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staff paper

A METHODOLOGY FOR
MEASURING THE DIRECT IMPACT
OF WEATHER ON AGRICULTURE

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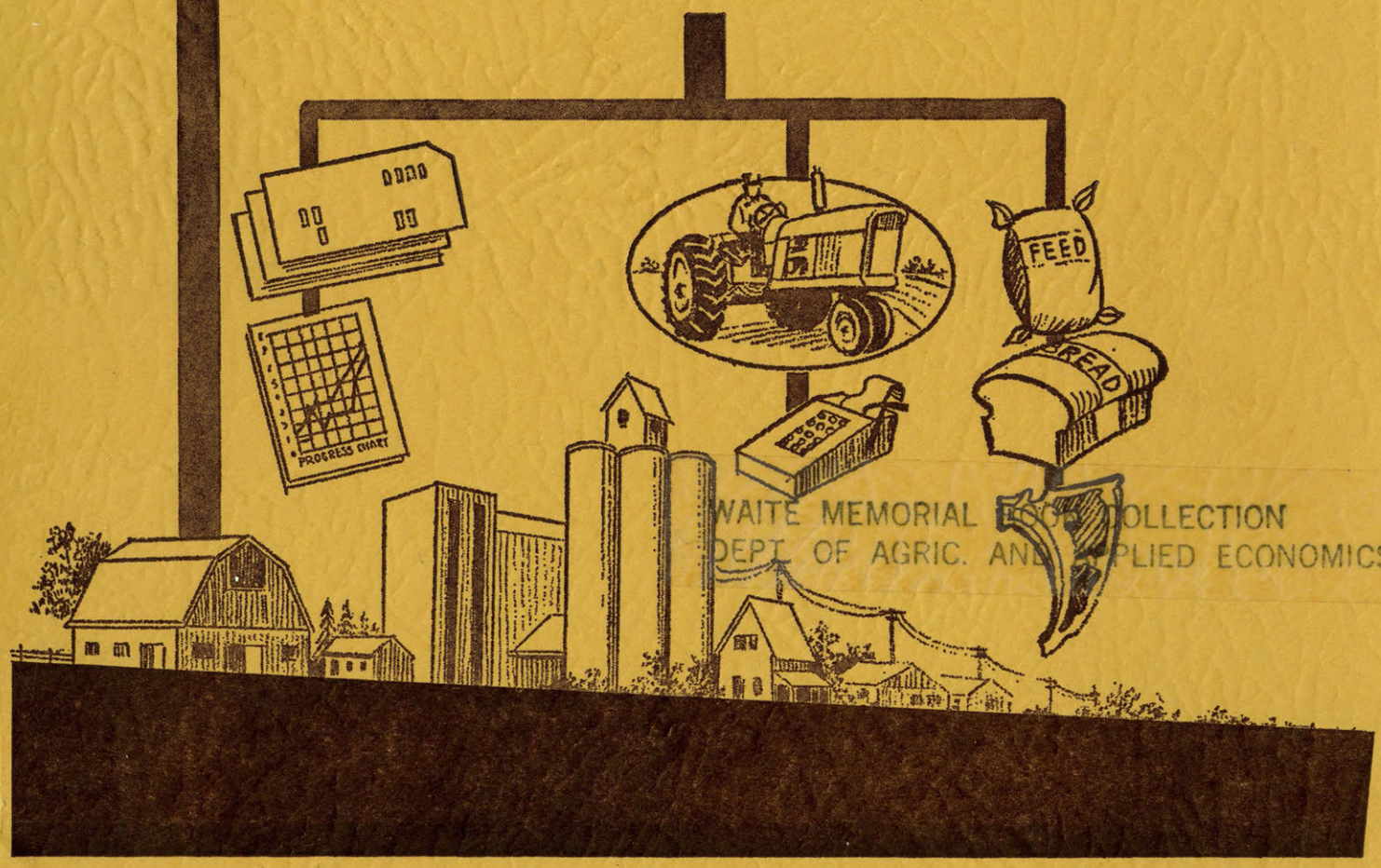

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MEASURING THE DIRECT IMPACT OF WEATHER ON AGRICULTURE

I. Introduction

Alternations in climatic conditions can directly affect agricultural production, such as a late freeze, an early frost, a hail storm, a rainy planting season, a rainy harvest season, a hot and dry growing season, or prolonged wet conditions. To be sure, the economic consequences of a weather variation can be significant. For example, in a retrospective evaluation of the 1980 heat wave and drought conditions, the Center for Environmental Assessment Services of NOAA/EDIS--U.S. Department of Commerce estimated crop and livestock destruction across the U.S. at between 13 and 16 billion dollars. Nebraska suffered approximately a 30 percent loss in corn production (valued at $663 million), a 15 percent loss in soybean production (valued at $57 million), and a 24 percent loss in sorghum production (valued at $173 million) [Center for Environmental Assessment Services, 1981].

Moreover, the direct agricultural impacts from aberrant weather conditions, lead to secondary effects for related agribusinesses. These impacts may result in significant losses in business volume, employment, investments and income. The magnitude of direct agricultural and secondary economic impacts will depend upon the magnitude, duration and geographical extent of the weather variation.

An important and related matter is the various income transfer programs available to the agricultural sector. These

programs consist of governmental programs such as disaster payments, government loan programs, and private and governmental crop insurance programs. Essentially, the economic impacts of a weather variation, without accounting for transfer payments, reflect the true economic value to society of the change (from average) in weather conditions. However, if one accounts for transfer payments, the economic impacts will be reduced and the agricultural sector will incur a reduced burden, because other elements of society share the costs associated with aberrant weather through income transfers. These benefits of transfer payment programs are probably not equally shared by those incuring the cost of the weather variation. For example, the transfer payment programs are an income transfer to farm-firms and not necessarily to agricultural suppliers, handlers and processors who have probably lost sales due to the weather variations.

In summary, weather variability not only has significant impacts on agricultural output values and incomes, but translates into secondary impacts through interindustry sales and services. The severity of the direct impacts ultimately determines the magnitude of secondary impacts. The lack of timely and reliable information on the extent of direct impacts may mean that the secondary impacts are greater than they would need to be, given that alternative responses exist.

For the farmer, major adjustments in input mixes, cropping patterns, etc., would require weather information for the season, prior to planting. If reliable (high probability) forecasts could be provided, the cost associated with aberrant weather

could be reduced. Moreover, farmer-operator responses to timely and reliable weather forecasts, when transmitted to agribusinesses, would translate into additional economic adjustments. Input suppliers could adjust inventories, for example, while grain processors can adjust storage and transportation facility plans. The impact of these adjustments also has public policy implications, such as disaster program planning and tax revenue projections. However, seasonal weather forecasts presently cannot be made with sufficient reliability to justifiy a priori adjustments on the part of the public or the private sector.

Of what use then is information on the economic impact of weather variability? Economic impact data is useful for two primary reasons: First, these data can provide public policy officials with a better basis for diaster program planning, tax revenue forecasting and related activities. Second, such information can lead to more efficient and, hence, profitable decisions on the part of agribusinesses.

To provide useful economic impact information to private and public decision makers a careful and thorough analysis of exactly how aberrant weather conditions impact on agriculture and agribusinesses must first be undertaken. However, to make such a study manageable, but reliable, the geographic area of study must be representative.

The state of Nebraska is an area well suited for weather impact analysis. Nebraska's climate is diverse from west to east and highly variable from season to season. The extreme

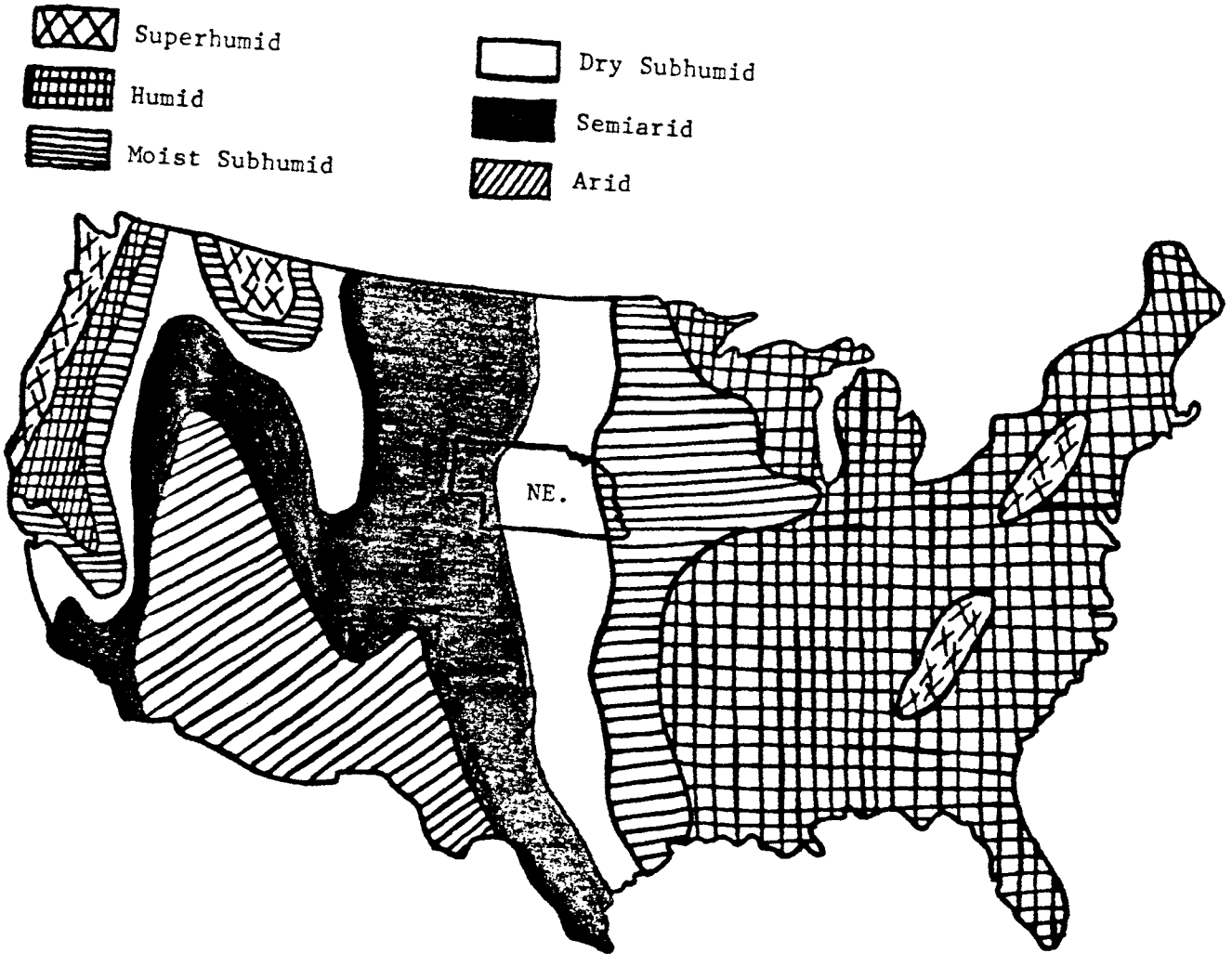
variability in climatic conditions over time and across the state, reflects the fact that Nebraska is positioned in the Central Great Plains. The State exists within the transition zone between dry-subhumid and semi-arid regions (see Figure One). In addition, southeastern Nebraska is approximately 1,000 feet above sea level, while the Panhandle (western) area has elevations of 4,000 to 5,000 feet. Both the above factors affect temperature and precipitation variables across the State. The long-run annual average precipitation for the southeast is over 30 inches, while in the west the long-run annual average is less than 15 inches. With respect to temperature, the annual average for the State is 50 Degrees F., ranging from a January mean of 23.5 degrees to a July mean of 76 Degrees Farenheit. In addition, the topography of the State has its impact upon the length of the growing season across the State.

Agriculture is the State's economic sector most affected by weather variability, with a growing season averaging over 170 days in the southeast to less than 120 days in the northwest [Leholm, 1981]. Moreover, Nebraska agriculture is quite diverse, including many different crops under both dryland and irrigated conditions.

Finally, agriculture is Nebraska's largest industry. Approximately 93 percent of Nebraska's total land area is directly used in agricultural production, with more than half of this land area classified as cropland [William, H. H., and D. Maurfield, 1977]. On the basis of cash receipts from farm marketings, Nebraska had total cash receipts of more than $6 billion for 1979 and was fifth among the states of the U.S.

Figure 1

U.S. Climatic Zones



Generalized normal distribution of the principal climate types in the U. S. (C. W. Thornthwaite, 1941, Atlas of Climate Types in the United States, 1900-39).

[Nebraska Crop and Livestock Reporting Service]. A recent study entitled The Economic Integration of Nebraska's Agricultural-Industrial Complex considered the significance of the total agribusiness complex on such aggregate economic indicators as employment, income and output. In 1976, the agricomplex employed 30 percent of the State's total civilian labor force, and produced approximately 26 percent of the State's gross private output. In addition, approximately 28 percent ($2.74 billion) of Nebraska's total personal income of $9.85 billion for 1976 came from the agricomplex and associated activity [Lamphear, 1979].

In 1977, irrigated acreage in Nebraska (5.75 million acres) accounted for approximately 37.3 percent of cropland acreage for the five principle crops (corn, grain sorghum, soybeans, alfalfa, and wheat). Under status quo conditions, this acreage is expected to increase to over 13 million acres by 2020, or 68.4 percent of cropland acreage for the five principle crops (Nebraska Natural Resources Commission, 1981).

Irrigation contributed significantly to reducing the production impact associated with weather variability, however, at a cost of increased input usage (energy for example). The remaining dryland acreage is especially subject to weather impacts with resultant effects on crop output values, net farm income and regional economic impacts.

II. Research Objectives

With Nebraska as the chosen study area, an investigation was undertaken that included the following objectives.

1. To analyze the impact of selected aberrant weather conditions on agricultural production, farm income and farm input use in Nebraska;
2. To assess the impact of insurance and income transfer programs on the economic impacts from aberrant weather conditions; and
3. To measure the sensitivity of weather induced economic impacts to selected variables such as commodity prices and amount of irrigated acreage.

Since the analysis required to answer the above objectives was quite extensive, this report includes only the study's methodology. Results of the investigation are presented in separate reports.

III. Overview of Methodology

To assess direct impacts on the agricultural economy of Nebraska, the study was based on a partial equilibrium framework. This means that the effect of weather on selected economic impact variables was estimated as a function of certain weather parameters, given crop prices, irrigation development, water application, farm programs, time, etc.

In implementing the partial equilibrium approach, the following step-by-step procedures were undertaken:

1. Historical climatological and crop production statistics for the state of Nebraska were evaluated to determine the types of non-average weather situations most significantly affecting the agricultural sector;

2. Weather parameters and impact variables appropriate for measuring the effects of weather variability on the agricultural sector were determined;
3. Changes in crop input requirements, and the resulting aggregate output values for a non-average weather situation, were calculated;
4. Direct economic impacts due to a certain specified non-average weather situation were calculated; and
5. Finally, available data and information on income transfer programs were evaluated to determine their effects on reducing the economic risks associated with weather variability.

The methodology for each of the above areas is discussed below in the same order as just presented.

Original recorded weather data consists of values about a weather phenomenon for a specific location and time, and are recorded at a specific frequency. From Nebraska's 400 weather stations, a large amount of climatological data are available through the Oklahoma Climate Survey, Norman, Oklahoma. These data consist of (for example) daily temperature and precipitation, number of freeze days, growing degree days, and drought indices. The data are available in several forms. These data were evaluated, along with crop production statistics from Nebraska Agricultural Statistics and other secondary data sources, to determine the types of weather situations which have historically affected agricultural production in Nebraska. Literature review, descriptive statistics and correlation

analysis were used to describe non-average weather situations common to Nebraska. These weather situations can consist of singular events, or multiple event situations which may result in greater direct agricultural impacts. Table 1 lists various types of singular and multiple event, non-average weather situations. As a matter of clarification, it should be remembered that those situations listed under the column for single weather events assume that for any single event that occurs, average weather conditions prevail for the remainder of the season.

TABLE 1

WEATHER IMPACT EVENTS

Single Weather Events:	Multiple Weather Events:
A colder-than-normal Spring	Wet Spring with a Colder-than-normal Spring
A colder-than-normal Fall	Wet Spring with a Dry Summer
Wet Spring	Dry Summer and a hot Season
Wet Summer	A colder-than-normal Fall and a colder-than-normal Spring with Precipitation below-Normal
Wet Fall	
Dry Spring	
Dry Summer	
Dry Fall	
Hot Season	

For each of the non-average weather events, weather data were used to construct appropriate weather parameters, i.e., precipitation during the growing season (May 1 to Sept. 30), or deviation of precipitation from normal during the growing season, to represent either a wet or dry summer; the number of growing

degree days during the growing season to represent a hot or cooler-than-average season; and the length of the frost free season from the latest spring freeze or an early fall freeze, etc. These weather parameters were then used to estimate the effect on direct impact variables of changes from average weather conditions. In other words, the weather parameters establish the behavorial linkage between weather and direct impact variables.

The direct impact variables that were measured consisted of both farm output and input variables (Table 2). Changes in the value of crop production, and more specifically, changes in net farm income provided a measure of the change in the welfare of the farm sector due to the aberrant weather conditions. Changes in input usage, however, provided a measure of the direct effects on the non-agricultural economy. These effects are useful in determining total regional economic impacts.

Stochastic models were constructed to determine the various behavioral relationships between yields per acre (by crop), cropping patterns, and non-average weather events. Input usage and associated production costs were computed through the use of deterministic "end use" or engineering cost relationships. Aggregate input and output value changes due to non-average weather events were simulated, making use of the above behavioral and

TABLE 2

DIRECT IMPACT VARIABLES

Value of Production/Crop:	Value of Production Inputs:
Dryland and Irrigated	Fertilizer
Corn	Other Chemicals
Grain Sorghum	Energy
Soybeans	Labor
Wheat	Other Inputs

Net Farm Income: Before Weather Induced Transfers

Net Farm Income: After Weather Induced Transfers

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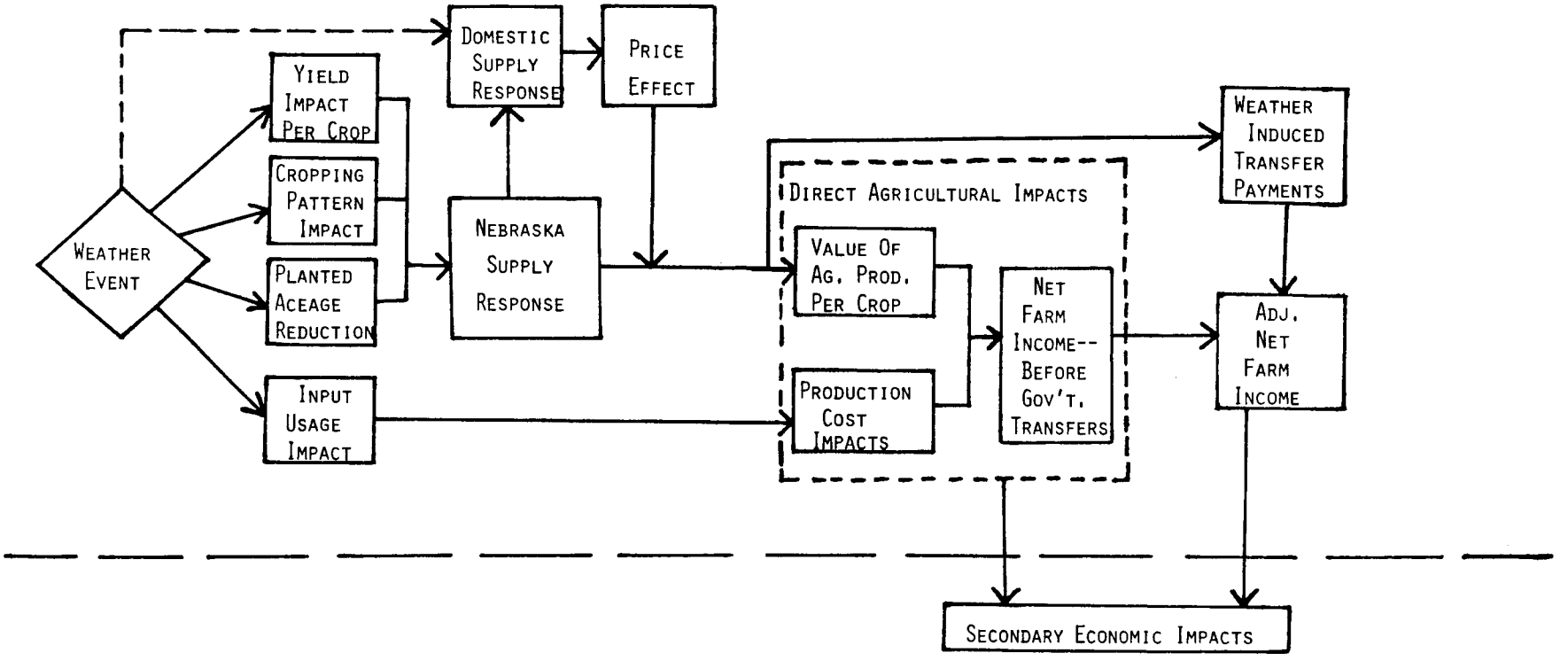
deterministic relationships. The direct impacts resulting from the assumed non-average weather event were determined by computing the differences in aggregate input and output values between the simulation results for the average weather year and the non-average weather year.

As an aid in understanding the overall methodological overview, Figure Two illustrates the inter-relationship between the exogenous weather events and economic impacts.

The discussion of model development that follows focuses on a measurement of direct impact. Estimates of direct impact can then be used within, say, an economic input-output framework to calculate secondary or indirect impacts. The use of input-output models to capture secondary effects is covered in several other reports prepared by NOAA.

FIGURE 2

METHODOLOGICAL OVERVIEW



IV. Model Specification

As noted in the previous section on methodology, direct agricultural economic impacts for any year consist of differences in (1) the value of production by crop and (2) production inputs between average and non-average weather conditions. These differences, as indicated by Figure Two, include a yield response impact, a cropping pattern impact, a planted acreage reduction impact, i.e., crop acres intended to be planted that never get planted, an input usage impact and a potential price effect. (Not included here, but a relevant impact, are those acres planted but not harvested due to 100 percent destruction by hail, fire, flood, etc.) The yield, cropping pattern, planted acreage reduction and input usage impacts are physical effects directly related to the non-average weather conditions that may occur within a crop season. The price effect is a monetary impact that may or may not be directly related to the non-average weather conditions. If the non-average weather event, is geographically isolated, the effect on, say, corn price is likely to be non-existent. However, if a drought condition (for example) is more widespread,including a multi-state impact area, the domestic price of corn would most likely increase (assuming constant demand). Alternatively, a small region, such as Nebraska, could incur average weather conditions, but receive the benefits of a domestic price increase due to widespread non-average weather conditions occurring elsewhere.

To estimate the direct agricultural impacts of non-average weather events, it was necessary to model the separate impacts associated with (1) yields, (2) cropping patterns, (3) planted

acreage reduction, (4) input usage, and (5) price effects. The first three impacts were measured econometrically, while input usage and price effects were measured deterministically. It should be noted here that the overall analytical construct is designed to permit the substitution of the deterministic model with the Missouri agricultural model for measuring price effects.

The remainder of this section is devoted to a discussion of the conceptual and empirical modelling effort that was associated with each of the above impacts.

Yield Impacts

An enormous amount of research and literature has been devoted to the estimation of crop yield response functions, relating crop yields to both technological and weather parameters. A generalized expression of a crop yield model is

$$Y_i = F_i(I_i, W_i)$$

where Y_i represents crop yield per acre, I_i represents production inputs, W_i represents weather related inputs, and the functional form specifies the annual technology used to produce the particular crop.

Such a function could be estimated using cross-section data. Given the availability of data on the necessary inputs, the static model would measure the impact on crop yield changes due to changes the weather parameters, assuming constant technology. Thus, it would not explain yield changes over time due to technology. With such changes, the functional form would be expected to change with technological progress. (Pope, C.

Arden, III, and Earl O. Heady, October, 1982).

An alternative specification is a system of equations incorporating a functional relationship explaining technological progress, using time series data. The generalized form would look like the following (modified from Pope and Heady, October, 1982):

$$T_t = F_t(EPC_{it}, EPR_{it}, ED_t, P_{lt}, S_{mt}, O_{nt})$$

$$Y_{it} = F_{it}(T_t, W_{it}).$$

where:

T_t = the level of technological progress in time (t).

t = time.

EPC_{it} = current and lagged levels of public expenditures on agricultural R & D.

EPR_{it} = current and lagged levels of private expenditures on agricultural R & D.

ED_t = educational level of farmers in time (t).

P_{lt} = political factors.

S_{mt} = social factors.

O_{nt} = all other factors that effect technological progress.

Y_{it} = yield/acre per crop in time (t).

W_{it} = various weather parameters in time (t).

As explained by Pope and Heady, this theoretical model cannot be empirically estimated because of the lack of adequately

defined, observed or quantifiable measures of most of the variables. For those who have attempted to measure technological progress, variables such as public expenditures or private expenditures on agricultural R & D have been used as proxy variables. The rational for using such variables has been that since agricultural productivity has steadily increased over the past several decades, any variable that is highly correlated with time is also highly correlated with technological progress and, therefore, an appropriate proxy. However, Pope and Heady point out several problems with using such proxy variables to measure technological progress. One, because of the autoregressive nature of public or private expenditures on agricultural R & D, a linear function of time would provide a closer approximation. A second problem relates to serious specification error inherent in using pulbic investment in agricultural R & D alone to model technological progress. The result is bias in the relationship expressed between yields and public expenditures on agricultural R & D.

Pope and Heady provided three conditions that must be met before a variable can be considered a good proxy for technological progress: (1) "reasonably accurate data on the variable can be obtained over time," (2) the variable "is highly correlated with technological progress," and (3) the variable "is not highly correlated with time." Pope and Heady concluded that when the first two conditions hold, but the third condition does not, it is more appropriate to use time as a proxy for technological progress.

For the second set of determinants of yield response functions, a review of the literature provides some guidance as to the specification of weather parameters. Research estimating the influcence of weather variables on yields of various crops using simple regression analysis dates back to the turn of the century. Multiple regression analysis using curvi-linear relations were being used by the latter 1950's. The usual specification of weather parameters included variables for both temperature and precipitation, separately, with technology represented by a time variable. By the 1960's, efforts were concerned with the interaction of weather variables. This was usually accomplished by specifying a weather index variable. (Stallings, James L., 1961 and Shaw, Lawrence H., February 1964) The weather index variable was typically expressed as the ratio of actual yield to a trend estimate of yield based on the use of experiment station data where technological factors were assumed controlled. The ratio was assumed to express the variability in yields due to weather variability. However, the disadvantage of this technique is that the use of experiment station data to estimate yield trend is a poor estimate of the technological factors inherent in regional or statewide yields.

In 1965, research by Bernard Oury concluded that the interaction of temperature and precipitation in the determination of crop yields could be specified by an aridity index, i.e., the ratio of precipitation to temperature (Oury, Bernard, May 1965). The use of an aridity index did not, however, adequately account for the "water balance" available for crop growth. In other words, precipitation and temperature alone, do not determine the

available moisture for crop plant growth. A certain amount of precipitation is consumed through evaporation from the soil surface, and in addition, plants lose water through transpiration during warmer temperatures, a certain amount of precipitation percolates below the crop root zone, and some precipitation is accounted for as run-off. However, Oury justified the use of a more simplified aridity index as a variable incorporating the interaction between temperature and precipitation until more sophisticated crop moisture indices become available that measured the total areal water balance situation (including the evapotranspiration process).

In 1966, research reported by Earl Heady and Ludwig Auer imputed crop yield responses for several technology variables after estimating a state crop production function which included a variable for weather and several technology factors. (Heady, Earl O., and Ludwig Auer, May, 1966) Weather was measured through the use of an index of the form previously mentioned, while the technology variables included a variable to measure crop variety improvements through a hybrid index, and fertilizer response through the use of nutrient-response functions. However, the limitation/disadvantage of this approach lies in the fact that the weather and technology variables are all estimated through the use of experiment-station test plot data. Even given the availability of such data, it is unlikely the information resulting from the estimation of such state crop production functions would be useful in determining economic impacts associated with statewide non-average weather events. Experiment

station data do not reflect the existing statewide crop production technology.

In the early 1960's and early 1970's, assessment of weather variability in yield response functions returned to the use of temperature and precipitation variables. Lois Thompson conducted research evaluating both weather factors and technology in the production of corn, soybeans, grain sorghum and wheat at the state level. (Thompson, Louis, 1969, 1970, 1975) Technology was specified as a trend variable, and temperature and precipitation were specified as deviations from normal with each related to yield in a parabolic pattern. In other words, temperature and precipitation were each entered in the estimation equation as deviations from normal, and in squared form to form the quadratic relationship for each weather variable. By holding all other variables constant, except for one weather variable, Thompson generated paroblic relationships for each monthly precipitation or temperature variable (expressed as deviations from normal). With the use of these relationships, Thompson was able to estimate the implications on yield response per crop for alternative deviations from normal, with respect to both temperature and precipitation variables, for any month (June-September). The limitation of Thompson's research is that it did not concern itself with cropping pattern impacts. In addition, yield response was measured on a statewide basis, with the consequent problem of aggregation inherent in such a method. However, because of the model's applicability to measurement of yield response to non-average weather occurances at different times of the growing season, Thompson's model was updated by the

Center for Climatic and Environmental Assessment, Columbia, Missouri after being modified to include an aridity index to replace precipitation and temperature variables for a particular month. The aridity index was computed by subtracting monthly potential evapotranspiration, using Thornthwaite's method, from monthly precipitation, or by dividing monthly precipitation by potential evapotranspiration. In addition, a temperature stress variable (degree-days above 90°F.) was included for the period approximating the time of plant heading.

In addition to being concerned with the correct specificiation of weather parameters in yield response functions, past literature indicates a concern with whether crop yields are random or "bunchy" over time, i.e., whether cyclical weather patterns have existed to produce cyclical patterns in yields, and whether crop yields have reached a plateau. In analyzing average yield data for the U.S. and several states, for wheat, corn, rye, barley and oats for the period 1866 to 1974, Luttrell and Gilbert concluded that there was little evidence of the existence of cycles or bunchiness. (Luttrell and Gilbert, August 1976) However, Black and Thompson, after analyzing yield data for several states with respect to drought periods that correspond to the upswing of the 11-year sunspot cycle, concluded that some empirical evidence supports drought cycles for corn, soybeans and wheat yields. (Black and Thompson, August 1978)

Lin and Seaver analyzed U.S. average yields for 19 crops for the period 1960-1977 and concluded that for 12 crops (including corn, wheat, oats and barley) yields were stationary, i.e., they

had reached a plateau. (Lin, Kuang-hsing, T., and Stanley K. Seaver, December 1978) Yields for soybeans, however, along with five other crops, were non-stationary, indicating no plateau. In contrast, research by Swanson and Nyankori studied corn and soybean yields for the period 1950-1976, acquired from the Allerton Trust Farms in Piatt County, Illinois, in addition to Piatt County yields. (Swanson, Earl R., and James C Nyankori, 1979) The authors concluded that weather factors did significantly effect yields during this period, and because there was no significant difference between linear trend equations incorporating technology and weather, and non-linear specifications, it was concluded that yield patterns have not reached a plateau. In addition, after comparing Allerton Trust Farm yields with Piatt County yields and finding that the Allerton Trust Farm yields were consistently higher by a significant margin, the authors concluded that a stock of economical, but unused, technology exists for yield potential.

From the above review, it is appropriate to conjecture that the literature is inconclusive as to whether yields are random or bunchy. However, additional research incorporating technological factors provide an indication that crop yields have probably not reached a plateau.

Perrin in 1968 used a polynominal function to estimate corn and grain sorghum yields at the state level. (Perrin, Richard K, 1968) The author included variables for nitrogen application rates, an index of hybrid adoption, a hybrid index and several weather variables. The conclusion of the research was that yields would likely continue on an upward trend. In addition, S.

H. Wittwer in 1977 reviewed numerous possibilities for technological advances that could increase crop yields. (Wittwer, S. H., 1977) These technologies include increases in photosynthetic efficiency, nitrogen fixation, nutrient absorption and improved fertiizer utilization, stress resistant varieties, pest and disease resistance, chemical growth regulants, and on-farm management potential.

From the above review of literature, it would be appropriate to conclude that weather parameters are an essential component of the explanation of the variation of past yields. Weather parameters are, therefore, an essential component of any theoretical model explaining crop yield variations over time. In addition, the model specification should incorporate the interaction between temperature and precipitation phenomena as a critical element effecting crop plant growth. However, the literature review provides no definitive answer as to how weather parameters are to be incorporated into a theoretical specification of a yield response model. The answer to this question depends primarily upon the purpose of the model estimation, i.e., the use of the model after estimation.

Given the objectives of this research study, as outlined earlier, and the broader objectives of the NOAA research project, i.e., development of the capability to assess the direct agricultural and secondary economic impacts associated with recent and near-term future abnormal weather events, the model developed for this study focuses on an ex-ante analysis of abnormal weather events. The theoretical specification of the

crop yield response model in generalized form is:

$$Y_{it} = F_{it}(T_{ht}, W_{pt}, TW_t, Z_t)$$

where:

Y_{it} = yield per acre per crop (i), per time (t).

T_{ht} = time trend variables for different historical periods explaining different rates of technological progress.

W_{pt} = weather parameters for both temperature and precipitation and there interaction.

TW_t = interaction between weather parameters and technological factors.

Z_t = random error

As for the time trend variable, technological progress has not been constant over the last thirty years. The introduction of various productivity increasing factors at different times and their interaction with weather conditions has resulted in the technological factor varying over time. Due to public and private R & D, the educational level of farmers and other factors discussed earlier, technology at the farm level has included the introduction of hybrid seed varieties, the application of fertilizers, herbicides and insecticides, machinery and equipment improvements, management practices involving the timing of operations, row spacing of crops, and contouring, etc. In analyzing U.S. average corn yields from 1950 through 1980, James McQuigg isolated several technology trends. (McQuigg, James D. 1981) From 1950-1969, corn yields increased steadily, but with small year-to-year variability. McQuigg attributes the steady increses, during the period 1950-1959, principally to the

increased use of hybrid seeds, and the increases in yields from 1960-1969 to increased use of fertilizers. The leveling off of U.S. average corn yields during the period 1970-1976 is atributed to the leveling off of fertilizer application. The increases in yields since 1976 is attributed to increased usage of fertilizers during this period.

With respect to weather parameters, a number of issues effect how and what meteorological variables are specified to explain the non-trend yield variability. These issues consist of aggregation effects geographically, and over time, interaction between meteorological variables, the applicability of the results, and the weather events to be measured.

The applicability of the approach used by Lois Thompson, in specifying both monthly temperature and precipitation variables as deviations from normal, and in quadratic form, has practical and theoretical merit. For any particular crop and region, intuition tells us that too little as well as too much rain, and that temperature stress as well as excessively cool weather is harmful to crop plant growth. For most crops, for a small amount of precipitation that has already occurred, water is considered scarce and additional water will increase yields at an increasing rate. At higher levels of available moisture, additional water increases yields at a decreasing rate until a point of soil saturation is reached and, this condition can, over time, cause yields to decrease. A similar relationship exists for temperature. As a result, the bell-shaped relationship between yield and an individual weather variable can be measured by a

quadratic function. The expectation would be that the coefficient for the linear term would be positive and the quadratic term negative. As a practical matter, specifying temperature and precipitation variables as deviations from normal on a monthly basis, provides an ability to measure the impacts of alternative weather events, either singular or multiple events per season. In addition, specifying the variables as deviations from normal, the meteorological impact for different crops and weather events has a common reference point.

With respect to aggregation, both the geographical extent and time-frame over which meteorological variables are specified, effect their ability to explain the non-trend yield variability. Temperature and precipitation vary over geographical space. Determination of an average value to represent a broad geographical area can nullify significant meteorological impacts at smaller district levels. The average for the larger area may be close to optimum, due to one or more smaller regions having an extreme value, when most geographical areas are realizing significant non-average weather conditions. The solution to the geographical aggregation problem, inherent in most past research at the state or national level, is estimating the yield response model for smaller substate regions. This study, however, estimated crop yield response models for each of the Nebraska Crop Reporting Districts (CRDs). These districts were organized, taking into account both agricultural and meteorological factors. Even though weather conditions do vary within a region, estimating yield response models at the CRD level appears to be a reasonable compromise, as opposed to estimating models for a

large number of counties, or at the state or national level with aggregation bias.

With respect to time, aggregation bias is incorporated into the estimated coefficients as a result of specifying seasonal weather parameters. This approach does not give appropriate weight to the impacts that various weather conditions have on the phenological growth stages of a crop. Again, the solution to this problem is a compromise position, i.e., specification of the temperature and precipitation variables on a monthly basis provides the ability to isolate, somewhat, alternative crop growth stages. The alternatives would be to specify such variables on a weekly or seasonal basis. In the first case, the loss of degrees or freedom due to the large number of explanatory variables effects the reliability of the parameter coefficients. On a seasonal basis, aggregation bias is incorporated into the parameter coefficients because of an inappropriate weight given to the occurance of an extreme value of a weather parameter not corresponding to phenological requirements. Even though calender time may not always correspond with phenological time, specifying weather parameters on a monthly basis appears to be the appropriate compromise.

As noted earlier, interaction between temperature and precipitation is an essential element of crop plant growth. In reality, crop plant growth, and ultimately crop yield, is affected by the interaction of more than temperature and precipitation. Affecting crop yields also, are the ability of the soil to hold water for plant use, the wind conditions of the

area, the ability of the plant's root system to make use of available subsoil moisture, and the ability of the plant itself to pass the moisture on through, i.e., transpiration. The interaction of all these factors has been traditionally measured through the use of a water balance model of the form: (Hownan, C.E., et al, 1975, p. 37)

$$P - Q - U - E - \Delta W = 0$$

where:

P = the precipitation or irrigation water.

Q = runoff.

U = the deep drainage passing beyond the root zone.

E = evapotranspiration.

ΔW = the change in soil-water storage.

In evaluating the water status of a specific crop at a specific site, the authors discuss the sorts of information required to measure the interaction between soil, plant and climatic characteristics. The measurement procedure is summarized as three problems: (Ibid, p. 18)

1. "The capability of the environment to induce evaporation and transpiration, i.e., an energy aspect involving the measurement of radiation and the horizontal advection of sensible heat.
2. The capability of the soil and plants to provide water for evaporation and transpiration, which requires an assessment of the efficiency of the soil-plant system as a reservoir and "pump" for supplying water to evaporate or transpire. This assessment

includes such problems as the physical and chemcial composition of the soil, including its water retention and release characteristics throughout the root zone.

3. The capability of the atmospheric environment to accept and disperse the vapor stream being fed into it from the soil and vegetation. This problems involves measurements of the profiles of wind speed, temperature and humidity."

Measures that approximate the above process are incorporated into two indices widely used among the climatological profession. They are Palmer's drought and crop moisture indices. Both indicate relative mositure conditions, however, the Palmer Index "is an index of prolonged and abnormal mositure deficiency or abundance; prolonged as measured in months or years and abnormal in the sense that the mositure supply consistantly falls below or above what is climatically expected." (Salisbury, Jayne M., OCS, p. 143) Whereas, the Crop Moisture Index (also developed by Palmer, in 1968) is an index "specifically designed to respond to short-term changes in weather conditions." (Ibid, p. 143)

A critical element in the measurement of both indices is the calculations of potential evapotranspiration (PE), i.e., the amount of water which can be evaporated and transpired ".....an extended surface of eight to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water." (Doorenbos, I., and W. C. Pruitt, 1975) As summarized by Paul T. Dyke:

> "This variable is used as a proxy for the amount of energy the plant has available for use in plant growth and development. More precisely, it represents various combinations of heat units (temperature) and daylight hours (carbon accumulation) which determine the development stages of the growing plant. PE is expected to vary from crop to crop and the use of standard grass cover is a gross simplification." (Dyke, Paul T., December 1977)

Because both indices make use of the Thornthwaite method of computing potential evapotranspiration, the choice of which index is the appropriate measure to explain the interaction of soil, plant and climatic characteristics depends upon the purpose of the index. In other words, since the purpose of the Crop Mositure Index is to measure the short-term changes in weather conditions, it is probably the more appropriate measure to use as the interaction variable in crop yield response models.

As a final theoretical consideration, once a model is specified, the functional form inherently precludes certain assumptions with respect to the performance of the model's determinants. Several of the more critical assumptions with respect to the above theoretical yield response model are as follows: (Runge, E.C.A., Sept. - Oct. 1968)

1. One inch of precipitation affects the crop yield by the same percentage, but in opposite directions, for precipitation above or below average. Similarily, a degree of temperature affects the crop yield by a given percentage (different from precipitation), but in opposite directions for temperature above or below average)

2. The total effect on crop yield is directly proportional to the number of inches of precipitation or degrees of temperature above or below average.

3. The effect on crop yield in each period, "t", is independent of the effect in any other time period.

Cropping Pattern and Planted Acreage Reduction Impacts

In addition to yield impacts, certain non-average spring/fall weather events affect the eventual cropping pattern within a region, and also, the final number of acres planted to a particular crop. Where cropping pattern refers to a shift in the allocation of planted acreage from one crop to another, planted acreage reduction refers to those acres intended to be planted, but, that never get planted to any crop. Together, yield impacts, cropping pattern impacts and planted acreage reductions compose a Nebraska physical supply response to any non-average weather event (Figure 2). A fourth impact concerns the crop production losses associated with hail damage, flooding of fields prior to harvest, fire caused by lightening storms, etc. In other words, the fourth supply impact is concerned with production losses associated with those crop acres plantec, but, that never get harvested. There is no intent to downgrade the importance of these impacts, but, due to their complexity and a lack of a measurement variable, these impacts will not be considered in this research effort.

To model cropping pattern and planted acreage reductions, conceptually, two approaches are available. The first approach

involves single-equation techniques which consist of estimating two equations for each crop: one, the ratio of crop(i) acres planted to total acres planted for all crops (cropping pattern) is expressed as a function of crop relative profitability, a lagged cropping pattern variable, non-average spring/fall weather events and a variable for all other factors and random error; and two, planted acreage reduction is expressed as a function of non-average spring/fall weather events and a random error variable. Notationally, the theoretical model can be expressed as:

$$CP_{i,t} = F_i(RP_{i,t}, CP_{i,t-1}, W_{i,t}, Z_t)$$

$$PAR_{i,t} = F_i(W_{i,t}, U_t)$$

Where:

$CP_{i,t}$ = the ratio of crop(i) planted acres to the total planted acres for all crops, for each time period (t).

$RP_{i,t}$ = relative profitability of crop(i) for time period (t). For example, the ratio of returns to land and management (RTLM), for crop(i), to the RTLM for crop (i's) competing crop.

$CP_{i,t-1}$ = cropping pattern for crop(i) in time period (t-1).

$W_{i,t}$ = weather parameters measuring non-average spring/fall weather events, for time period (t).

$PAR_{i,t}$ = planted acreage reduction for crop(i) in time period (t). In other words, those crop(i) acres intended to be planted, but, that never get planted.

Z_t = a variable for all other factors explaining cropping pattern variation and random error.

U_t = a variable for random error.

Relative profitability, as measured by the appropriate ratios of returns to land and management per crop, accounts for

differences in yields/acre, prices and production costs per crop. Variation in these factors among crops are given consideration by individual farmer/operators in their determination of a farm cropping pattern. Therefore, relative profitability is a necessary explanatory variable for any regional model of cropping patterns. An increase in this variable for crop(i), would be expected to increase the share of total acres planted to (CP_i).

Lagged cropping pattern, as measured by the lagged ratio of planted acreage for crop(i) to total planted acres for all crops, accounts for those environmental and psychological factors that explain why a farmer/operator will repeatedly plant a certain amount of his base acreage to a particular crop. These factors may consist of soil and/or climatic characteristics for a region, and personal satisfaction associated with viewing a field of corn, for example, as opposed to soybeans. A positive relationship is expected between ($CP_{i,t}$) and ($CP_{i,t-1}$), unless crop(i) acreage planted is sensitive to farm policy and weather variables, resulting in crop(i) acreage planted to vary from year to year, in opposite directions. In this case, the expected sign on the lagged cropping pattern variable is negative.

Weather events for both of the above equations are limited to those events occurring in the spring or fall. The events are limited because it is only necessary to be concerned about those weather events that would potentially alter a cropping pattern or cause planted acres to be reduced for a crop. Both fall and spring events are considered (depending upon the region) because

fall weather events tend to have a greater influence on the amount of acreage planted to winter wheat, whereas spring weather events tend to have a greater influence on the cropping pattern for such crops as corn, grain sorghum and soybeans.

The second approach to modelling cropping pattern and planted acreage reduction impacts of non-average spring/fall weather events, makes use of the theoretical approach defined by J.P. Houck, Abraham Subotnik, M.E. Ryan and M.E. Abel, in estimating crop acreage functions that emphasis the relationship between crop acreage and government farm programs. These crop acreage response functions have been estimated using single equation estimation techniques, i.e., ordinary least squares. However, because a regions cropping pattern in a given year reflects an interdependent adjustment to various economic, environmental and government policy processes, crop acreage response functions can be estimated by applying a simultaneous equations estimation technique. Cropping pattern and planted acreage reduction impacts due to year to year weather variations can be estimated by incorporating spring/fall weather variables.

As defined in several of the above authors' publications, the purpose of estimating crop acreage response functions was to investigate the implications on crop acreage of government policy programs. To do so, the above authors made use of a theoretical model of the form (Houck, J.P., and M.E. Ryan, May 1972):

$$A = F(PF, DP, M, Z)$$

Where:

A = crop acreage planted.

PF = an "effective crop support price", or crop support price weighted by crop planting restrictions.

DP = a supply shifter which reflects changes in diversion levels and eligible diversion acreage.

M = market influences, such as competing crop support prices.

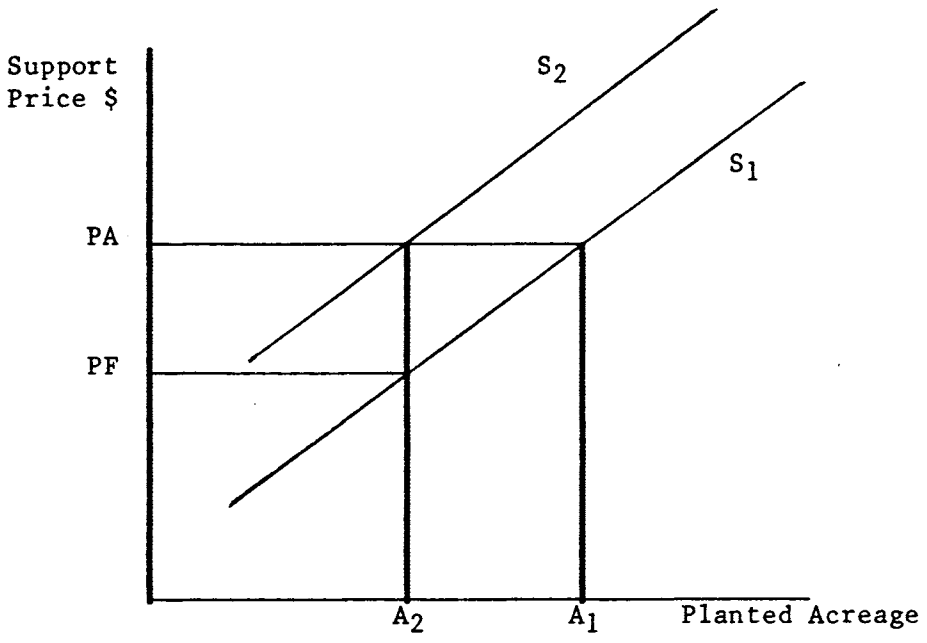
Z = all other supply determinants and random error effects.

The use of both (PF) and (DP) as policy variables, was introduced as a means of expressing the various forms of acreage restrictions and crop price support provisions of farm programs as two variables. In the case of (PF), this variable measures movement along a crop acreage supply curve. (DP) however, measures shifts in the acreage supply curve. Figure 3 illustrates this model. From "Corn Acreage Response & the Set-Aside Program," by Mary E. Ryan, and Martin E. Abel, October 1972, this theoretical model is summarized as follows: The curve S_1 is a static acreage supply function for a crop at various price support levels. At the announced support price of PA, farmer/producers would plant A_1 if there were no acreage restrictions attached to the price support. If government policy makers wished to reduce acreage to A_2, then four policy options are available. Policy makers could: (1) drop the support rate to PF, (2) maintain the support price at PA and attach acreage restricting conditions so that,on balance, acreage planted falls to A_2, (3) make diversion payments (DP) sufficient to shift the supply function to S_2, or (4) employ some combination of the first three options. If policy makers adopt option (2), that is, impose

acreage restrictions of $(A_1 - A_2)$ along with a price support of (PA), then the "effective crop support price" is (PF). In other words, (PF) is a normalized announced support price by means of

Figure 3

Administered Price and Acreage Restriction



the acreage restrictions imposed on participating farmers. The analytical and empirical problems are to determine how to calculate PF and DP for any given set of farm program provisions. (PF) is assumed to be proprotional to (PA), the announed price support rate, i.e., PF = rPA. While (DP) is assumed proportional to the announced diversion payment rate, i.e., DP = wPR. Both

(r) and (w) range from zero to 1.0. If there are no planting restrictions associated with obtaining PA, then r = 1.0. Similarily, if all acreage for a crop were diverted for payment, then w = 1.0. The more restrictive the planting restrictions for a crop, associated with PA, the closer (r) will be to zero; and the smaller the permitted diversion acreage, the closer (w) will be zero. Therefore, changes in any one of the payment levels for (PA) and (DP), or the eligible support and diversion acreages, holding the others constant, will affect crop acreage planted.

In computing (PF), according to the equation PF = rPA, Houck and Subotnik (1969) determine that (r) is approximately equal to the "ratio of the permitted to the desired acreage," i.e., (A_2 / A_1). Therefore, with policy option (2), (r) is the proportion of the base acreage permitted for crop planting by program participants. If the policy option is defined to allow for a range of permitted planting, the minimum and maximum shares allowed are averaged. Similarly for (DP), (w) represents the proportion of acreage eligible for diversion payments. In the case of a range of diversion allowed, minimum and maximum provisions are averaged.

Given the above two theoretical approaches to modelling cropping pattern and planted acreage reduction impacts, the question now is: Which approach is most appropriate, given the objectives of this proposed research effort? The first approach is a single equation system. In other words, each function, for each cropping pattern ratio is estimated separately. The model, to be complete, must also include estimation of a planted acreage

reduction equation per crop. Estimation of this model could result in over or under accounting of weather related impacts. In addition, the lack of historical data on returns to land and management and planted acres reduced per crop, prevents the computation of relative profitability ratios and the estimation of impacts associated with those acres intended to be planted, but, that never get planted. The second approach uses effective crop support prices and crop diversion rate payments as the prime determinants of economic considerations. Even though both variables were designed to measure government policy instruments, they make reasonable proxies for economic considerations. It should be recognized however, that cropping pattern shifts due to technological and production cost factors are poorly measured with the use of such economic variables, applying a single equation estimation technique.

Given the above considerations, this research effort made use of the second approach to estimating cropping pattern and planted acreage reduction impacts. Three modifications were incorporated: (1) the variable for "all other determinants and random error effects" was further disaggregated to (W), (CRA-1), and (Z'). (W) represents spring/fall weather events that influence both cropping pattern shifts and planted acreage reductions, while (CRA-1) represents a lagged crop acreage varible measuring environmental and psychological factors. (2) The model was constructed as a system of equations, to be estimated with the use of a simultaneous equation's estimation technique, to ensure against under or over accounting of total acres as crop acres shift from one crop to another, and to

capture the simultaneous nature of decision making envolved with any particular cropping pattern. (3) The interdependent nature of a regions cropping pattern was captured through the use of endogenous variables as independent variables in each crop response function. The endogenous variables on the right-hand side of each function were expressed as ($CRA_{j,t}$), where (j = i). The system of crop acreage response functions (depending upon the crop reporting district) include a crop acreage function for each of the crops (dryland and irrigated): corn, grain sorghum and soybeans. Additionally, a response function was included for wheat. The system of equations model includes two identities: (1) the first identify ensures that balancing occurs, in that total acres for the major crops (those mentioned above) equal the sum of the individual major crop acres, (2) the second identify accounts for the fact that total acres within a cropping pattern for the major crops depends upon the acreages devoted to minor crops and other acres. This identify was expressed as: "other acres" being equal to a maximum level of acreages that historically have been devoted to crop production, minus total acres devoted to major crops within the system, minus acres devoted to minor crops (defined as including acres for oats, barley, rye, and dryland and irrigated aflafla production).

The general system of crop acreage response functions can be expressed notationally as:

$$CRA_{i,t} = F\,(CRA_{i} \quad CRA_{i,t} \quad ESP_{i,t-1} \quad DRP_{i,t} \quad ESP_{i,t} \quad W_{j,t} \quad Z'_{p,t})_{t}$$

$$TSCA_{t} = DCA_{t} + ICA_{t} + DGSA_{t} + IGSA_{t} + WHA_{t} + DSYA_{t} + ISYA_{t}$$

$$\text{Other Ac} = MacAc_{t} - TSCA_{t} - MinorAc_{t}$$

Where:

$CRA_{i,t}$	=	Crop acreages per crop(i) in time period (t), for both dryland and irrigated crops.
$CRA_{j,t}$	=	Crop acreages per crop (j) in time period (t), for both dryland and irrigated crops. (The cross-product acreage variable for endogenous variables on the right-hand side of each crop acreage response function.
$CRA_{i,t-1}$	=	A variable for crop(i) acreages in time period (t-1). (A lagged crop acreage variable.)
$ESP_{i,t}$	=	Effective support price for crop(i) in time period (t).
$ESP_{j,t}$	=	Cross-product effective support price for crop (j) in time period (t). (For a substitute crop.)
$DRP_{i,t}$	=	A supply shifter reflecting diversion payment rates and eligible diversion acreages.
$W_{p,t}$	=	Weather parameters measuring non-average spring/fall weather events, for events (p) in time period (t).
Z'_t	=	All other supply determinants and random error effects.
$TSCA_t$	=	Total crop acres for all crops within the system, i.e., that have an acreage-response function. (Crops within the system include the major crops, dryland and irrigated corn, grain sorghum, soybeans, and wheat.)
MaxAc	=	A constant representing the maximum level of acres that historically have been devoted to major and minor crop production within the crop reporting district. (This maximum level is used to determine the acreages devoted to "other acres", a combination of idle acres and acreages devoted to miscellaneous agricultural output.)
$MinorAc_t$	=	Acreages devoted to minor crops, where minor crops consist of oats, barley, rye, and dryland and irrigated alfalfa acres.

$OtherAc_t$	=	A variable for "other acres," consisting of a combination of idle acres and acreages devoted to miscellaneous agricultural output. This variable was computed by determining "MaxAc", minus the sum of acreages devoted to major and minor crops, per time period.
DCA_t	=	Dryland corn acres in time period (t).
ICA_t	=	Irrigated corn acres in time period (t).
$DGSA_t$	=	Dryland grain sorghum acres in time period (t).
$IGSA_t$	=	Irrigated grain sorghum acres in time period (t).
WHA_t	=	Wheat acres in time period (t).
$DSYA_t$	=	Dryland soybean acres in time period (t).
$ISYA_t$	=	Irrigated soybean acres in time period (t).

Price Effects

Determination of price effects are relevant to the determination of weather impact assessments for several reasons. Adverse weather events that are isolated in relatively small geographic areas will most likely have only minor effects on domestic supply, and therefore, negligible effects on crop prices. However, weather events that occur within multistate areas are likely to have a significant impact on domestic supply, and therefore, price. Because price is a principal determinant of farm income which is subsidized through the use of government commodity programs and disaster payment programs (See Figure Two), price becomes an important factor in assessing those weather events that have an impact on domestic supply.

The second reason for accounting for price effects is related to the assessment of secondary economic impacts. The

approach expected to be used in this assessment (as part of the NOAA project research effort) is economic input-output analysis. Input-output derived impact multipliers must be adjusted for price changes to provide an accurate assessment of economic impact.

The final reason to account for price effects is the usefulness of knowledge on a per unit basis. Farmer/operators from year-to-year make many short term, cash-flow related decisions based on expected crop prices. Knowledge of the magnitude of price effects of probable non-average weather events, which occur within a sufficiently large geographical area to effect domestic supply, provide farmer/operators with a measure of potential cash flow impacts.

Determination of the price effects of a particular non-average weather event will differ depending upon whether the research is assessing the impacts of a past event or a near-term future event, i.e., expost or ex ante analysis. For a past event, the seasonal average market price for a crop already accounts for the supply impact of the non-average weather event. The objective, for an expost event, would be first to measure the supply impact of the weather event to approximate what supply would have been under normal weather conditions, and, second, to project or simulate crop prices for normal weather conditions. The difference between the existing seasonal average market crop price and the price projection for normal weather conditions would be the price effect of the weather event.

The price effect of an ex ante event, a near-term future non-average weather event, can be determined in a similar manner,

i.e., the difference between crop price under normal weather conditions and price given a non-average weather condition. However, the price determination process differs in that the assumed base price is a seasonal average expected market price, as of a particular date, say, April 1. This expected price would reflect market expectations with respect to supply and demand conditions, with supply reflecting normal weather conditions. The expected price could be measured, as of April 1, by the average of the crop's futures prices for the months of January through March of the following year. The price effect of the prospective non-average weather event can be determined by first estimating the supply impact of the weather event and, second, by assuming that the weather event is geographically dispersed so as to impact domestic supply. A national crop price projection model would determine price given supply conditions under the assumption of the non-average weather event. The difference between the expected market price and the price under the assumption of the non-average weather event would be the crop price effect of the weather event.

The determination of price effects for the situations just described, differs in two respects. First, the seasonal average market crop price for a past weather event, serving as the base price, incorporates the supply impact of the weather event. The base price of an _ex ante_ weather event, however, is the expected crop price as of, say, April 1, as measured by a three-month average of futures prices, and is assumed to reflect market supply-demand expectations that reflect normal weather

conditions. Second, for an expost weather event, the projected price is an adjusted crop price reflecting market supply-demand conditions under the assumption of normal weather conditions. For an ex ante weather event, the projected crop price reflects market supply-demand conditions assuming the occurance of a non-average weather event.

With respect to both the expost and the ex ante situations described above, the price effect was determined assuming that the weather event was dispersed geographically so as to impact domestic supply sufficiently to effect domestic price. As a result, a national crop price projection model was the basis for estimating an adjusted crop price reflecting: (1) a revised market demand-supply situation assuming normal weather conditions, for an analysis of an expost weather event, and (2) a revised market demand-supply situation assuming the occurance of a non-average weather event, for an ex ante analysis.

At this point, the answers to several questions become important. Will the non-average weather events to be analyzed be sufficiently dispersed geographically, such that the event impacts domestic supply, and therefore, crop prices? Or, will the events be isolated to a small area and, therefore, have an insignficant impact on domestic supply? On the other hand, if the weather event is such that domestic supply is significantly affected, how is the total domestic supply change estimated, and which national crop price projection model is most appropriately used to estimate an adjusted crop price? An finally, are there alternatives to using a national crop price projection model?

Clearly, the geographical extent of a weather event is an

important factor that determines the impact on crop prices. It is possible for several scenarios to exist. One, a weather event is isolated to a small area, and therefore, the supply impact is so small as to have an insignificant impact on domestic supply and price, or the local supply impact is assumed to be compensated for by opposite weather impacts elsewhere. Given this scenario, the price effect would be expected to be near zero. The impact of concern to the local area in question would consist of the income effects due to the weather event's production and input usage changes. A second scenario could involve a hypothesized weather event geographically encompassing a multi-state region, with the supply impact being offset by opposite weather events elsewhere. A third scenario could consist of normal weather occurring in a small area, with, significant drought conditions, for example, occurring elsewhere. Crop prices would most likely be affected. A final scenario involves a weather event that is sufficiently geographically dispersed so as to significantly impact domestic supply, and, hence, prices.

The intent of this research effort was to include in the economic assessment of non-average weather events situations corresponding to scenarios one, two and four as described above. Scenarios one and two do not require the assessment of crop price effects, but scenario four requires the assessment of price effects. Short of an agricultural model, such as the one developed at the University of Missouri, price effects under scenario four were determined by hypothesizing a domestic supply

and crop price impact. Given a hypothesized price effect, the direct economic impacts of non-average weather events were computed.

Input Usage Impact

The rationale for the estimation of changes in input usages is: (1) to acquire a more complete estimate of the direct impacts of a non-average weather event and (2) to provide the information necessary for the estimation of secondary economic impacts.

Changes in agricultural input usage alters the structure of a local economy. As a result, the economic multiplier process is altered. For a non-average weather event that reduces input usage and crop production, the economic multipliers are reduced. This is the case for both final demand and output multipliers. In other words, if initially, less dollars circulate throughout the farm economy due to reduced farm-firm input purchases and farm household expenditures, then, those firms making sales to the farm sector make adjustments in their inventories, and other purchases of inputs to their business. These adjustments are the secondary economic impacts accounted for through the multiplier process. In addition, farm product processors may be forced to make purchases from outside the region to sustain their inventory requirements. Because the associated dollars leave the region, they no longer contribute to the multiplier process within the regional economy. This impact on the multiplier process works in reverse for those non-average weather events that result in increased purchases of agricultural inputs, and increased crop production.

To acquire reasonable estimates of either final demand or output multipliers per sector, given the occurance of a non-average weather event, it is necessary to re-estimate the structure of the regional economy. This is accomplished by re-establishing the regional transactions matrix, the matrix of dollar flows indicating, for each column sector, the dollar purchases of inputs for that sector from each other economic sector. The rows express the dollar sales of output, for a row sector, to all other sectors.

The transactions matrix is re-estimated by making use of the information acquired from the estimation of input usage (and output) changes due to the occurance of a non-average weather event. Once the transactions matrix is re-estimated, adjusted final demand and output multipliers can be calculated. Given either of these multipliers, secondary economic impacts of a non-average weather event can be estimated by multiplying a crop sector's multipliers by that sector's direct impact (change in output value due to a non-average weather event).

For this study, analysis of input usage changes was confined to three principle agricultural inputs: energy, fertilizer use, and short-term interest costs. For energy use, separate estimations were made for field energy and energy use for irrigation. Field energy use changes because cultural practices change with non-average weather events. A crop budgeting approach was used to estimate these changes. For irrigation energy use, adaptations of variable irrigation cost equations were used to estimate irrigation energy use by type. Given such

information as average feet of lift, average gallons per minute (GPM - pumping rate), pounds per square inch (PSI - pressure), the price of energy, and irrigated acres for an irrigation system and energy source, a change in irrigation energy use and cost was estimated using similar functions as below, for each energy type:

$$(\text{Energy Cost})_D = \frac{.1143[L + PSI(2.31)]W}{12.50} (P_D) \cdot (\text{Acres})_{SD}$$

This equation computes a diesel energy cost per acre for a ground water sprinkler irrigation system powered by a diesel engine. When multiplied times $(\text{Acres})_{SD}$, total diesel irrigation energy costs are estimated. By altering (W) - water application, and $(\text{Acres})_{SD}$ - total acres devoted to sprinkler irrigation using a diesel engine, to reflect a non-average weather event, energy costs assuming the non-average weather event can be estimated. The differences between the computations assuming a non-average weather event and the computed costs under normal weather conditions is the energy use impact associated with the non-average weather event. Similar equations were used for other energy sources, such as, electricity, propane, and natural gas.

Fertilizer usage changes were estimated on the basis of changes in nitrogen applications per acre. Nitrogen application functions, as a function of yield per acre, were specified for corn, grain sorghum and wheat. Given yield per acre for both average and non-average weather conditions from the yield response equations and cropping pattern adjustments from the average response functions, fertilizer usage impacts were estimated and multiplied times price to estimate the value of

usage impacts.

Since fertilizer and energy use are a significant portion of variable costs per acre for crop production, then short-term interest costs should also vary as fertilizer and energy costs change with non-average weather events. So, given the estimated changes in fertilizer and energy use, short-term interest costs were re-estimated for a specified short-term interest charge.

Summary

Adverse weather conditions, such a late spring freeze, a day season, etc. result in tens of millions of dollars loss in agricultural output annually. But, the dollar loss of secondary economic effects, triggered by this direct impact to agriculture, can run still higher.

The primary purpose of this study was to identify and empirically measure the various ways that certain non-average weather events impact directly on agriculture. These ways include changes in (1) crop yields, (2) cropping patterns, (3) input usage, and (4) market prices for raw farm products. A fifth factor, due to federal government programs, is the so-called income effect of farm subsidies.

To manage the empirical analysis of the direct economic impact of weather on agriculture in a way as noted above, a representative agricultural producing state, Nebraska, was chosen. As suggested earlier, findings for Nebraska ought to be reflective of many other areas that make-up the agricultural mid-west.

Finally, as noted throughout this report, the empirical analyses and related findings are provided in separate reports. This report includes only an overview of the study's methodology and empirical models.

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