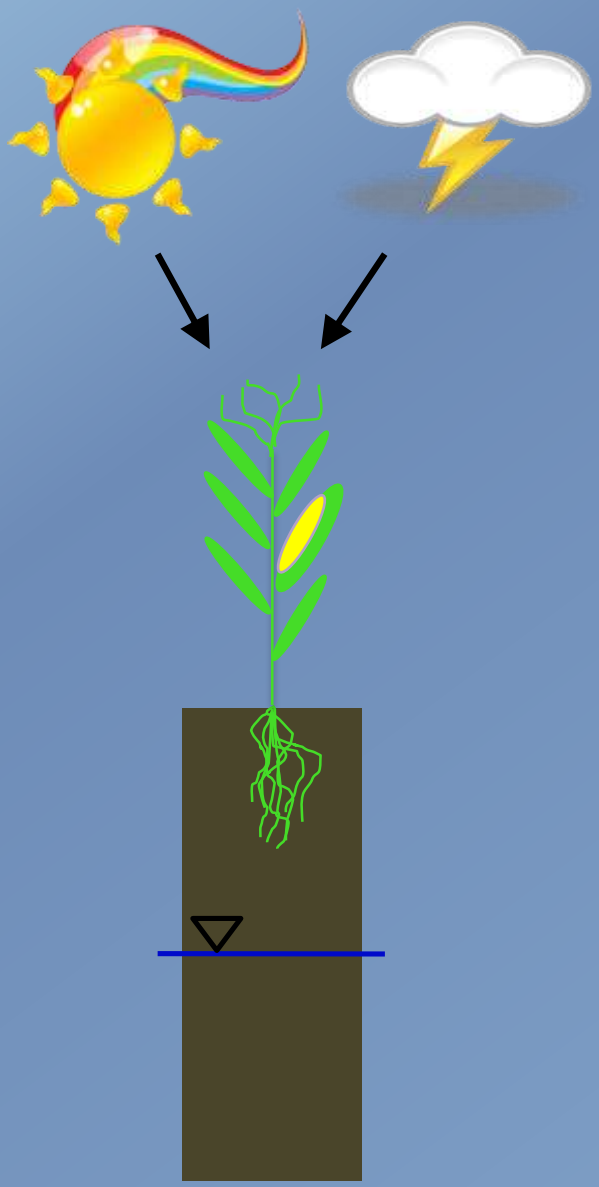
38x WTD (0.10-4.75 m + free drainage)

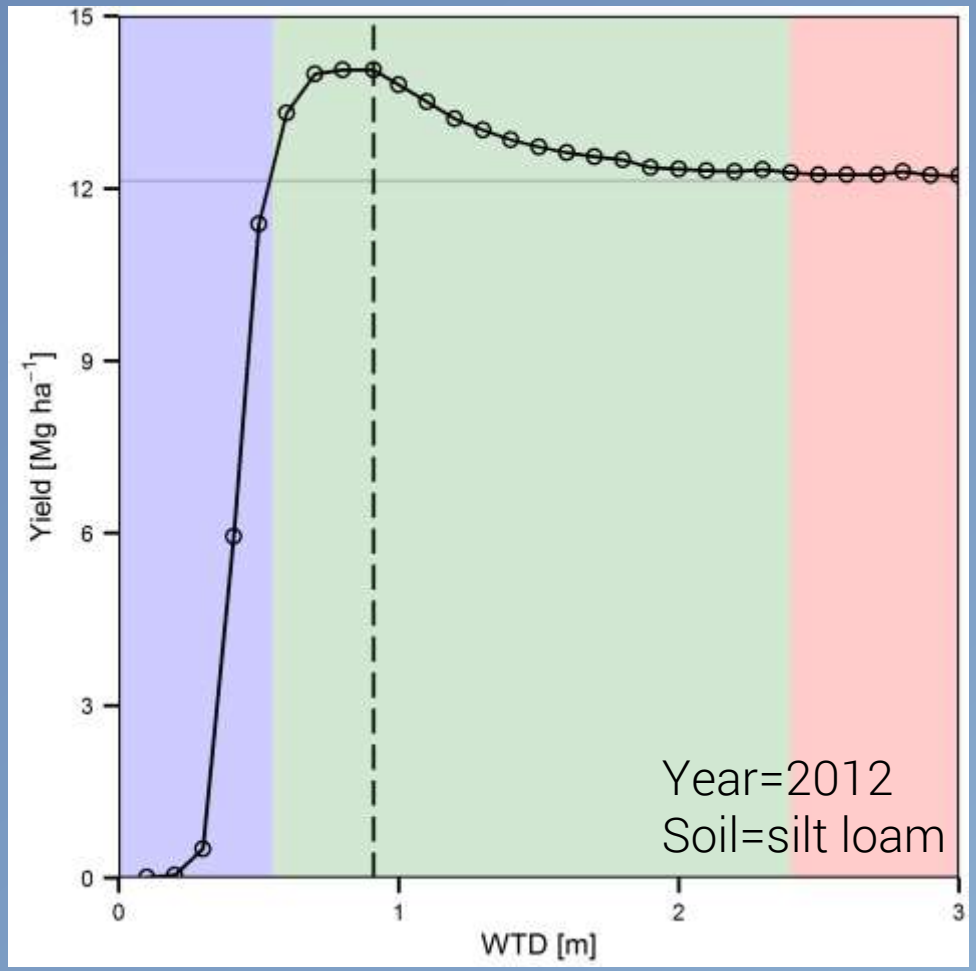
Model Results: Calculating the Optimum WTD





Model Results: Calculating the Optimum WTD





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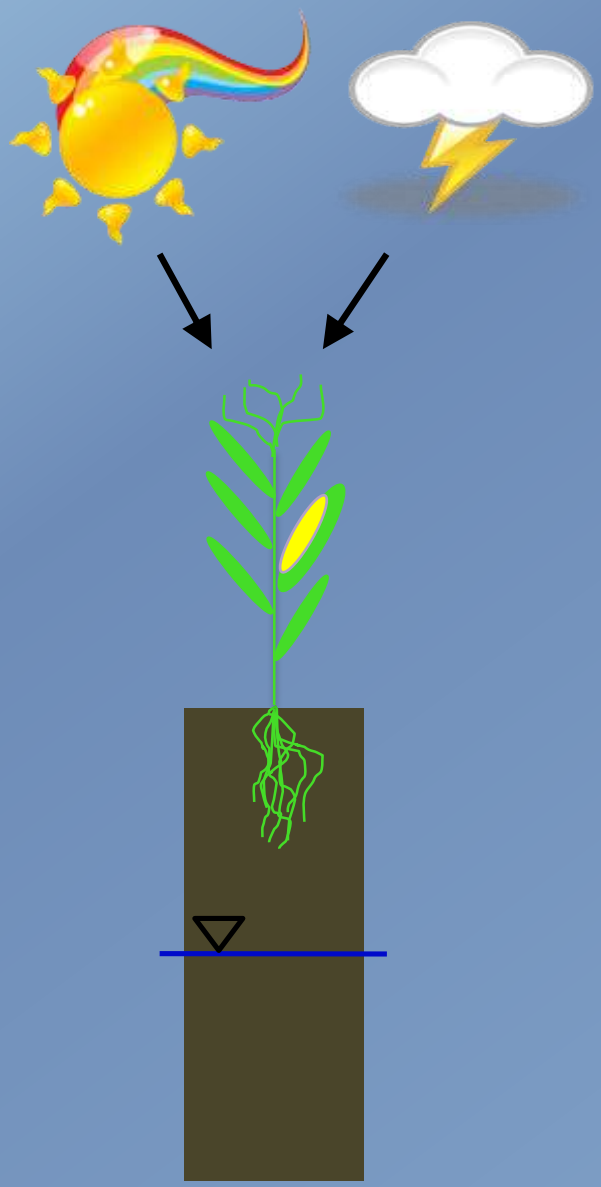

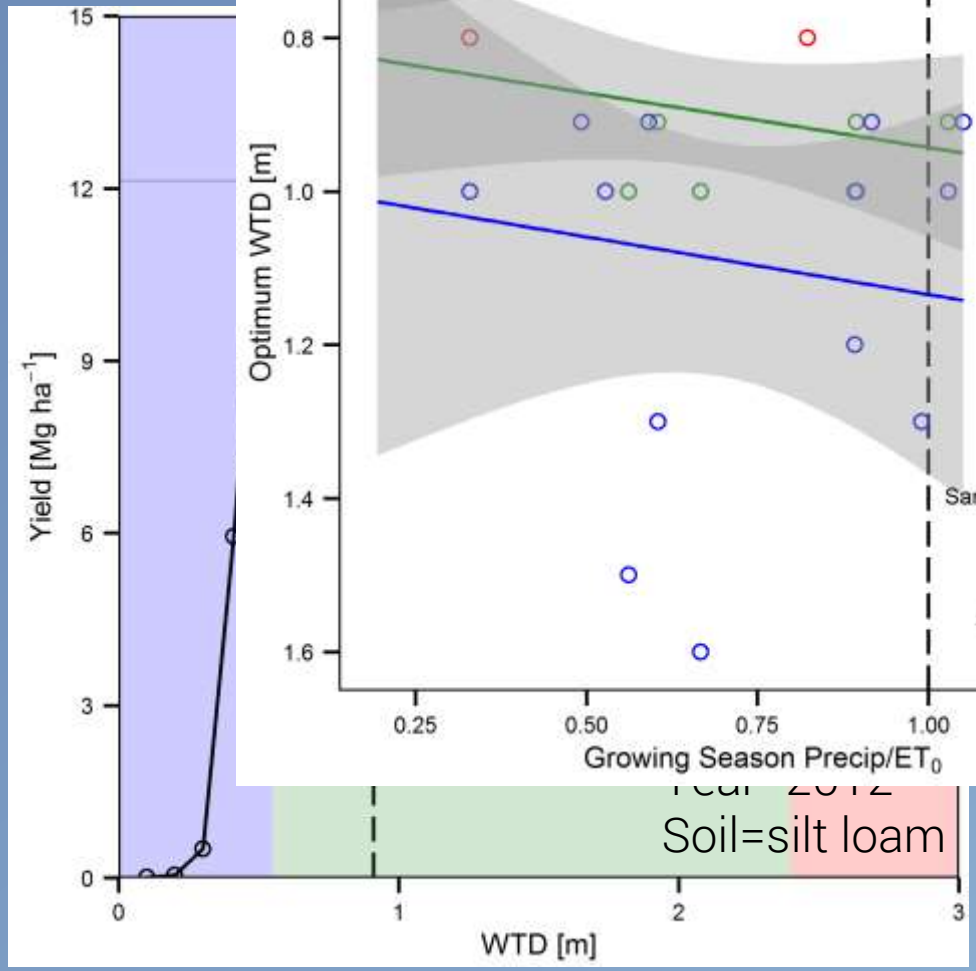

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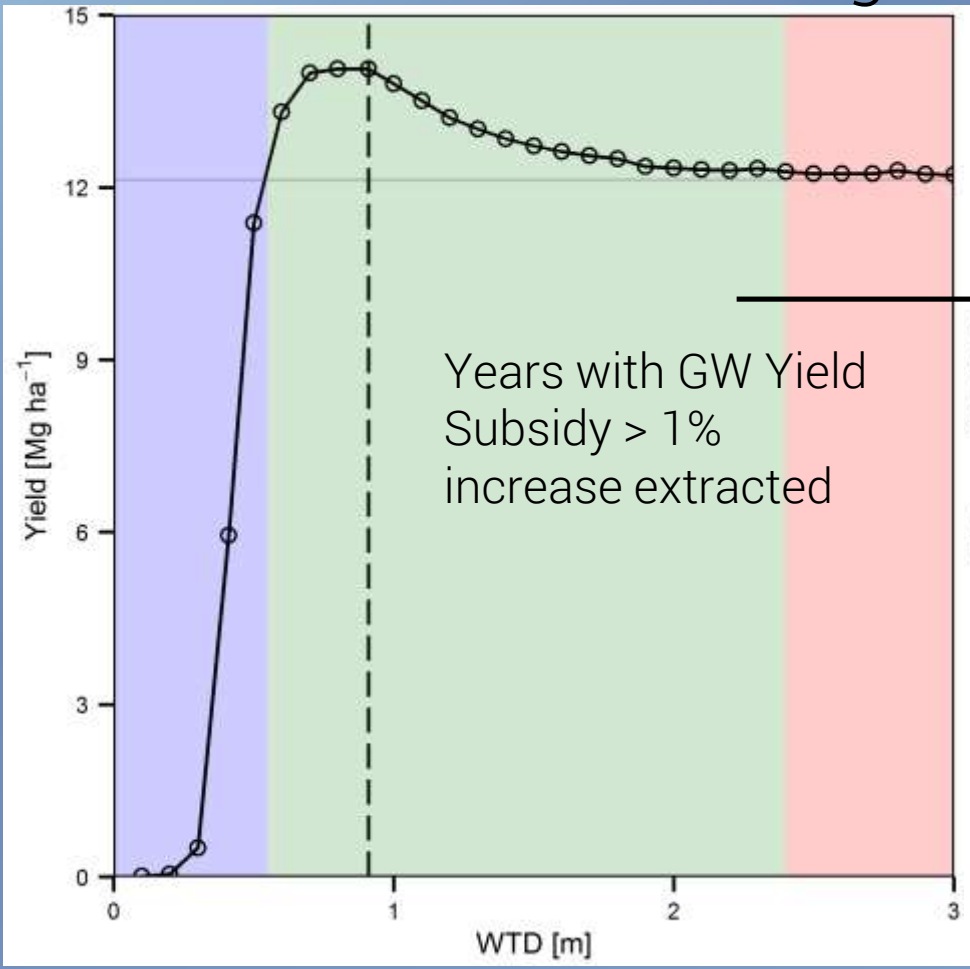
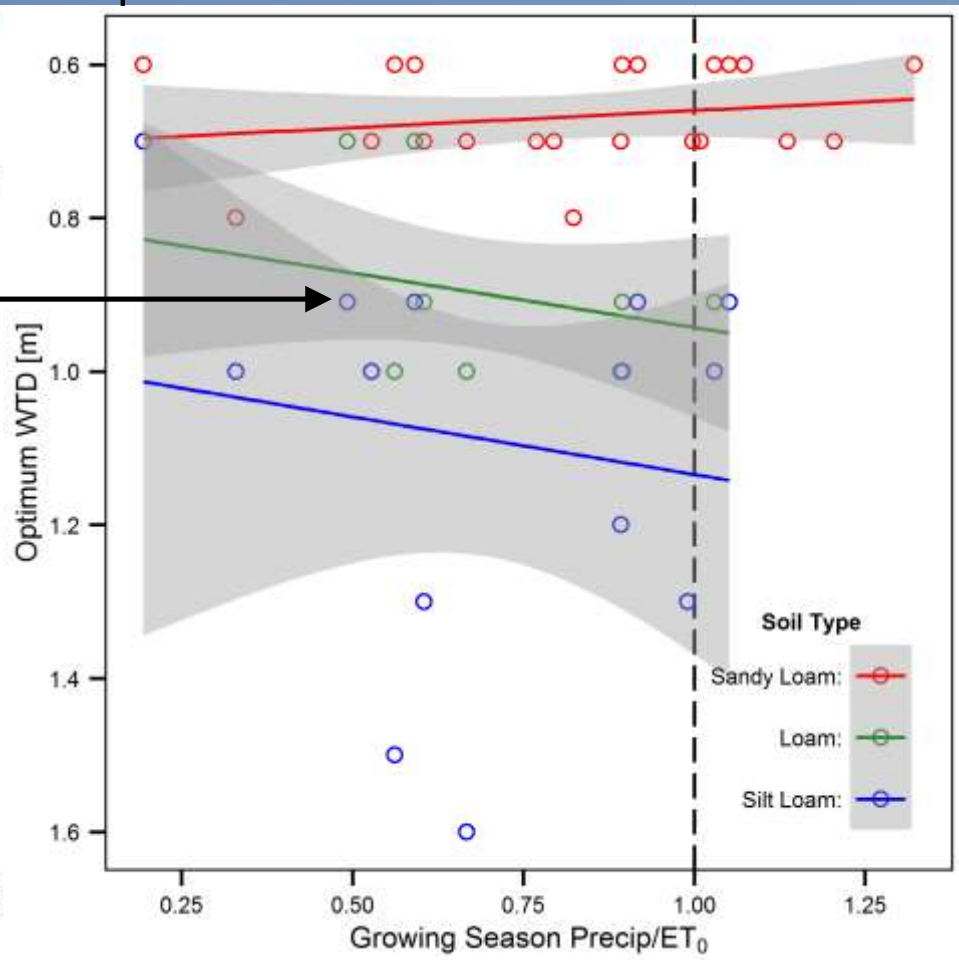


Years with GW Yield Subsidy > 1% increase extracted



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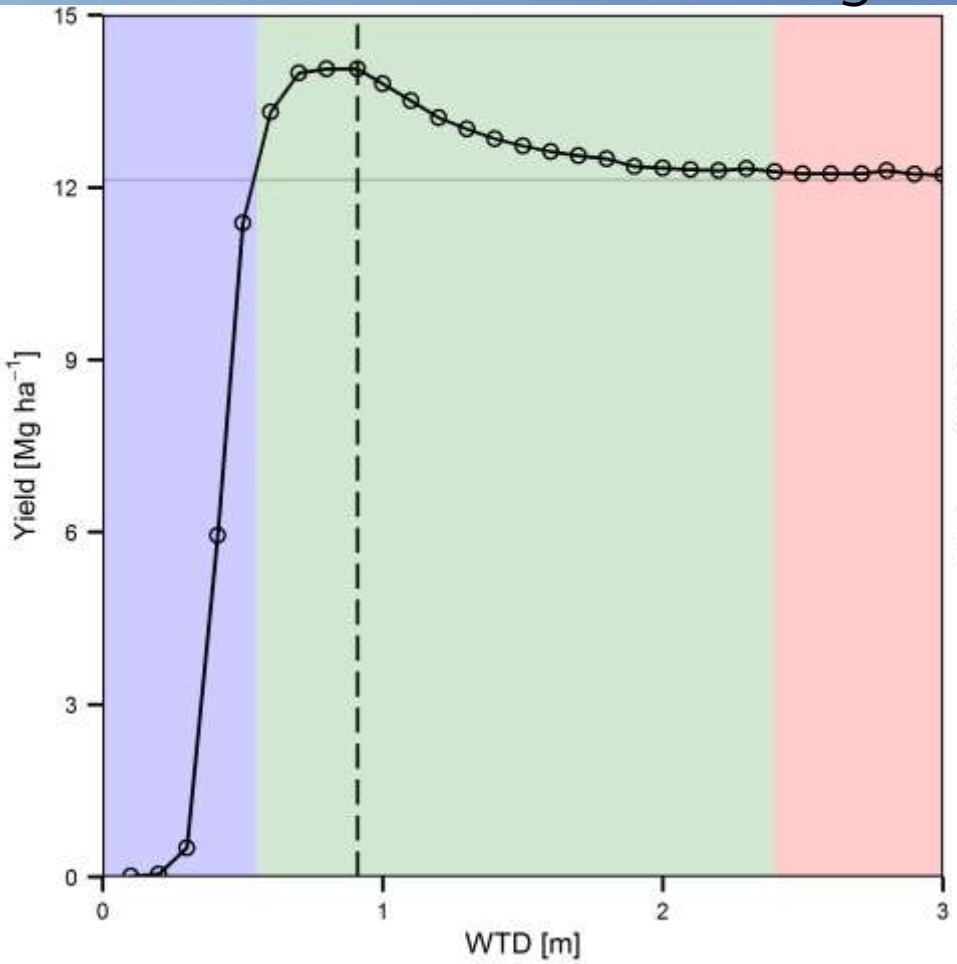
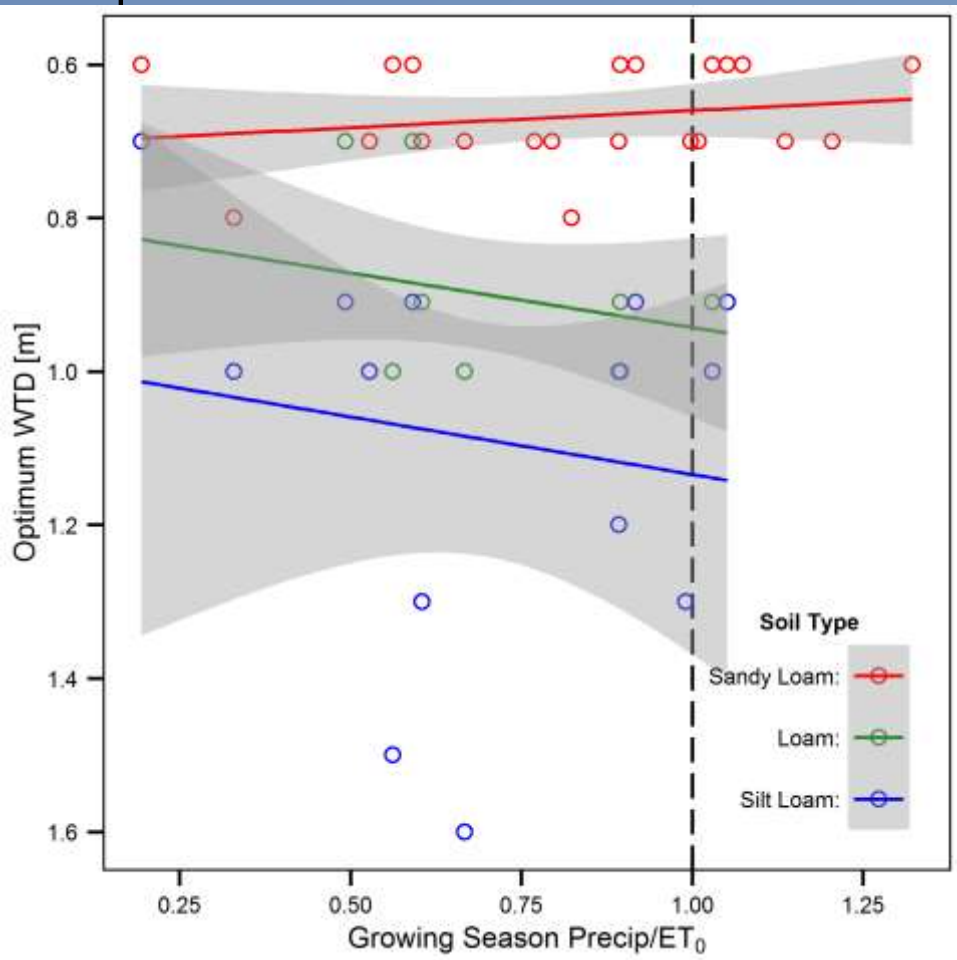
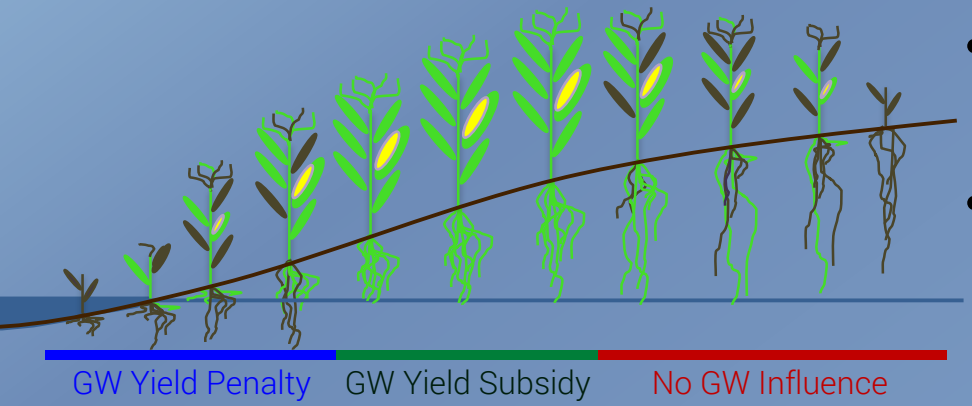




- Coarser soils: Frequent GW yield subsidy @ consistent depth
- Intermediate soils: Wetter year → deeper optimum WTD
- Fine soils: Poorly constrained, only when precip ≤ ET_0

Conclusions

(1) Can shallow water tables provide a groundwater yield subsidy and/or penalty to corn production? **Yes.**



- Sensitivity classification confirms hypothetical model
- GW Yield Subsidy possible in all soil types

(2) How do soil texture and growing season weather conditions influence relationships between WTD and corn yield?

- Coarser soils: Optimum WTD is shallow and GW Yield Subsidy possible in all growing seasons
- Intermediate/Fine Soils: GW Yield Subsidy dependent on growing season precip/ET_0 ratio

Next Steps:

- Simulations to determine relative influence of soil & WTD on field-scale yield patterns

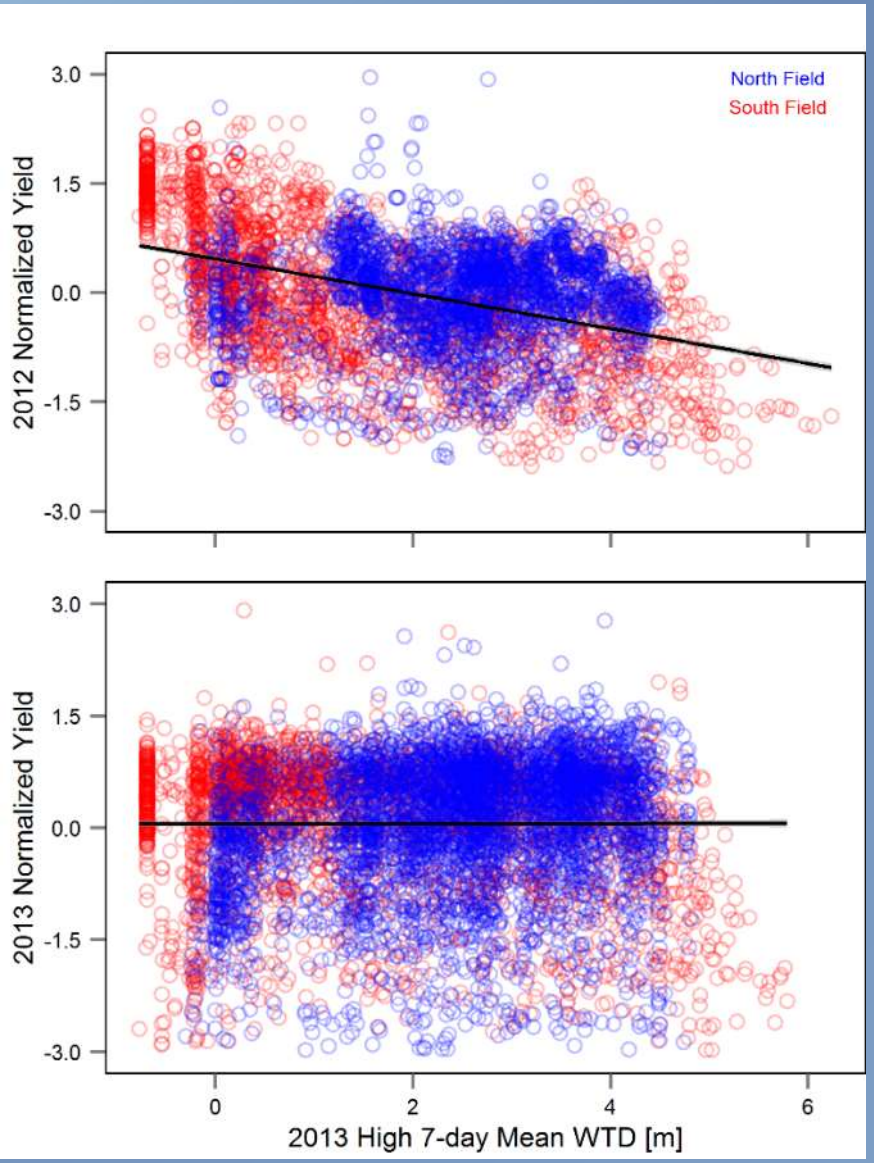
With help from:

Kyle Ankenbauer, Galen Bergquist, Eric Booth, Doug Brugger, Dom Ciruzzi, Erin Crabb, Hannah Friedrich, Sean Gillon, Erin Gross, Jeff Hatzel, Allison Lobue, Missy Motew, Mallika Nocco, Taylor Pomije, Jason Schatz, Kim Scherber, Evren Soylu, Carolyn Voter, Jiangxiao Qiu.

GLBRC: Chris Kucharik, James Tesmer & Gregg Sanford

Mack Naber, Francisco Arriaga

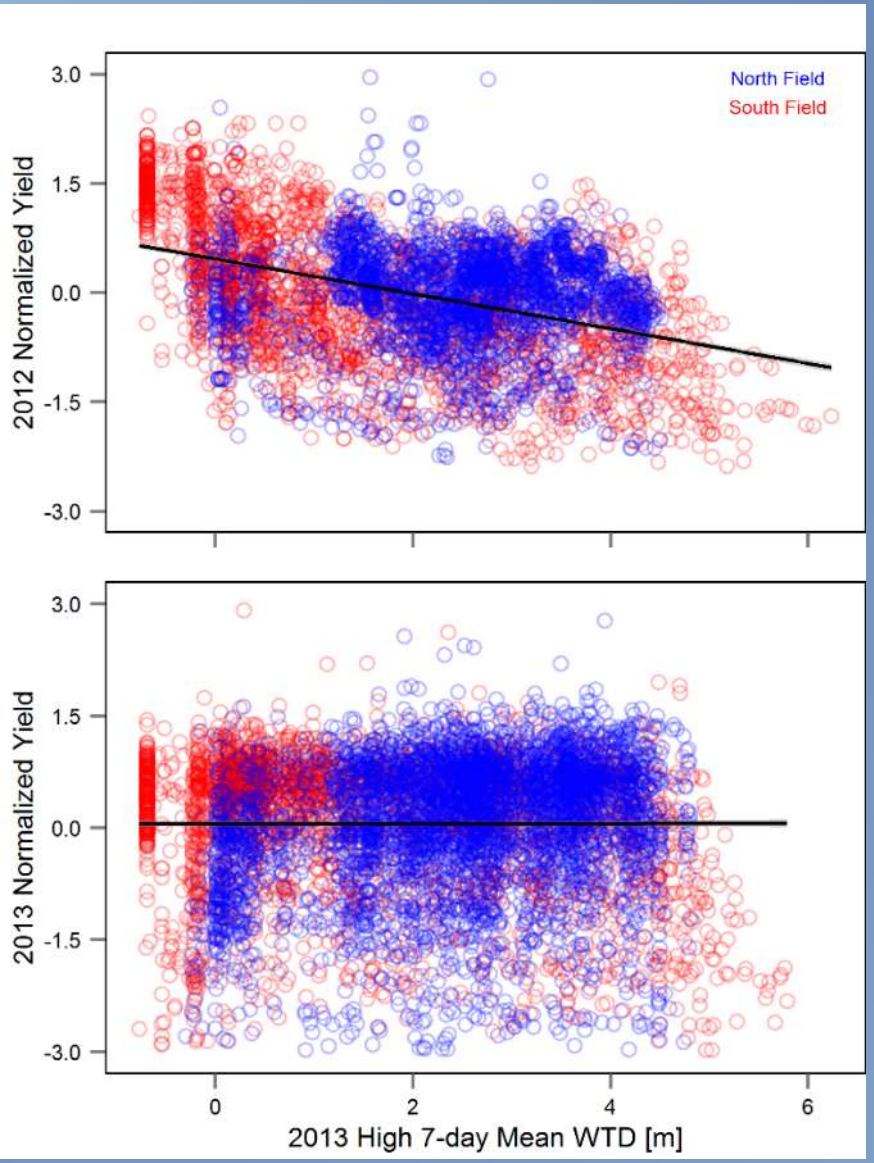
Yield-Groundwater Relationship



2012: Negative correlation between yield and WTD

→ Shallow water table leads to groundwater yield subsidy during extreme drought

Yield-Groundwater Relationship



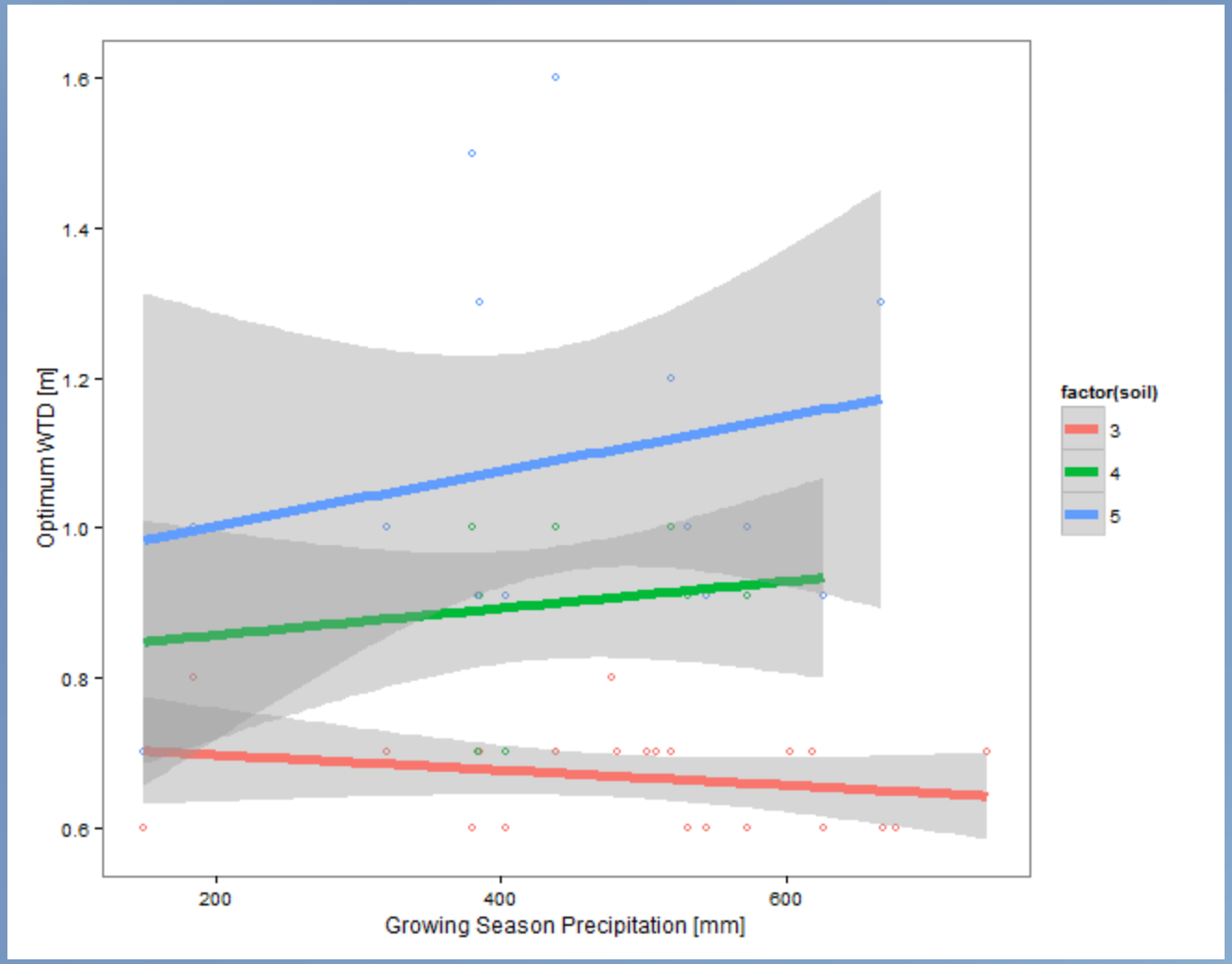
2012: Negative correlation between yield and WTD

→ Shallow water table leads to groundwater yield subsidy during extreme drought

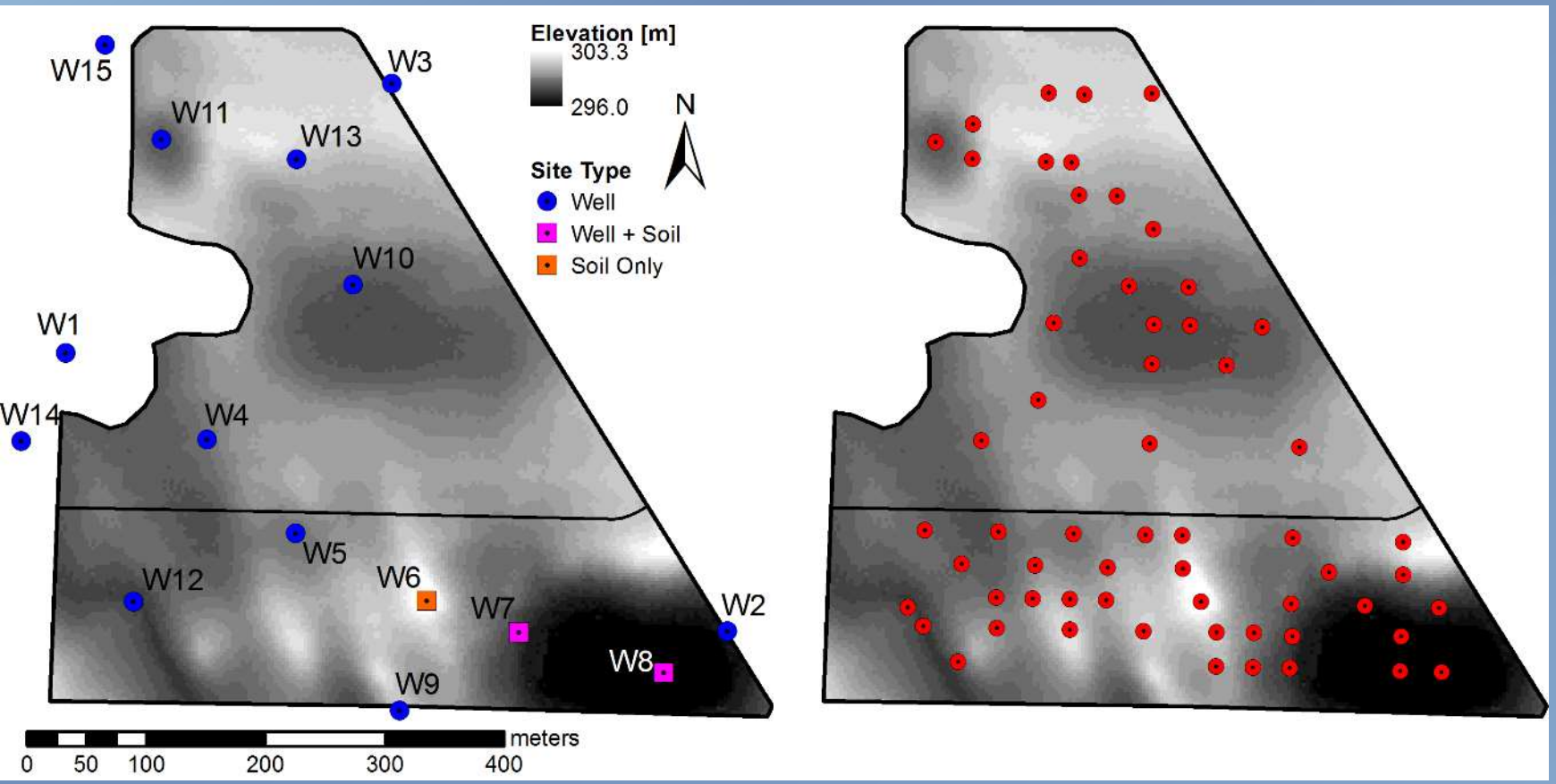
2013: No relationship between yield and WTD

→ Shallow water table neither beneficial nor harmful

→ Other factors and/or mixed impact?

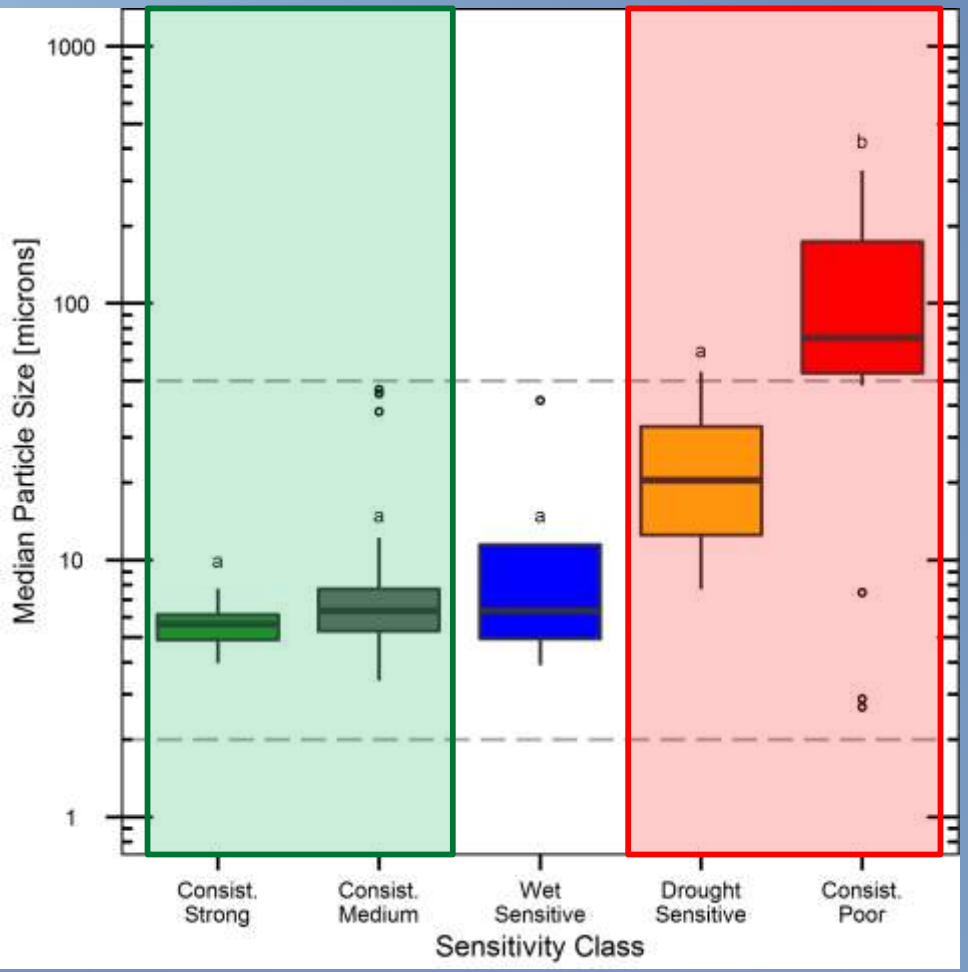

1.6
1.4
1.2
1.0
0.8
0.6
Optimum WTD [m]
200
400
600
Growing Season Precipitation [mm]
factor(soil)
3
4
5

Soil Texture Data



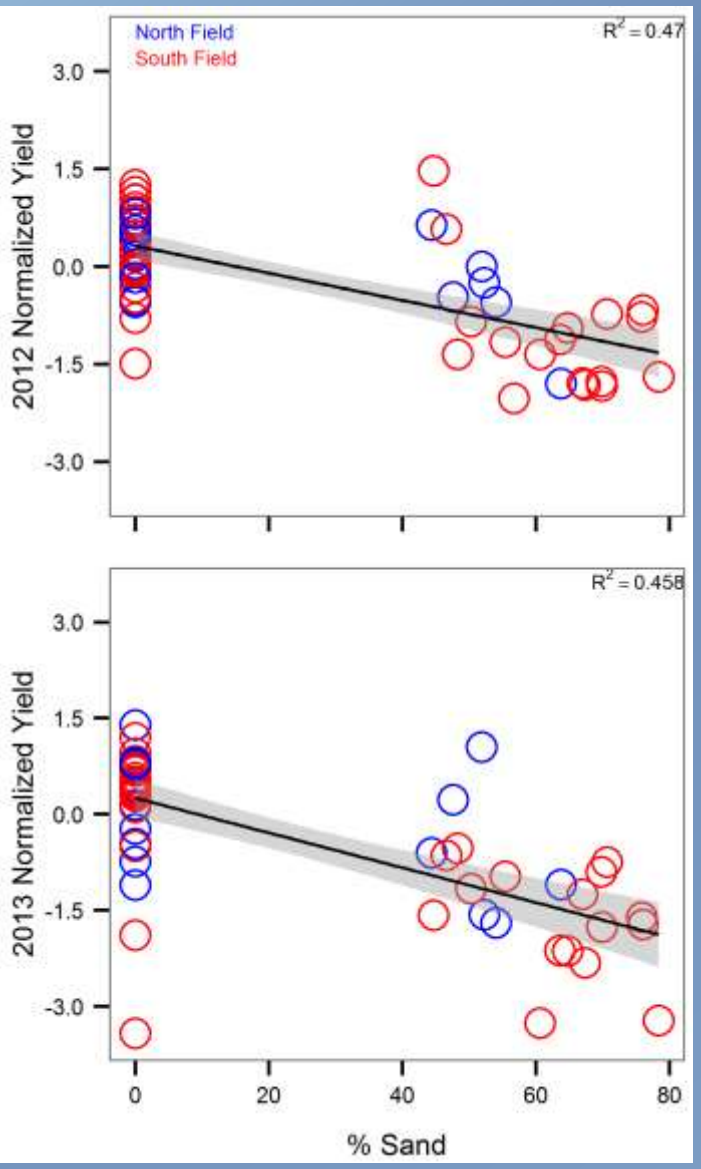
- Samples collected at each well/soil site, plus 51 other randomly selected sites
- Analyzed for porosity, bulk density, organic content, and particle size distribution

Field-Scale Sensitivity: Soil texture as a driver



- Except Consistently Poor, difference between classes not statistically significant
- Fine grained soils → Resilient to wet & dry growing season
- Sandier soils → Generally low yielding, especially in dry years

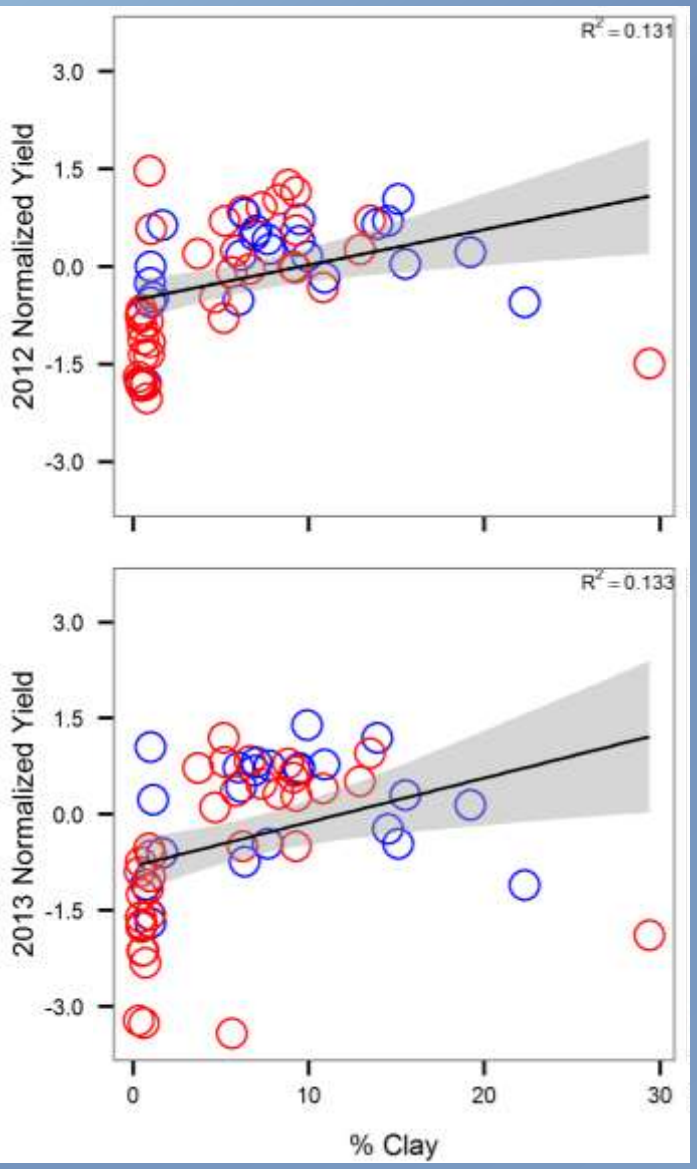
Yield-Soil Relationship



Negative correlation between sand content & yield

→ Coarse soil bad for yield

Yield-Soil Relationship



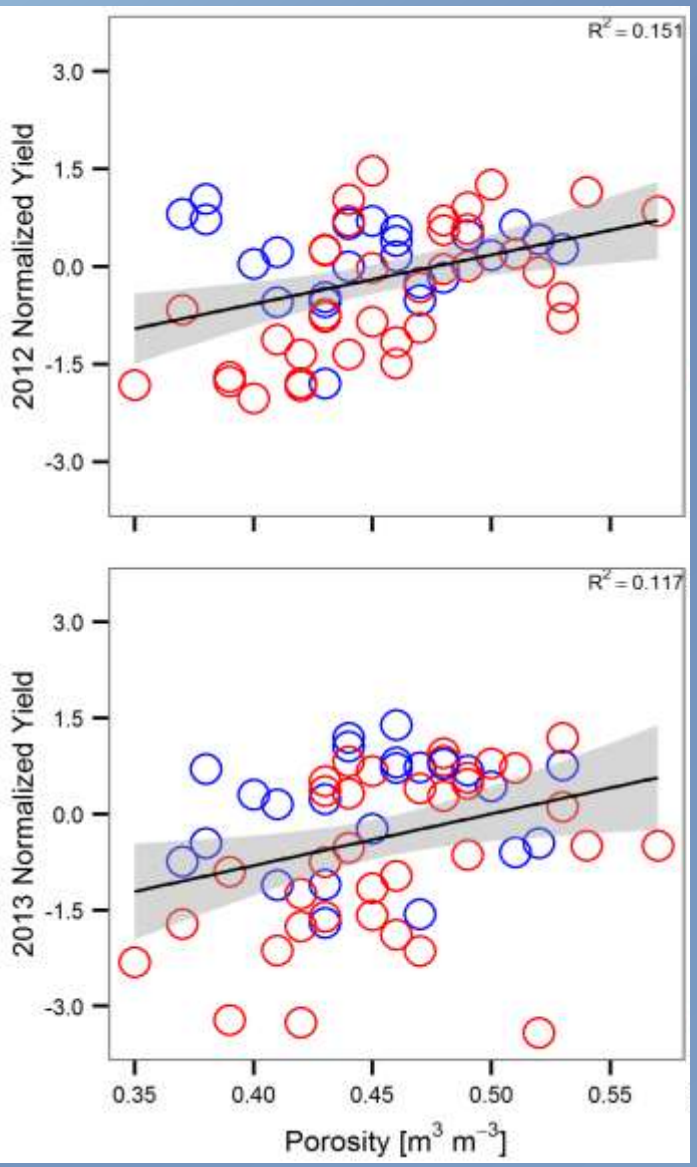
Negative correlation between sand content & yield

→ Coarse soil bad for yield

Positive correlation between clay content & yield

→ Fine soil good for yield

Yield-Soil Relationship



Negative correlation between sand content & yield

→ Coarse soil bad for yield

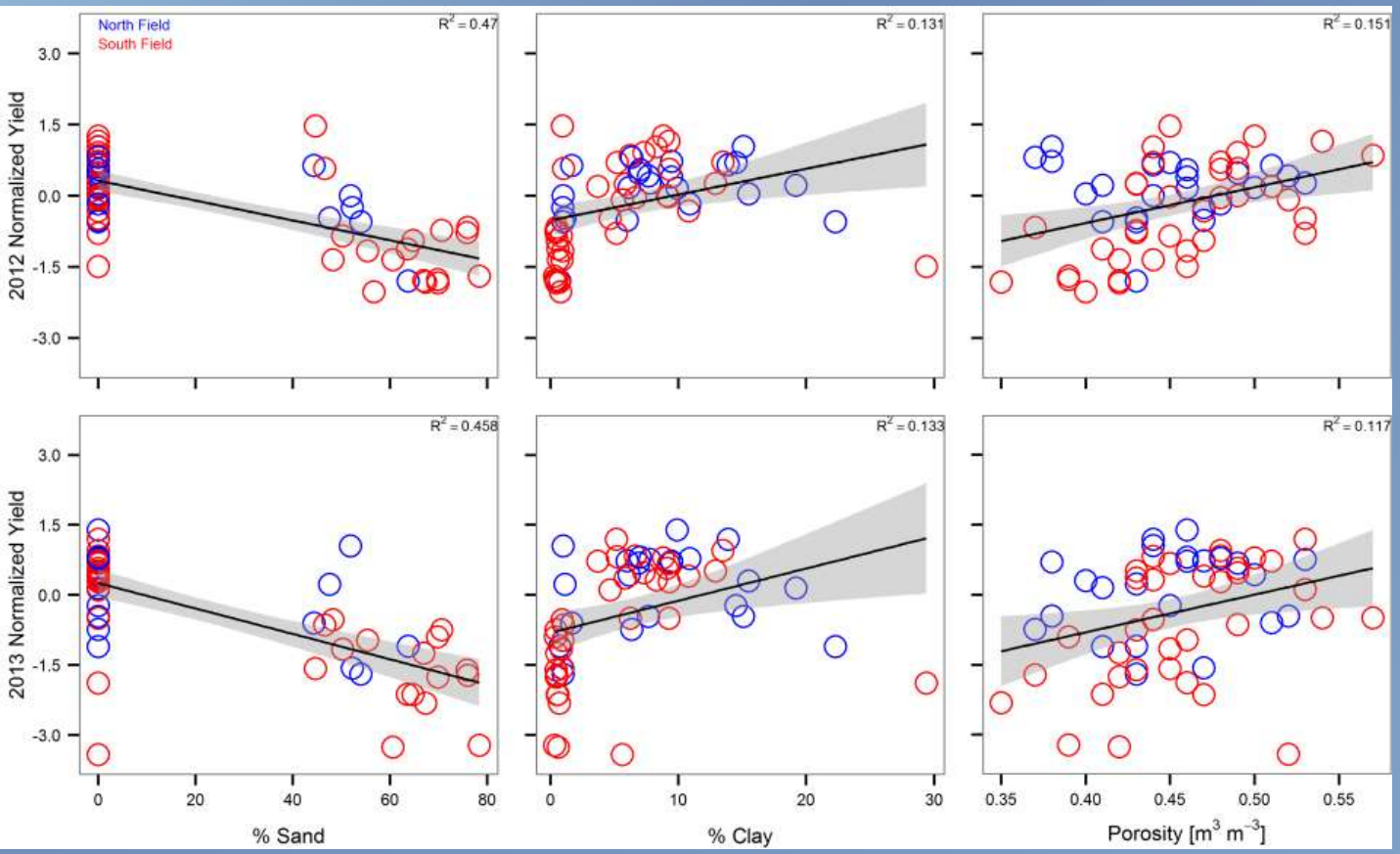
Positive correlation between clay content & yield

→ Fine soil good for yield

Positive correlation between porosity & yield

→ Higher water holding capacity good for yield

Yield-Soil Relationship



Consistent relationship between each variable and yield both years

→ Yield-soil interactions not dependent on growing season weather conditions

Yield-Soil Relationship