Erosion and Sediment Yield: Global and Regional Perspectives (Proceedings of the Exeter Symposium, July 1996). IAHS Publ. no. 236, 1996.

Regional analysis of erosion from agricultural fields using global change scenarios

A. D. NICKS, R. D. WILLIAMS
US Department of Agriculture – Agricultural Research Service, PO Box 1430, Durant, Oklahoma 74702, USA

J. R. WILLIAMS
US Department of Agriculture – Agricultural Research Service, 808 East Blacklands Road, Temple, Texas 76502, USA

Abstract Field data were collected from 162 sites in 22 US states to assess the effectiveness of vegetative filter strips in reducing soil and chemical losses. Installed under the Conservation Reserve Program sponsored by the US Department of Agriculture, each site was surveyed for crop rotation, soil properties, chemical and cultural management practices. The sites were then parameterized for erosion and water quality evaluation using the Chemicals, Runoff, Erosion, and Agricultural Management Systems (CREAMS) continuous simulation model. Daily climate data required by CREAMS were obtained from a database of observed data developed for the Water Erosion Prediction Project (WEPP) model. The climate and field management data were used to estimate the impact of erosion before and after filter strip installation. Using these same sites and the soil, management, and climate data, global change scenarios were developed for climate change and the sites were parameterized for Erosion-Productivity Impact Calculator (EPIC) model runs. Climate change scenarios were developed by using trend analyses of precipitation and maximum and minimum air temperature at each site for a 40-year period (1950-1989) and the CLIGEN weather generator. Monthly trends of these climate elements were used to modify the weather generator to produce EPIC model climate files representing changed climate conditions. EPIC model simulations with and without change were compared to assess the seasonal changes in erosion. Impacts of the changed climate are presented for runoff, soil loss and other simulated model outputs.

INTRODUCTION

Changes in the climate for regions of the earth have been indicated by large scale simulation models such as Global Circulation Models (GCM) (e.g. Hansen & Lebedeff, 1987). Other indications of change have been derived from trend analysis of long-term air and sea surface temperature observations (Shiffer & Unninayar, 1992). More recently, Nicks *et al.* (1993) calculated trends of climate change for regions of the USA from analysis of monthly precipitation and air temperature for short-term periods (40 years). It is the latter of these analyses, focusing on precipitation and temperature trends, that are of interest here for exploring regional runoff, erosion, and crop yield patterns resulting from climate change. Utilizing the monthly trends of these climate elements, a weather generator, and a continuous simulation erosion model, comparisons of climate change scenarios with a no-change scenario are made for three corn producing regions of the USA.

METHODS

The Natural Resource Conservation Service of the US Department of Agriculture (formerly the Soil Conservation Service) provided surveys of 229 field sites (a 10% random sample of 2776 contracts) where vegetative filter strips had been installed as part of the Conservation Reserve Program (CRP). The performance of these filter strips was evaluated for reduction of sediment and chemicals in the surface runoff (Williams, *et al.*, 1993) by using the CREAMS (Chemical, Runoff, Erosion, and Agricultural Management Systems) model (Knisel, 1980). Soils, topography, tillage and chemical management data were obtained from the survey for each site. Climate data required for CREAMS model continuous simulation runs were obtained from the database of daily precipitation and temperature stations developed for the WEPP (Water Erosion Prediction Project) model (Nicks & Gander, 1994).

The EPIC (Erosion-Productivity Impact Calculator) model (Williams *et al.*, 1984) (Sharpley & Williams, 1990) was chosen for simulation of runoff and erosion from each of 69 field site in 19 US states. This model simulates on a continuous daily time step the processes associated with erosion. It is a process-based model with physically based components for hydrology, erosion-sedimentation, nutrient cycling, plant growth, tillage, and weather simulation. EPIC uses the NRCS curve number method of partitioning rainfall into runoff and the MUSLE (Modified Universal Soil Loss Equation) model for estimating soil loss. Also, the plant growth model has provision for adjusting atmospheric CO_2 concentrations to future projections. Planting and harvest dates are also adjusted depending on the accumulation of heat units before, during and after the normal growing season. Therefore, the growing season is adjusted depending on the temperature regime. These features of the plant growth component are necessary for climate change simulations.

Model parameters were developed for each site using the survey data obtained from NRCS field personnel. In most cases the crop and management data received were for corn and soybeans or wheat in 1 to 3 year rotations. For the purposes of this study we used continuous corn with conventional tillage for each of the sites in both the climate change and no change condition. The USLE (Universal Soil Loss Equation) conservation practice factor P (Wischmeier & Smith, 1978) was set equal to 1.0, indicating rows without contouring. Atmospheric CO_2 concentrations were set at 320 and 640 ppm for no change and the climate change conditions, respectively. Hydrology and erosion parameters were developed using the soil and topography of each site. Model simulation runs were then made with changed and no change 40-year generated climate input files. Climate change scenarios were developed by the methods given below.

CLIMATE CHANGE SCENARIOS

Climate change scenarios were developed using CLIGEN (Nicks & Gander, 1994), the weather generator and database developed for the WEPP model. CLIGEN generates 11 daily weather elements that are required by most hydrologic simulation models. These are precipitation occurrence, amount, duration, maximum storm intensity, time to peak intensity; maximum, minimum, and dew point temperatures; solar radiation; and wind speed and direction. Distribution parameter values for each of these elements have been calculated for more than 1000 station in the US, Puerto Rico, and nine Pacific Islands using daily data from the National Climate Data Center, Ashville, North Carolina. Climate stations selected are spaced on a 1° by 1° grid of latitude and longitude in the conterminous USA. This parameter database has been adapted for use with the EPIC model.

A first order Markov chain is used to generate the occurrence of wet or dry days from a four state array of wet-dry day probabilities. Precipitation amount is generated from a skewed normal distribution of daily mean precipitation for each of 12-monthly periods. Temperature values are generated from normal distributions of maximum and minimum temperature. It is assumed that the time series of these values is stationary with respect to the time period used in calculating the moments of these distributions from the raw climate data. Therefore, no trend is attributed to the generated time series of these elements.

Modification of the generator to simulated trends that may be present in the data is accomplished by calculating the linear trend of the raw data for precipitation and air temperature elements using

$$Y_i = a_i u_i + b_i \tag{1}$$

where Y is the yearly adjusted mean of the raw variate, u the year number from the beginning of the series, a the trend coefficient and b the intercept of the regression for $i = 1, 2, 3, \ldots, 12$ monthly intervals. Then, the trend coefficients a_is are entered into a version of the generator modified to calculate the yearly incremental adjustment for the respective monthly means. Long term simulations are run with incremental adjustments to the respective means with daily data generated in the EPIC model weather data format.

Trend calculations

Daily values of precipitation and maximum and minimum temperature were processed for nearly 1000 stations by a two pass method to fill in missing daily values. First the data were read and generator parameters were calculated for estimating the occurrence and amount of precipitation, and the minimum and maximum temperature for each of 12 monthly periods. Then the data were read again and the missing data generated using the statistical parameters calculated in the first pass. Next, monthly, seasonal, and annual linear trends were calculated for each station with complete records, observed and estimated using the procedures given above, for the 40-year period from 1950 through 1989. Trend coefficients, a, were calculated using equation (1). Average monthly temperatures were calculated from the maximum and minimum monthly values and trends calculated in the same manner. Two EPIC format climate files representing a changed and a no change climate were generated for each of the 69 sites selected for comparison.

RESULTS

For the purpose of comparison, models results within each state were averaged and the states grouped into regions representing the east, midwest, and south portions of the USA. The south region was the area bounded by the states of Alabama (AL), Arkansas (AR), Georgia (GA), Kentucky (KY), Mississippi (MS), South Carolina (SC), and Tennessee (TN). The midwest region comprised the "Cornbelt" states of Iowa (IA), Illinois (IL), Indiana (IN), Kansas (KS), Minnesota (MN), Missouri (MO), Nebraska (NE), Oklahoma (OK), South Dakota (SD), and Wisconsin (WI). The east region was represented by sites in Maryland (MD) and New York(NY)). Table 1 provides an annual summary of the climate change and no climate change scenarios for precipitation, runoff, evapotranspiration (ET), soil loss, and crop yield results calculated by EPIC. Percent change in precipitation between scenarios ranged from 6 to 45%, 4 to 37%, and 2 to 43% for the south, midwest and east regions, respectively. Similarly, corresponding increases in runoff, soil loss and crop yield resulted from the increased precipitation trends. However, in most states ET decreased.

Figures 1 and 2 compare the differences between the average values for the two scenarios for the three regions. Precipitation increases for the south were the largest, and as would be expected runoff, soil loss, and crop yield increase as well. Similar results with smaller magnitude of change were found for the other two regions. Figure 3 illustrates what happens when the temperature regime is modified to a cooler period before the normal planting date. This figure depicting a yearly ET distribution for a site in the east region (Maryland) evidences a one month shift in the peak ET rate from June until July.

DISCUSSION

The results of these simulation runs show the impact of the climate change scenario based on trends in the observed data. We recognize that the trends exhibited in the 40-year record of observed data may not continue into the future. Also, the technique of generating climate data using equation (1) should be limited to a period equal to that from which the trends were derived (in this case 40 years). However this method may be superior to the technique of adding a fixed percentage increase to each daily amount of precipitation or maximum and minimum temperature, because the stochastic nature of the time series was only modified by the trend for that monthly period. For example in Fig. 3, the distribution of the ET amounts shifted toward the later part of the year, indicating a cooler spring and summer in the changed scenario. A fixed percentage increase or decrease would not have indicated this feature in the simulation.

Figures 1 and 2 show in all cases that the climate change scenario increased runoff, soil loss, and crop yield. However, in Table 1, 14 out of the 19 values of average annual ET for all sites in a state decreased. The same effect can be seen in Fig. 2 for regional

Table 1 Average annual percent change in precipitation, runoff, evapotranspiration, soil loss and crop yield.

State	No. sites	Precipitation (%)	Runoff (%)	Evapotranspiration (%)	Soil loss (%)	Yield (%)
			South			
AL	2	44.9	86.5	2.2	56.1	33.5
AR	2	27.2	57.5	−4.6	43.9	50.1
GA	2	6.1	36.2	−9.1	36.1	19.1
KY	4	42.3	91.7	0.8	82.0	41.7
MS	5	41.4	72.4	−1.5	53.5	24.0
SC	3	19.6	45.3	−6.5	45.0	22.8
TN	9	30.2	59.7	−1.0	45.6	53.6
			Midwest			
IA	2	17.6	42.7	−5.5	33.3	20.7
IL	4	23.2	49.1	−1.5	41.5	31.5
IN	2	3.6	15.4	−10.0	10.7	22.6
KS	3	12.5	41.3	−0.8	38.8	46.2
MN	6	16.1	34.6	−3.2	22.5	58.6
MO	9	37.3	88.1	−1.5	83.9	29.1
NE	2	11.9	27.8	−4.5	26.7	26.7
OK	1	30.1	69.6	7.8	81.0	14.3
SD	1	7.1	30.1	2.6	24.9	161.5
WI	2	24.0	56.4	−9.1	34.0	52.6
			East			
MD	8	2.3	13.3	−8.2	19.3	19.9
NY	1	42.6	62.9	4.7	55.9	9.1

average ET estimates. The decrease in ET may be directly attributed to an increase in CO_2. In general terms, as suggested by Acock (1990), the increase in CO_2 increases stomatal resistance and decreases transpiration rate, with an increase in plant tissue temperature. Both the increased temperature and improved plant water use efficiency can increase crop yield. When the increase in stomatal resistance and the reduced transpiration rate are considered, quantitative estimates indicate savings of water of the order of 34% (Körner, 1993). Whether water consumption on a ground area basis is altered depends upon the extent to which parallel changes in leaf area index occur (Körner, 1993).

Table 1 appears to agree with these suppositions. However, these plant effects cannot be separated from increased precipitation and temperature in all cases studied. Contrastingly, in a previous study of climate change (Nicks *et al.*, 1994) where crops were not included, ET increased with increase in precipitation and temperature.

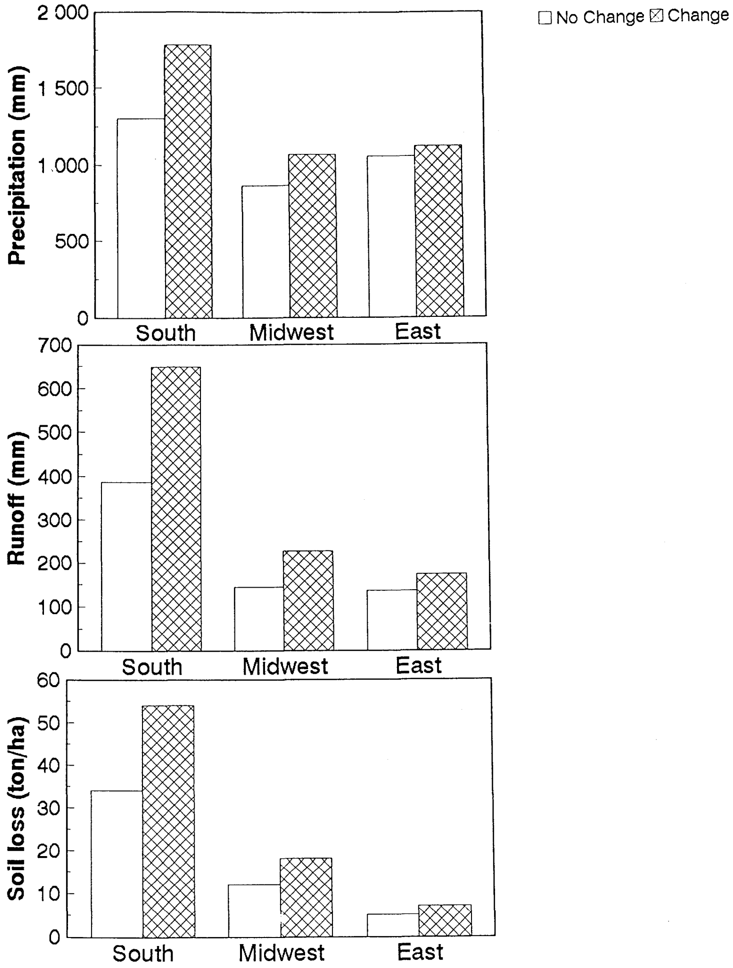

Fig. 1 Comparisons between regional average annual precipitation, runoff, and soil loss for climate change and no climate change scenarios.

CONCLUSIONS

Field survey data from 69 sites in 19 states were parameterized for EPIC model runoff, erosion, and crop yield simulations. Climate change and no change scenarios were constructed for each site using the CLIGEN weather generator. Monthly trends of precipitation and maximum and minimum temperature were used to generate a climate change time series. Additionally, atmospheric CO_2 concentrations were doubled from a present concentration of 320 ppm to a future concentration of 640 ppm. Results from these simulations were grouped by states into three regions of the US. In all cases, regional annual mean precipitation, runoff, erosion, and crop yield increased. In most cases, the ET decreased for individual state average ET, due to increased plant efficiency.

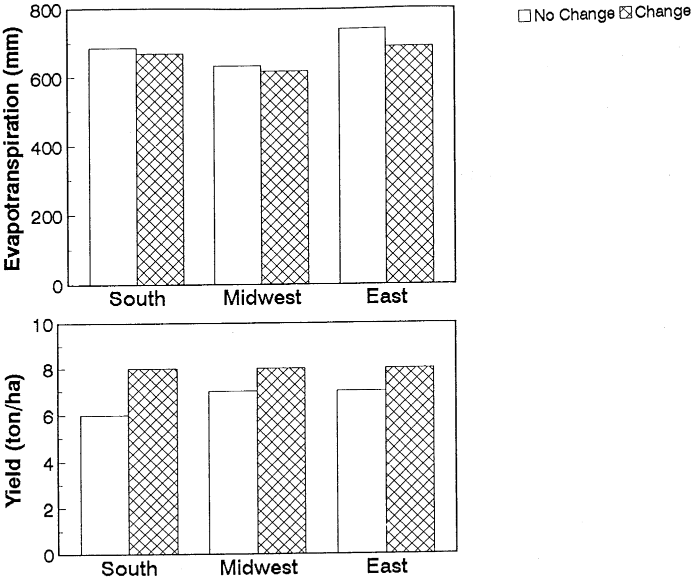

Fig. 2 Comparisons between regional average annual evapotranspiration and crop yield for climate change and no climate change scenarios.

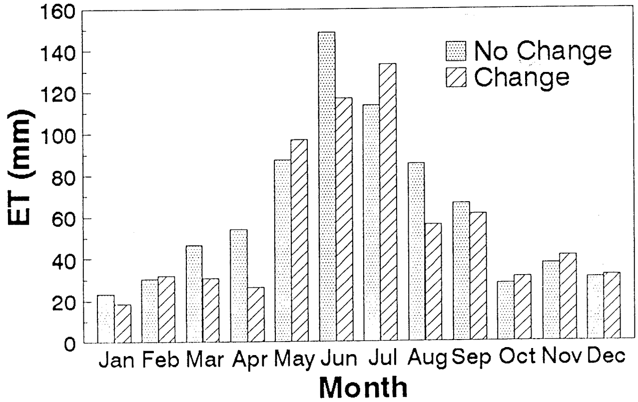

Fig. 3 Monthly distribution of evapotranspiration for climate change and no change scenarios for a site in the east region (Maryland).

REFERENCES

Acock, B. (1990) Effects of carbon dioxide on photosynthesis, plant growth, and other process. In: *Impact of Carbon Dioxide, Trace Gases, and Climate Change on Global Agriculture*, 45-60. ASA Special Publ. no. 53, Am. Soc. Agron., Madison, Wisconsin, USA.

Hansen, J. & Lebedeff, S. (1987) Global trends of measured surface air temperature. *J. Geophys. Res.* **92**, 13 345-13 372.

Körner, C. (1993) CO_2 fertilization: the great uncertainty in future vegetation development. In: *Vegetation Dynamics and Global Change* (ed. by A. M. Soloman & H. H. Shugart), 53-70. Chapman & Hall, New York, USA.

Knisel, W. G. (1980) *CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems*. US Dept Agriculture, Conservation Research Report no. 26.

Nicks, A. D., Lane, L. J., Gander, G. A. & Manetsch, C. (1993) Regional analysis of precipitation and temperature trends using gridded climate station data. In: *Advances in Hydro-Sciences and Engineering* (ed. by S. S. Y. Wang), vol. 1, Part A, 497-502. The University of Mississippi.

Nicks, A. D. & Gander, G. A. (1994) CLIGEN: a weather generator for climate inputs to water resource and other models. In: *Computers in Agriculture 1994* (ed. by D. G. Watson *et al.*) (Proc. 5th Int. Conf. ASAE), 903-909. Am. Soc. Agric. Engrs, St Joseph, Michigan 49085, USA.

Nicks, A. D., Williams, R. D. & Gander, G. A. (1994) Estimating the impacts of global change on erosion with stochastically generated climate data and erosion models. In: *Variability in Stream Erosion and Sediment Transport* (ed. by L. J. Olive, R. J. Loughran & J. A. Kesby) (Proc. Canberra Symp., December 1994), 473-478. IAHS Publ no. 224.

Sharpley, A. N. & Williams, J. R. (eds) (1990) *EPIC – Erosion/Productivity Impact Calculator* 1. *Model Documentation*. US Dept Agric. Tech. Bull. no. 1768.

Shiffer, R. A. & Unninayar, S. (1992) *The Detection of Climate Change Due to Enhanced Greenhouse Effect: A Synthesis of Findings Based on the GEDEX Atmosphere Temperature Workshop*. NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, USA.

Williams, J. R., Jones, C. A. & Dyke, P. T. (1984) A modelling approach to determine the relationship between erosion and productivity. *Trans. Am. Soc. Agric. Engrs* **27**, 129-144.

Williams, R. D., Nicks, A. D., Lewis, J. A. & Krider, J. N. (1993) Impact of vegetative filter strips on soil loss and water quality. In: *Proceeding of Conference XXIV*, 279-287. International Erosion Control Association, Steamboat Springs, Colorado 80477, USA.

Wischmeier, W. H. & Smith, D. D. (1978) *Predicting Rainfall Erosion Losses – A Guide to Conservation Planning*. US Dept Agric. Handbook no. 537, Washington DC, USA.