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THE COMPLEXITY OF MEASURING THE IMPACT OF POSSIBLE CLIMATIC CHANGE ON AGRICULTURE*

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INTRODUCTION

Much geological and paleontological evidence exists of major changes in climate over widespread areas of the world including Nebraska. What is now Nebraska was once warm enough to support flora and fauna found now only in tropical areas. During the last Ice Age the climate of what is now Lincoln was similar to Igvitut at the base of the large glacier covering most of Greenland.

Recent weather fluctuations and consequent variations in essential food (Newman and Pickett, 1974), fuel, and water supplies have prompted speculation that climate is changing toward some former extreme. Massive purchases of grain by the Soviet Union, fuel shortages in the eastern United States during the cold winter of 1976-77, water shortages in the western United States, record heat in northern Europe in the summer of 1976, and drought and famine in the African Sahel (Wade, 1974) are among the adverse effects of weather causing concern.

Some scientists report data suggesting that the Northern Hemisphere is cooling (Starr and Oort, 1973); others cite increasing atmospheric carbon dioxide from fossil fuels as a basis that the earth may be warming (Mitchell, 1970). There are those endorsing neither of these hypotheses who believe that a period of benign weather is ending and extreme fluctuation beginning (Thompson, 1975). There are also differing opinions concerning possible precipitation changes and whether they are random or cyclic and thereby hopefully predictable (Thompson, 1973).

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Nebraska is, in itself, a unique natural area to study effects of changes in weather and technology on agricultural production. It is large, relatively uniform, and gently rising from 1,000 feet elevation along the Missouri River to over 4,000 feet near Wyoming, 400 miles to the west. Precipitation and length of freeze-free season progressively decrease from east to west.

This region contains the marginal limits of adaptability for important grain crops. Western Nebraska does not usually receive enough precipitation to produce "dryland" corn. The growing season for the northwest half usually is too cool and too short to mature the more drought-tolerant grain sorghum. Variations in weather cause these limits to shift eastward or westward from season to season.

It is likely that agricultural manifestations of climate changes will first appear in transitional regions that contain the sensitive crop fringes. Most of the cultivated land in the Soviet Union, a region of particular interest since the 1972 grain purchase, is similar to the northern Great Plains in this respect.

Attempts to measure the impact of possible climate changes in such areas is severly limited by extreme weather variability and limited records. Technological advances and resource developments that have major impacts on crop production also make the problem more complex.

The discussion to follow will concern these complexities as related to climate and agriculture in Nebraska. Also discussed will be a computer method to conduct simulation studies involving different types of synthesized changes in climate.

VARIATION AND BREVITY OF WEATHER RECORDS

The effects of variations resulting in season-to-season shifts in the precipitation pattern and crop yields in Nebraska are quite evident in comparing precipitation and corn yields in the East, Central, and Northwest Crop Reporting Districts during 1973, a year of above normal precipitation, and 1974, a year of drought (Table I). During 1973 the annual precipitation was 38.95, 30.75, and 20.45 respectively for these districts. Dryland corn yields decreased respectively from 87.1 and 61.1, to a submarginal 31.0 bu/A in the Northwest District. The precipitation pattern shifted in the 1974 drought year and was only half the amount of the preceding year. The East District received about the same amount in 1974, as did the Northwest in 1973. Irrigated corn, well supplied with moisture, produced high stable yields over Nebraska in both years.

Presented in Table II are the results of an analysis of long-term records for three of the locations across the Corn Belt from North Platte, Nebraska near the western precipitation limit to Peoria, Illinois in its interior. Precipitation increases from 18.56 inches at North Platte to 39.94 inches at Peoria. The record maximum at North Platte has been about equal to the average at Peoria in the center of the Corn Belt, but the minimum at Peoria has never been as low as the average at the western fringe limit.

The C.V., a measure of precipitation uncertainty, decreases from the fringe to the interior. It is 28.1 percent at North Platte and 18.3 percent at Peoria. This statistic was used in the following formula to determine the number of years of record needed to measure a significant precipitation change:

$$n = t^2 c^2/p^2$$

where: n = number of years
t = level of significance
c = coefficient of variability
p = percent change

The number of years required decreases rapidly with the amount of precipitation change. Only eight years are required to determine a significant 20 percent change at North Platte compared to 775 years for a 2 percent change. The data also show that it would take over twice as long to determine a precipitation change at the fringe limits of the Corn Belt as in the interior. For example, 124 years are required to determine a 5 percent precipitation change at North Platte compared with only 52 years at Peoria.

IMPACT OF TECHNOLOGICAL ADVANCES AND RESOURCE DEVELOPMENT ON AGRICULTURAL PRODUCTION

Nebraska, unlike some lesser-developed regions embracing the variable crop adaptability fringes, has achieved a high level of production in spite of severe weather adversity. A portion of this phenomenal increase can, as in other states, be attributed to improved crop nutrition, the development of hybrids, control of pests, and better equipment facilitating more timely planting and harvest, as well as other technologies. Another important factor is the development of water resources for irrigation. The effects of improved management and irrigation are apparent in corn-production statistics for Hamilton County, the leading corn-producing county in Nebraska, during the 25-year period, 1950-1974. The acreage

TABLE I

Precipitation and Corn Yields in Nebraska in 1973 and 1974

District	1973 Precipitation inches	1973 Bushel per acre dryland	1973 Bushel per acre irrigated	1974 Precipitation inches	1974 Bushel per acre dryland	1974 Bushel per acre irrigated
East	38.95	87.7	116.5	20.45	25.9	101.3
Central	30.75	61.1	110.2	16.49	26.3	106.5
Northwest	20.45	31.0	93.0	11.88	20.0	87.5

TABLE II

Variability and the Number of Years Needed to Measure Significance of Precipitation Change in the Corn Belt

	Annual precipitation				Years needed to prove change*			
	Average	Minimum	Maximum	C.V.	2%	5%	10%	20%
North Platte (1878-1974)	18.56	10.01	34.44	28.1	775	124	31	8
Des Moines (1879-1974)	31.44	17.07	56.81	22.3	487	78	19	5
Peoria (1856-1974)	34.94	23.18	53.34	18.3	330	52	13	3

*5% significance level.

and yield for dryland and irrigated corn and the total production and yield per acre are summarized as averages for different five-year periods in Table III.

Corn production in Hamilton County increased from 4,383,000 bushels per year during 1950-54 to 17,332,000 bushels per year during 1970-74. Most of this four-fold production increase resulted from higher yield rather than increased acreages. Yield increases associated with improved technology were achieved under both dryland and irrigated systems of farming. Dryland corn yielding 29.1 bushel per acre during 1950-54 increased to 55.0 bushel per acre during 1970-74. Irrigated corn yields also doubled from 61.2 to 115.6 bushel. Water resource development accompanied by a shift from dryland to irrigated farming was of major significance. Dryland corn decreased from over 100,000 to less than 5,000 acres between 1950-54 and 1970-74, while irrigated corn increased from less than 25,000 to almost 150,000 acres.

Improved management has resulted in large production increases in other agricultural enterprises. For example, in the early 1950's Nebraska produced about 4,000,000 bushels of grain sorghum each year on about 225,000 acres. The yield was less than 20 bushels per acre. High-yielding hybrid seed became available in 1957. In the early 1960's over 1,500,000 acres were being planted producing over 100,000,000 million bushels of grain each year. Hybrids, yielding over three times greater, were also much more easily havested. This in turn increased production by stimulating an increase of an acreage.

Equally dramatic changes can be seen in the production of livestock. The census in 1931 reported 608,550 herd of cattle in the Nebraska Sandhills. Changes in land use and management have allowed cattle numbers to increase at a rate of 13,700 head per year since this time so that the cattle population had doubled to over 1,200,000 head by 1973.

Agriculture has developed through man's ability to select and create an increasingly favorable environment and to direct and hasten evolution in certain selected species. These effects have been far greater than the effects of any climatic change that may have taken place in the brief period of time since agriculture was first invented about 6,000 years ago.

Because of extreme weather variation, dramatic increases in production associated with technological improvements, water resource development and land use change, and the brevity of weather records, the historic data available is not of sufficient length to measure the effect of any climatic cange that has or may be taking place.

Sufficient data are available, however, to construct statistical models to determine the responses of crops to weather variations and to model climatic change by computer. This enables simulation studies of the expected crop response over a hypothetical period of years during which synthesized climatic changes occur. The effects of different types and rates of change can thereby be studied. This contributes to planning for change and, hopefully, an earlier recognition of a type of change that may be occurring.

SIMULATION OF CLIMATIC CHANGE

Temperature Response Models

There are threshold temperatures below which specific crops do not grow. Plant growth and development are closely

TABLE III

Acreage, Yield, and Total Production of Corn in Hamilton County, Nebraska, 1950-1974

	Irrigated		Dryland		Total	
	Acres (ooo)	Yield (bu)	Acres (ooo)	Yield (bu)	Production (ooo bu)	Yield (bu)
1950-54	22.6	61.2	101.8	29.1	4,384	35.2
1955-59	74.0	73.6	35.8	27.6	6,287	57.5
1960-64	86.9	84.8	16.5	42.0	8,148	78.6
1965-69	102.0	110.2	3.3	55.2	11,428	108.4
1970-74	147.5	115.6	4.6	55.0	17,332	113.8

*Nebraska State-Federal Crop and Livestock Reporting Service, 1925-1974. Agricultural Statistics. Nebraska Department of Agriculture, Lincoln, Nebraska.

related to the accumulation of temperature above this threshold. A system called "growing degree days" based on this relationship can determine the expected crop development response using daily temperature data for a location of interest. Growing degree day models are also used to follow crop progress and forecast its development from temperature accumulations during a particular season. Such models have been constructed for different corn and grain sorghum hybrids commonly grown in Nebraska (Neild and Seeley, 1977).

Synthesized Climate

A magnetic tape file of historic daily weather records for a 50-year period, 1925-1974, from David City in Butler County was used to synthesize two different types of climate change resulting in a 2°F decrease in the average annual temperature over a 50-year period. One kind of change, Type I, was generated by lengthening the "cold spells" or the series of consecutive days in each of the 50 years when the temperature was below normal. Type II was generated by increasing the amplitude of the negative daily temperature departures in each of the 50 years. The assumptions for these changes were that conditions resulting in below normal temperatures in the past would have similar but greater effects if the climate were to change in the future. There are, of course, numerous types of change that can be synthesized: increasing or decreasing temperature at different rates, greater daily or seasonal variability in temperature, and changes in temperature in combination with various precipitation changes. Effects of these changes on crop development as well as yield can be simulated and studied.

This report is limited to simulations of the development response of corn planted May 15 using the actual daily records from 1925-1974 and the synthesized Type I - 2°F and Type II - 2°F changes. The development model determines the date when various different stages would have occurred in these data sets and shows the number of times the crop did not mature because the season was too cool and/or short. The simulation involved a hybrid and planting time best suited to Butler County. The simulation using actual 1925-1974 data shows the crop would develop completely and mature before the first fall freeze in all years. The Type I - 2°F simulation showed that the crop would not have matured in two of the 50 years. The Type II - 2°F simulations showed that the crop would not have matured in 12 of the 50 years.

A type II change would have a drastic effect upon agriculture. Major and rapid adjustments would be required to avoid catastrophe. A Type I change would be subtle, much less drastic and not easily recognized. It seems reasonable to speculate that a Type II change was responsible for the sudden extinction of large herbivores owing to starvation. Such conditions would not permit migration or adaptations to take place in sufficient time to adjust food supplies suddenly limited by rapid year-to-year succession of untimely and early frosts.

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