

Parish et al. Supplemental Material

<u>crop - block</u>	<u>depths (cm)</u>	<u>% sand</u>	<u>% silt</u>	<u>% clay</u>
<u>maize - 400</u>	10	7	67	26
	25	5	66	28
	50	3	65	32
	100	10	56	33
<u>switchgrass - 400</u>	10	8	64	28
	25	6	66	28
	50	3	66	32
	100	15	52	33
<u>miscanthus - 400</u>	10	11	69	21
	25	11	66	23
	50	8	66	26
	100	8	64	28
<u>hybrid poplar - 400</u>	10	14	61	25
	25	17	56	27
	50	12	56	32
	100	24	46	30
<u>maize - 200</u>	10	6	71	23
	25	5	71	23
	50	3	71	26
	100	3	66	31
<u>switchgrass - 200</u>	10	11	66	23
	25	8	69	23
	50	8	64	28
	100	11	61	28

Table S1 - Soil texture at 10, 25, 50, and 100 cm depths for each analysis and duplicate sub-plot.

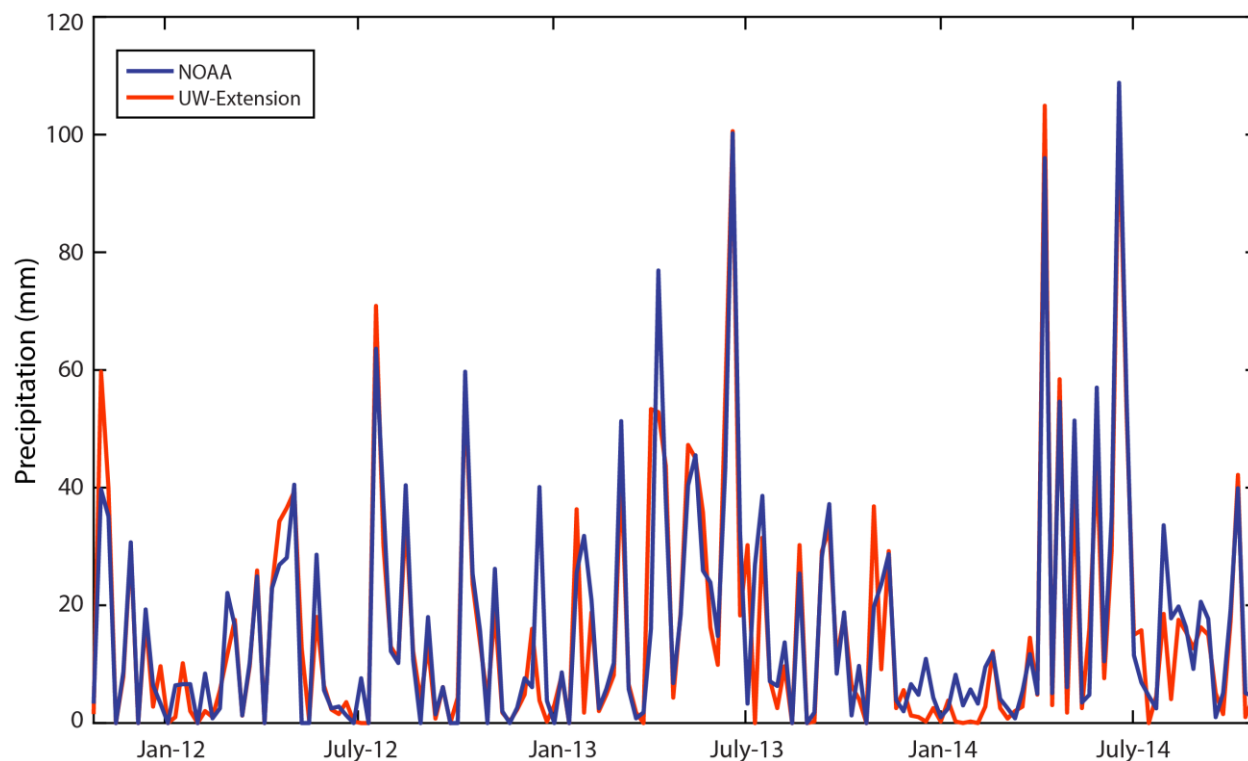


Figure S1- NOAA and UW-Extension precipitation aggregated weekly over the three year study period. NOAA data were obtained through Global Historical Climatology Network. Discrepancies existed primarily during snow fall and/or snowmelt events ($R^2 = 0.84$) during the late dormant season.

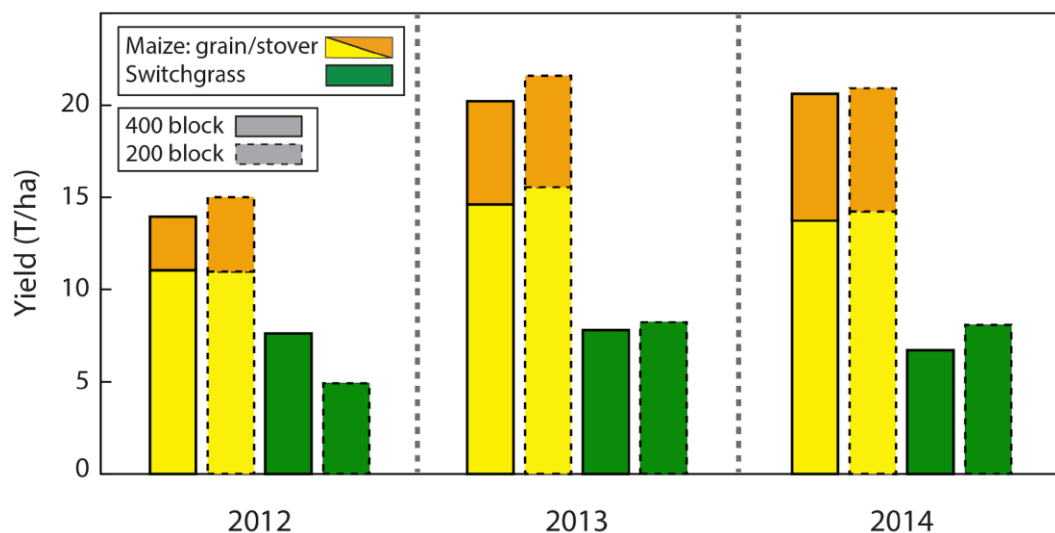


Figure S2 - Duplicate yield measurements of maize grain (bottom segment) and stover (top segment) and switchgrass. Micro-plots within the 400 block (solid line) were used in the analyses while plots within the 200 block (dotted line) were used as duplicates.

	Duplicate yield standard error (T/ha)		
	maize grain	maize stover	switchgrass
2012	0.02	0.43	1.04
2013	0.36	0.17	0.16
2014	0.19	0.07	0.52

Table S2 – Standard error (T/ha) of averaged 200 and 400 block yields for maize and switchgrass

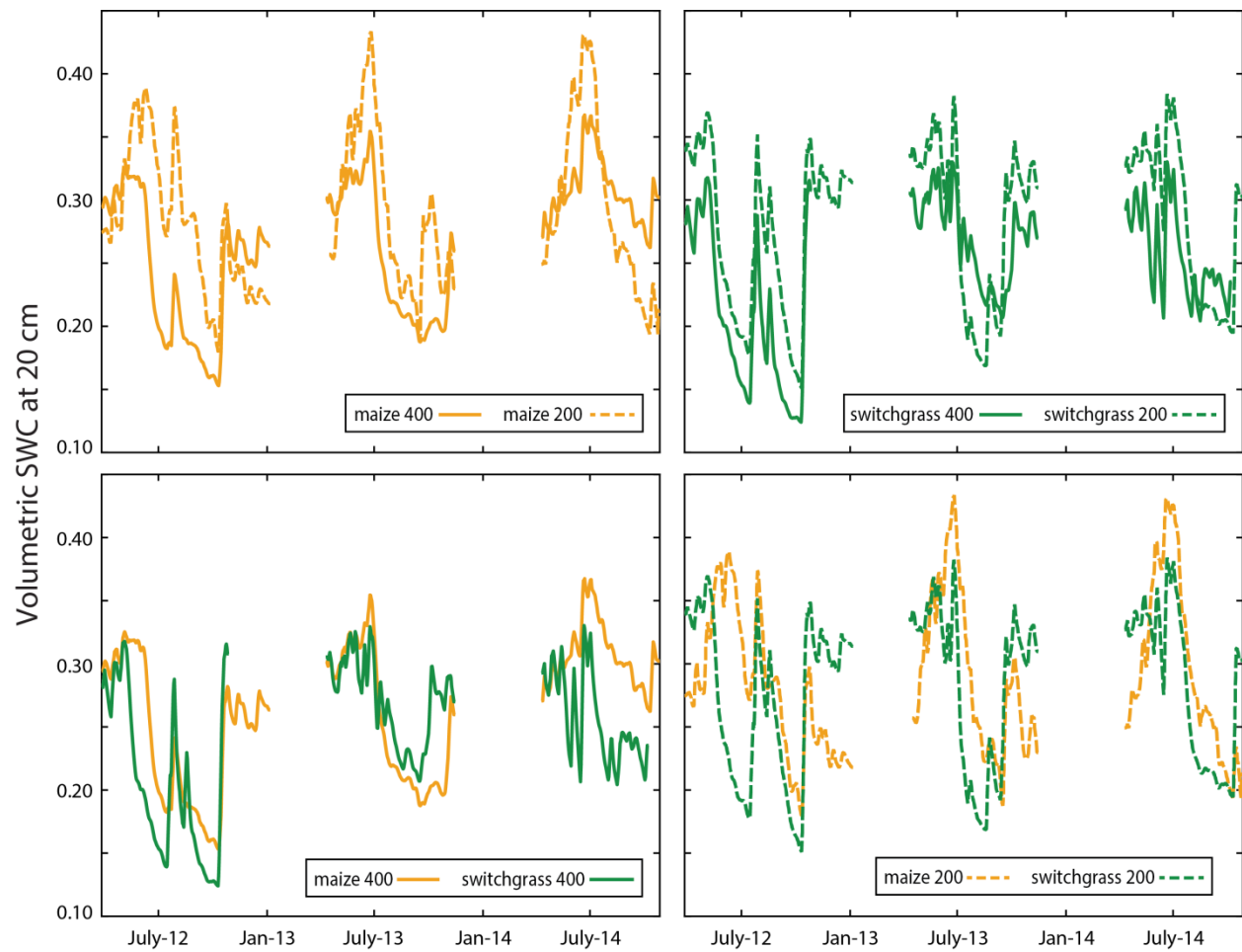


Figure S3 - Duplicate SWC measurements under maize (top-left) and switchgrass (top-right) within the main 400 block (bottom-left; solid) and duplicate 200 block (bottom-right; dotted) micro-plots at 20 cm.

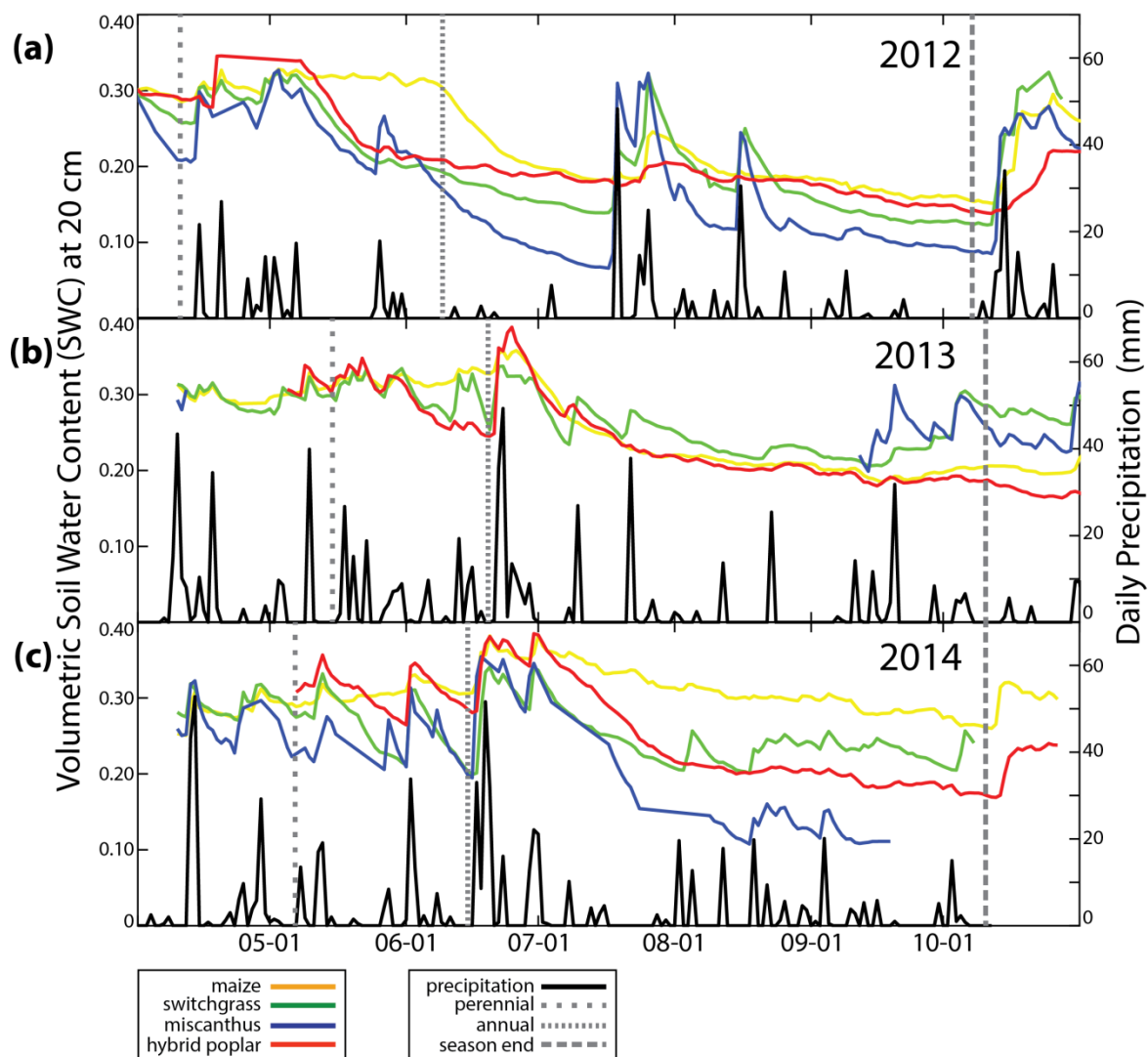


Figure S4 – Precipitation and soil moisture along with determined growing and dormant season and cutoffs used for the perennial (switchgrass, miscanthus, and hybrid poplar) and annual (maize) systems in **a)** 2012, **b)** 2013, and **c)** 2014.

	Lysimeter depth (cm)	
	north	south
maize-400	105	100
switchgrass-400	195	
miscanthus-400	185	
hybrid poplar-400	80	90
maize-200	90	
switchgrass-200	90	110

Table S3 – Lysimeter installation depths for each plot in the main 400 block and replicate 200 block. Intra-plot duplicates were installed to the north and south of the lysimeter. Plots with only one lysimeter are shown in the north column.

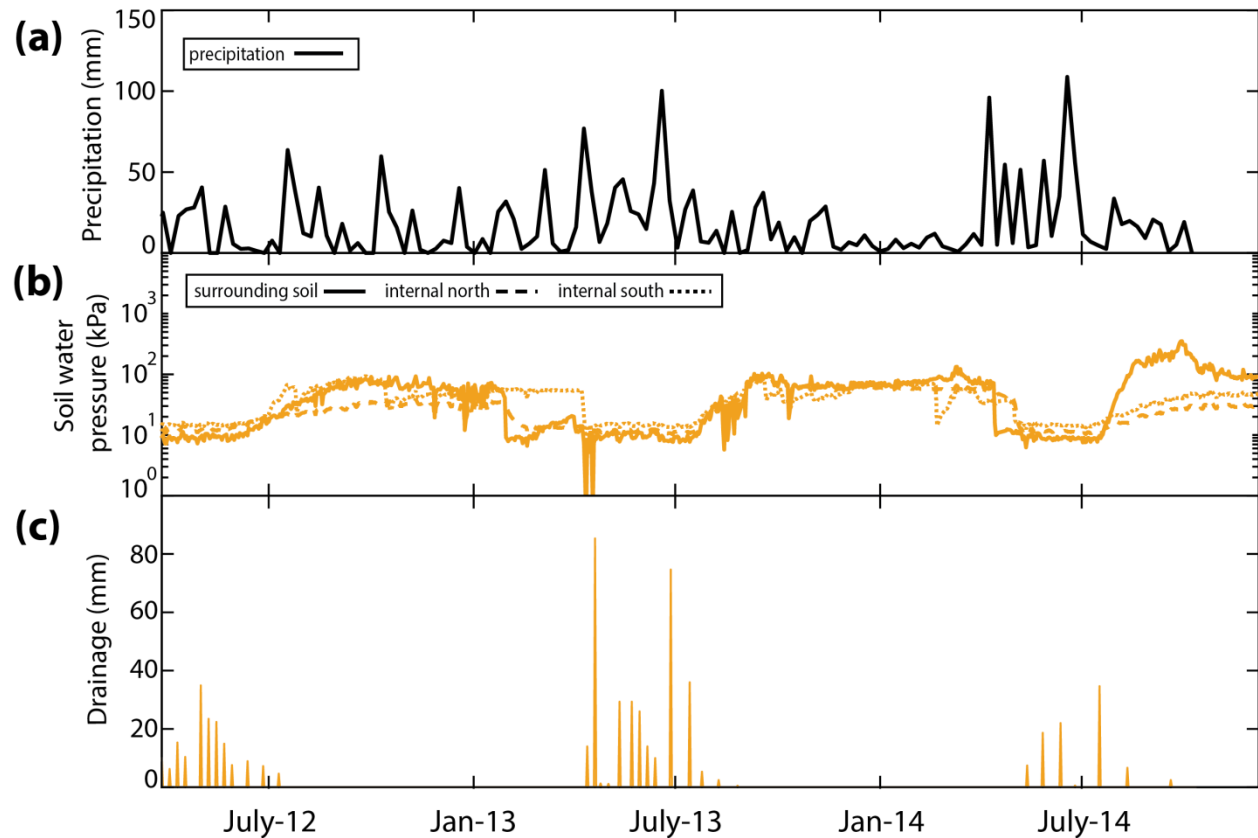


Figure S5 – **a)** Precipitation (mm), **b)** soil water pressure (kPa) in the soil surrounding the lysimeters (solid line), directly above the north lysimeter (dashed line), and directly above the south lysimeter (dotted line), and **c)** drainage (mm) in the 400 block maize plot.

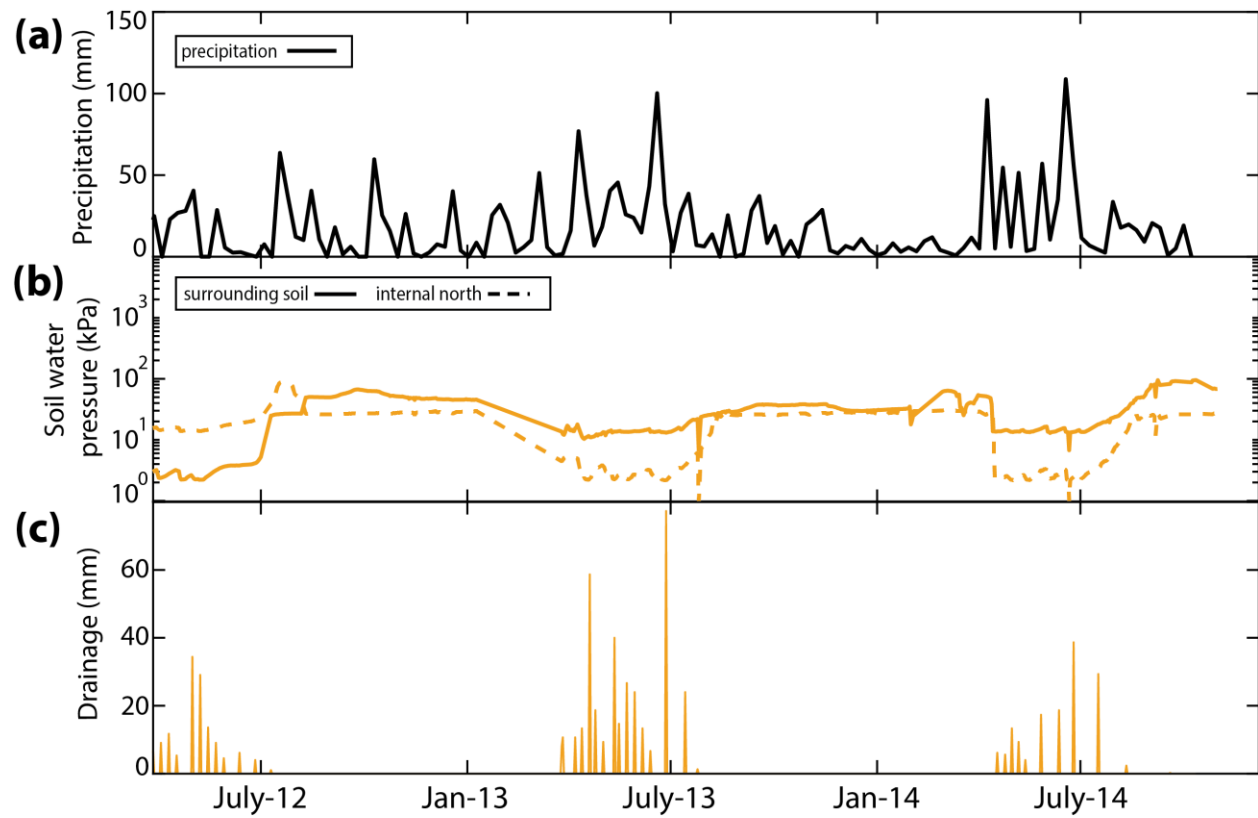


Figure S6 – a) Precipitation (mm), **b)** soil water pressure (kPa) in the soil surrounding the lysimeters (solid line) and directly above the north lysimeter (dashed line), and **c)** drainage (mm) in the 200 block maize plot.

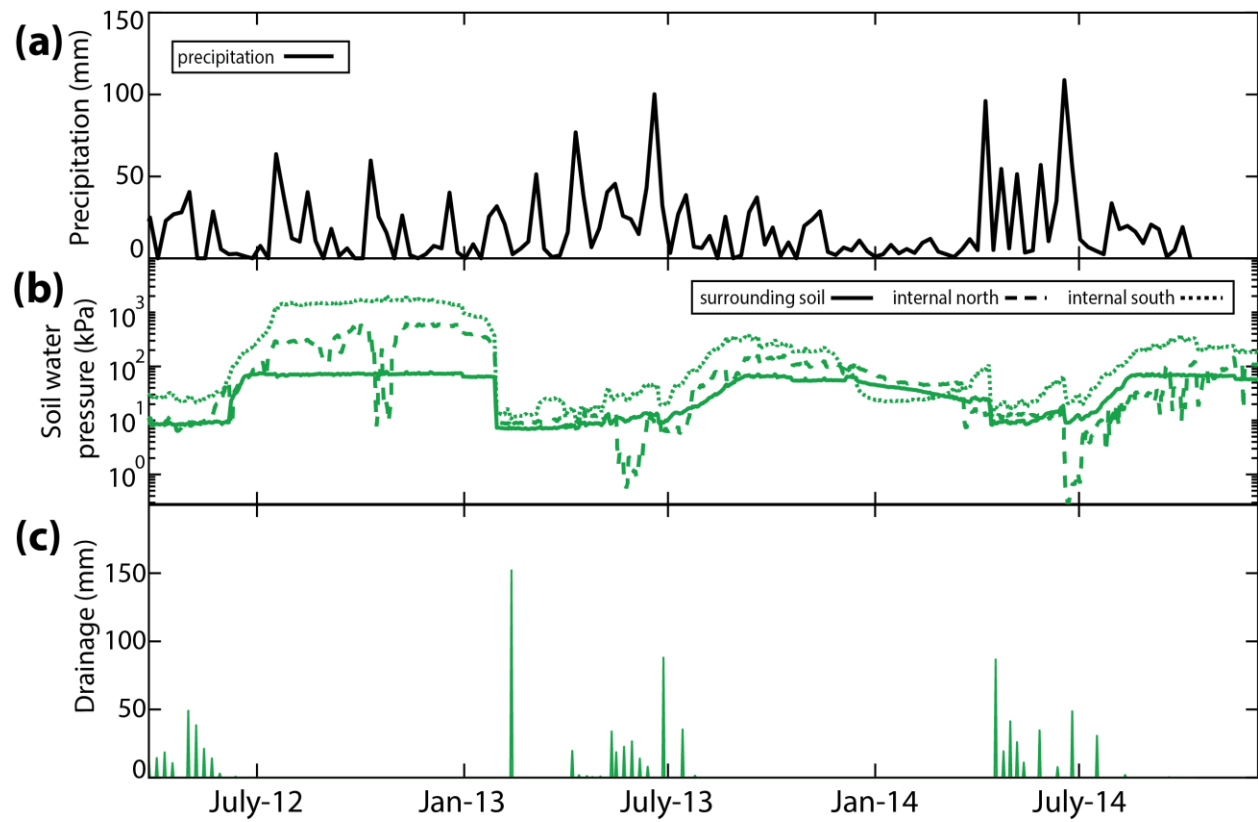


Figure S7 – a) Precipitation (mm), **b)** soil water pressure (kPa) in the soil surrounding the lysimeters (solid line), directly above the north lysimeter (dashed line), and directly about the south lysimeter (dotted line), and **c)** drainage (mm) in the 200 block switchgrass plot.

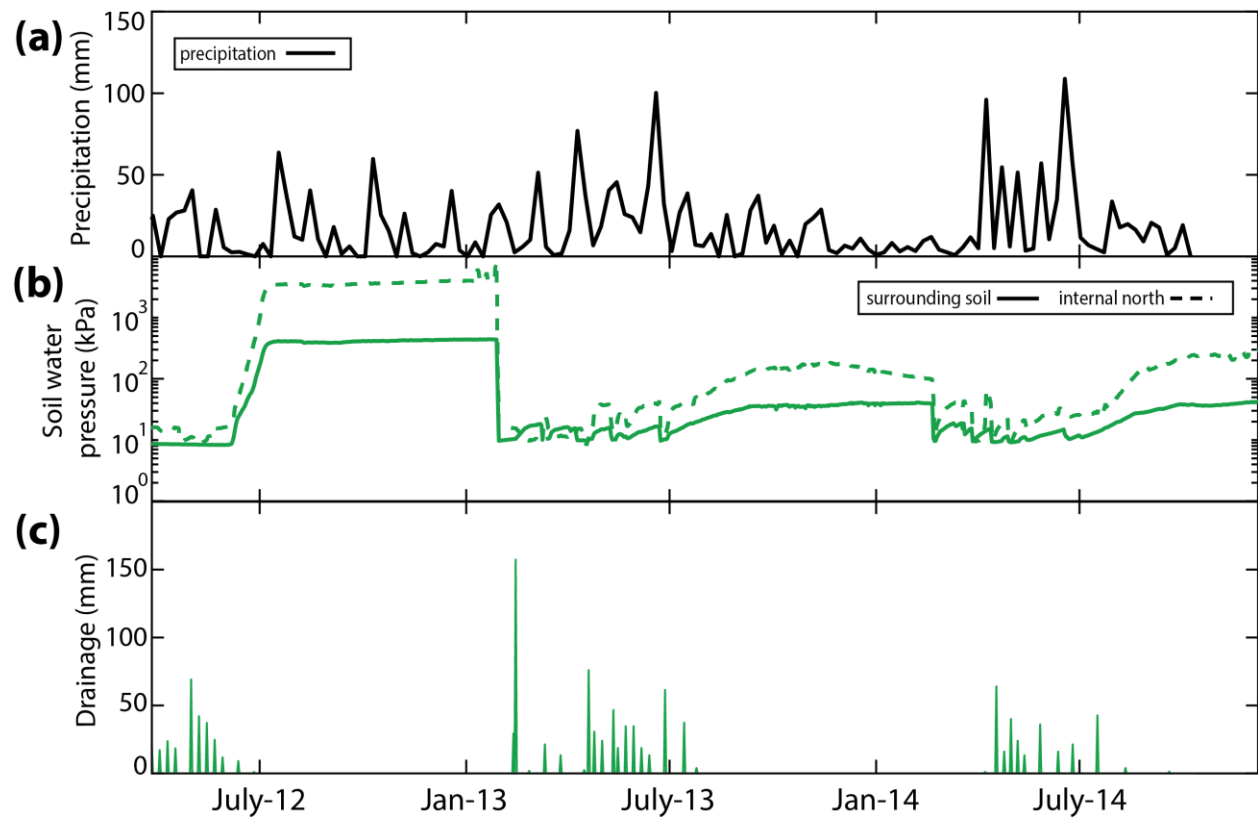


Figure S8 – a) Precipitation (mm), **b)** soil water pressure (kPa) in the soil surrounding the lysimeters (solid line) and directly above the north lysimeter (dashed line), and **c)** drainage (mm) in the 400 block switchgrass plot.

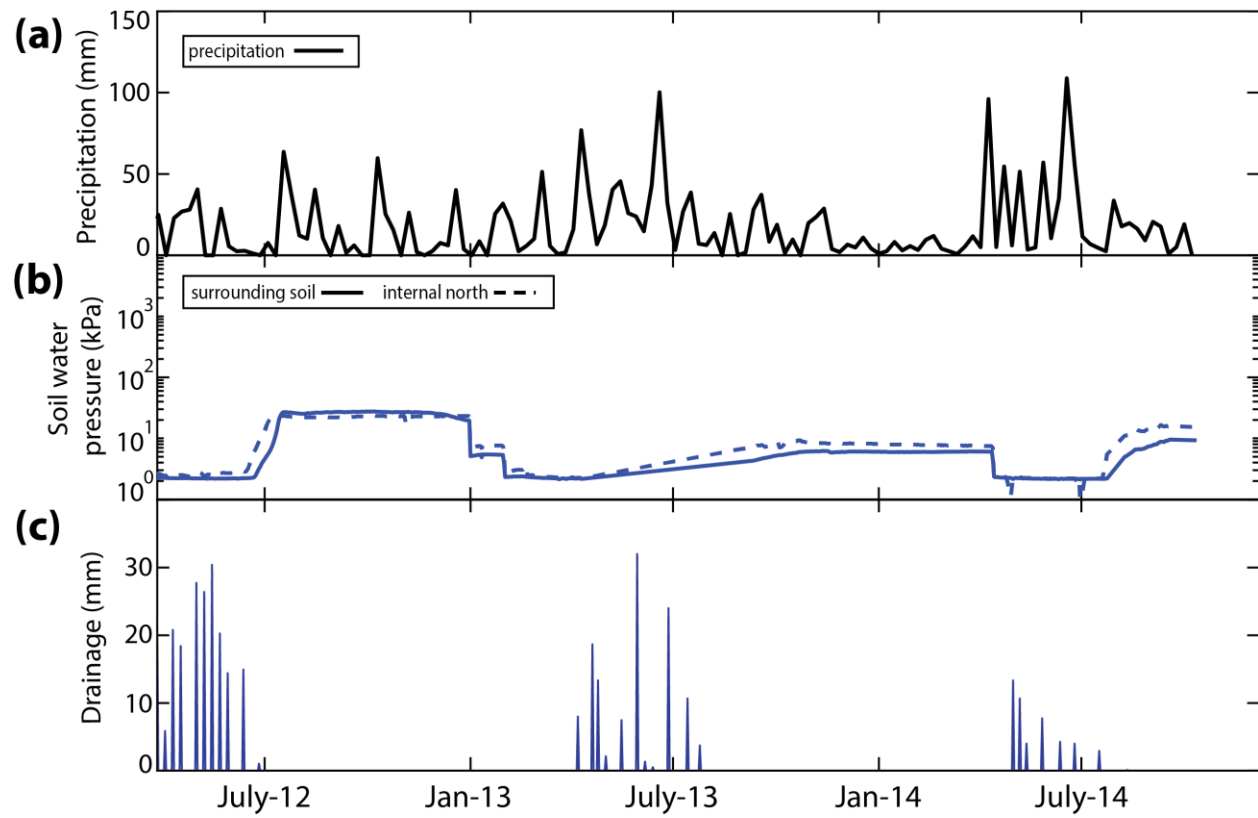


Figure S9 – a) Precipitation (mm), **b)** soil water pressure (kPa) in the soil surrounding the lysimeters (solid line) and directly above the north lysimeter (dashed line), and **c)** drainage (mm) in the 400 block miscanthus plot.

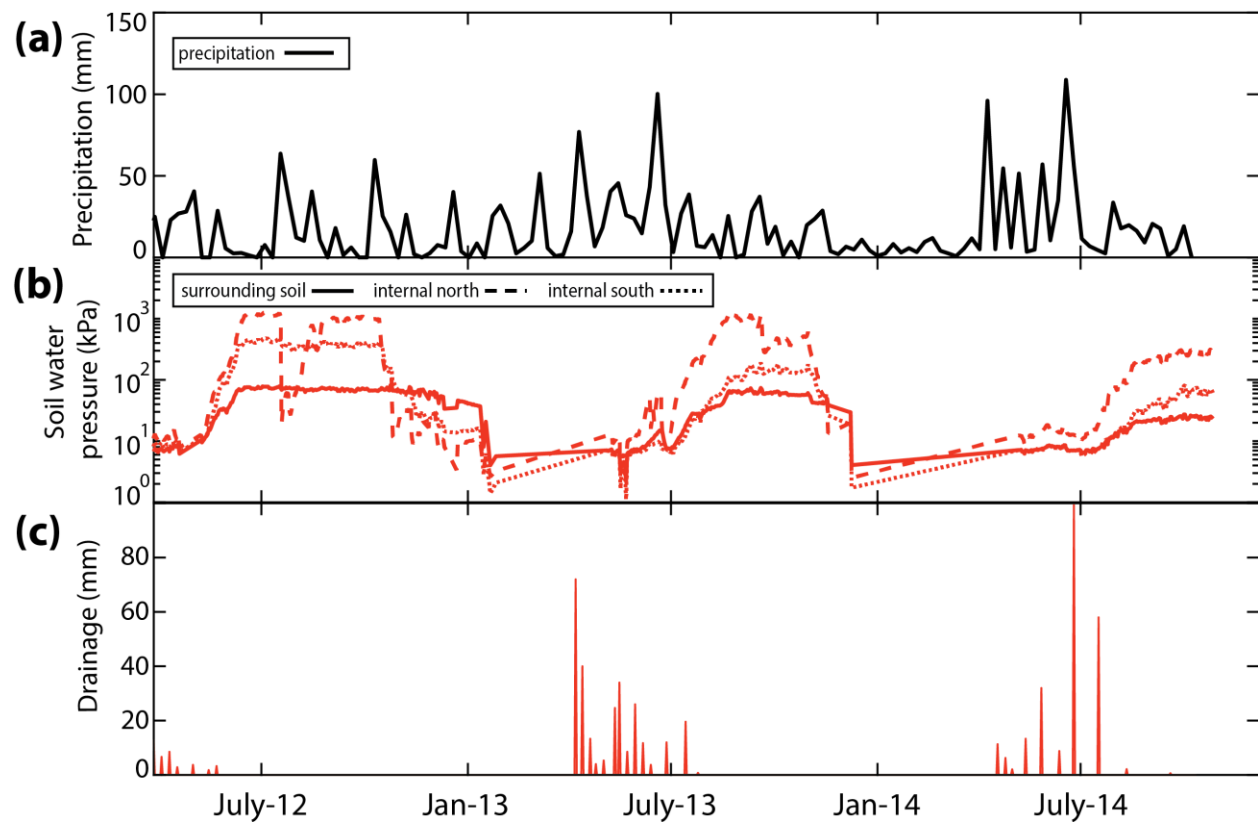


Figure S10 – a) Precipitation (mm), **b)** soil water pressure (kPa) in the soil surrounding the lysimeters (solid line), directly above the north lysimeter (dashed line), and directly about the south lysimeter (dotted line), and **c)** drainage (mm) in the 400 block hybrid poplar plot.

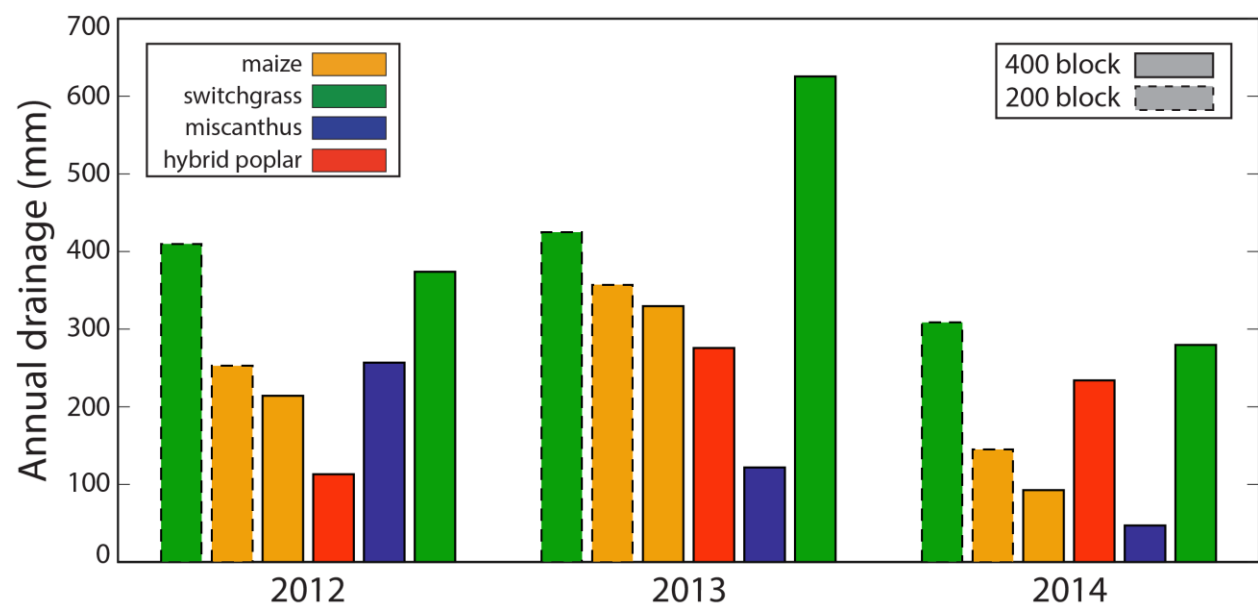


Figure S11 – Annual drainage in the four main plots and two duplicate plot arranged by slope position (see Figure 1) to test for the effect of the 3% slope to the east. Bars are arranged such that left to right is going downslope.

		Duplicate seasonal drainage standard error (mm)	
		maize	switchgrass
2012	dormant	23.8	39.5
	growing	9.68	26.8
2013	dormant	18.6	68.2
	growing	8.86	2.78
2014	dormant	12.1	9.99
	growing	6.38	0.18

Table S4 – Standard error (mm) of averaged 200 and 400 block seasonal drainage measurements for maize and switchgrass

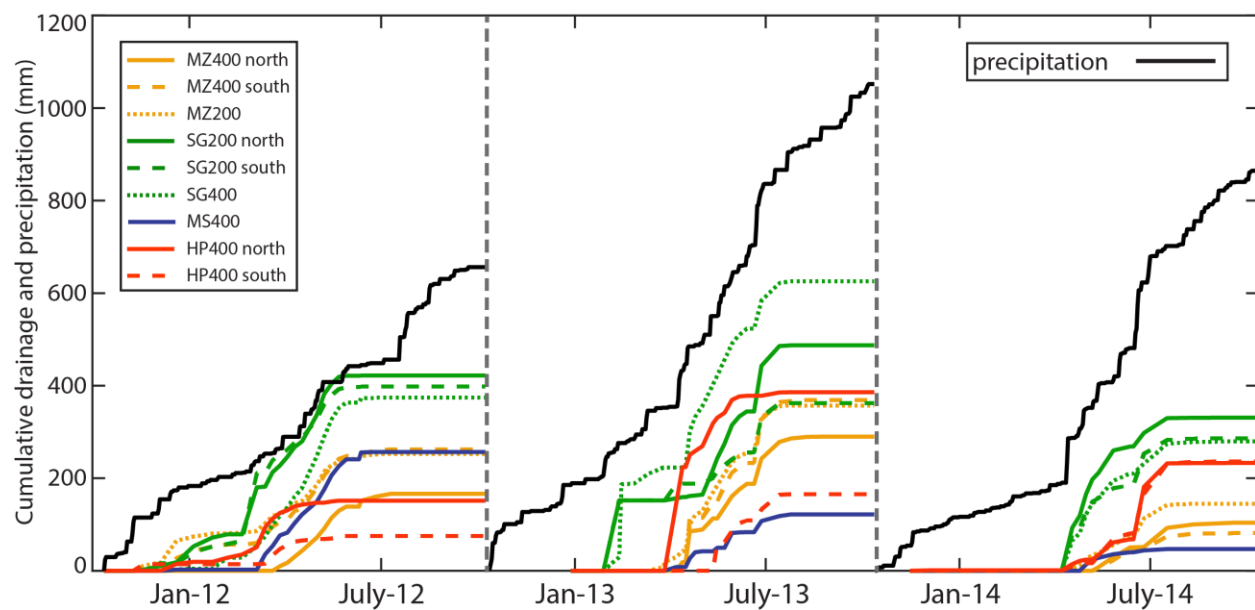


Figure S12 - Cumulative precipitation (mm) and drainage (mm) of replicate lysimeters in water years starting on October 12th, 2011.

	maize yield (T/ha)		cellulosic yield (T/ha)		
	grain	stover	switchgrass	miscanthus	hybrid poplar
2012	12.1	3.8	6.9	12.5	na
2013	16.6	6.4	8.8	20.6	36.7
2014	15.6	7.3	8.1	21.7	na
average	14.8	5.8	7.9	18.3	6.1

Table S5 – Annual yield (T/ha) for maize grain and stover, switchgrass, miscanthus, and hybrid poplar. Total 6-year yield and annualized average yield for hybrid poplar are shown.

a)

	annual drainage (mm)			
	maize	switchgrass	miscanthus	hybrid poplar
2012	233.5	391.8	256.8	113.1
2013	343.5	525.2	121.9	275.7
2014	118.8	294.1	47.1	234.6
average	231.9	403.7	141.9	207.6

b)

	dormant season precipitation to drainage (%)			
	maize	switchgrass	miscanthus	hybrid poplar
2012	38.8	74.7	35.6	34.9
2013	27.6	59.0	9.0	35.1
2014	4.8	45.2	6.8	5.6
average	24.1	59.6	17.1	25.2

c)

	growing season precipitation to drainage (%)			
	maize	switchgrass	miscanthus	hybrid poplar
2012	32.9	47.8	48.1	3.2
2013	37.0	39.9	14.4	16.4
2014	19.8	45.2	4.4	41.8
average	29.9	38.0	20.2	20.4

d)

	change from 2013 dormant to growing season (%)			
	maize	switchgrass	miscanthus	hybrid poplar
2013	29.4	-32.4	59.9	-53.2

Table S6 – a) Annual drainage (mm), **b)** dormant season and **c)** growing season portion of precipitation to drainage (%), and percent change in 2013 dormant to growing season portion of precipitation to drainage (%) under maize, switchgrass, miscanthus, and hybrid poplar.

a)

	<u>Q₀ day of water year</u>			
	<u>maize</u>	<u>switchgrass</u>	<u>miscanthus</u>	<u>hybrid poplar</u>
2012	53	53	69	37
2013	97	46	100	100
2014	167	149	167	154
average	106	83	112	97

b)

	<u>Q₂₅ day of water year</u>			
	<u>maize</u>	<u>switchgrass</u>	<u>miscanthus</u>	<u>hybrid poplar</u>
2012	118	153	167	145
2013	113	47	118	100
2014	186	158	167	193
average	139	119	151	146

c)

	<u>Q₅₀ day of water year</u>			
	<u>maize</u>	<u>switchgrass</u>	<u>miscanthus</u>	<u>hybrid poplar</u>
2012	188	181	202	160
2013	146	129	153	135
2014	209	173	173	222
average	181	161	176	172

Table S7 –a) Day of water year of drainage onset (Q₀), **b)** 25% of annual drainage (Q₂₅), and **c)** 50% of annual drainage (Q₅₀) under maize, switchgrass, miscanthus, and hybrid poplar

a)

	<u>evapotranspiration (mm)</u>			
	<u>maize</u>	<u>switchgrass</u>	<u>miscanthus</u>	<u>hybrid poplar</u>
2012	352.3	355.3	342.5	495.6
2013	405.5	372.7	537.1	532.8
2014	482.6	514.6	578.2	396.4
average	413.5	414.2	486.0	474.9

b)

	<u>water use efficiency (T/ha/mm)</u>				
	<u>maize</u>		<u>cellulosic</u>		
	<u>grain</u>	<u>stover</u>	<u>switchgrass</u>	<u>miscanthus</u>	<u>hybrid poplar</u>
2012	34.5	10.9	20.5	36.7	12.3
2013	41.1	15.9	23.6	38.3	11.4
2014	32.5	15.2	15.9	37.5	15.4
average	36.0	12.3	20.0	37.6	13.0

Table S8 - a) Growing season evapotranspiration (mm) and **b)** water use efficiency (mm/T/ha) of maize grain and stover, switchgrass, miscanthus and hybrid poplar. Hybrid poplar was grown in a 6-year rotation and harvested in 2013 with the 6-year average shown.

	<u>Growing season ET/PET</u>				
	<u>PET (mm)</u>	<u>maize</u>	<u>switchgrass</u>	<u>miscanthus</u>	<u>hybrid poplar</u>
2012	1412	0.25	0.25	0.24	0.35
2013	1022	0.40	0.36	0.52	0.52
2014	1171	0.41	0.44	0.49	0.33
average	1202	0.35	0.35	0.42	0.40

Table S9- Growing season potential ET (PET) (mm) and ET/PET fraction for maize, switchgrass, miscanthus, and hybrid poplar.

Observed portion of GSAW to ET

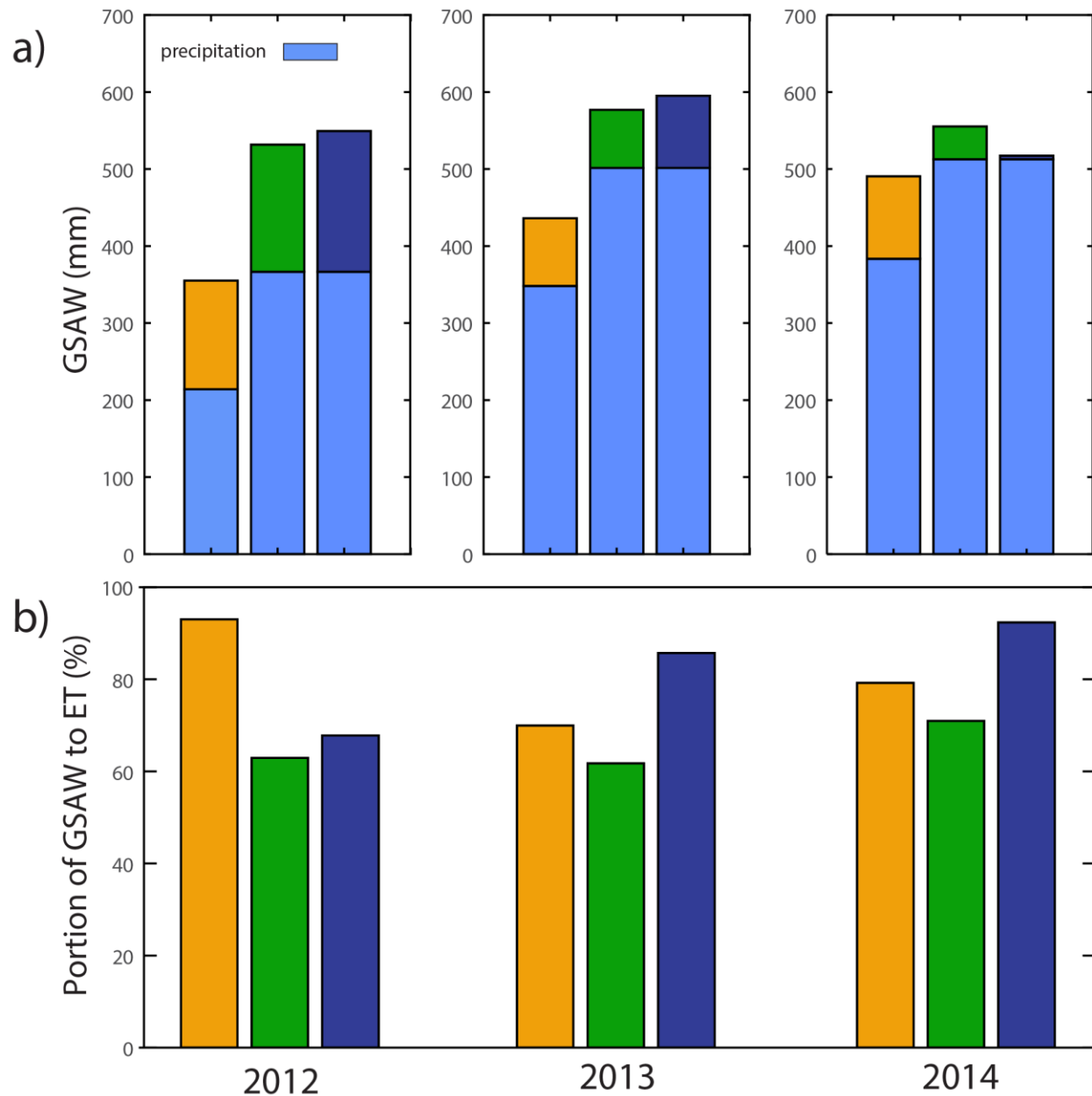


Figure S13: Demonstration of **a)** GSAW and **b)** portion of GSAW to ET (%) using annual (maize) and perennial (switchgrass and miscanthus) precipitation amounts and change in growing season soil storage from 2012-2014.

Salus model development

<u>crop</u>	<u>depth (cm)</u>	<u>% sand</u>	<u>% silt</u>	<u>% clay</u>	Bulk Density (g/cm ³)
<u>maize</u>	10	7	67	26	1.30
	25	5	66	28	1.38
	50	3	65	32	—
	100	10	56	33	—
<u>switchgrass</u>	10	8	64	28	1.30
	25	6	66	28	1.39
	50	3	66	32	—
	100	15	52	33	—
<u>miscanthus</u>	10	11	69	21	1.34
	25	11	66	23	1.41
	50	8	66	26	—
	100	8	64	28	—

Table S10: Soil texture and bulk density measurements at 10, 25, 50, and 100 cm depth intervals taken in 2008 and 2009. Bulk density was only measured to 50 cm.

<u>crop</u>	<u>depth (cm)</u>	<u>lower limit</u>	<u>upper limit</u>	<u>saturation</u>
<u>maize</u>	10	0.15	0.30	0.48
	25	0.15	0.30	0.45
	50	0.25	0.43	0.45
	100	0.25	0.43	0.45
<u>switchgrass</u>	10	0.13	0.29	0.48
	25	0.13	0.29	0.45
	50	0.28	0.45	0.46
	100	0.28	0.45	0.46
<u>miscanthus</u>	10	0.09	0.26	0.46
	25	0.09	0.26	0.44
	50	0.31	0.46	0.47
	100	0.31	0.46	0.47

Table S11: Estimated soil water limits, measured saturation, and estimated Ksat using the Ritchie algorithm for 10, 25, 50, and 100 cm depths intervals. Lower and upper limits were determined using soil drying curves near the wilting point and saturation, respectively.

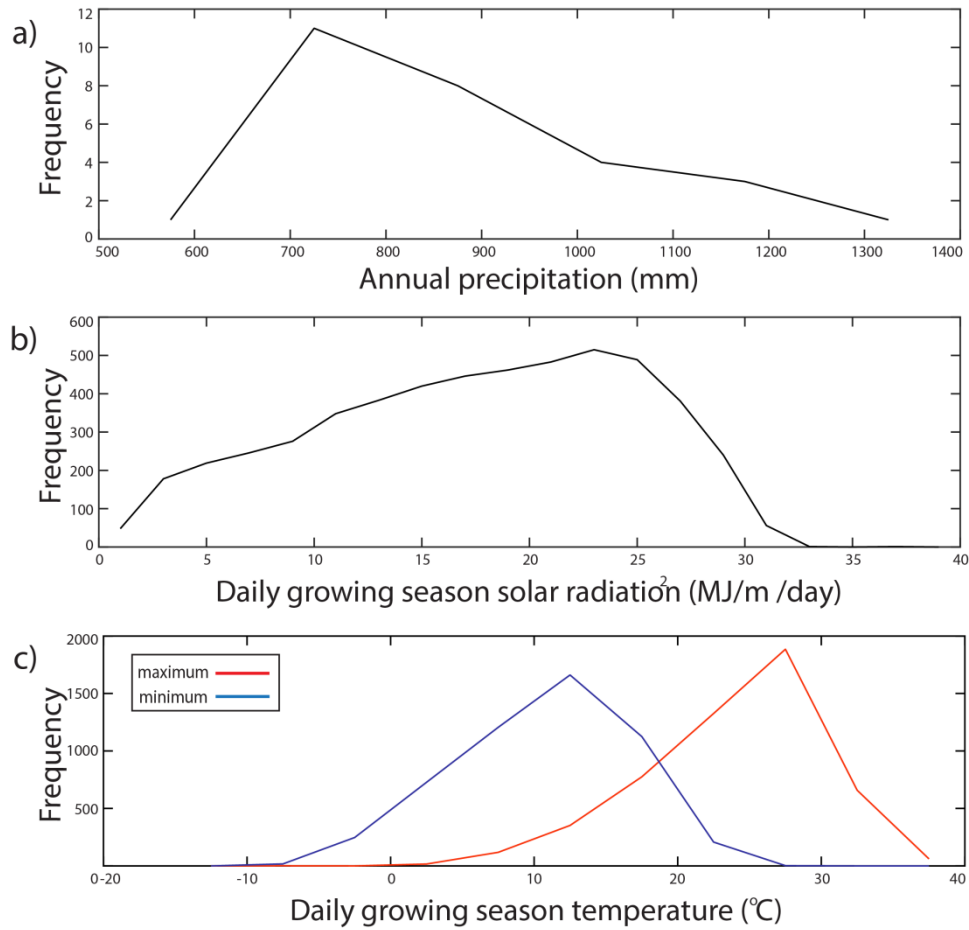


Figure S14: Summary of climate inputs to SALUS model: **a)** annual precipitation (mm), **b)** growing season solar radiation (SRAD) (MJ/m²/d), and **c)** growing season minimum and maximum temperature (degrees C) from 1985-2014.

crop	depth (cm)	initial		optimized	
		SHF	Ksat (cm/hr)	SHF	Ksat (cm/hr)
<u>maize</u>	10	0.80	0.58	0.80	4.77
	25	0.80	0.20	0.80	70.8
	50	0.80	0.12	0.80	38.5
	75	0.80	0.41	0.80	15.6
	100	0.20	0.41	0.05	72.5
	200	0.20	0.41	0.05	28.2
<u>switchgrass</u>	10	0.80	0.54	0.77	204
	25	0.80	0.20	0.77	9.12
	50	0.80	0.08	0.77	0.39
	75	0.80	0.50	0.77	13.3
	100	0.20	0.50	0.05	0.07
	200	0.20	0.50	0.05	0.06
<u>miscanthus</u>	10	0.80	0.66	0.90	2.29
	25	0.80	0.37	0.90	6.72
	50	0.80	0.29	0.90	9.23
	75	0.80	0.29	0.90	1.80
	100	0.20	0.29	0.05	1.17
	200	0.20	0.29	0.05	0.07

Table S12: Initial and Optimized Salus SHF and Ksat (cm/hr) inputs for depth intervals 10, 25, 50, 75, 100, and 200 cm.

	Annual yield (%)	Shallow soil moisture (%)	Deep soil moisture (%)	Cumulative drainage (%)
<u>maize</u>	14.8	7.74	11.7	228
<u>switchgrass</u>	28.0	5.22	5.19	-66.0
<u>miscanthus</u>	-10.9	4.60	5.95	166

Table S13: Validation results for annual yield (% difference), shallow and deep soil moisture (RMSE) and cumulative drainage (% difference) for 2014.

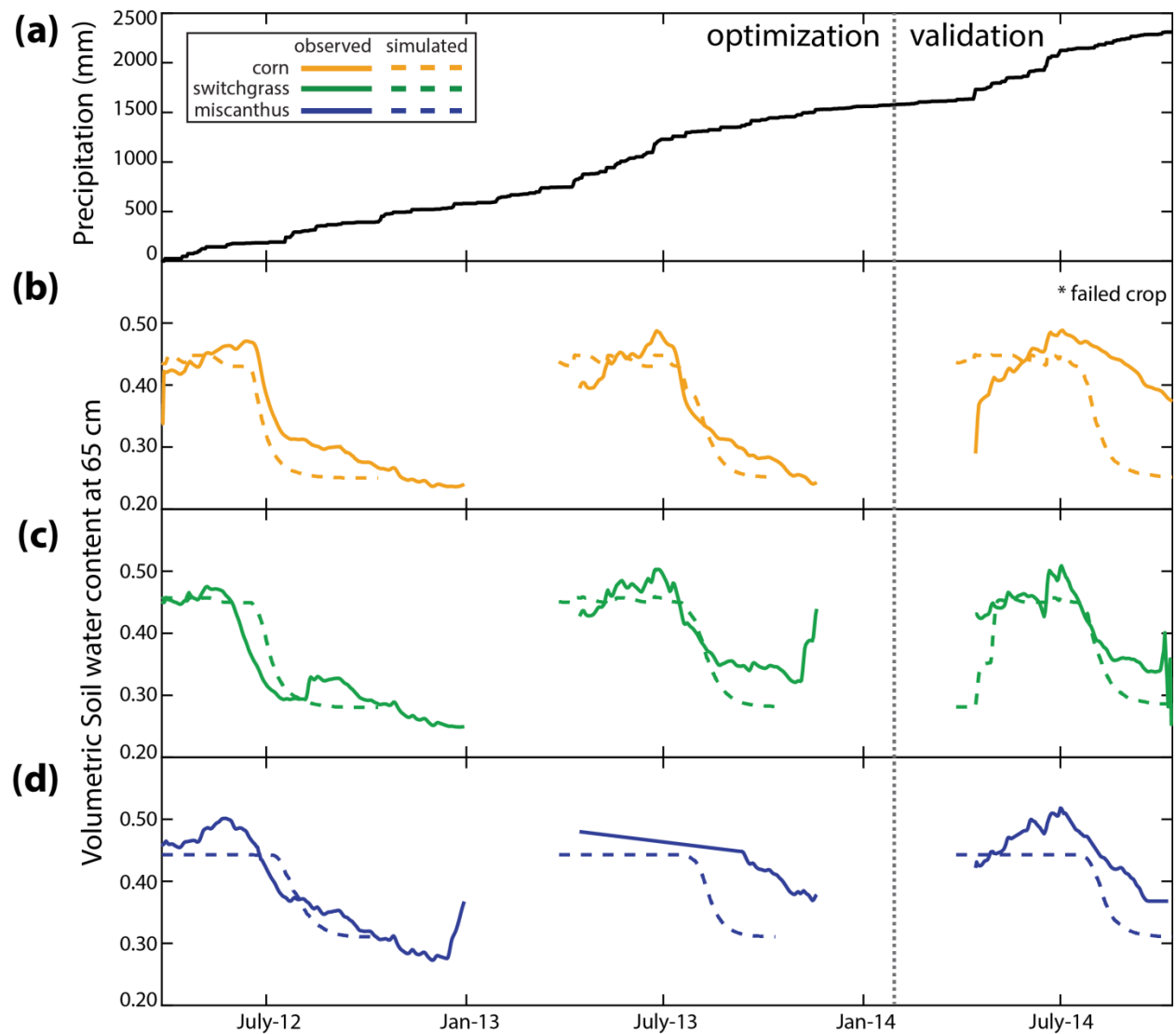


Figure S15: a) Cumulative daily precipitation (mm) and observed (solid) and SALUS simulated (dashed) volumetric SWC at 20 cm for the 2012 to 2014 growing seasons in **b)** maize, **c)** switchgrass, and **d)** miscanthus plots. 2012 and 2013 were used in optimization and 2014 was used as validation. Note that the maize crop used in the experiment failed in 2014. Data from a duplicate maize were used in simulation design and validation.

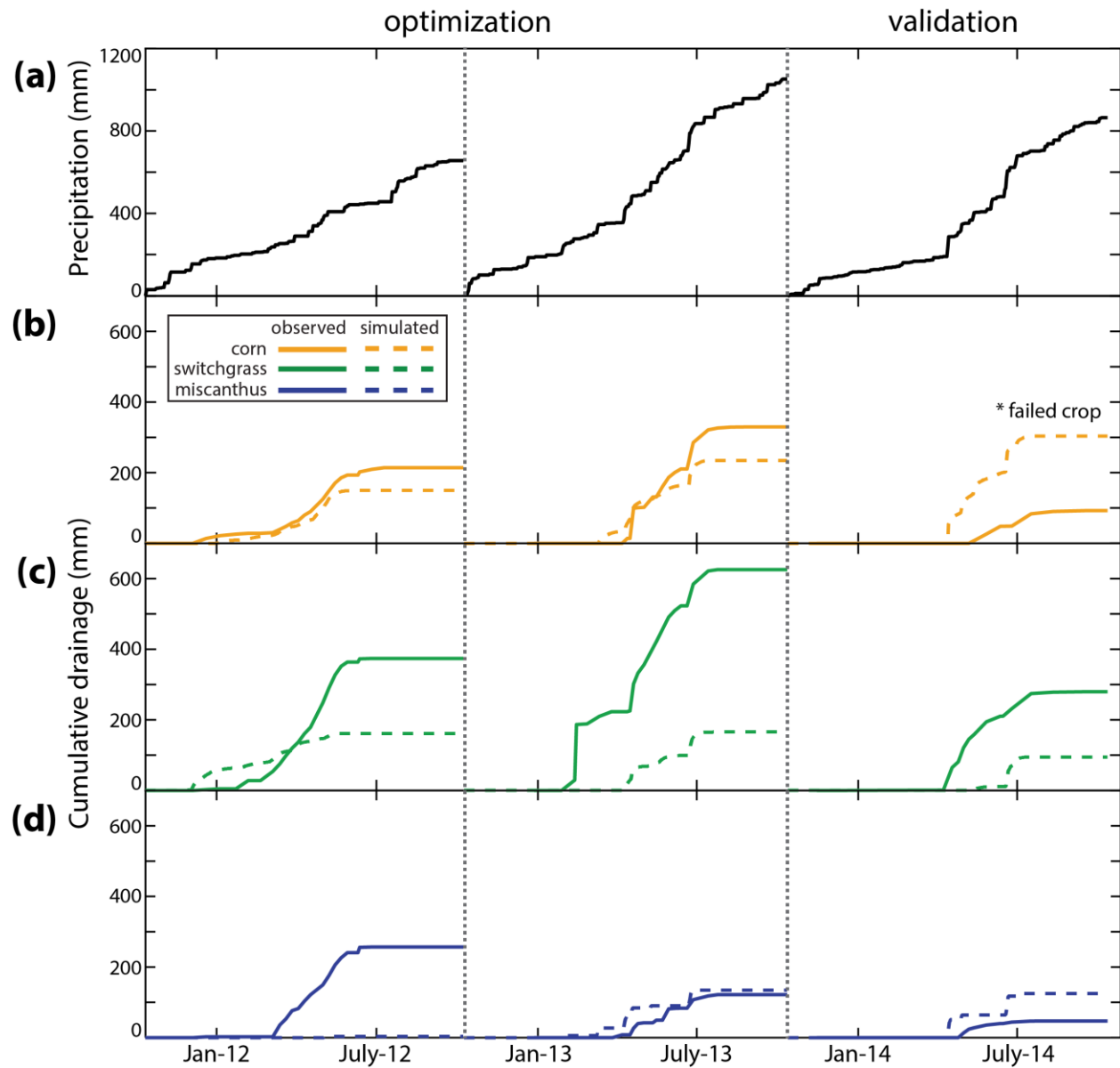


Figure S16: a) Cumulative daily precipitation (mm) and Observed (solid) and SALUS simulated (dashed) cumulative annual drainage in 2012-2014 in **b)** maize, **c)** switchgrass, and **d)** miscanthus plots. 2012 and 2013 were used in optimization and 2014 was used as validation.

		Runoff (mm)		
		maize	switchgrass	miscanthus
Observed	2012	5.77	0.79	3.56
	2013	15.7	2.13	5.76
Simulated	2012	0	0	3.56
	2013	0	0	0.26

Table S14: Observed and simulated runoff in 2012 and 2013 for maize, switchgrass, and miscanthus

	<u>Range in yield (T/ha)</u>		
	<u>maize</u>	<u>switchgrass</u>	<u>miscanthus</u>
<u>Observed</u>	7.34	1.28	9.11
<u>Simulated</u>	7.93	3.16	2.96

Table S15: Range in observed and simulated yield (T/ha) in maize, switchgrass, and miscanthus plots.

Analysis of precipitation, ET, and yield

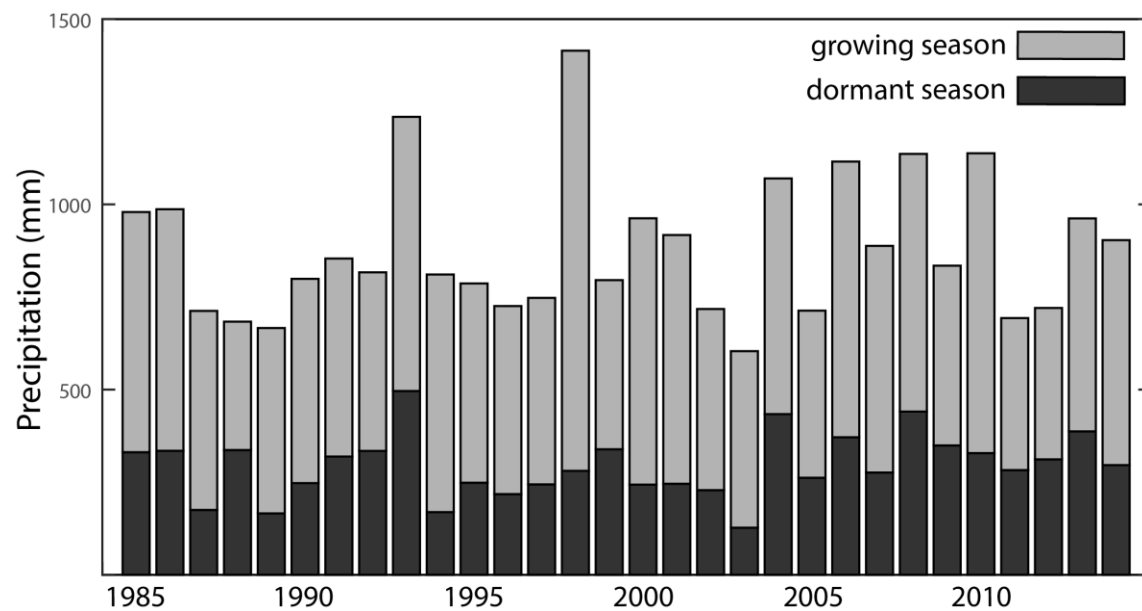


Figure S17: 30 year annual precipitation divided into dormant (lower portion) and growing (upper portion) season. Water stored within the soil profile on the first day of the growing season was added to growing season precipitation to represent GSAW.

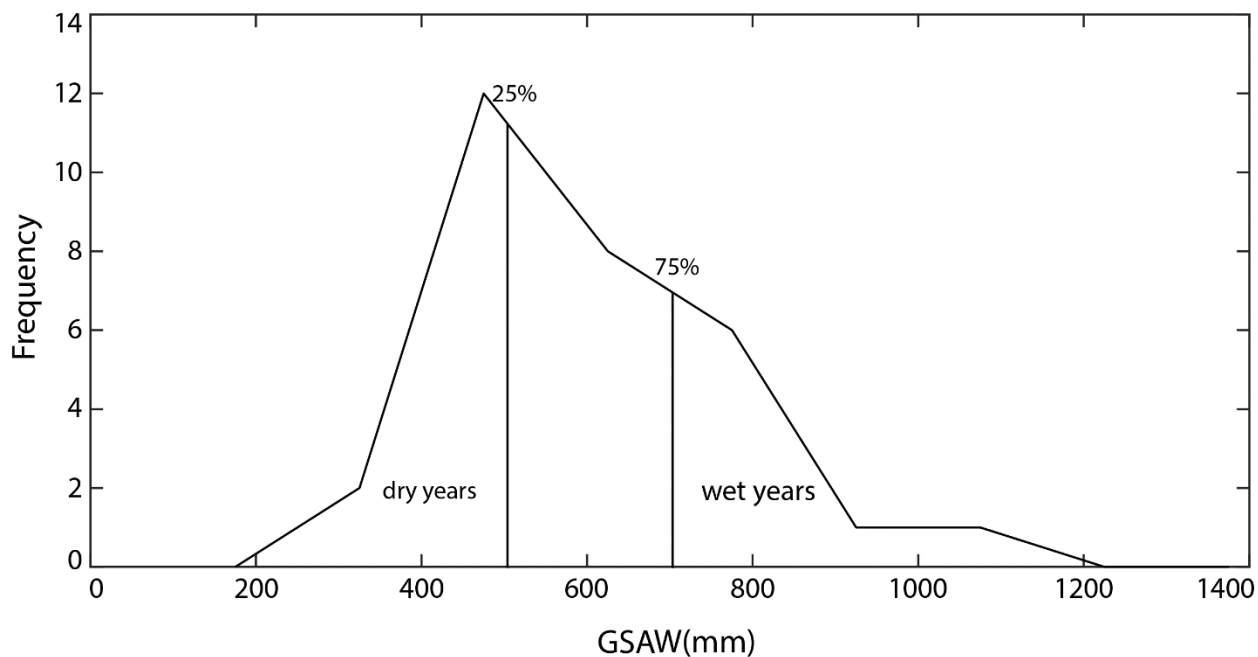


Figure S18: Frequency distribution of GSAW illustrating dry (< 25th percentile) and wet (> 75th percentile) years.

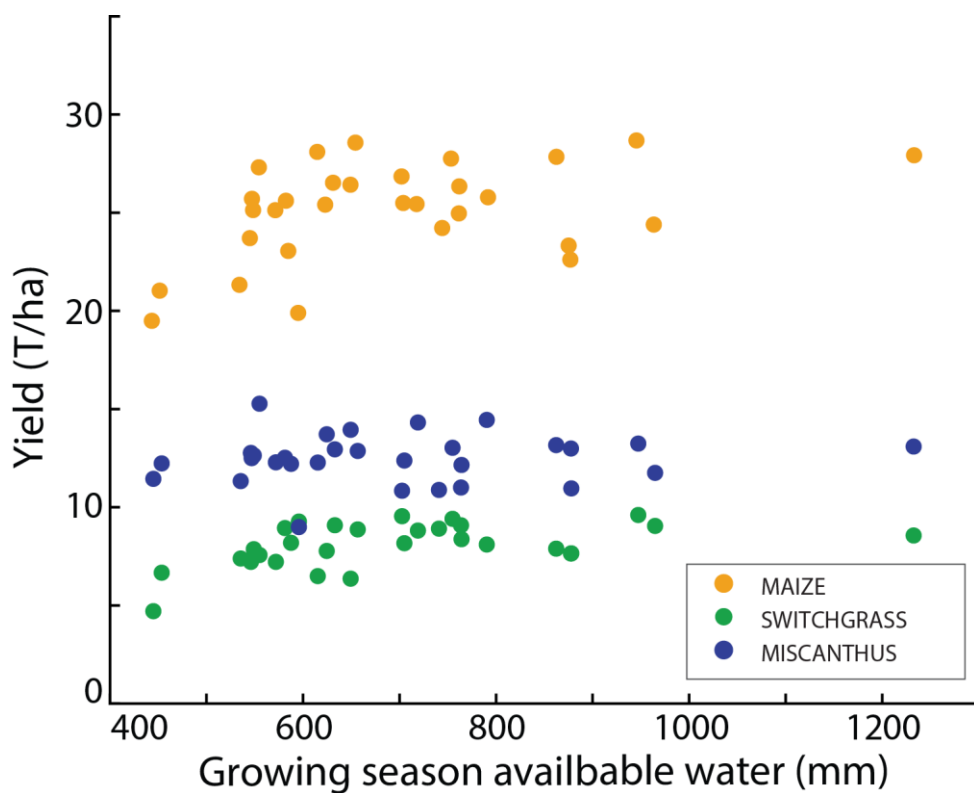


Figure S19: GSAW(mm) vs yield (T/ha) for each year from 1985 – 2014. The three years of no yield were due to a failed crop within the model for those years.

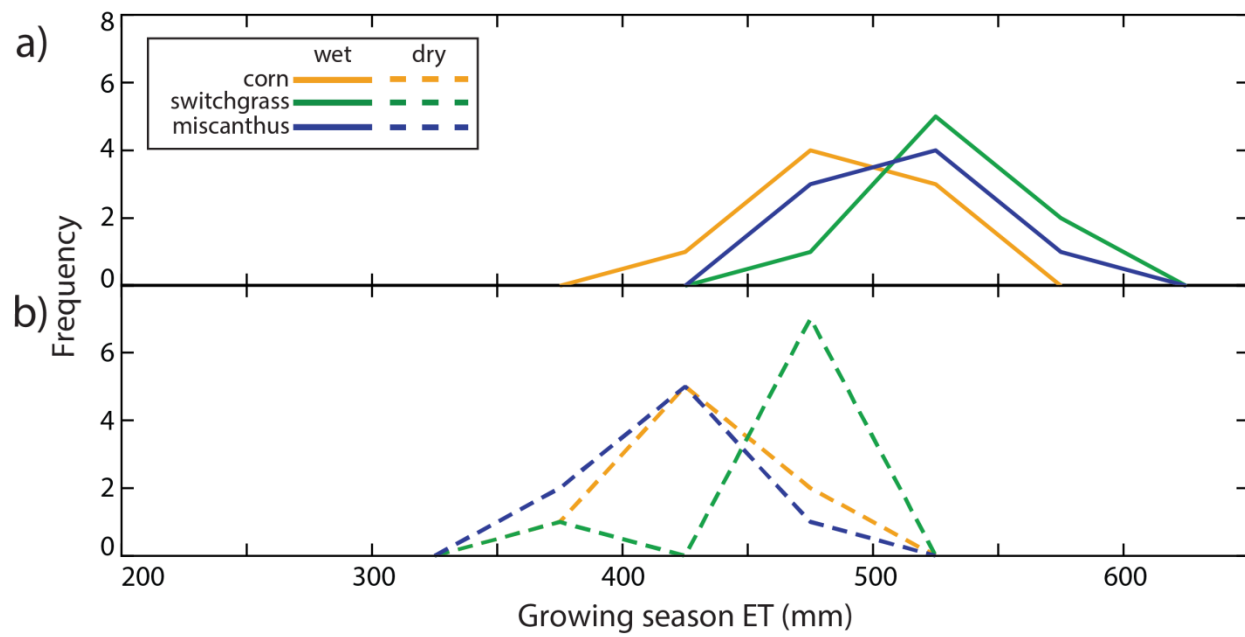


Figure S20: Frequency distribution of growing season ET in **a)** wet (solid) and **b)** dry (dashed) years from 1985 - 2014.