Assessment of the Impacts of Weather on Maize, Soybean, and Alfalfa Production in the Great Lakes Region of the United States Using Crop Simulation Models

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INTRODUCTION

Weather and climate remain among the most important variables involved in crop production in the U.S. Great Lakes region states of Michigan, Minnesota, and Wisconsin. Major constraints include precipitation and associated availability of soil moisture, heat stress due to high air temperatures, lack of warmth and limited length of growing season, late spring freezes, and excessive precipitation and flooding during the growing season.

Analyses of the impact of weather and climate on agriculture are frequently constrained by the lack of long term time series data for detailed assessment. Lack of such data is associated with the limited number of experimental treatment combinations available from field experiments and observations, especially those which hold technological factors at a constant level. An alternative strategy is the use of deterministic crop simulation models which are based on the underlying physiological processes governing plant growth and development. Such models provide a more convenient and less expensive tool than long term field research in the evaluation of crop response to environmental and management factors.

Given relatively few past studies concerning climate and agriculture in the Great Lakes region, the major objective of this study was the deterministic simulation of crop behavior for alfalfa, maize, and soybean at a local level as a function of weather and climate alone, under both historical and projected future climates. Particular attention was given to areas within the region where agricultural activities have historically been limited by climatological and soil constraints, but which could become more favorable for agriculture in the future given a warmer climate.

MODEL SIMULATIONS

CERES-Maize and SOYGRO models from DSSAT v3.0 (Tsuji et al., 1994) were used for maize and soybean simulations. The DAFOSYM model (Rotz et al., 1989) was used for alfalfa simulations. All models were verified for suitability at 5 regional sites per crop for the period 1961-1990.

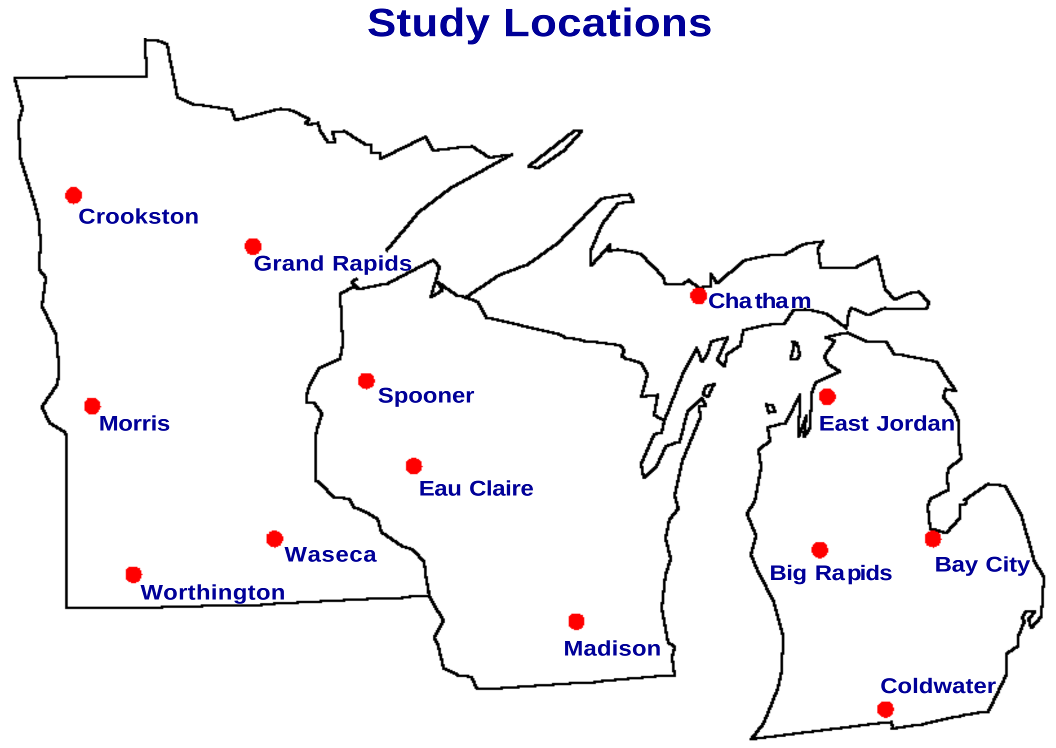
Agronomic input variables for the simulations were chosen to reflect current levels (i.e. late 1990's) of technology. Fertility was assumed to be non-limiting. The effects of insects, disease, and weeds were not considered.

The models were each modified to incorporate the effects of CO_2 enrichment according to Curry et al. (1990) and Rogers et al. (1983). Ambient CO_2 concentrations were held constant at 330 ppm for historical simulations and allowed to increase according to the Joos et al. (1996) series (based on the IPCC IS92a scenario) for future simulations.

Historical study locations chosen on basis of climatological continuity and record completeness of available stations (1895-1996). Maximum and minimum temperatures and precipitation data taken from NOAA/NCDC Summary of Day series. Daily solar radiation totals generated synthetically following Richardson and Wright (1984).

Projected future data were based on monthly projections of temperature and precipitation from two transient GCM simulations through year 2099: the United Kingdom Meteorological Office Hadley Centre HADCM2 (Johns et al., 1998) and the Canadian Climate Center CGCM1 model (Flato et al., 1998). The GCM simulations assumed the IPCC IS92a scenario concerning future greenhouse gas and aerosol emissions. Daily weather series were generated synthetically from the monthly GCM projections (UCAR, 1999) and gridded to a 0.5° x 0.5° resolution data set of the U.S. (VEMAP2: Kittel et al., 1997). Data for each study location were taken from the closest available grid point.

Study Locations

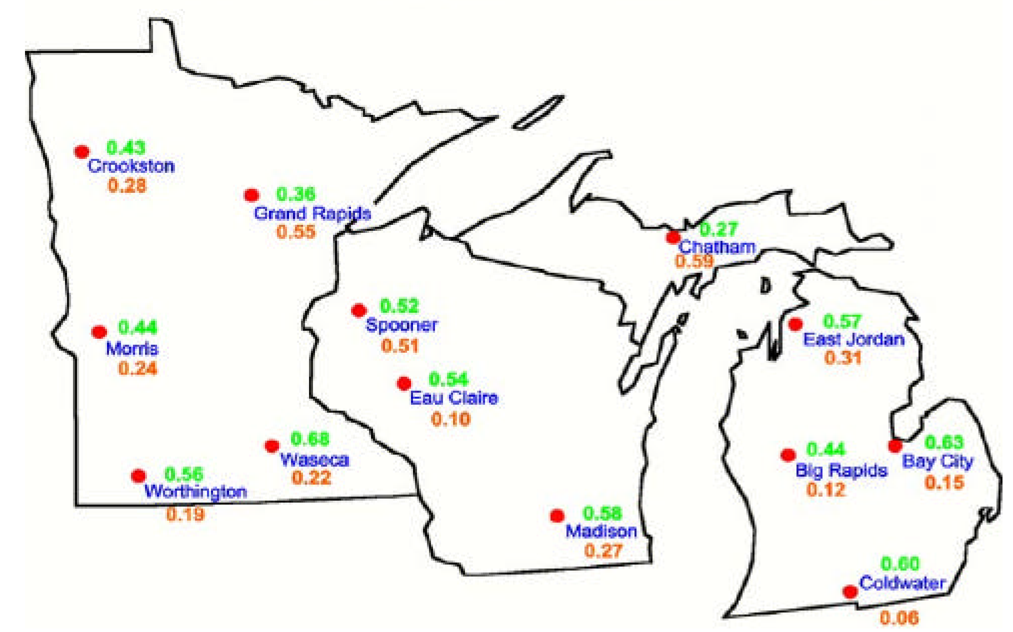


Trends(yr^{-1}) of Simulated Seasonally Summed Agro-Climatological Variables for Soybean, 1895-1996[1]

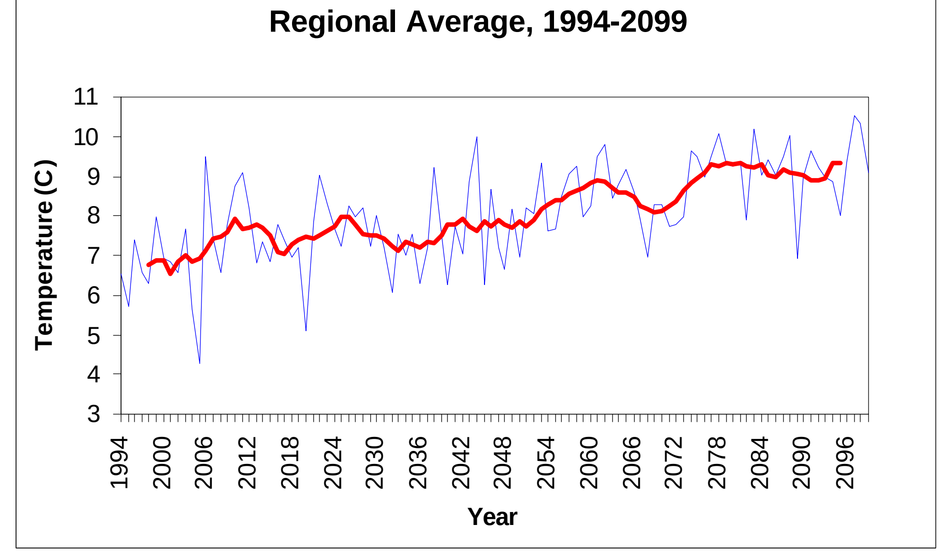
Station	Yield (kg ha^{-1})	Precipitation (mm)	ET (mm)	PET (mm)	Plant Avail. H_2O @1st pod (mm)
Bay City	0.85	0.02	-0.01	-0.19*	0.05
Big Rapids	1.26	0.50	-0.03	-0.12	-0.03
Chatham	9.19*	0.72	0.49*	0.13	0.23*
Coldwater	1.78	0.07	-0.04	-0.35*	0.17
Crookston	0.82	-0.05	-0.05	-0.17*	0.07
East Jordan	2.74	0.25	0.05	-0.45*	0.19
Eau Claire	4.54*	0.23	0.19	-0.13*	0.00
Grand Rapids	9.65*	1.88*	0.74*	0.09	0.25*
Madison	4.94*	0.46	0.14	0.05	0.19
Morris	2.00	0.12	0.02	-0.15*	0.10
Spooner	5.41*	0.44	0.19	-0.25*	0.13
Waseca	15.10*	1.29*	0.46*	-0.37*	0.48*
Worthington	6.39*	-0.24	0.19	-0.56*	0.17

[1]Trends estimated non-parametrically following Sen (1968).
*Trend significant at 0.05 level with Kendall's tau method.

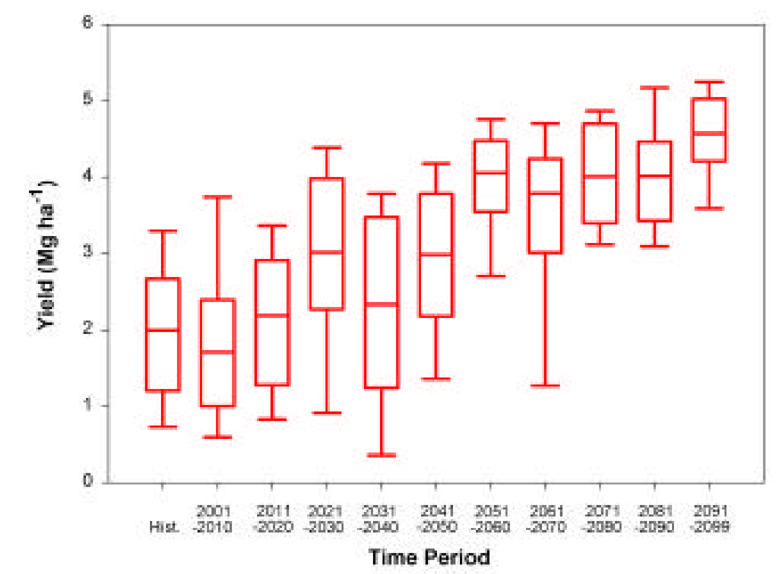
Coefficents of Determination for Seasonally Summed ET/PET (Top) and Summed Growing Degree Day Accumulations (Bottom) vs. Maize Yield, 1895-1996



Mean annual HadCM2 Temperatures Regional Average, 1994-2099



Simulated Historical and Future Soybean Yields by Decade*, CGCM1 Model Data with CO_2 Enrichment, Waseca, MN



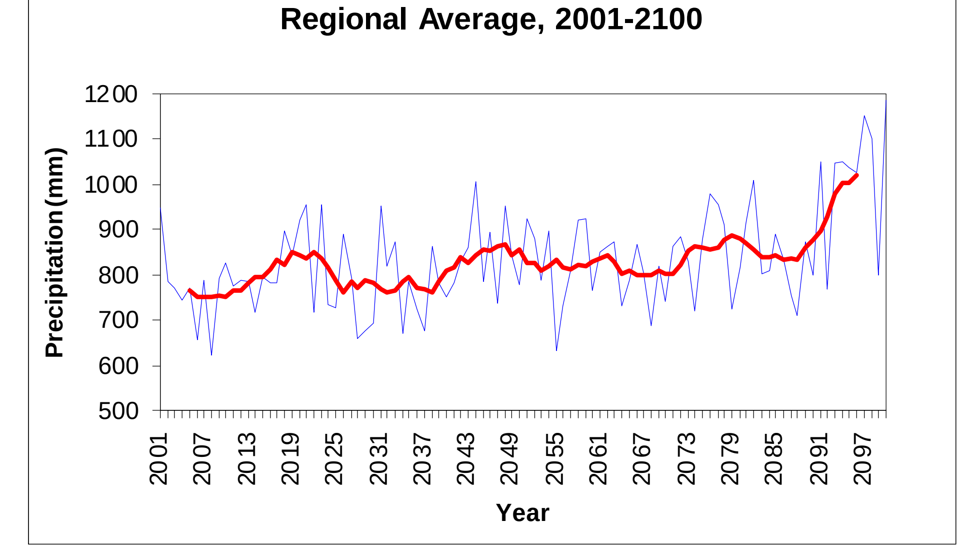
*Lower, middle, and upper horizontal bars in the boxes represent the 25th, 50th, and 75th percentiles, respectively, while bottom and top whiskers represent the 10th and 90th percentiles.

Ratios of Crop Yields* for Historical and GCM-Projected Future Scenarios Averaged Over all 13 Stations

	Alfalfa		Maize		Soybean	
Scenario	HADCM2	CGCM1	HADCM2	CGCM1	HADCM2	CGCM1
Future without CO_2 vs. Historical	1.06	1.06	1.11	1.26	1.13	1.24
Future with CO_2 vs. Historical	1.16	1.16	1.23	1.40	1.64	1.81
Future with CO_2 vs. Future without CO2	1.11	1.09	1.11	1.11	1.45	1.46

* 'with' and 'without' CO_2 refer to the inclusion and exclusion, respectively, of the effects of carbon dioxide enrichment in the simulations in addition to the climate change impacts.

Total Annual CGCM1 Precipitation Regional Average, 2001-2100

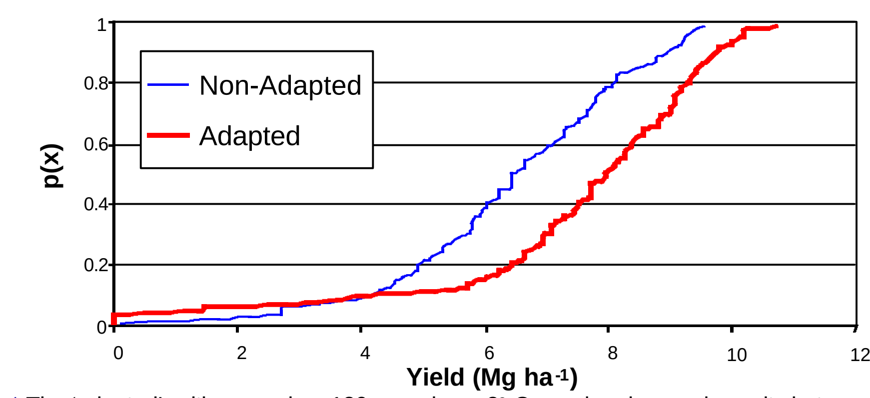


Simulated Historical and Projected Future Growing Season Water Balance* for Maize, Bay City MI

	Precipitation		Evapo-transpiration		Runoff		Drainage		Change in Storage	
Time Period	HAD	CGC	HAD	CGC	HAD	CGC	HAD	CGC	HAD	CGC
2025-2034	446	404	-445	-423	-26	-19	-40	-54	75	92
2090-2099	520	374	-397	-359	-43	-29	-107	-48	27	62
Historical	385		-456		-25		-36		132	

* Averaged over future (HAD=HADCM2, CGC=CGCM1) and historical (1896-1996) periods of record. All values expressed in millimeters.

Cumulative Simulated Frequency Distributions of Adapted* vs. Non-adapted Crop Cultivars, HADCM2 Projections 2000-2099, Coldwater, MI



* The 'adapted' cultivar requires 120 more base 8° C growing degree day units between silking and maturity than the non-adapted, and was planted 15 days earlier each season. All other input data were identical.

SUMMARY

1) Positive time trends of simulated maize and soybean yields existed across the region during 1940-1996, due partially to concurrent increases in growing season precipitation and decreases in moisture stress. Simulated alfalfa yields during the same period were steady or decreased slightly.

2) With the warmer and wetter climate suggested by the two GCM projections across the region, future alfalfa and soybean yields were greater than historical yields and tended to increase with time through 2100. Simulated future maize yields with the HADCM2 projections were greater than historical yields, but less so than for soybean and alfalfa. Maize yields with the relatively warmer CGCM1 projections were greater than historical yields through 2050, but tended to decrease with time from 2051-2100, especially at southern and western study locations. The majority of projected future yield increases were and wetter climate, the future scenarios suggest greater agronomic potential for northern sections of the region, even with less suitable soils. Simple adaptations to a changing climate such as a switch to a longer season variety or earlier planting date were found to result in significant increases in crop yield.

3) Interannual variability of all projected future crop yields tended to decrease with time, especially after 2050. This decrease is associated with corresponding decreases of variability in the GCM projections, especially CGCM1.

4) Based on projections of a warmer simulations as well as inclusion of other projections of future climate would allow for a more realistic assessment of future agronomic potential.

5) This simulation study considered the effects of weather and climate on three crops under idealized conditions. Incorporation of other agronomic and economic factors and limitations (e.g. fertility, insect/disease/weed pressure, commodity prices) into the associated with the effects of CO_2 enrichment.