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Global Climate Change: Implications of Extreme Events for Soil Conservation Strategies and Crop Production in the Midwestern United States

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ABSTRACT

Climate models indicate that there will be an increase in both average annual temperature (+4.5°C) and rainfall in the Midwestern U.S. by the year 2050 which may result in warmer, wetter conditions. Perhaps the most important factor will be less predictable weather patterns that will emerge, increasing the frequency of extreme weather events such as heavy downpours of precipitation, late season frosts and droughts. For example, July rainfall may increase 20% and might come in just two rainfall events.

This study combines expertise from several disciplinary areas with modeling strategies to assess the impact of global climate change on midwestern agriculture. Predictions of warmer summers, wetter springs, and more extreme events indicate that the cropping system may need to be adjusted to effectively conserve soil, maintain timely planting, avoid early season frost damage, and respond to warmer growing conditions. Climate projections (HADCM2), crop growth models (DSSAT), the Water Erosion Prediction Project (WEPP) model as well as net farm returns computations are used to study some of the choices farmers will have.

Management practices to be evaluated in this study include altering the crop mix and changing the time of planting. Planting of cover crops and reducing the amount of tillage performed may also be viable alternatives to reduce the amount of soil loss resulting from more intense storm events.

This paper will address some of the key findings from the project to date, and emphasize the extent to which extreme events under climate change raise special concerns about soil erosion. It will offer insights into the conditions midwestern farms may face and offer alternatives for preserving the quality of the soil resource. As yet we do not account for improvements in crop genetics.

INTRODUCTION

Warmer and wetter conditions, more frequent extreme weather events such as heavy downpours of rain, late season frosts and droughts simulated by global circulation models (GCM) for the period 2050 to 2059 may become a reality for Midwestern U.S. farmers. These weather conditions will impact not only farm yields and returns per acre but will have implications for soil conservation strategies as well.

The purpose of this study is not to challenge or confirm the validity of the global climate change premise of upcoming temperature and rainfall changes. Instead this study combines expertise from several disciplinary areas with modeling strategies to assess the impact global climate change may have on a representative Midwestern farm, if it occurs. Predictions of warmer summers, wetter springs, and more extreme events indicate that the Midwestern cropping systems may need to be adjusted to effectively conserve soil, maintain timely planting, avoid early season frost damage, and respond to warmer growing conditions. Some management practices farmers may adopt to reduce soil loss include altering the crop mix, changing the time of planting, planting cover crops and reducing the amount of tillage performed. We expect seed improvement technologies to be adopted but this study will not be addressing this form of adaptation to climate change.

In this paper, we will restrict our analysis to the impact global climate change is expected to have on the management practices, yields, returns per acre, and soil erosion of a representative Eastern Illinois farm (Champaign). As our research continues, up to 10 other representative farms in the Midwestern United States will be examined to broaden the scope of the study to include more ecological zones.

OBJECTIVE OF STUDY

The objective of this study is to determine how production practices will impact yield, soil erosion rates, and economic returns in the Midwestern U.S. with and without climate change. Several crop tillage systems will be modeled under three climate scenarios and the erosion rates and impact on returns assessed. In the near future, as this research effort progresses, we intend to compute the costs of compliance by plugging the soils-constrained practices back into a farm-level economic model and comparing the resultant returns with the unconstrained profit-maximizing returns.

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The various components of the study are described below and when possible, the discussion is put in the context of related research.

Study Design

Scope of study

This study is a portion of a project funded by the United States Environmental Protection Agency (USEPA). Researchers at Indiana University, Purdue University and the University of Illinois are working to address the impact of global climate change on farm level yields and profits in the Midwestern United States (Doering et al., 1997). Climate projections for the years 2050 to 2059 using the Hadley Center Unified Model (HADCM2), current climate data using VEMAP, crop growth models using the Decision Support System for Agrotechnology Transfer (DSSAT), and the soil erosion (Water Erosion Prediction Project-WEPP) model are used to study some of the choices farmers will have. Farm production and returns are estimated and net returns computed using spreadsheet budgets.

The results are present in three ways. First, a base production practice (continuous corn, chisel plowed 30 April, planted 1 May), hereafter referred to as "the base", is used by our representative farmer and estimated future soil erosion and economic returns per acre are compared with those for the current climate situation (using DSSAT yields). Second, alternative management practices to reduce soil erosion are adopted by the representative farmer and the possible future change in soil erosion, yields, and economic returns are measured and compared to the base (current) climate scenario. Third, the change in returns associated with these management options is estimated using changes in erosion and net returns compared to the base.

Soils model

The Water Erosion Prediction Project (WEPP) (Nearing et al., 1989; Laflen et al., 1997) model based at the National Soil Erosion Laboratory at Purdue University is used to model soil erosion on our representative farm under current and future climate and production scenarios. Current and future climate simulation data, biomass, and management practices information obtained from the project's crop growth and future climate simulation models were used to calibrate the WEPP model temperature, rainfall and biomass input files. WEPP is process-based and well suited for studying the effects of environmental system changes on hydrologic and erosion processes, including interactions between climate change, hydrologic response, and sediment generation (Laflen et al., 1997). The model has been extensively tested for the types of conditions to be considered in this study and has performed well (Zhang et al., 1996; Williams et al., 1996; and Liu et al., 1997).

Climate models

The future climate data was obtained from the Hadley Center Unified Model (HADCM2). Our research used the period of 2050 to 2059 for climate scenarios. Using a single scenario has limitations, as it is not possible to capture the range of uncertainties as described by the IPCC. Therefore, in this study two model scenarios were used to represent the likely upper and lower boundaries of future (2050's) climate change. These are (1) a greenhouse gas only (GHG) scenario that uses the combined presence of all greenhouse gases as an equivalent CO_2 concentration equal to approximately 554 ppmv of CO_2 by the year 2050 (assuming a 1% increase in CO_2 per year), and (2) a sulfate scenario that uses combined equivalent CO_2 concentration plus the negative influence from sulfate aerosols (SUL) also equivalent to approximately 554 ppmv of CO_2 by the year 2050. Sulfates have a cooling effect on the atmosphere thereby counteracting the impacts of the greenhouse gases and resulting in less extreme climate conditions.

The results from HadCM2-GHG and HadCM2-SUL cannot be viewed as a forecast or prediction, but rather as two possible realizations of how the climate system may respond to a given forcing. A comparison of the main three climate datasets (Table 1) highlights the differences in projected climate data. Hence, a range of probable climate change scenarios was examined to determine their impacts on crop growth and erosion.

The HADCM2 has been improved to perform climate change experiments with increased consistency with real climate systems. This was accomplished in three ways: First, the observed climate system is simulated using estimated perturbations beginning in 1860 instead of the 1980s such as the case for other GCM produced by the Goddard Institute for Space Studies (GISS), the Geophysical Fluid Dynamics Laboratory (GFDL) and the United Kingdom Meteorological Office (UKMO), for example. Second, HADCM2 is characterized by a finer spatial resolution than other GCM, i.e., a 2.5° x 3.75° (latitude x longitude) grid compared to 7.83º x 10º, 4.4º x 7.5°, and 5.0º x 7.5º for GISS, GFDL and UKMO, respectively (Rosenzweig and Parry, 1994). Third, the change in average global temperature for a doubling of CO_2 is equivalent to a more conservative 2.50°C (compared to 4.2°C, 4.00°C and 5.20°C for GISS, GFDL and UKMO, respectively).

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The current climate data are taken from VEMAP and are monthly mean observations. VEMAP is constructed to be a "typical" year of climate over the period 1960-1990.

Crop models

Crop yields under future climate and production scenarios are modeled using the Decision Support System

Table 1. Differences in 2050 - VEMAP climate scenarios: Champaign County, IL

	HADCM2GHG - VEMAP				HADCM2SUL -VEMAP			
	MaxT change (°C)	MinT change (°C)	Solrad change ($MJ/m^2/day$)	Precip change (mm/month)	MaxT change (°C)	MinT change (°C)	Solrad change ($MJ/m^2/day$)	Precip change (mm/month)
Jan	-2.30	8.31	-3.83	7.84	-1.47	7.95	-2.88	-0.68
Feb	-1.90	8.58	-3.66	52.78	-2.54	8.26	-3.92	19.49
Mar	2.71	6.16	-3.22	23.23	1.53	5.02	-3.10	19.20
Apr	1.97	5.27	-5.88	47.38	0.82	4.51	-5.93	38.68
May	0.04	4.40	-6.85	82.83	-0.03	3.81	-4.96	40.78
Jun	3.16	6.11	-1.18	46.57	-1.04	2.64	-2.66	58.85
Jul	9.34	9.13	1.23	17.35	5.82	6.60	0.19	30.82
Aug	13.29	11.79	1.68	-4.11	10.43	10.34	2.01	-14.16
Sep	9.36	9.98	1.12	-15.41	6.78	8.73	-0.05	22.03
Oct	3.71	5.90	-1.11	31.11	1.18	4.07	-1.53	6.08
Nov	4.18	6.42	-2.70	2.91	0.58	3.17	-2.68	1.56
Dec	-0.93	6.42	-2.70	1.63	-1.62	5.31	-2.70	-0.15

for Agrotechnology Transfer (DSSAT) suite of models. DSSAT is a shell incorporating the CERES-maize, CERES-wheat and SOYGRO models. The DSSAT suite of models have been extensively validated at sites both in the United States and abroad (Dhakhwa et al., 1997; Hoogenboom et al., 1995). Mavromatis and Jones (1998) found that using the CERES-wheat model coupled with a weather generator (WGEN or SIMMETEO) to simulate daily weather from monthly mean values is an efficient method for assessing the impacts of changing climate on agricultural production. Properly validated crop simulation models can be used to determine the influences of changes in environment, such as climate change, on crop growth (Peiris et al., 1996).

Intensive site-specific validation was also undertaken for this study to ensure the model could mirror reality. Detailed experimental farm level data were used to ensure that yields produced by the model reflected the actual yields in this area. For example, CERES-maize was initially validated using experimental data reported by Nafziger (1994) for maize planted at two locations in Illinois, USA. Experimental data were available for four planting dates over the period 1987-90, and measured yields were compared against yields simulated using CERES-maize. Simulated yields corresponded to within +/- 10% of the observed maize yields. The results for this farm were also validated using historical yield data and past daily climate information. This validation was used to ensure the model could replicate past yields. These results were consistent with expectations of hybrid performance in this region.

Representative Farm

The representative farm used in this study is a 1750 acre cash-grain farm in Champaign County in eastern Illinois. Our representative soil series is Drummer silty clay loam. The base practice selected for this study is continuous corn, chisel plowed on 30 April, planted 1 May and harvested 11 October. It is compared with no-till continuous corn with and without a winter rye cover crop, a corn-soybeans rotation, and two alternative planting dates. Modeled management practices conform to those typical for the area. Expected net returns and yields are calculated for each management practice under current and future climate scenarios.

Model limitations

This study does not attempt to predict future climate, but rather, is an evaluation of possible future changes in agricultural production in the Midwestern United States that might result from future changes in climate. Such potential changes provide insight into possible larger societal changes needed to control and reduce CO_2 in the atmosphere and to help select appropriate strategies to prepare for change (Adams et al., 1990).

The DSSAT-models, as with all models, contain several assumptions. Weeds, insects and crop diseases have no detrimental effect on yield. Also, extreme climate-related events such as floods are not taken into account by the model in terms of extreme crop losses resulting from such events. Other limitations relate to the simplified reality represented by the representative farms, the use of a single soil type at each location, and hence, the loss of the spatial variability of soils, although the selected soil type was that predominant at each location. However, the extensive validation and analysis at the farm level is in itself a more detailed analysis than most previously undertaken.

Preparing agriculture for adaptation to climate change requires advance knowledge of how climate will change and when. The direct physical effects on plants and the indirect effects on soils, water, and other biophysical factors also must be understood. Currently, perfect knowledge is not available for either the direct or indirect effects of climate change. However, guidance can be obtained from an improved understanding of current climatic vulnerabilities of agriculture and its resource base. This knowledge can be

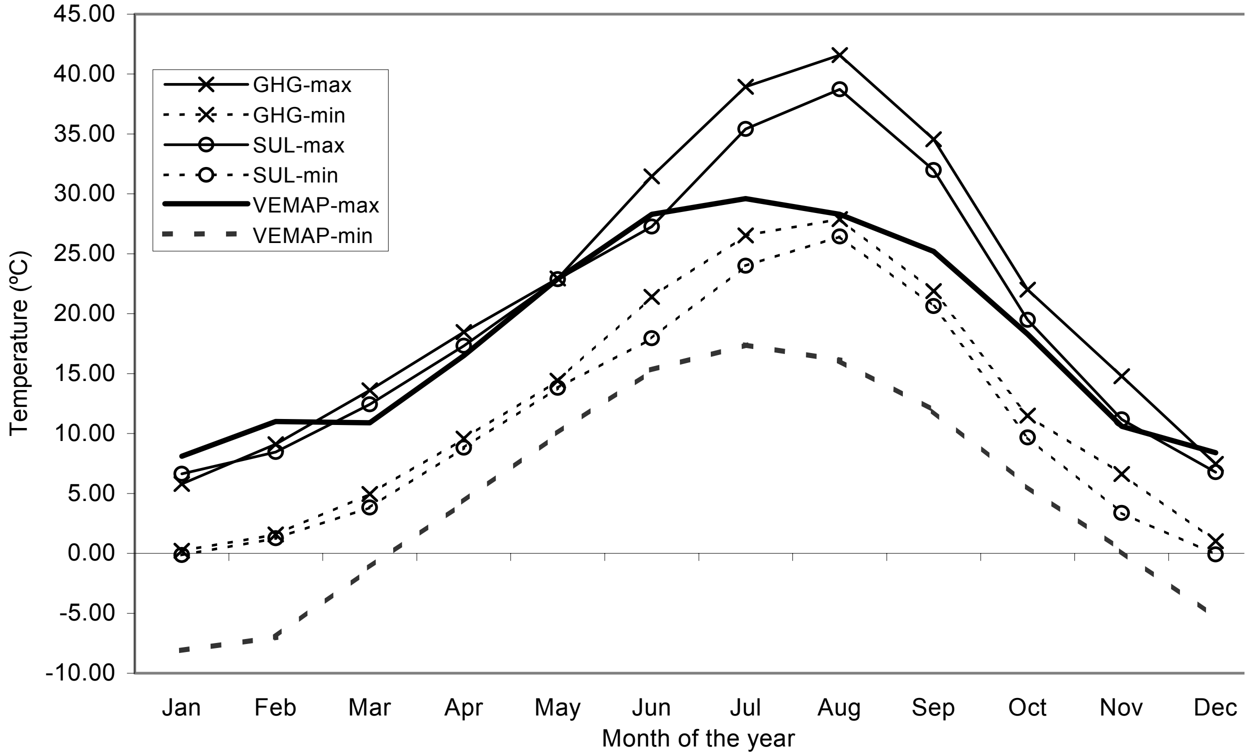

Figure 1. Comparison of maximum and minimum temperatures (ºC) for Champaign County, Illinois, USA under VEMAP, GHG, and SUL scenarios.

Table 2. Erosion, yield, and net return results within various management practices under current and future climate scenarios (no adaptation).

Management Practice	Runoff (mm)	Erosion (T/A)	Yields (Bu/A)	Net returns ($/A)
Base – corn, chisel plow, April 29, planted May 1				
VEMAP[1]	112	3.40	218	384
GHG	167 (+49%)[2]	5.22 (+54%)	147 (-33%)	241 (-37%)
SUL	152 (+36%)	4.54 (+34%)	177 (-19%)	301 (-22%)
No-till, continuous corn				
VEMAP	131	1.35	218	379
GHG	194 (+48%)	1.80 (+33%)	147 (-33%)	236 (-38%)
SUL	176 (+34%)	1.72 (+27%)	177 (-19%)	297 (-22%)
No-till, corn-rye cover crop				
VEMAP	119	1.15	218	325
GHG	165 (+39%)	1.45 (+26%)	147 (-33%)	182 (-44%)
SUL	154 (+29%)	1.44 (+25%)	177 (-19%)	242 (-26%)
Corn/beans (2 year rotation)				
VEMAP	130	4.02	235	329
GHG	190 (+46%)	6.16 (+53%)	158 (-33%)	173 (-47%)
SUL	176 (+35%)	5.50 (+37%)	190 (-19%)	268 (-19%)
Early planting April 20, corn				
VEMAP	118	3.24	211	368
GHG	175 (+48%)	5.06 (+56%)	152 (-28%)	253 (-31%)
SUL	160 (+36%)	4.35 (+34%)	177 (-16%)	301 (-18%)
Early planting April 15, corn				
VEMAP	119	3.27	211	369
GHG	177 (+49%)	5.08 (+55%)	155 (-27%)	257 (-30%)
SUL	162 (+36%)	4.40 (+35%)	177 (-16%)	302 (-18%)

[1]VEMAP=typical current climate GHG=greenhouse gas SUL=sulfate aerosols forcing
[2]Numbers between parentheses indicate percent change from current (VEMAP) values.

Table 3. Changes in erosion, yields, and returns from the base to other management practices for VEMAP and GHG scenarios.

Management Practices	Erosion (T/A)	Change from base erosion (T/A)	Yields (Bu/A)	Change from base yields (Bu/A)	Net returns ($/A)	Change from base net returns ($/A)
VEMAP						
Base – chiseled corn	3.4	---	218	---	384	---
No-till corn	1.35	-2.05	218	0	379	-5
No-till corn-rye	1.15	-2.25	218	0	325	-59
Corn-beans	4.02	+0.62	235	+17	329	-55
April 20 planting	3.24	+0.16	211	-7	368	-16
April 15 planting	3.27	+0.13	211	-7	369	-15
GHG						
Base – chiseled corn	5.22	---	147	---	241	---
No-till corn	1.80	-3.42	147	0	236	-5
No-till corn-rye	1.45	-3.77	147	0	182	-59
Corn-beans	6.16	+0.94	158	+11	173	-68
April 20 planting	5.06	-0.16	152	+5	253	+12
April 15 planting	5.08	-0.14	155	+8	258	+17

obtained from the use of a realistic range of climate change scenarios and from the inclusion of the complexity of current agricultural systems and the range of adaptation techniques and policies now available and likely to be available in the future (Rosenburg, 1992).

Farm-level net returns

Net returns reported in the results section are comparisons between corn production practices under current and future climate scenarios. Farm returns are computed using a worksheet budget. The estimated net returns include the costs of fertilizer, pesticides, fuel, seed, and part-time labor; they do not include charges for the cost of owning the land, depreciation or maintenance of machinery, except for diesel fuel required to operate the machinery, interest, taxes, nor any allowance for owner labor.

RESULTS

In this section we examine changes in climate (Fig. 1 and Table 1), farm yields, returns and erosion within each management practice (Table 2) and compare the estimated future and current situations. In Table 3, we compare the base with alternative management practices and order these practices in terms of changes in erosion, yields, and returns from the base. No genetic adaptations are considered in this analysis.

Climate change

The representative farmer will experience increases in average daily maximum temperature of about 3.5°C (under the greenhouse gas scenario). This falls within the range reported by the Intergovernmental Panel on Climate Change (IPCC) of 1.5°C to 4.5°C, assuming a doubling of CO_2 (IPCC 1995). The overall warming effect reported by the Hadley Center Model Simulation is evident as average daily minimum temperatures also increase by about 7°C. The sulfate aerosol scenario gives slightly less drastic maximum temperature increases of 1.7°C and minimum temperature increases of 5.9° C.

The differences in average maximum and minimum temperatures under the current and two future climate scenarios are illustrated by Figure 1. Summer and fall months are expected to be much warmer (with an increase in temperature of 8.6°C and 5.6°C respectively) while winter months may be cooler (by about 1.7°C). Maximum temperatures of 39°C to 42°C (Figure 1) and minimum temperatures of 28°C in July and August may be sources of stress to the plant at the critical grain-filling stage. Note also that the future minimum temperatures in late summer are nearly as high as the maximum temperatures under the current climate.

The mean precipitation increase is projected to be 25 mm per month with the heaviest increase in rainfall during the beginning of the growing season in May (83mm), April and June (47mm) and the biggest decrease in August (4mm) and September (15mm) (Table 1). October, however, is characterized by a 31 mm increase in precipitation. Reduced rainfall in late summer may have a negative impact on crop yields.

Table 2 reports the runoff, erosion, yields, and net returns for the base and various management practices and compares simulated climate and current situations. Corn yields are highest under the current climate conditions for all management practices. Yields drop approximately 3% under the GHG scenarios and 20% under the SUL scenario. These results coincide with those of Adams (1989) who reported a 12 to 19% decrease in corn yields for the Corn Belt area and Northern Plains using the GDFL climate simulation. Earlier planting dates are slightly less affected than the chisel and corn bean rotation by the changing climate. Possible future yield decreases under climate change have been reported by Rosenzweig et al. (1994) and Adams (1989) and are driven primarily by increased temperatures causing the crop growth cycle to be shortened especially during the critical grain-filling period.

The base management practices also provide the farmer with the highest net returns in all scenarios. Net returns decrease 20% to 40% under the future climate conditions; again, earlier planting dates are impacted to a lesser degree. Runoff and erosion increase approximately a 30% under the sulfate and almost 50% under the greenhouse gas scenario.

These decreases in corn yields and net returns are indicative of the farmers' need to adapt their cropping systems to future conditions. These adaptations include systems that are less prone to erosion and produce higher yielding crops as well as those more adapted to warmer, wetter springs, and hotter summers. This could mean a move toward a shorter growing season to avoid the very high temperatures of July, August, and September.

Tradeoffs between management practices, net returns, and soil erosion rates

Table 3 presents changes in erosion and net returns associated with various management practices under GHG compared to the base. Values for the more moderate SUL scenario are not given, but lie between the base and GHG. The least erosive practices under both current and future climate scenarios are the no-till options. The no-till continuous corn is characterized by a future erosion rate of 2 ton per acre compared to 5 tons per acre for the base practice. No-till continuous corn shows a 2 percent decrease in returns compared to the base; the no-till corn-rye crop cover is characterized by 1.5 tons of erosion but a 24 percent loss in net returns compared to the base under the greenhouse gas future climate scenario. Other management practices considered in this study do not reduce erosion in a significantly.

Of the options studied the management practice which results in the highest yields in the future (under the greenhouse scenario) is the chisel plowed corn-soybeans two-year rotation. However, the high erosion rate of 6 tons per acre compared to the base 5 tons per acre and a 28% decrease in returns from the base make this option less desirable economically as well as environmentally. Under the greenhouse gas scenario, the highest returns (or a 6% increase in returns from the base) are obtained by adopting early planting continuous corn management practices. However, the early planting practices are not associated with a significant decrease in erosion.

CONCLUSIONS

Warmer maximum and minimum temperatures in eastern Illinois, particularly a drier, hotter summer, combined with more rainfall in the spring will challenge farmers in this area to adapt. Without any adaptive strategies, corn yields and net returns are expected to decrease, and erosion significantly increase under the future climate conditions.

To reduce soil erosion under the simulated future climate, the farmer may consider adopting a no-till conservation strategy (the most conserving of soil under both current and future climate scenarios). Most appealing may be no-till continuous corn characterized by a low erosion rate and only a slight decrease in returns. If our representative farmer does not adapt, he will experience higher yields, but greater erosion, and lower net returns. The sustainability of the farm may be in jeopardy if no adaptive action is taken. Many studies previous to this have not looked at the flexibility of the farmer. The options examined here are currently viable and relatively easy for a farmer to adopt. Historically farmers have adapted to changes – in technology, in marketing, in labor requirements – and we are confident they will be able to do the same under the future climate in an effort to conserve the soil resource.

Our intention, as we pursue our research efforts, is to include up to 10 other representative farms in the Upper Midwest increasing the representation of the very different ecological zones included in this project. Once this is done more conclusions will be drawn about the costs of compliance associated with various soil conservation strategies available to the farmer as well as the production options enabling him or her to remain competitive in the world market.

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