Predicted Sweet Sorghum Yields in Oklahoma by Soil and Climate Region

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Methods

The Soil and Water Assessment Tool (SWAT) model was used to predict sweet sorghum (dryland and irrigated) yields on 468 soils and 9 climate zones in Oklahoma. The state was broken into 9 climate zones based on annual rainfall as estimated by the Parameter-elevation Regressions on Independent Slopes Model (PRISM) Model. Each county was assigned to a single climate zone, a Cooperative Observer network station was selected within each zone to represent the climate for that zone.

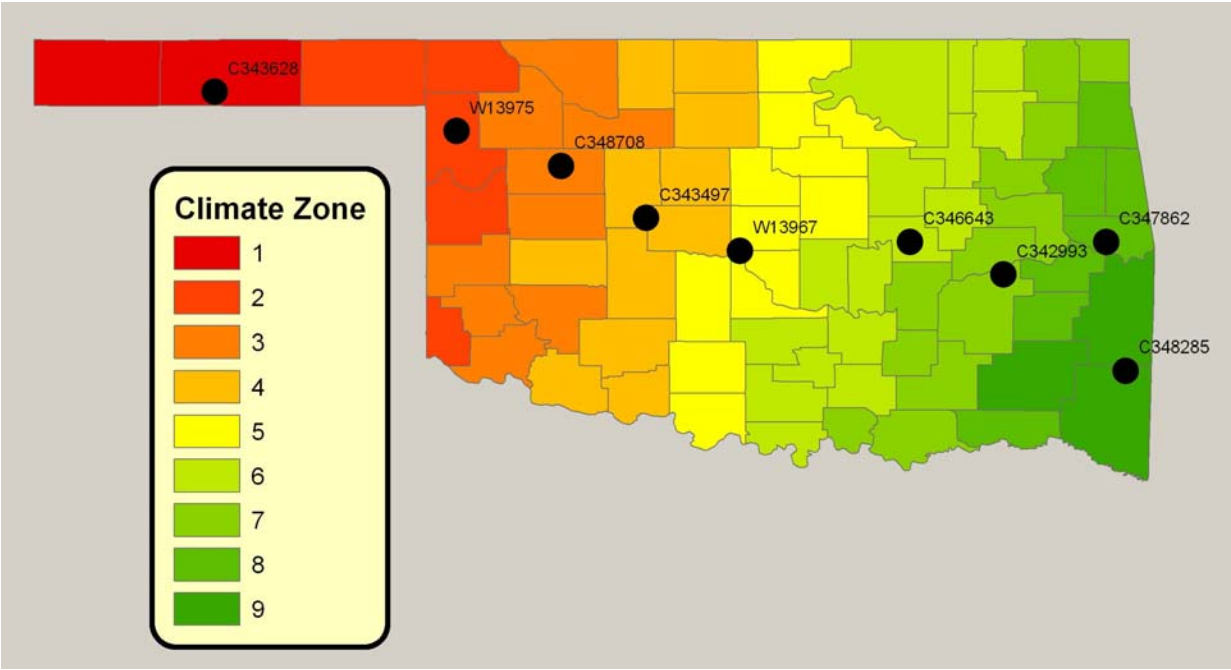

Figure 1 Oklahoma climatic zones, and the Cooperative Observer Network representative weather station selected for each zone.

Table 1 Precipitation from 1955 - 2004 at representative Cooperative Observer Network stations for each zone.

Climate Zone	Precipitation (mm)	Precipitation (in)
1	429	16.9
2	543	21.4
3	701	27.6
4	737	29.0
5	865	34.1
6	1021	40.2
7	1123	44.2
8	1166	45.9
9	1385	54.5

Soils were derived from the State Soil Geographic (STATSGO) database. These soil data are native to the SWAT model and are already parameterized for use with the model. Other soils information such as Soil Survey Geographic (SSURGO) are preferable, but would require significant effort to utilize these data with the SWAT model.

A single Hydraulic Response Unit (HRU) SWAT model was developed to simulate one soil, one management scenario, and one climate zone at a time. The SWAT model was directed by custom software written in Microsoft Visual Basic to perform each run and record the necessary statistics. Each simulation took approximately 4 seconds, the entire set required about 6 hours.

The SWAT Model was not calibrated for sweet sorghum, insufficient data were available for that purpose. Only two published datasets were located, one from Minnesota (Undersander et al., (1980)) and one from Mississippi (USDA Agriculture Handbook No. 441 (1973)). It is likely that some unpublished data exist for sweet sorghum production, however none could be located during the data search for this project.

Data from Meridian, Mississippi (USDA Agriculture Handbook No. 441 (1973)) did not contain year(s) of production, limiting their utility for model calibration. These data are given in Table 2. These data indicate little response to applied nitrogen fertilizer, however without additional information about the period of production, these data may not adequately describe the response of sweet sorghum to nitrogen. Nitrogen response varies from year to year, and even a crop with a significant nitrogen response may show no response in any given year. We do not know how may years of data were collected in this dataset.

The primary data used to guide the modeling was collected at Waseca, Minnesota (Undersander et al., (1980)). These data were collected in 1987 and 1988 and contained total dry harvested biomass. These data are given in Table 3.The average for all varieties listed was used in the SWAT model.

Models such as SWAT make predictions of dry biomass production. Sorghum producers are interested in stripped stalk yield or juice production, records of dry biomass may be more difficult to find. Undersander et al., (1980) recorded moisture content, percent stalk, and total dry matter. From this we calculated stripped stalk yield. These data were used to develop a relationship between stripped stalk yield and total dry biomass production (Figure 2). This relationship was used to estimate dry biomass in the Meridian, Mississippi (USDA Agriculture Handbook No. 441 (1973)) data.

Data from both the Waseca and Meridian sites were included in the SWAT model. Daily climate and precipitation was taken from nearby weather stations for use in the model. The exact timeframe of data from Meridian was unknown, but the variety used and the publicaiton date put the data somewhere between 1955 and 1970. This 15 year period was used in all simulations of Meridian. Tillage at both sites was taken as a clean till using several disk passes. Tillage has very little effect on yield in the SWAT model. Sweet sorghum was planted on May 1 and harvested at the end of the growing season. Fertilization was just after planting. The Waseca study did not define the fertilization rate used in the plot studies, this was taken as a rate of 80 lb N/acre. The same study recommenced between 60 and 120 lb N/acre for dryland sweet sorghum.

Sweet sorghum is not described in the SWAT crop growth database. To simulate its growth a set of crop growth parameters were developed from other crops. Parameters were taken from corn, sorghum hay, and sugarcane. The exact parameter used were based on professional judgment and guided by the yield data at Waseca and Meridian. The parameters used are given in Table 5. SWAT predictions and observed yield are given in Table 4.

Table 2 Data collected at Meridian, Mississippi (USDA Agriculture Handbook No. 441 (1973)).

N Rate	P Rate	Stripped Stalks (t/a)	Sirup (gallon/acre)
0	0	17	312
0	40	17.2	324
0	80	17.3	324
40	0	21.1	418
40	40	20.5	390
40	80	20.1	380
80	0	21.1	401
80	40	21.6	412
80	80	22.2	416

Table 3 Data collected at Waseca, Minnesota (Undersander et al., (1980)).

Varieties	Total dry matter (ton/a)	Percent stalk[1] %	Stalk moisture %	Brix[2]	Fermentable carbohydrate yield[3] (ton/a)	Calculated ethanol yield[4] (gal/a)	Stalk lodging[5] (%)
	Average of 2 years						
Sorghum							
Northrup King 301	9.4	52	68	13.2	1.81	247	47
Rox	10.6	46	75	10.3	1.84	250	33
Northrup King 405	11	60	70	7.3	1.25	170	70
Keller	10.1	70	72	13.4	2.96	403	97
Dale	10	70	74	12.3	3	408	98
Northrup King 8361A	11.7	67	70	8.9	1.85	252	72
M81E	10	66	73	12.7	2.83	385	96
Northrup King 8361	13.1	68	73	7.4	1.96	267	93
LSD (.05)	1.5	3	3	1.7	0.49	66	18
	Sorghum varieties grown only in 1988						
Cargill Mor-Cane	8.6	40	76	8.9	1.19	161	13
DeKalb	9.2	41	73	10	1.25	171	8
NC +940	9.2	51	70	13.2	1.83	248	15
LSD (.05)	2	4	3	1.9	0.56	74	17

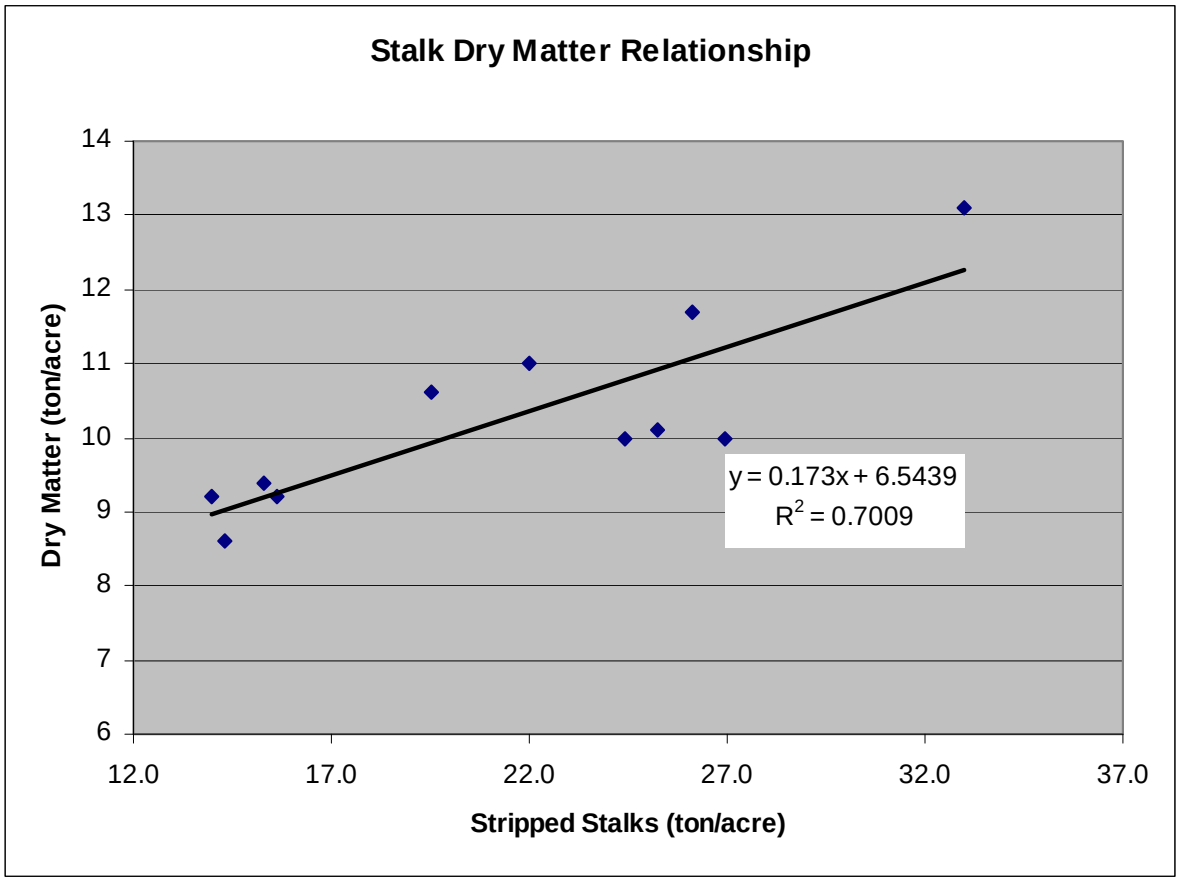

Figure 2 Relationship between stripped stalk yield and total dry biomass production based on Undersander et al., (1980).

Table 4 Observed and SWAT predicted dry biomass in Mg/ha.

Meridian,MS Timeframe unknown			
N rate lb/acre	Observed (estimate)	Predicted	Relative Error (%)
0	21.4	8.7	59%
40	22.4	20.3	10%
80	23.3	21.5	7%
WASECA,MN 1987-88			
Timeframe	Observed	Predicted	Relative Error (%)
1987-1988 ave	24.1	21.4	11%
1988 ave	20.2	21.5	-7%

Table 5 Crop growth parameters used in SWAT to simulate sweet sorghum.

Crop Growth Parameter	Sweet Sorghum		Corn	Sorghum Hay	Sugarcane
Biomass/Energy Ratio.	39.00		39.00	33.50	25.00
Harvest index.	0.90		0.50	0.90	0.50
Max leaf area index.	6.00		3.00	4.00	6.00
Fraction of the plant growing season corresponding to the 1st. Point on the optimal leaf area development curve.	0.15		0.15	0.15	0.15
Fraction of the max. leaf area index corresponding to the 1st. point on the optimal leaf area development curve.	0.05		0.05	0.05	0.01
Fraction of the plant growing season corresponding to the 2nd. point on the optimal leaf area development curve.	0.50		0.50	0.50	0.50
Fraction of the max. leaf area index corresponding to the 2nd. point on the optimal leaf area development curve.	0.95		0.95	0.95	0.95
Fraction of growing season when leaf area starts declining.	0.64		0.70	0.64	0.75
Max canopy height.	1.50		2.50	1.50	3.00
Max root depth.	2.00		2.00	2.00	2.00
Optimal temp for plant growth.	25.00		25.00	30.00	25.00
Min temp plant growth.	8.00		8.00	11.00	11.00
Fraction of nitrogen in seed .	0.0050		0.0140	0.0199	0.0000
Fraction of phosphorus in seed.	0.0008		0.0016	0.0032	0.0000
Fraction of N in plant at emergence .	0.0100		0.0470	0.0440	0.0100
Fraction of N in plant at 0.5 maturity.	0.0040		0.0177	0.0164	0.0040
Fraction of N in plant at maturity.	0.0025		0.0138	0.0128	0.0025
Fraction of P at emergence.	0.0075		0.0048	0.0060	0.0075
Fraction of P at 0.5 maturity.	0.0030		0.0018	0.0022	0.0030
Fraction of P at maturity.	0.0019		0.0014	0.0018	0.0019
Lower limit of harvest index.	0.90		0.30	0.90	0.01
Min value of USLE C factor applicable to the land cover/plant	0.200		0.200	0.200	0.001
Max stomatal conductance (in drough condition).	0.005		0.007	0.005	0.005
Vapor pressure deficit corresponding to the fraction maximum stomatal conductance defined by FRGMAX	4.000		4.000	4.000	4.000
Fraction of maximum stomatla conductance that is achievable at a high vapor pressure deficit.	0.750		0.750	0.750	0.750
Rate of decline in radiation use efficiency per unit increase in vapor pressure deficit.	10.000		7.200	8.500	10.000
Elevated CO2 atmospheric concentration.	660.000		660.000	660.000	660.000
Biomass-energy ratio corresponding to the 2nd. point on the radiation use efficiency curve.	36.000		45.000	36.000	33.000
Plant residue decomposition coefficient.	0.050		0.050	0.050	0.050

Results

The single HRU model was used to predict biomass yields on each combination of soil and climate. A fixed rate of 80 lb/acre of nitrogen was applied. Conventional tillage was used. Planting was May 1 with fertilization shortly thereafter. Harvest was after plants reached maturity. Due to the large amount of data, only a few results are given in this document. Figure 3 illustrates model predictions of yield for a common Oklahoma agricultural soil (Kirkland). Figure 4 illustrates the degree of annual variability in yields. Figure 5 Illustrates the variability among soil types. Figure 6 shows the variability due to annual weather.

Figures 7 and 8 are maps of MIADS soil series with model estimated biomass. Some soils available in MIADS were not simulated because these soil are not contained in STATSGO. For these areas the average yield from of all soils was used. Approximately 15% of soils listed in MIADS do not appear in STATSGO. Manual substation of similar soils for missing soils could lower this fraction to <5%, but this was not done. Figure 9 is the difference between irrigated and dryland sweet sorghum production

The entire database is available in a single Microsoft Excel Workbook. Included are summary statistics for each simulation. All data included are in dry biomass. The Waseca data set contained information to relate fermentable carbohydrate yield to dry biomass, but no significant relationship was found. The Waseca data contained several varieties of sweet sorghum, relationships may exist for individual varieties.

Limitations and Future Work

The lack of suitable data to calibrate and validate the model interjects a great deal of uncertainty in these predictions. Of particular interest is the response of sweet sorghum to climate. Both data sets were in areas with abundant moisture, these data tell us nothing about the response of sweet sorghum to moisture stress or its water requirements. SWAT did predict a significant reduction in yields in lower rainfall areas, but the true response could differ significantly. We have no data to verify the model predictions.

Lack of data is the primary limitation of this work. More data need to be collected. To that end, below is a list of data that will be necessary to refine these model predictions.

- Yield data on known soils in different climate regions of Oklahoma, both dryland and irrigated.
- Detailed measurement of dry biomass, fraction of stalks, stripped stalks, fermentable carbohydrate for a single cultivar to better define relationships between the measured parameters.
- Yield data under several differing fertilization rates for several years to define the response of sweet sorghum to nitrogen.
- Measured or estimated leaf area index throughout the growing season.

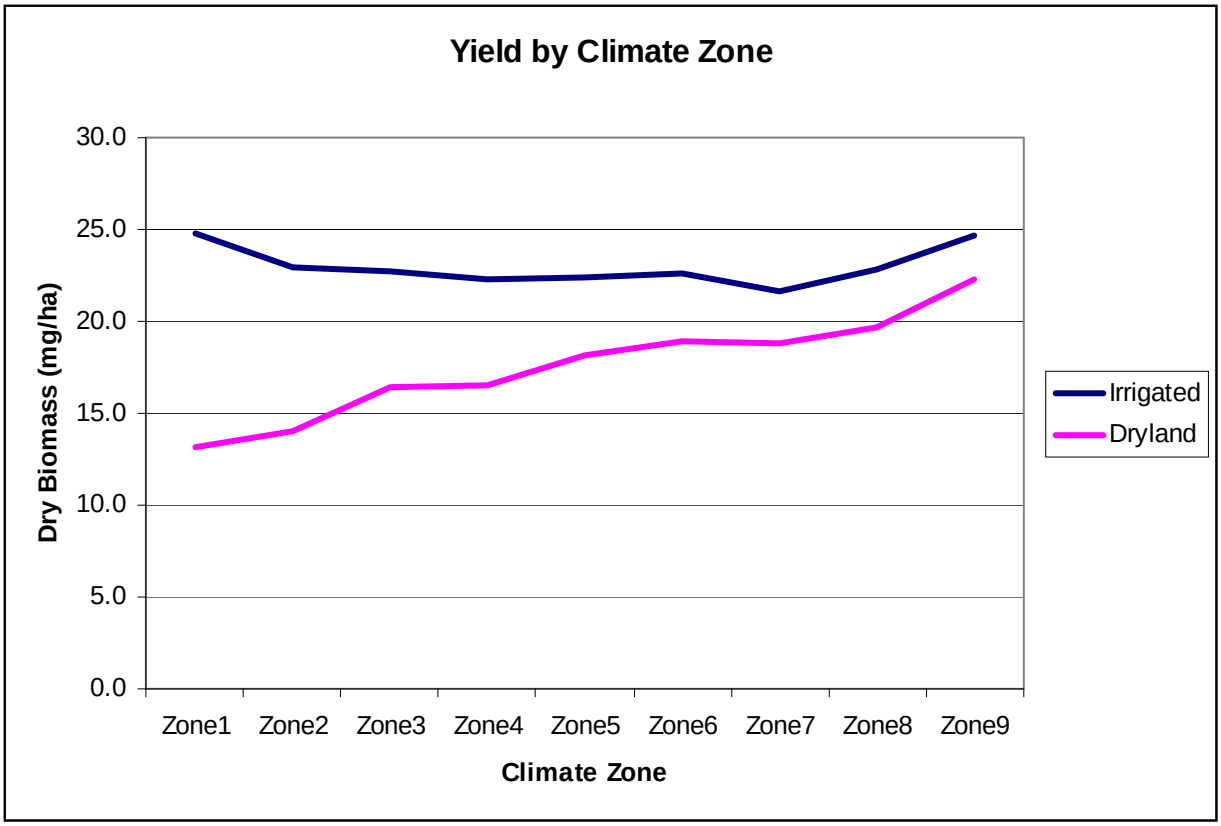

Figure 3 Sweet Sorghum dry biomass yield by climate zone and fertilization for the Kirkland soil series.

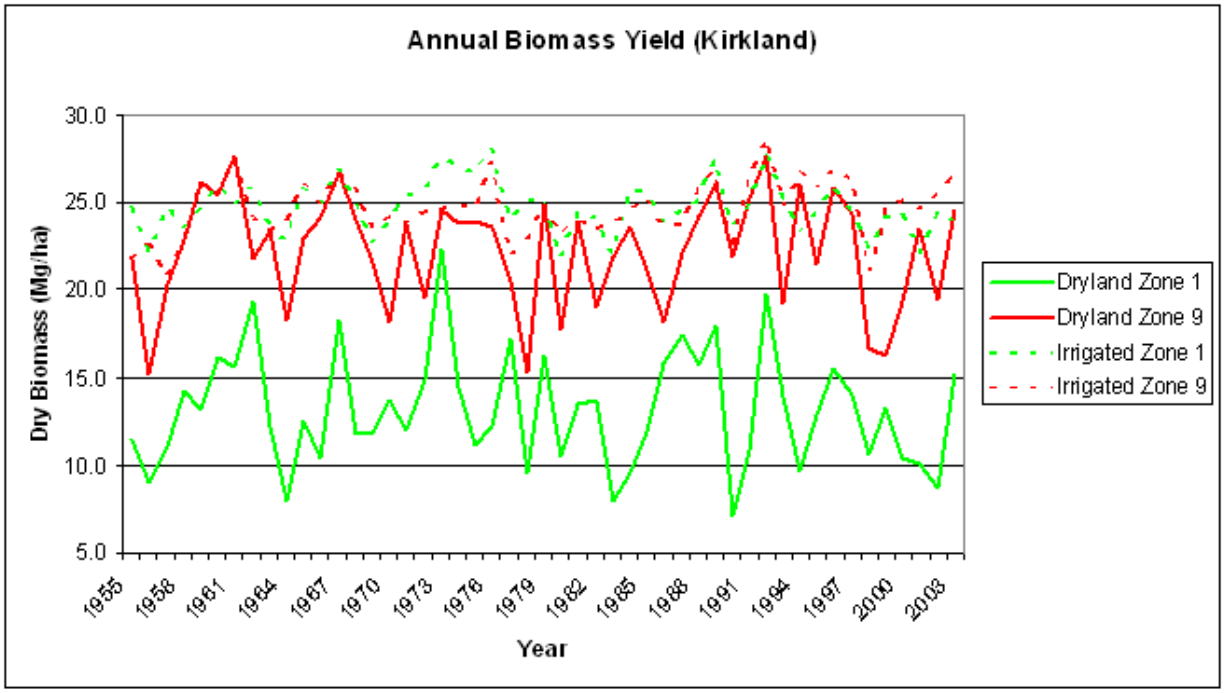

Figure 4 Yield by climate zone by year for the Kirkland soil series.

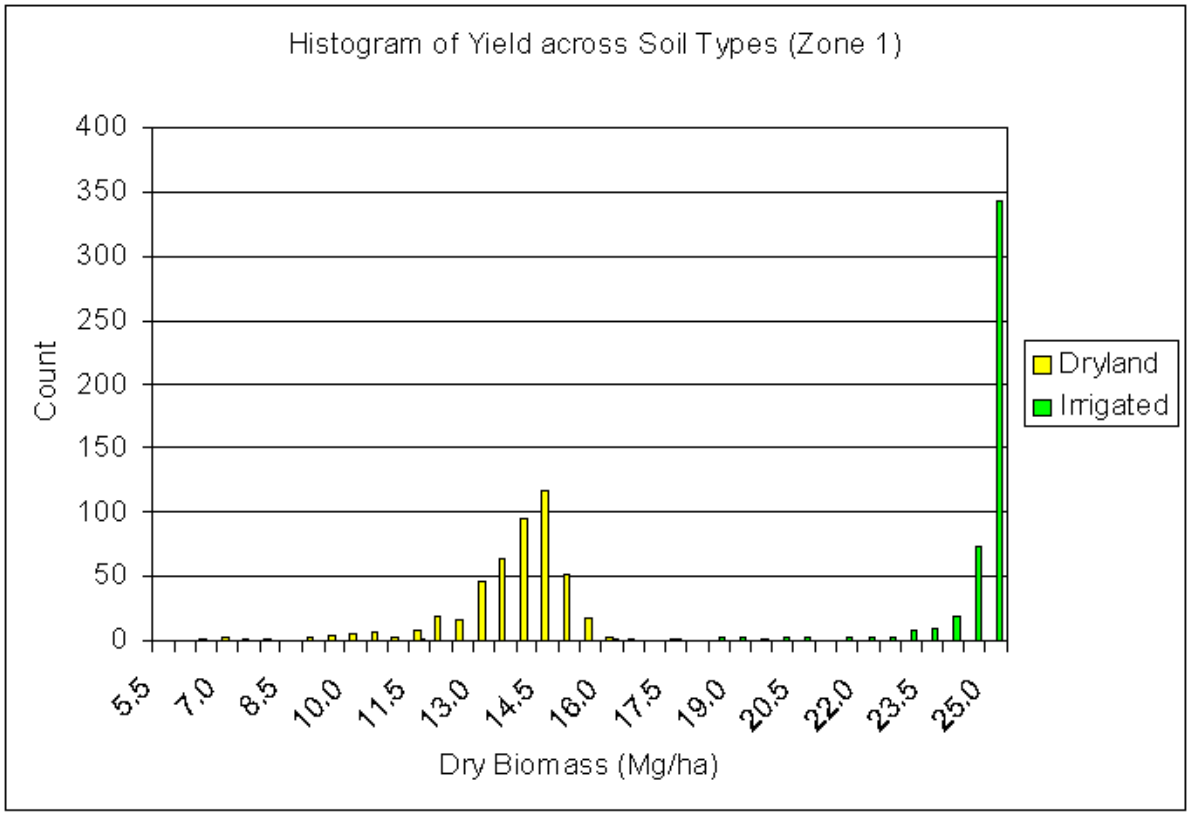

Figure 5 Histogram of average annual yield across all soils. Restricted to climate Zone 1

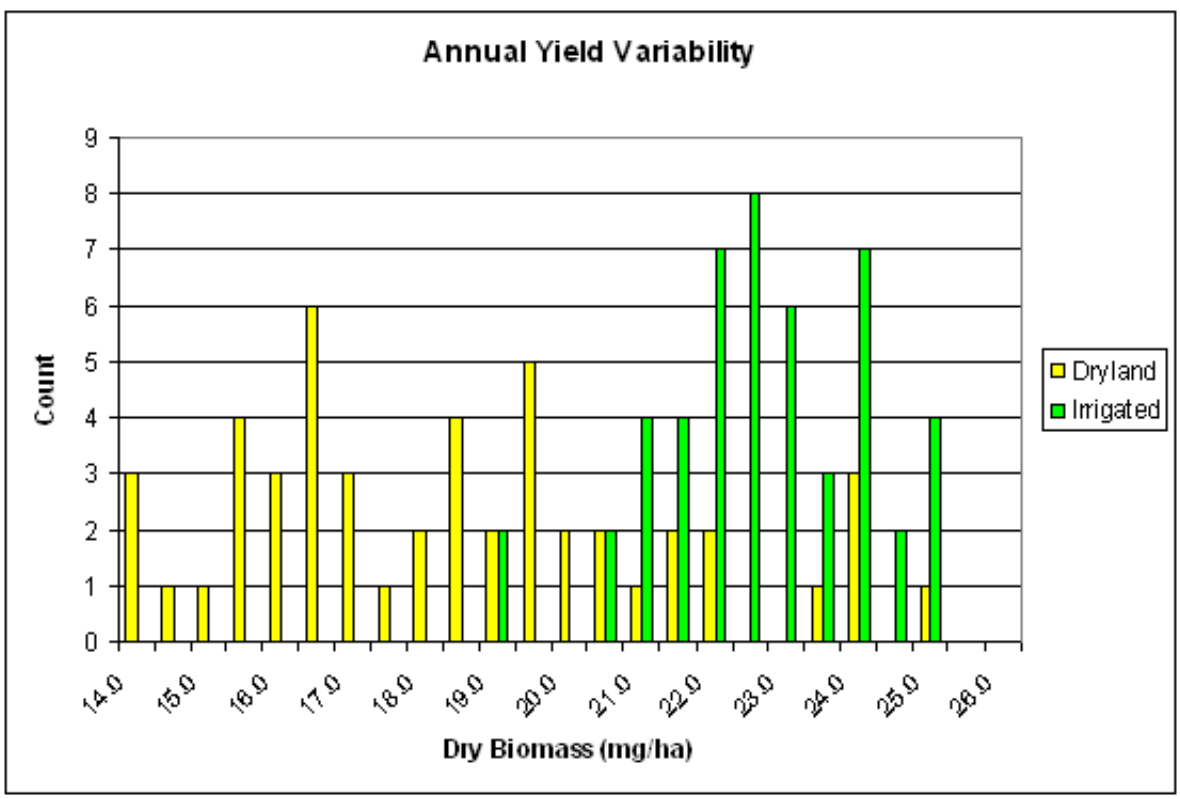

Figure 6 Histogram of annual yield across all years, Kirkland soil type, climate zone 5.

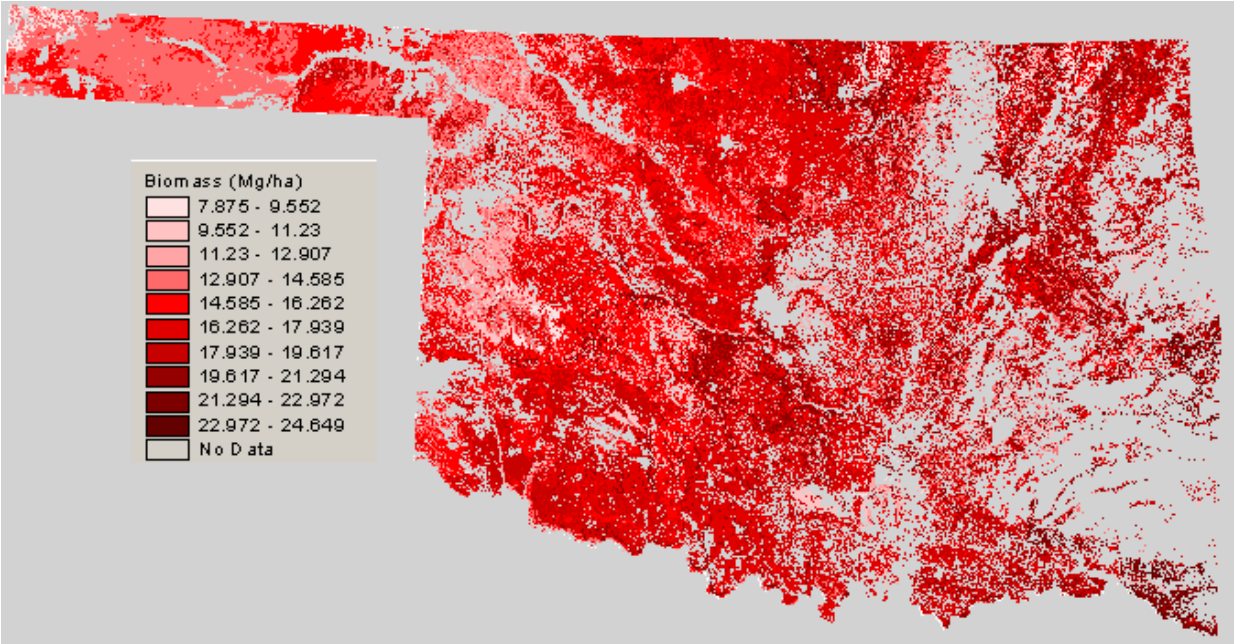

Figure 7 Dryland sweet sorghum biomass extrapolated to MIADS GIS data for the state of Oklahoma.

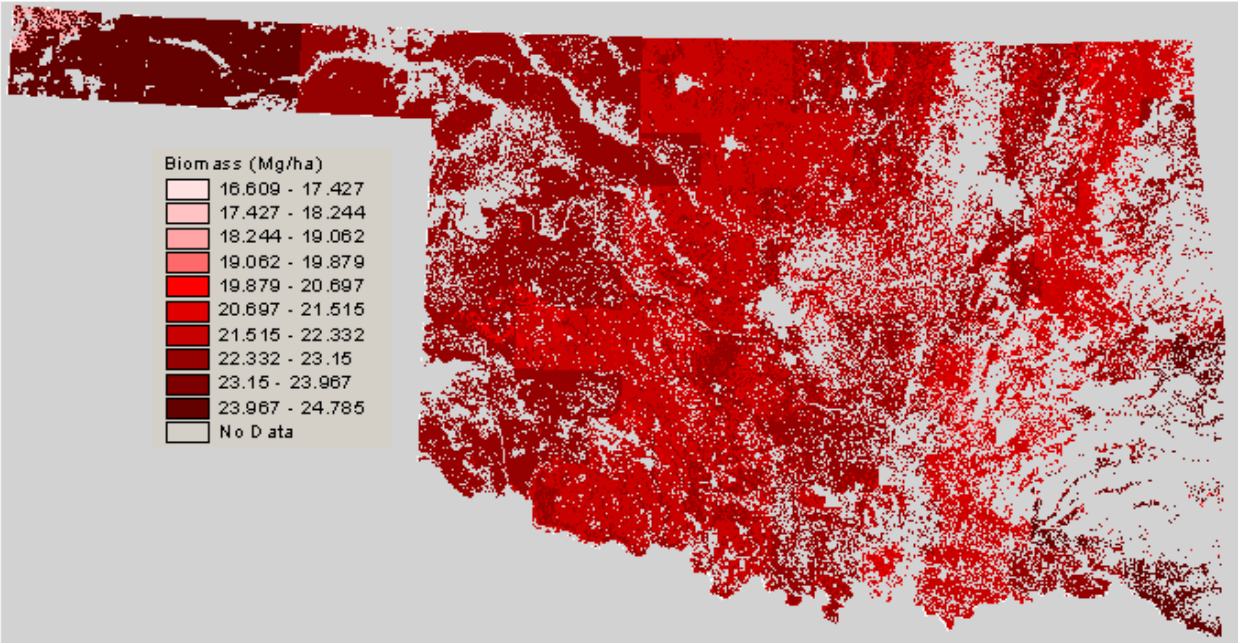

Figure 8 Irrigated sweet sorghum biomass extrapolated to MIADS GIS data for the state of Oklahoma.

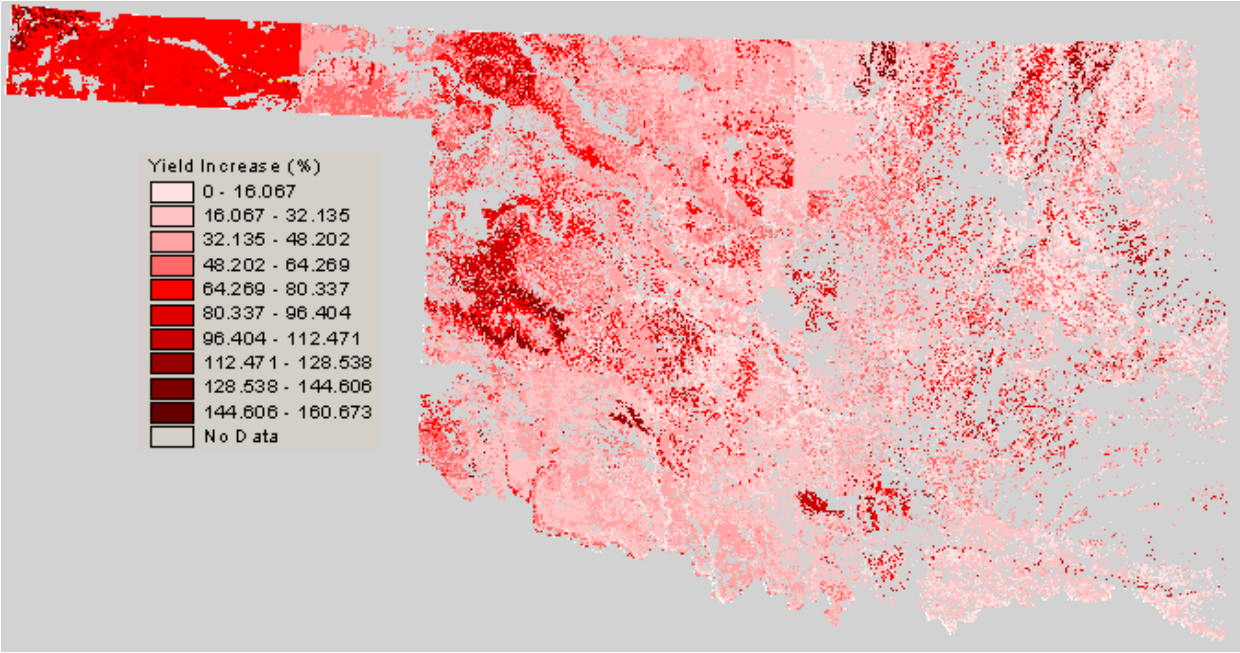

Figure 9 Percent increase in sweet sorghum biomass due to irrigation for the state of Oklahoma.

References

D. J. Undersander, W. E. Lueschen, L. H. Smith, A. R. Kaminski, J. D. Doll1, K. A. Kelling, and E. S. Oplinger Departments of Agronomy and Soil Science, College of Agricultural and Life Sciences, 1990.

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