EXAMINATION OF THE LEEPER CORN YIELD MODEL, A WEATHER BASED-PHENOLOGICALLY TIMED YIELD FORECASTING MODEL

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ABSTRACT

This report presents yield forecasting potential for the Leeper Corn Yield Forecasting Model through sensitivity analysis, small area application, and large area application. Sensitivity analysis results indicate: reasonable response with initial soil moisture between 6"-14", temperature establishes yield level, and precipitation creates yield change. Model does not function at field level and performs modestly well for small area. Adjustment factors were not computable for either level. Model performed consistently in Illinois, Indiana, and Iowa providing direction of change and adjustment factors. The model did not work in Missouri.

Key words: Yield forecasting; sensitivity analysis, precipitation; temperature; pollen shed; plant available soil moisture.

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INTRODUCTION

With increasing importance of domestic agriculture in the international market, interest has rekindled in accurate early forecasts of grain production. Objective techniques currently employed by ESCS are dominated by fruit related measurements (suoh as number of ears, length of ears, etc.); thus, forecasting models do not respond well to current growing conditions until fruit development has occurred. This procedure limits early forecasts to August 1 for corn. In an attempt to obtain earlier forecasts of corn production utilizing weather, ESCS is currently examining a multiple linear regression model developed by R.A. Leeper (1974) under the direction of E.C.A. Runge. The variables required to run the Leeper model are average weekly maximum temperature, total weekly precipitation, plant available soil moisture at planting, field tasseling date, and an empirical adjustment factor which converts model yield to harvested yield.

The four objectives of this paper are: (1) to determine model effectiveness through the relationship between input variables and yield by conducting sensitivity analysis; (2) to report on the method and quality of data collected in a 1977 field study for implementing the model during the growing season completed in cooperation with the University of Missouri; (3) to examine the capability of the model to provide reliable yield forecasts at a field and a small area level; and (4) to examine model forecasts over a large area.

The model was found to be extremely sensitive to changes in water in the form of both plant available soil moisture at planting and precipitation. Generally, increases in water increased yield, increases in temperature decreased yield, or a later tassel date decreased yield.

The collection of current year weather data for implementing the model was feasible. However, improvement in the quality of measurement for temperature and soil moisture data could be made.

The model showed very little relationship to grower yields at the field level and only a modest relationship at the small area level. The large area application of the model produced favorble correlations with Board yields in Illinois, Indiana, and Iowa; and unfavorable correlations in Missouri.

Model Development

The basic structure for the model was developed by Fisher (1924) when he used orthogonal polynomials to preserve degrees of freedom when excamining the influence of rainfall on wheat yields at Rothamstead. This procedure, as modified by Hendricks and Scholl (1943), permitted the incorporation of many input variables in a regression equation through a weighted sum technique. For example, if average weekly maximum temperature was employed for each week over a ten-week period as independent variables, ten degrees of freedom would be required. Using the weighted sum technique, a single variable is produced with a value equal to

$$WX = \sum_{i=1}^{10} X_i W_i \qquad (1)$$

where

WX = sum of the weighted temperature data

X_i = the average weekly maximum temperature

W_i = the weight is the number of the ith week.

Changes to the summation variable can be made by applying a transformation to the summed variable or the weight variable.

This method has served as a basis for weather yield investigations by Davis and Pallesen (1940) and Houseman (1942). Runge (1958, 1968) also used this approach in examining the effects of rainfall and temperature on corn yield. Leeper (1972) added the affect of plant available soil moisture to Runge's work. The Leeper model examined in this paper was then used by Benci and Runge (1975) to estimate yield under variable soil and climatic conditions for all or parts of six Midwestern states. The equation developed by Leeper is:

$$MY = 1566.37 - 83.068W - 1.069W^2 + 42.9392\sum_{i=1}^{10} (R_i t_i) - 8.1130 \sum_{i=1}^{10} (R_i t_i^2) + 0.3654 \sum_{i=1}^{10} (T_i t_i) - 0.1013 \sum_{i=1}^{10} (T_i t_i^2)$$

$$- 0.5014 \sum_{i=1}^{10} (R_i T_i t_i) + 0.0974 \sum_{i=1}^{10} (R_i T_i t_i^2) - 3.9802W \sum_{i=1}^{10} (R_i t_i)$$

$$+0.7907W \sum_{i=1}^{10} (R_i t_i^2) - 0.061W \sum_{i=1}^{10} (T_i t_i) + 0.0121W \sum_{i=1}^{10} (T_i t_i^2)$$

$$+ 0.0482W \sum_{i=1}^{10} (R_i T_i t_i) - .0097W \sum_{i=1}^{10} (R_i T_i t_i^2) \qquad (2)$$

where

MY = model yield (bu/acre).

W = amount of plant available stored soil water (inches) at planting to a depth of 48 inches.

R_i = total weekly precipitation (inches) for the ith week.

T_i = mean of maximum daily temperature (^oF) for the ith week.

t_i = i, the number of the week where i=1, 2, ..., 10.

A ten-week period of temperature and precipitation data is required in the model. This ten-week period includes the five weeks of weather immediately before pollination, the week of pollination, and the four weeks following pollination.

After a model yield is produced, an empirical adjustment is applied to derive a harvested yield. This is necessary since the model was developed using experimental plot data under intensive management. The equation becomes

$$Y = A(MY) \qquad (3)$$

where

Y = harvested yield
A = empirical adjustment
MY = model yield.

Sensitivity Analysis

This model is a fairly complex multiple regression equation; therefore, sensitivity analysis is performed to better understand the model under alternative situations and to identify critical input variables and variable values. This analysis begins by considering the basic model structure. Model values are produced using a general set of initial conditions applicable to the Midwest.

Once the basic model framework is considered, the sensitivity analysis is completed by examining changes in yield due to changes in average weekly maximum temperature (temperature), total weekly precipitation (rainfall), plant available soil moisture at planting (soil moisture), and tassel date by week.

Basic Model Structure, Form and Value

The Leeper model is an additive model consisting of four major components: (1) an intercept, (2) a soil moisture component without weather or time, (3) a weather component over time and (4) a soil moisture component with weather over time. This ordering of the model, though the simplest in appearance, does not reveal the most information about the affects of model components. In the following discussion components (2) and (3) are reversed.

The intercept is a large positive number with a value of 1566.37; thus, the remaining components must reduce this initial value to a final model yield between 0-300 bushels for an appropriate harvested yield to be produced.

The third component, weather over time, is produced from the fourth through ninth model terms.

$$+ 42.9392\sum_{i=1}^{10}(R_i t_i) - 8.1130\sum_{i=1}^{10}(R_i t_i^2) + 0.3654\sum_{i=1}^{10}(T_i t_i) - 0.1013\sum_{i=1}^{10}(T_i t_i^2) - 0.5014\sum_{i=1}^{10}(R_i T_i t_i) + 0.0974\sum_{i=1}^{10}(R_i T_i t_i^2) \quad (4)$$

This component has a negative affect on yield. If average midwestern temperature and precipitation conditions are assumed, this component will produce a value equal to -1,481. This effect is dominated by temperature.

The soil moisture component without weather or time is computed from the second and third model terms.

$$- 83.068W - 1.069W^2 \quad (5)$$

This component also reduces the intercept. The last model component, soil moisture with weather over time, is calculated from the remaining model terms 10 through 15.

$$- 3.9802W \sum_{i=1}^{10}(R_i t_i) + 0.7907W_i \sum_{i=1}^{10}(R_i t_i^2) - 0.061W \sum_{i=1}^{10}(T_i t_i)$$

$$+ 0.0121W_i \sum_{i=1}^{10}(T_i t_i^2) + 0.0482W_i \sum_{i=1}^{10}(R_i T_i t_i) - 0.0097W_i \sum_{i=1}^{10}(R_i T_i t_i). \quad (6)$$

This component is zero when soil moisture is zero and increases as soil moisture increases.

Values of each component and selected sums for components are contained in Table 1 with soil moisture set equal to 0", 4", 8", 12" and 16". These values were chosen to present both extreme values and common midwestern conditions.

Table 1: Average Model Yield Values by Component and for Model

Component and Sum	Plant Available Soil Moisture at Planting (inches)				
	0.0	4.0	8.0	12.0	16.0
Intercept.........	1566.37	1566.37	1566.37	1566.37	1566.37
Ave. value of 3rd component (3)	-1481.00	-1481.00	-1481.00	-1481.00	-1481.00
Sum of (1) & (2)..	85.37	85.37	85.37	85.37	85.37
Value of 2nd component (2)....	0	- 349.38	- 732.96	-1150.75	-1602.75
Ave. value of 4th component (4)	0	405.00	807.00	1211.00	1614.00
Sum of (2) & (4).	0	55.62	74.04	60.25	11.25
Sum of (1),(2),(3) & (4) = Model Yield...........	85.37	140.99	159.41	145.62	96.62

Soil moisture components (2) and (4), offset each other under low or high soil moisture conditions. Thus, temperature and rainfall dominate while soil moisture components for midrange soil moisture account for 40 to 50% of the final yield value. A more detailed breakdown of final yield is given in Table 2 with the same moisture conditions: temperatures equal to 74°F, 82°F, 88°F, and 96°F and rainfall equal to 0.0", 0.5", 1.0", 2.0" and 3.5". This table shows that within these ranges of values the model responds favorably to lower maximum temperature, and combinations of either low soil moisture and high rainfall, or high soil moisture and low rainfall. Yield values enclosed between the vertical bars would be more representative of actual model yields from normal weather and soil moisture conditions. The next portion of this analysis examines which variables create the greatest change in these basic model values.

Table 2: Model Yields Under Constant Soil Moisture, Temperature and Precipitation Conditions

Plant Available Soil Moisture at Planting (in)	Average Weekly Maximum Temp(°F)	Total Weekly Precipitation (inches)				
		0.0	0.5	1.0	2.0	3.5
0.0	74	168	154	140	112	71
	82	16	42	68	120	197
	88	- 97	- 42	14	125	292
	96	-248	-153	-58	133	419
4.0	74	204	201	198	191	182
	82	95	114	133	171	229
	88	12	48	84	156	264
	96	- 97	- 39	19	136	311
8.0	74	206	214	221	236	259
	82	138	151	164	188	226
	88	88	104	120	153	202
	96	20	41	62	105	169
12.0	74	174	192	211	247	301
	82	148	154	160	172	189
	88	129	125	122	115	105
	96	102	86	71	39	- 8
16.0	74	108	137	166	223	310
	82	124	123	122	120	118
	88	135	112	89	43	- 26
	96	151	98	46	- 60	-218

Changes in Temperature or Precipitation

The change in yield due to a change in temperature for a specific week (i) is written as a difference equation where:

$$\Delta MY_i = MY(W,R_i,T_i,+\Delta T_i) - MY(W,R_i,T_i)$$

$$=[(0.3654 - 0.1013t_i) + (-0.5014 + 0.0974t_i) R_i$$

$$+ (-0.061 + 0.0121t_i) W + (0.0482 - 0.0097t_i)R_iW]t_i\Delta T_i. \quad (7)$$

The change in yield due to a change in precipitation for a specific week (i) is derived from a similar difference equation where:

$$\Delta MY_i = MY(W,R_i + \Delta R_i,T_i) - MY(W,R_i,T_i)$$
$$=[(42.9392 - 8.1130t_i) + (-0.5014 + 0.0974t_i) R_i$$
$$+ (-0.061 + 0.0121t_i) W + (0.0482 - 0.0097t_i)T_iW]t_i\Delta R_i. \quad (8)$$

If both temperature and precipitation are allowed to change, the result of the difference equation is equal to the change in yield due to a change in temperature (7), plus the change in yield due to a change in precipitation (8), plus the change in yield due to a joint change in both temperature and precipitation (9).

$$\Delta MY_i = MY(W,R_i + \Delta R_i,T_i + \Delta T_i) - MY(W,R_i,T_i) = (7) + (8)$$
$$+ [-0.5014 + 0.0974t_i + 0.0482W - 0.0097Wt_i] t_i\Delta R_i\Delta T_i. \quad (9)$$

Changes in yield due to an increase in temperature of $+1^{o}F$ with soil moisture equal to 0", 4", 8", 12", 16" and weekly rainfall equal to 0.0, 0.5, 1.0, 2.0, 3.5, 5.0 are presented in Table 3.

A temperature "decrease" of $1^{o}F$ can be found in the table by changing the sign of the yield value. For example, for week = 1, water = 8.0", and rainfall = 1.0"; a $1^{o}F$ change in temperature would be expected to change the probable yield by -0.22 bushels/acres. On the other hand, if all initial conditions remain constant except for a temperature change of $-1^{o}F$, then the change in yield would be +0.22 bushels/acre.

Table 3--The change in yield by week due to a 1°F change in average weekly maximum temperature

Week No. and Total Weekly Precip. (inches)	Plant Available Soil Moisture at Planting (inches)				
	0.0	4.0	8.0	12.0	16.0
WEEK 1					
0.0	0.26	0.07	-0.13	-0.32	-0.52
0.5	0.06	-0.06	-0.18	-0.29	-0.41
1.0	-0.14	-0.18	-0.22	-0.26	-0.31
2.0	-0.54	-0.43	-0.32	-0.21	-0.09
3.5	-1.15	-0.81	-0.46	-0.12	0.22
5.0	-1.76	-1.18	-0.61	-0.03	0.54
WEEK 3					
0.0	0.18	-0.11	-0.41	-0.70	-1.00
0.5	-0.13	-0.31	-0.49	-0.67	-0.86
1.0	-0.44	-0.51	-0.58	-0.64	-0.71
2.0	-1.07	-0.91	-0.75	-0.58	-0.42
3.5	-2.01	-1.51	-1.00	-0.49	0.01
5.0	-2.95	-2.10	-1.25	-0.40	0.44
WEEK 5					
0.0	-0.71	-0.72	-0.73	-0.74	-0.75
0.5	-0.74	-0.75	-0.77	-0.78	-0.79
1.0	-0.78	-0.79	-0.81	-0.83	-0.84
2.0	-0.85	-0.87	-0.89	-0.92	-0.94
3.5	-0.96	-0.99	-1.02	-1.05	-1.08
5.0	-1.07	-1.11	-1.15	-1.19	-1.23
WEEK 6					
0.0	-1.45	-1.18	-0.90	-0.62	-0.34
0.5	-1.21	-1.05	-0.89	-0.73	-0.57
1.0	-0.96	-0.92	-0.88	-0.84	-0.80
2.0	-0.46	-0.66	-0.86	-1.06	-1.26
3.5	0.29	-0.27	-0.83	-1.40	-1.96
5.0	1.04	0.11	-0.81	-1.73	-2.65
WEEK 8					
0.0	-3.56	-2.41	-1.27	-0.12	1.02
0.5	-2.45	-1.77	-1.10	-0.42	0.25
1.0	-1.34	-1.13	-0.93	-0.72	-0.52
2.0	0.88	0.15	-0.59	-1.32	-2.06
3.5	4.22	2.07	-0.08	-2.22	-4.37
5.0	7.55	3.99	0.44	-3.12	-6.68
WEEK 10					
0.0	-6.48	-4.08	-1.68	0.72	3.12
0.5	-4.11	-2.69	-1.26	0.16	1.58
1.0	-1.75	-1.30	-0.85	-0.41	0.04
2.0	2.98	1.47	-0.03	-1.54	-3.04
3.5	10.06	5.63	1.20	-3.23	-7.66
5.0	17.15	9.79	2.43	-4.93	-12.29

In general, an increase in temperature of 1°F results in a net decrease in yield with 147 decreases in the 186 simulated cases presented in Table 3. The largest decreases for the weeks up to tasseling occur with the combination of low soil moisture and high rainfall. For the weeks after tasseling, the model indicates higher yields as a result of a combination of low soil moisture and high rainfall or high soil moisture and low rainfall. In fact, the conditions that reduce model yields the most during the early weeks (1-5) increase yield during the later weeks (6-10) and vice versa. The greatest changes in the model indicated yield occur during weeks 8-10 (two to four weeks after tasseling).

Model indicated changes in yield due to an increase in rainfall of 0.1" with initial conditions for soil moisture equal to 0", 4", 8", 12", 16" and temperature equal to 60°F, 74°F, 82°F, 88°F, 96°F and 110°F are presented in Table 4. The effects of a "decrease" of 0.1" in rainfall is found in the table by changing the sign of the yield value.

The model values in Table 4 indicate that the general effect of an increase in rainfall is an increase in yield with 130 increases in the 180 cases examined: however, in week 10 there are as many increases as decreases. The combination of low soil moisture and high temperature is the most damaging during the early weeks (1-5) and the most beneficial combination in later weeks (6-10). As with temperature, those conditions that are unfavorable to model yield during the early weeks (1-5) are favorable to model yields during the late weeks (6-10) and vice versa. The greatest response to additional rainfall occurs in weeks 8-10 with as much as 13.8 bushels being added with each additional 0.1" of rain in week 10.

The joint effect of an increase in temperature of 1°F and an increase in rainfall of 0.1" in producing a change in yield is presented in Table 5. For weeks 5 and 6, regardless of the amount of soil moisture or for soil moisture between 8" and 12" regardless of week, an increase in temperature or rainfall usually creates a decrease in yield. In weeks 1-4, relative increases in yield occur with low soil moisture, low temperature, and low rainfall; or with high soil moisture, high temperature, and high rainfall. In weeks 7 to 10, relative increases in yield occur with combinations of low soil moisture, high temperature and high rainfall; or with high soil moisture, low temperature and low rainfall. Changes in temperature and precipitation

Table 4-- The change in yield by week due to a +0.1" change in total weekly precipitation

Week Number and Avg. Weekly Maximum Temperature (°F)	Plant Available Soil Moisture at Planting (inches)				
	0.0	4.0	8.0	12.0	16.0
WEEK 1					
60	1.06	0.71	0.36	0.00	-0.35
74	0.49	0.36	0.22	0.08	-0.05
82	0.17	0.16	0.14	0.13	0.12
88	-0.07	0.01	0.09	0.17	0.25
96	-0.40	-0.19	0.01	0.21	0.41
110	-0.96	-0.54	-0.12	0.29	0.71
WEEK 3					
60	1.81	1.26	0.71	0.15	-0.40
74	0.94	0.70	0.47	0.23	0.00
82	0.43	0.38	0.33	0.28	0.23
88	0.06	0.14	0.23	0.32	0.41
96	-0.44	-0.17	0.10	0.37	0.64
110	-1.32	-0.73	-0.14	0.45	1.04
WEEK 5					
60	0.76	0.67	0.58	0.49	0.40
74	0.65	0.56	0.46	0.36	0.26
82	0.60	0.49	0.39	0.29	0.19
88	0.55	0.45	0.34	0.23	0.13
96	0.50	0.38	0.27	0.16	0.05
110	0.40	0.28	0.16	0.04	-0.08
WEEK 6					
60	-0.46	-0.06	0.33	0.73	1.12
74	0.24	0.30	0.36	0.41	0.47
82	0.64	0.51	0.37	0.24	0.10
88	0.94	0.66	0.38	0.10	-0.17
96	1.34	0.87	0.40	-0.07	-0.54
110	2.03	1.23	0.42	-0.38	-1.19
WEEK 8					
60	-4.24	-2.38	-0.52	1.34	3.20
74	-1.13	-0.58	-0.04	0.50	1.05
82	0.65	0.44	0.23	0.02	-0.19
88	1.99	1.21	0.44	-0.34	-1.11
96	3.76	2.24	0.71	-0.82	-2.34
110	6.87	4.03	1.19	-1.66	-4.50
WEEK 10					
60	-9.83	-5.84	-1.84	2.15	6.15
74	-3.22	-1.96	-0.69	0.57	1.83
82	0.56	0.26	-0.04	-0.34	-0.63
88	3.40	1.93	0.46	-1.01	-2.48
96	7.18	4.15	1.11	-1.92	-4.95
110	13.80	8.03	2.27	-3.50	-9.26

Table 5: The change in yield by week [illegible] +0.1" change in total weekly precipitation with five values of soil moisture;

Plant Available Soil Moisture at Planting (inches)	Total Weekly Precip. (inches)	Week 1 Ave. wkly. max. temp. (°F) 74	82	88	96	Week 3 Ave. wkly. max. temp. (°F) 74	82	88	96	Week 5 Ave. wkly. max. temp. (°F) 74	82	88	96
0.0													
	0.0	0.7	0.4	0.2	-0.2	1.1	0.6	0.2	-0.3	-0.1	-0.1	-0.2	-0.2
	0.5	0.5	0.2	-0.1	-0.4	0.7	0.2	-0.1	-0.6	-0.1	-0.2	-0.2	-0.3
	1.0	0.3	-0.0	-0.3	-0.6	0.4	-0.1	-0.4	-1.0	-0.1	-0.2	-0.2	-0.3
	2.0	-0.1	-0.4	-0.7	-1.0	-0.2	-0.7	-1.1	-1.6	-0.2	-0.3	-0.3	-0.4
	3.5	-0.7	-1.0	-1.3	-1.6	-1.1	-1.6	-2.0	-2.5	-0.3	-0.4	-0.4	-0.5
	5.0	-1.3	-1.6	-1.9	-2.2	-2.1	-2.6	-3.0	-3.5	-0.4	-0.5	-0.5	-0.6
4.0													
	0.0	0.4	0.2	0.1	-0.1	0.6	0.2	-0.0	-0.3	-0.2	-0.2	-0.3	-0.3
	0.5	0.3	0.1	-0.1	-0.3	0.4	0.0	-0.2	-0.5	-0.2	-0.3	-0.3	-0.4
	1.0	0.2	-0.0	-0.2	-0.4	0.2	-0.2	-0.4	-0.7	-0.2	-0.3	-0.4	-0.4
	2.0	-0.1	-0.3	-0.4	-0.6	-0.2	-0.6	-0.8	-1.1	-0.3	-0.4	-0.4	-0.5
	3.5	-0.5	-0.7	-0.8	-1.0	-0.8	-1.2	-1.4	-1.7	-0.4	-0.5	-0.5	-0.6
	5.0	-0.8	-1.0	-1.2	-1.4	-1.4	-1.8	-2.0	-2.3	-0.6	-0.6	-0.7	-0.7
8.0													
	0.0	0.1	0.0	-0.1	-0.1	0.0	-0.1	-0.2	-0.3	-0.3	-0.3	-0.4	-0.5
	0.5	0.0	-0.0	-0.1	-0.2	-0.0	-0.2	-0.3	-0.4	-0.3	-0.4	-0.4	-0.5
	1.0	-0.0	-0.1	-0.1	-0.2	-0.1	-0.3	-0.4	-0.5	-0.4	-0.4	-0.5	-0.5
	2.0	-0.1	-0.2	-0.2	-0.3	-0.3	-0.4	-0.5	-0.7	-0.4	-0.5	-0.6	-0.6
	3.5	-0.3	-0.3	-0.4	-0.5	-0.5	-0.7	-0.8	-0.9	-0.6	-0.6	-0.7	-0.8
	5.0	-0.4	-0.5	-0.5	-0.6	-0.8	-0.9	-1.0	-1.2	-0.7	-0.8	-0.8	-0.9
12.0													
	0.0	-0.2	-0.2	-0.2	-0.1	-0.5	-0.4	-0.4	-0.3	-0.4	-0.5	-0.5	-0.6
	0.5	-0.2	-0.2	-0.1	-0.1	-0.4	-0.4	-0.3	-0.3	-0.4	-0.5	-0.6	-0.6
	1.0	-0.2	-0.1	-0.1	-0.0	-0.4	-0.4	-0.3	-0.3	-0.5	-0.5	-0.6	-0.7
	2.0	-0.1	-0.1	-0.0	0.0	-0.3	-0.3	-0.3	-0.2	-0.6	-0.6	-0.7	-0.8
	3.5	-0.0	0.0	0.1	0.1	-0.3	-0.2	-0.2	-0.1	-0.7	-0.8	-0.8	-0.9
	5.0	0.1	0.1	0.1	0.2	-0.2	-0.1	-0.1	-0.0	-0.8	-0.9	-1.0	-1.0
16.0													
	0.0	-0.5	-0.4	-0.3	-0.1	-1.0	-0.7	-0.6	-0.3	-0.5	-0.6	-0.6	-0.7
	0.5	-0.4	-0.3	-0.1	0.0	-0.8	-0.6	-0.4	-0.2	-0.5	-0.6	-0.7	-0.8
	1.0	-0.3	-0.2	-0.0	0.1	-0.7	-0.5	-0.3	-0.0	-0.6	-0.7	-0.7	-0.8
	2.0	-0.1	0.0	0.2	0.3	-0.4	-0.2	0.0	0.2	-0.7	-0.8	-0.8	-0.9
	3.5	0.2	0.4	0.5	0.7	0.0	0.3	0.4	0.7	-0.8	-0.9	-1.0	-1.0
	5.0	0.5	0.7	0.8	1.0	0.5	0.7	0.9	1.1	-1.0	-1.0	-1.1	-1.2

Table 5 (cont'd): The change in yield by week due to a +1°F change in average weekly maximum temperature and due to a +0.1" change in total weekly precipation with five values of soil moisture.

Plant Available Soil Moisture at Planting (inches)	Total Weekly Precip. (inches)	Week 6 Ave. wkly. max. temp. (°F) 74	82	88	96	Week 8 Ave. wkly. max. temp. (°F) 74	82	88	96	Week 10 Ave. wkly. max. temp. (°F) 74	82	88	96
0.0													
	0.0	-1.2	-0.8	-0.5	-0.1	-4.5	-2.7	-1.4	0.4	-9.2	-5.4	-2.6	1.2
	0.5	-0.9	-0.5	-0.2	0.2	-3.4	-1.6	-0.2	1.5	-6.9	-3.1	-0.2	3.5
	1.0	-0.7	-0.3	0.0	0.4	-2.2	-0.5	0.9	2.6	-4.5	-0.7	2.1	5.9
	2.0	-0.2	0.2	0.5	0.9	-0.0	1.8	3.1	4.9	0.2	4.0	6.8	10.6
	3.5	0.6	1.0	1.3	1.7	3.3	5.1	6.4	8.2	7.3	11.1	13.9	17.7
	5.0	1.3	1.7	2.0	2.4	6.6	8.4	9.8	11.5	14.4	18.2	21.0	24.8
4.0													
	0.0	-0.9	-0.6	-0.5	-0.3	-2.9	-1.8	-1.1	-0.0	-5.8	-3.5	-1.9	0.3
	0.5	-0.7	-0.5	-0.4	-0.2	-2.2	-1.2	-0.4	0.6	-4.4	-2.1	-0.5	1.7
	1.0	-0.6	-0.4	-0.2	-0.0	-1.6	-0.6	0.2	1.2	-3.0	-0.8	0.9	3.1
	2.0	-0.3	-0.1	0.0	0.2	-0.3	0.7	1.5	2.5	-0.2	2.0	3.7	5.9
	3.5	0.1	0.3	0.4	0.6	1.6	2.6	3.4	4.4	4.0	6.2	7.8	10.1
	5.0	0.4	0.6	0.8	1.0	3.5	4.6	5.3	6.4	8.1	10.3	12.0	14.2
8.0													
	0.0	-0.5	-0.5	-0.5	-0.5	-1.3	-1.0	-0.8	-0.5	-2.3	-1.6	-1.1	-0.5
	0.5	-0.5	-0.5	-0.5	-0.5	-1.1	-0.8	-0.6	-0.4	-1.9	-1.2	-0.7	-0.1
	1.0	-0.5	-0.5	-0.5	-0.5	-0.9	-0.7	-0.5	-0.2	-1.5	-0.8	-0.3	0.3
	2.0	-0.5	-0.5	-0.5	-0.5	-0.6	-0.3	-0.1	0.2	-0.6	0.0	0.5	1.2
	3.5	-0.5	-0.5	-0.5	-0.4	-0.1	0.2	0.4	0.7	0.6	1.2	1.7	2.4
	5.0	-0.4	-0.4	-0.4	-0.4	0.4	0.7	0.9	1.2	1.8	2.5	3.0	3.6
12.0													
	0.0	-0.2	-0.4	-0.5	-0.7	0.3	-0.2	-0.5	-1.0	1.2	0.3	-0.4	-1.3
	0.5	-0.3	-0.5	-0.6	-0.8	0.0	-0.5	-0.8	-1.3	0.6	-0.3	-1.0	-1.9
	1.0	-0.4	-0.6	-0.8	-0.9	-0.3	-0.8	-1.1	-1.6	0.0	-0.9	-1.5	-2.4
	2.0	-0.7	-0.8	-1.0	-1.2	-0.9	-1.4	-1.7	-2.2	-1.1	-2.0	-2.7	-3.6
	3.5	-1.0	-1.2	-1.3	-1.5	-1.8	-2.3	-2.6	-3.1	-2.8	-3.7	-4.4	-5.3
	5.0	-1.3	-1.5	-1.6	-1.8	-2.7	-3.2	-3.5	-4.0	-4.5	-5.4	-6.1	-7.0
16.0													
	0.0	0.1	-0.3	-0.6	-0.9	1.9	0.7	-0.2	-1.5	4.6	2.2	0.3	-2.1
	0.5	-0.1	-0.5	-0.8	-1.2	1.1	-0.1	-1.0	-2.2	3.1	0.6	-1.2	-3.7
	1.0	-0.4	-0.7	-1.0	-1.4	0.4	-0.9	-1.8	-3.0	1.6	-0.9	-2.7	-5.2
	2.0	-0.8	-1.2	-1.5	-1.9	-1.2	-2.4	-3.3	-4.6	-1.5	-4.0	-5.8	-8.3
	3.5	-1.5	-1.9	-2.2	-2.5	-3.5	-4.7	-5.6	-6.9	-6.1	-8.6	-10.5	-12.9
	5.0	-2.2	-2.6	-2.9	-3.2	-5.8	-7.0	-7.9	-9.2	-10.8	-13.2	-15.1	-17.5

at these levels tend to offset each other. In practice, however, relative departures in average weekly maximum temperature from normal will not be severe from one year to the next but departures in total weekly precipitation can be quite large. For this reason, rainfall tends to dominate the change in yield.

Changes in Plant Available Soil Moisture at Planting

A change in yield due to a change in soil moisture is represented by the sum of two components. The first component provides the change in yield strictly due to a change in soil moisture, while the second component distributes the change in soil moisture across all temperature and precipitation terms in the model.

The change in yield due to a change in soil moisture is:

$$MY = MY\ (W\ only) + MY\ (W, T, R)\ \text{where} \tag{10}$$

$$MY\ (W\ only) = W - 1.069(2W + \Delta W) - 83.068 \tag{11}$$

$$MY\ (W,T,R) = \sum_{i=1}^{10} MY_i\ (W,T,R)$$

$$= \sum_{i=1}^{10} (.0482R_iT_i - 3.9802R_i - 0.061T_i)t_i$$

$$+ (.7907R_i + 0.0121T_i - 0.0097R_iT_i)t_i^2W\ . \tag{12}$$

Table 6 presents changes in yield for soil water only (11).

Table 6: The Change in Yield Due to a +1.0" Change in Plant Available Soil Moisture at Planting Disregarding Weather for Five Values of Soil Moisture

	Plant Available Soil Moisture at Planting (inches)				
	0.0	4.0	8.0	12.0	16.0
Change in Yield (bu/ac)	-84.27	-92.7	-101.2	-109.8	-118.3

Table 7 presents the change in yield for the second component on a weekly basis for temperature equal to 74°F, 82°F, 88°F, 96°F and rainfall equal to 0.0", 0.5", 1.0", 2.0", 3.5", 5.0". These two tables reveal large changes in yield due to changes in soil moisture; however, these two components are somewhat offsetting.

Table 7: The Change in Yield by Week Due to a 1.0" Change in Plant Available Soil Moisture at Planting and Weather

Week No. and Total Weekly Precipitation (inches)	Average Weekly Maximum Temperature (°F)					
	60	74	82	88	96	110
Week 1						
0.0	- 2.93	- 3.62	- 4.01	- 4.30	- 4.69	- 5.38
0.5	- 3.37	- 3.79	- 4.03	- 4.20	- 4.44	- 4.86
1.0	- 3.81	- 3.96	- 4.04	- 4.10	- 4.19	- 4.33
2.0	- 4.69	- 4.30	- 4.07	- 3.91	- 3.68	- 3.29
3.5	- 6.01	- 4.81	- 4.12	- 3.61	- 2.92	- 1.72
5.0	- 7.33	- 5.32	- 4.17	- 3.31	- 2.16	- 0.15
Week 3						
0.0	- 4.45	- 5.48	- 6.08	- 6.52	- 7.11	- 8.15
0.5	- 5.14	- 5.78	- 6.14	- 6.41	- 6.78	- 7.41
1.0	- 5.83	- 6.07	- 6.20	- 6.30	- 6.44	- 6.67
2.0	- 7.22	- 6.65	- 6.33	- 6.08	- 5.76	- 5.19
3.5	- 9.30	- 7.53	- 6.52	- 5.76	- 4.75	- 2.98
5.0	-11.38	- 8.40	- 6.70	- 5.43	- 3.73	- 0.76
Week 5						
0.0	- 0.15	- 0.18	- 0.21	- 0.22	- 0.24	- 0.28
0.5	- 0.26	- 0.31	- 0.33	- 0.35	- 0.38	- 0.42
1.0	- 0.37	- 0.43	- 0.46	- 0.49	- 0.52	- 0.57
2.0	- 0.60	- 0.67	- 0.72	- 0.75	- 0.80	- 0.87
3.5	- 0.93	- 1.04	- 1.10	- 1.15	- 1.21	- 1.32
5.0	- 1.27	- 1.41	- 1.49	- 1.55	- 1.63	- 1.77
Week 6						
0.0	4.18	5.15	5.71	6.12	6.68	7.66
0.5	4.67	5.22	5.54	5.78	6.09	6.65
1.0	5.16	5.29	5.37	5.43	5.51	5.64
2.0	6.14	5.44	5.04	4.73	4.33	3.62
3.5	7.62	5.65	4.53	3.69	2.57	0.60
5.0	9.10	5.87	4.03	2.64	0.80	- 2.42
Week 8						
0.0	17.18	21.19	23.48	25.20	27.49	31.50
0.5	19.51	21.87	23.22	24.24	25.59	27.95
1.0	21.84	22.55	22.96	23.27	23.68	24.40
2.0	26.49	23.91	22.44	21.33	19.86	17.29
3.5	33.46	25.95	21.65	18.43	14.14	6.62
5.0	40.44	27.99	20.87	15.53	8.41	- 4.04
Week 10						
0.0	36.00	44.40	49.20	52.80	57.60	66.00
0.5	40.99	45.98	48.83	50.96	53.81	58.79
1.0	45.99	47.56	48.45	49.12	50.02	51.59
2.0	55.98	50.71	47.70	45.45	42.44	37.18
3.5	70.96	55.45	46.58	39.93	31.07	15.56
5.0	85.94	60.18	45.46	34.42	19.70	- 6.06

If temperature is fixed at 85°F, rainfall at 0.0", 0.5", 1.0", 2.0", 3.5", and soil moisture at 0", 4", 8", 12" and 16" then a 1" change in soil moisture would produce the yield changes recorded in Table 8. In general, an increase in soil moisture will cause an increase in yield until soil moisture becomes excessive.

Table 8: The Change in Yield for a Change in Soil Moisture of +1.0" with Maximum Weekly Average Temperature Fixed at 85°F, for Various Soil Moisture and Precipitation Levels

Total Weekly Precipitation (inches)	Plant Available Soil Moisture at Planting (inches)				
	0	4	8	12	16
0.0	47.9	39.3	30.8	22.2	13.7
0.5	44.1	35.5	27.0	18.4	9.9
1.0	41.5	32.9	24.4	15.8	7.3
2.0	34.8	26.2	17.7	9.1	.6
3.5	25.2	16.6	8.1	- .5	- 9.0
5.0	15.5	6.9	- 1.6	-10.2	-19.7

Changes in Tassel Date

The analysis thus far has considered the affect of changes in soil moisture and weather data in the model. Soil moisture is determined at planting but the set of weather data to be used is not determined until the tassel date is known. This is because the weeks of weather data used in the model are selected to bracket tassel date with five weeks before, the week of, and four weeks after tasseling. This limits model use until a tassel date can be forecasted or estimated. Therefore, a change in tassel date causes a change in the weather inputs.

To gain insight into the tassel date affect, many different weather patterns are needed. This was accomplished by using 30-year normals for 55 counties in Missouri as weather data input. This particular data was selected due to a research study described later in this paper. For each county five different tassel dates with seven different soil moisture values were examined. Yields were compared within moisture value across tassel weeks. For these 385 moisture values, 329 resulted in a decrease in yield over all weeks when a later tassel date was used. For each soil moisture value, pairs of yields are created from concurrent tassel dates. For the 1,540 pairs, 1,477 pairs produced a decrease in yield with a one-week shift to later tassel date. The average shift in yield was approximately 10 bushels.

Methods of Measuring Variables for Current Year Forecasts

The variables required to run the Leeper Model are average weekly maximum temperature, total weekly precipitation, plant available soil moisture, field tasseling date, and an empirical adjustment factor. All but the empirical adjustment will be discussed in this section. The adjustment will be examined later. To assess model output, a measure of final farmer yield was obtained.

Sample Locations

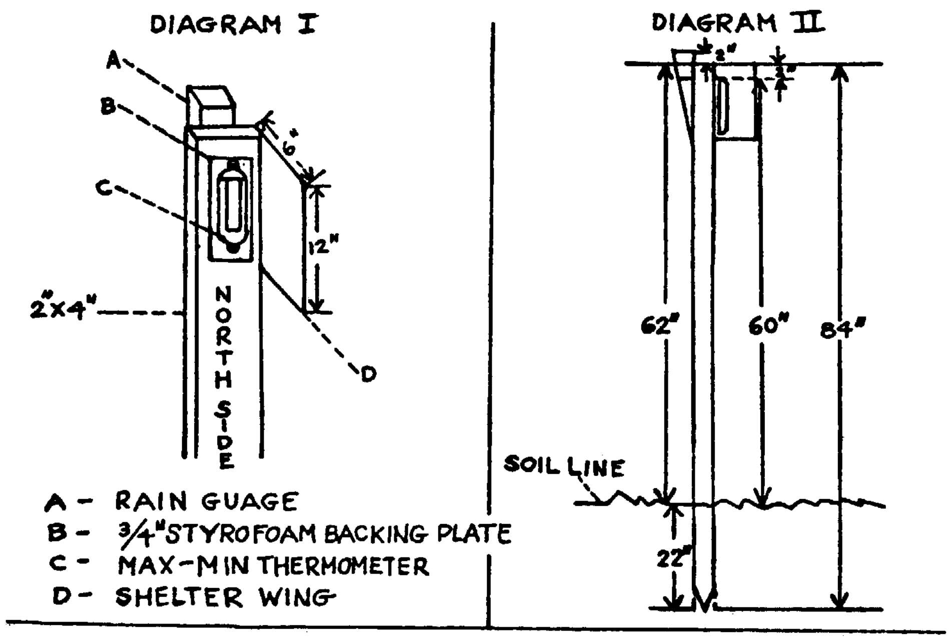
In 1976, the Agricultural Stabilization and Conservation Service (ASCS) of Missouri established a critical weather monitoring system composed of 114 county offices to provide daily precipitation measurements. For this study, 55 of these offices located in major corn-producing areas agreed to also provide daily maximum temperature readings from weather stations. A one-square mile segment was constructed so that the weather station was not more than .35 miles from the center of the segment. Each County Executive Director provided a list of farm operators who were planting corn for grain within the segment. These farm operators were visited in a random order. A farm operator qualified for the study if he planned to haul grain directly to an elevator from at least one field in the segment. If the farmer granted permission to use his fields, a series of screening questions was asked by the enumerator to identify all qualifying fields. One or two qualifying fields were randomly selected from all qualifying fields. Information about the agricultural practices used and directions to each selected field were obtained.

Once initial interviews with the operators were completed, 100 fields were selected in 55 counties under 82 different operators. A goal of two operators in a segment with each operator providing one field was not satisfied in 29 of the 55 segments due to a lack of candidate operators. In these 29 segments, eleven had a single field, 17 had two fields under one operator, and one had three fields under two operators.

After field selection was completed, one field was measured for size and shape in each county. On a later visit, a University technician obtained soil moisture measurements from one field in each segment. Due to an early, yet short, planting season, it was not possible to obtain the four desired soil cores in every field. In 25 fields only two core samples were obtained. From the 55 fields sampled for soil moisture, twenty were selected for tasseling observations. Final farmer yield was obtained for 99 fields. One field was used for silage.

Weather Data

For each segment weather data obtained by the ASCS cooperator consisted of readings from a calibrated Taylor Max/Min thermometer and a Tru Check Rain Gauge mounted on a post. The post (diagrams 1 & 2) was located at most 0.35 miles from the center of the segment and no more than 1.06 miles from the field.



Temperature and precipitation data from this station, temperature and precipitation data from nearby primary or secondary NOAA weather stations, and thirty-year historical temperature and precipitation normals were used as input. The primary or secondary weather station and historic temperature and precipitation values were interpolated for each segment using a technique developed by S.L. Barnes (1964).

The rain gauges used in this study had been previously tested by many sources and found reliable. A University of Missouri test of the gauge concurred with this finding. The daily precipitation readings obtained from the ASCS segment stations were used for model evaluation.

Based on some previous work done by the Extension Service in Maryland, the temperature readings might be expected to have a degree or two of upward bias. The three methods of reporting segment temperatures, ASCS station, current weather station, and historical normals, were compared using eight weeks of common data. A fixed effects factorial design with appropriate orthogonal comparisons was employed.

When comparing all methods across counties and weeks, all main effects and interactions were significant at the .001 level. In fact, historical normals produced a mean and variance significantly lower than both current estimation techniques (Table 9). Historical normals were not included in the remaining temperature analysis because of dissimilarity.

Table 9: Mean and Standard Deviation of Average Maximum Temperatures (°F) Determined by Different Methods for all Segments

Statistic	METHOD		
	Historical	Current Interpolated	Current Observed
Mean	86.6	88.6	90.1
Standard Dev.	0.4	3.5	4.6

A comparison of current methods across counties and weeks produced significant main effects at the .0001 level and significant interactions at the .05 level. Comparing current methods by week across counties revealed significant differences in means for weeks 2 through 7 at the .0002 level and in variances for all weeks at the 0.005 level (Table 10). At the county level, there were significant differences in 31 of 55 counties.

The ASCS-observed temperatures deviated from interpolated weather station data by one to four degrees. Unfortunately, the deviations varied in sign and by segment. The interpolation procedure had proven reliable previously. Therefore, the University of Missouri conducted a test of the segment weather station and a test of the thermometer to try to discover the cause of the inconsistency in segment-observed temperature data.

Table 10: Average Weekly Maximum Temperature (^{o}F) and Standard Deviation by Method and Week for all Segments

Method	Week Number 1	2	3	4	5	6	7	8
Current (mean) Interpolated	85.7	86.7	84.7	85.9	91.5	91.2	94.1	88.9
(st.dev.)	1.4	2.0	1.8	0.8	1.7	.9	.6	2.0
Current (mean) Observed	86.3	88.8	86.0	88.2	93.8	92.6	95.7	89.0
(st.dev.)	3.9	3.9	3.4	2.9	3.2	2.8	2.5	3.0

In the first test, a weather station post was located next to a reporting weather station. Temperature readings were taken from both devices over a 27-day period. The Taylor thermometer recorded a higher temperature than the weather station thermometer for 22 days, the same temperature for 2 days, and a lower temperature for 3 days. If one assumes equivalence of instruments, the probability of at least 22 days with a higher reading is 0.00296. When a paired t-test was applied, the readings were different at the 0.025 level.

In a second test conducted after the 1977 study, 29 thermometers were calibrated. The mean and range of the deviations to a standard over several trials for the 29 thermometers were 1.2^{o} and 12.0^{o} for the maximum reading and 3.1^{o} and 7.7^{o} for the minimum reading. Again, there was no consistent error by device, but the mean error was always positive.

Due to the questionable accuracy of the Taylor thermometers and the constructed weather stations, interpolated temperature data from primary or secondary stations were used for each segment.

Plant Available Soil Moisture

The University provided soil moisture estimates for each field in the study. Soil moisture was measured for one field in each segment. The procedure to measure soil moisture was as follows. Two or four soil samples were taken in one field in each of the 55 segments. In a normal work day, three segments were visited. Four cores were taken from the field in the first segment visited each day, two cores from the field in the second segment and two or four cores from the field in the third segment depending on remaining hours of daylight. All cores were taken from random plots laid out from different corners of the field. If only two cores were obtained, they were randomly located from opposite corners.

The soil was probed in 6-inch increments to a depth of 48 inches and soil texture was noted. Each soil increment was placed in a seamless 6-oz. can and brought to a lab to be weighed. Wet and dry weights of samples and tare weight of can were obtained to the nearest tenth of a gram. Next, soil bulk density and percent moisture at 15 bar were read from standard tables for each classified soil sample. Using these five values, plant available soil moisture was computed.

Problems occurred in the sampling and laboratory procedure. The hand probe technique used to pull soil cores did not always produce an undisturbed core. Also, some sample cores dried out before laboratory work could be completed.

Date of Tasseling

In order to use the Leeper model, the week in which a corn field reaches the point of full tasseling must be determined. Full tasseling was defined for enumerators and farm operators to be that time when examining the field from a distance all plants appear to be tasseled. This definition did not seem adequate so an empirical definition was created from the study. The empirical definition is that full tasseling occurred on the day when 70% of the plants in a field had tasseled. This definition seemed acceptable for three reasons: 1) a field would appear to be fully tasseled to an observer, 2) a portion of plants in a field never tassel, and 3) the rate of tasseling begins to decrease past this cutoff. The adequacy of the empirical definition will be examined in this section.

Date of tasseling was obtained in three ways:

1. from a heat summation model provided by the University of Missouri,

2. from a mail report completed by each cooperating farm operator, and,

3. estimated in 20 selected fields using plant counts made in 16 plots in each field.

The heat summation method used by the University starts at planting and accumulates a total difference of maximum daily temperature minus a base temperature of 56°F. The day when this sum reaches or exceeds 612°F is the day tassel initiation occurs (Leng, 1951). The constant 40 is added to this Julian date since an average of 40 days elapses between tassel initiation and anthesis (Runge, 1957).

Julian Tassel Date =

$$\text{Julian Date} \left\{ \sum_{i=1}^{k} (\text{max temp})_i - 56 \geq 612 \right\} + 40 \qquad (13)$$

The farm operator completed the following information on the mail report:

1. date first observed tasseling; and,

2. date fully tasseled and beginning to silk.

The response rate for the 100 cards was 55% mail returns, 28% phone calls, and 17% enumerator interviews.

The third method of obtaining tassel date was from objective counts. Four plots were located from each of four corners in twenty purposely selected fields. Once counting began, field visits were targeted at three-day intervals. Counts made during a visit were:

1. number of stalks in Row 1,

2. number of stalks tasseled in Row 1, and

3. number of stalks that had ears or silked ear shoots in Row 1.

Problems occurred in one field so tassel dates could only be estimated for 19 fields.

Tassel dates from enumerated data were determined at the plot or field level using the 70% definition of tasseling, the daily tasseling rate, and interpolation or extrapolation to a Julian date from the closest enumerator visit to 70% tasseled. The average length of tassel period was 8.4 days with a standard deviation of 3.4 days. Plot tassel estimates were examined to determine adequate sample size requirements. If we assume the variation within field is the same across all fields, the variance estimates produce a standard error of 0.51. This suggests that 8 plots per field is adequate. Using the largest individual field level standard deviation of 3.8, the standard error of the mean would be 1.3 days or the field estimate would be within 2.7 days 95% of the time.

Three paired t-tests with 18 degrees of freedom were employed to compare (1) the enumerated tassel date (standard), (2) the farmer reported tassel date, and (3) the heat summation tassel date. The t-value for the differenc of (1) and (2) -0.7139 was not significant ($\alpha = 0.4$). From this we conclude that farm operators are capable of providing an estimate of full tasseling by visually examining the field.

The t-values for (1) and (3) and for (2) and (3) both exceed 10 and were highly significant ($\alpha < .001$). The heat sum model was always early with a mean difference of 4.8 days. This may suggest that the heat sum model be employed in a real time mode to schedule enumerator visits to observe tasseling.

Farmer reported tassel dates or enumerated tassel dates when available were used to run the model.

Field Yield Data

The farm operators were requested to harvest the research fields separately. Yield data was obtained in 99 of the 100 research fields. Of the 99 fields, 92 were taken to an elevator for moisture determination and weighing. Farmer estimates or grain bin estimates were made for the remaining seven. From this data, a yield per acre was computed using farmer estimates of field size.

Examples of Forecasts Using the Leeper Model

Forecasted yields of the unadjusted Leeper model were examined in three ways

1. Weather data, simulated for 1969 at Columbia, Missouri, was used to produce model forecasts for Columbia, Missouri for 1969 with four, three, two, and one week of unknown weather.

2. Pseudo forecasts for 1977 were compared for 99 Missouri research fields with different amounts of unknown weather data and historical data combined.

3. Actual forecasts for fixed dates in 1977 were created for 99 Missouri research fields for June 1, July 1, August 1 and September 1.

Forecasts from the last two procedures were examined to develop an empirical adjustment factor.

Forecasts with Simulated Weather

Since the results of sensitivity analysis indicated significant changes in yield due to tassel date, the forecasting approach used will be to wait until the actual tassel date is known before running the model. At this point in time, six weeks of weather data is known and four weeks of weather data unknown. This unknown weather data will be produced by using simulated data.

Bond (1979) developed procedures to simulate sequences of possible future weather data based upon historical weather patterns. Procedures developed for Columbia, MO were used to simulate possible sequences of weather data around four tassel dates: June 28, July 5, July 12, and July 19. Bond used 1969 weather data to evaluate his procedure so weather data from that year was used to determine yield check values.

The input to start the weather simulation process was the actual weather conditions (maximum temperature and precipitation) for the last day in the last week of known weather in 1969. For four hypothesized tassel dates, 100 possible sequences for the remaining one, two, three or four weeks of unknown 1969 weather were generated. Results from these runs are presented in Table 11.

The range of forecasted yield produced with low or high soil moisture generally exceeded 100 bushels regardless of tassel date or number of weeks of simulated weather used. The range of possible yields was reduced to about 40 bushels with middle values of soil moisture (8" or 12"). The average yields produced using the one hundred runs of simulated weather regardless of tassel date or number of weeks of unknown weather for middle values of soil moisture were never more than 13 bushels from the model yield produced with all ten weeks of 1969 data. This data would suggest that the simulation technique of individual year data may be appropriate with mid-range moisture values but not adequate with low or high soil moisture values.

The simulation technique was also used to produce simulated 30-year normals to be substituted for the unknown weather for the tassel date of July 5. Three thousand values of each variable of simulated weather data were converted to 100 30-year normals of maximum temperature and precipitation for the remaining one, two, three and four weeks of unknown weather. Results from these runs as well as earlier results from the individual year runs are presented in Figures 1-4. The range of yield values employing these 30-year normals was not very wide yet the final unadjusted yield value was not contained in 19 of the 40 generated confidence intervals. This result is due to the strong influence precipitation has on yield in weeks 7 through 10. Historical normal data smooths this precipitation effect since weekly rainfall in this period is between 0.7 and 1.1 inches. Current year data on the other hand may vary for the same period from 0.0" to 5.0". Because of model sensitivity to weather, neither forecasting method using simulated weather was extremely successful.

Table 11: Yields Produced from 100 Simulations Run of 1969 Weather for Columbia, Mo. with Different Numbers of Weeks of Unknown Weather, Four Different Tassel Dates and Five Values of Soil Moisture

Tassel Date	Plant Available Soil Moisture at Planting (inches)	6 weeks actual: 4 weeks sim $\bar{x}$	6 weeks actual: 4 weeks sim s	7 weeks actual: 3 weeks sim $\bar{x}$	7 weeks actual: 3 weeks sim s	8 weeks actual: 2 weeks sim $\bar{x}$	8 weeks actual: 2 weeks sim s	9 weeks actual: 1 week sim $\bar{x}$	9 weeks actual: 1 week sim s	10 weeks actual my
6/28	0	35.4	43.0	49.7	37.3	102.9	37.6	101.4	29.8	76
	4	92.2	26.8	100.0	22.8	130.4	22.4	129.0	17.6	114
	8	125.0	11.5	126.5	8.9	133.9	7.5	132.7	5.6	129
	12	133.8	9.8	129.0	8.3	113.5	9.1	112.4	7.4	120
	16	118.7	24.7	107.6	22.1	69.1	24.1	68.1	19.5	86
7/5	0	34.9	41.6	74.3	38.4	60.1	31.3	49.4	27.2	43
	4	88.2	25.4	111.3	23.5	102.2	19.2	96.0	16.0	92
	8	117.6	10.3	124.4	9.2	120.3	7.6	118.6	5.0	117
	12	123.0	10.2	113.4	8.0	114.5	6.4	117.4	6.9	119
	16	104.5	25.3	78.6	22.2	84.7	18.0	92.1	17.9	97
7/12	0	41.9	36.9	31.5	35.6	26.1	34.8	18.8	23.4	12
	4	89.0	22.7	81.9	22.1	78.1	20.8	74.5	14.0	72
	8	112.0	10.1	108.4	9.1	107.4	7.3	106.3	5.0	109
	12	111.2	7.4	110.8	7.5	112.1	8.2	114.1	5.5	118
	16	86.4	19.4	89.4	20.1	92.8	21.8	97.9	14.6	105
7/19	0	8.1	43.6	10.4	34.6	- 1.1	33.0	- 6.5	27.3	- 35
	4	64.4	27.3	65.9	21.3	59.0	20.3	56.1	16.3	39
	8	96.8	11.8	97.4	8.6	95.1	7.9	94.7	5.6	90
	12	105.2	8.9	105.0	7.9	107.3	6.9	109.4	6.4	116
	16	89.7	23.6	88.7	20.5	95.5	19.1	100.2	17.2	118

Figures 1-4: Distribution of 100 Yield Values for 1969 at Columbia, MO with 10 values of Soil Moisture and a Decreasing Number of Weeks of Unknown Weather using Simulated Year (|) and Simulated 30-Year Normals (=). Model Yield for Actual 1969 Weather = ●.

Figure 1: 6 Weeks Actual
4 Weeks Simulated

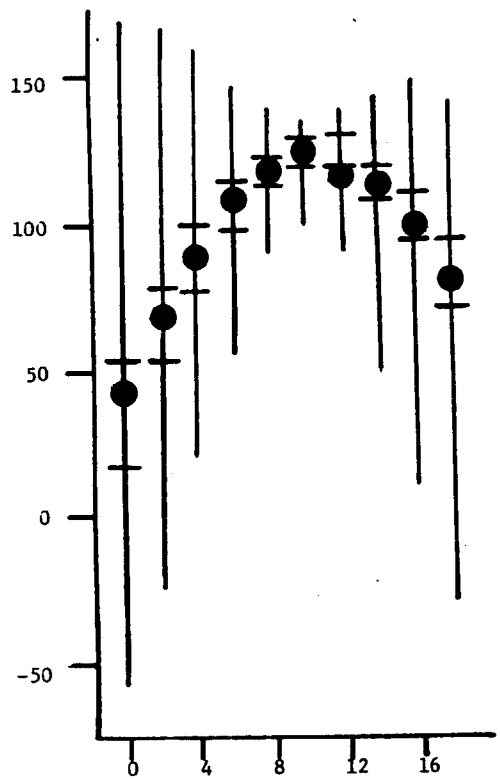


Figure 2: 7 Weeks Actual
3 Weeks Simulated

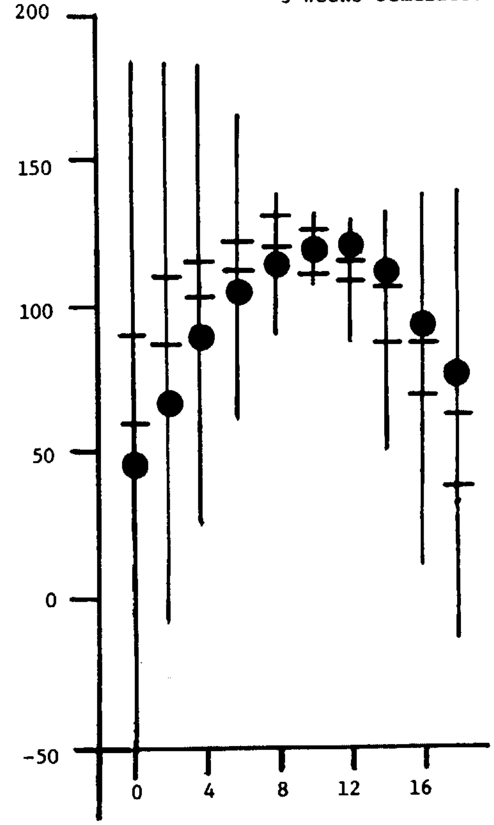


Figure 3: 8 Weeks Actual
2 Weeks Simulated

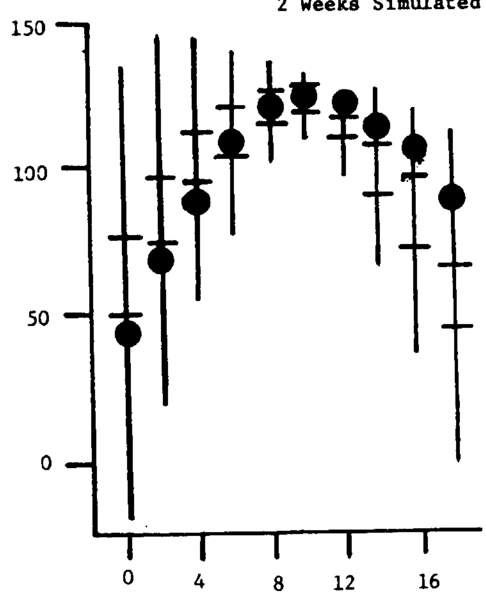
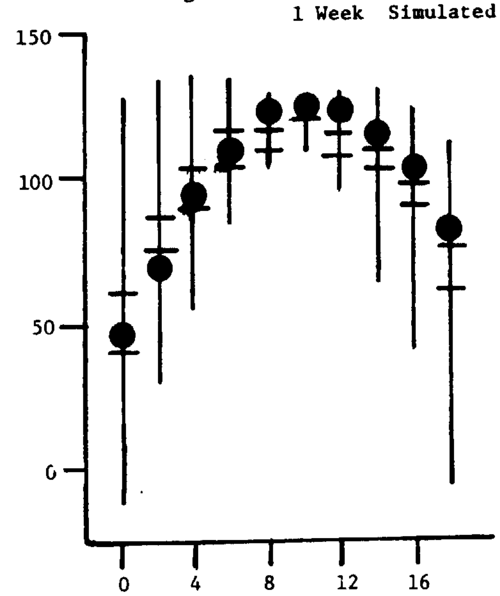


Figure 4: 9 Weeks Actual
1 Week Simulated



Pseudo Forecasts for 1977 with Different Amounts of Unknown Weather

In the previous analysis, the effect of unknown weather for one site was considered. To further compare the influence of unknown weather, pseudo forecasts for 99 corn fields located in the major corn growing regions were created. These are pseudo forecasts since fields are pooled by the number of weeks of unknown weather and not by date of tasseling. Historical 30-year normals for temperature and precipitation were employed for the unknown weather. Table 12 presents the results of these pseudo forecasts.

The unadjusted model yield data is presented in two-way table format. The nine-class intervals (columns) are based on actual harvested yield. The data presented for each pseudo forecast are mean unadjusted model yield, range of unadjusted model yield, mean deviation from actual harvested yield, and correlation to actual farmer yield for each interval and total. The number of fields in each interval is listed at the top of each column.

The mean unadjusted model yields by intervals for each pseudo forecast were not consistent with actual harvested yields, except for intervals whose values were near the sample mean. The average unadjusted yield over all fields for the five pseudo forecast periods was not significantly different from final harvested yield. Notice particularly that the tenth week of actual weather was far enough from normal to change the predicted yield by an average of 9.0 bushels. The correlations were not consistent, changing from .34 to -.05 which raises a question about the appropriateness of the model.

Forecasts for June 1, July 1, August 1, and September 1 for the Current Year

A method used to produce model forecasts for the current year was next examined for the 99 Missouri corn fields. Forecasts for June 1 were created by:

1. using the heat summation tassel model to create a tassel date for each field,

Table 12: Pseudo Forecasts with Different Numbers of Weeks of Unknown Weather Against Farmer Reported Harvested Yield

Pseudo Forecasts or Final Estimate	STAT	Farmer Reported Harvested Yield by Class and Total									
		$Y \le$ 45.05: n=8	45.05 $< HY \le$ 55.05: n=9	55.05 $< HY \le$ 65.05: n=13	65.05 $< HY \le$ 75.05: n=9	75.05 $< HY \le$ 85.05: n=14	85.05 $< HY \le$ 95.05: n=12	95.05 $< HY \le$ 105.05: n=12	105.05 $< HY \le$ 115.05: n=8	115.05 $< HY$: n=13	Total: n=99
Pseudo forecast	$\bar{x}$	71.3	60.3	72.0	74.3	86.6	80.5	94.6	89.0	87.7	80.5
6 wks known	R	60.7	26.1	60.7	40.3	96.8	82.2	96.9	66.5	84.0	106.8
4 wks unknown	$\bar{d}$	40.0	10.2	12.3	5.5	6.1	- 9.5	- 4.3	-23.4	-42.4	- 2.1
weather	r	0.34	0.51	0.50	0.57	0.25	-0.05	0.16	0.36	-0.22	0.34
Pseudo forecast	$\bar{x}$	66.6	58.1	66.7	71.3	86.0	79.7	92.8	89.7	86.4	78.4
7 wks. known	R	71.5	24.0	71.5	61.7	96.6	87.8	105.8	46.7	80.8	121.5
3 wks. unknown	$\bar{d}$	35.2	8.1	6.9	2.4	5.5	-10.2	- 6.1	-22.6	-43.7	- 4.2
weather	r	0.36	0.29	0.47	0.41	-0.23	-0.27	0.21	0.08	-0.28	0.35
Pseudo forecast	$\bar{x}$	64.6	61.0	66.8	65.2	80.7	81.9	89.7	86.8	84.7	76.6
8 wks. known	R	77.3	26.5	77.3	55.5	84.6	97.4	101.3	71.5	90.7	110.4
2 wks. unknown	$\bar{d}$	33.3	10.9	7.1	- 3.7	0.2	- 8.0	- 9.3	-25.6	-45.4	- 5.9
weather	r	0.23	0.07	0.53	0.67	-0.17	-0.16	0.23	0.23	-0.17	0.34
Pseudo forecast	$\bar{x}$	62.6	76.4	72.3	73.9	77.0	79.9	89.7	77.0	78.5	77.0
9 wks. known	R	85.7	48.7	95.0	62.3	66.2	124.9	100.1	75.2	121.8	152.9
1 wk. unknown	$\bar{d}$	31.2	26.3	12.5	5.1	- 3.5	-10.0	- 9.2	-35.3	-51.6	- 5.5
weather	r	0.41	-0.01	-0.20	0.61	-0.06	-0.02	0.37	0.23	-0.16	0.16
Final forecast	$\bar{x}$	74.5	98.5	82.9	103.6	83.2	94.0	84.7	74.1	79.2	86.0
10 wks. known	R	108.8	139.9	120.7	133.4	89.3	147.1	97.9	80.7	113.7	193.3
0 wks. unknown	$\bar{d}$	43.2	48.5	23.1	34.8	2.7	4.1	-14.3	-38.2	-50.9	3.5
weather	r	0.55	-0.02	-0.44	0.06	-0.13	0.26	0.37	0.49	0.01	-0.05
Farmer average reported harv. yld. ..	$\bar{x}$	31.3	50.1	59.8	68.8	80.5	89.9	99.0	112.3	130.1	82.5

2. selecting historical 30-year normal temperature and precipitation data based on the modeled tassel date,

3. using the soil moisture estimate provided by the University of Missouri for each field, and,

4. running the model for all fields with these input data.

The procedure for the July 1 forecasts was the same as June 1 except that historical weather data was replaced with current weather data as it became available.

For the August 1 and September 1 forecasts, farmer estimated or enumerated tassel dates were substituted for the heat summation tassel date. A new sequence of weather was selected, when needed, based upon the revised tassel date. More current weather was available in August and all current weather was used in September. Table 13 provides data similar to that in Table 12 for June 1, July 1, August, and September 1 forecasts dates.

Planting was extremely early for Missouri in 1977 so that a June 1 forecast was possible. This would not happen in most years. Model forecasts for most size groups departed substantially from harvested yield. However, the June, July and September forecasts for the total sample were not significantly different from the actual harvested yield. The June and July forecasts were within 1 bushel of final yield. Unfortunately, the correlations were never higher than .3. This leads to questions about the appropriateness of the model.

The final forecast values again demonstrate the powerful influence of water on the model that was observed in the sensitively analysis. The early June and July forecasts were dominated by the early season soil moisture. By the August forecast, an actual tassel date was determined for all fields; so current weather data was substituted for at least six of the 10 weeks of weather data for each field. A dry period occurred in late July so that the August yield forecast was depressed. Early August was quite wet so that model yields recovered substantially by September 1. These results suggest that in using the model to make forecasts, it may be better to use either all historical weather (July 1) or all current weather (September 1). Mixing the two may produce unusual response as experienced in August.

Table 13: Unadjusted Model Yield Forecasts for June, July, August and September by Class and Total Against Farmer Reported Harvested Yield

Forecast Date and Final Estimate	STAT	Farmer Reported Harvested Yield by Class and Total									
		HY ≤ 45.05 n=8	45.05 < HY ≤ 55.05 n=9	55.05 < HY ≤ 65.05 n=13	65.05 < HY ≤ 75.05 n=9	75.05 < HY ≤ 85.05 n=14	85.05 < HY ≤ 95.05 n=12	95.05 < HY ≤ 105.05 n=12	105.05 < HY ≤ 115.05 n=8	115.05 < HY n=13	Total n=99
June 1 forecast	$\bar{x}$	89.2	76.7	82.1	88.9	85.9	81.7	78.3	86.8	84.9	83.6
	R	35.4	22.7	69.9	36.3	35.8	49.5	47.8	36.7	39.8	76.7
	$\bar{d}$	57.8	26.7	22.3	20.1	5.4	- 8.2	-20.7	-25.5	-45.2	1.0
	r	0.40	-0.03	-0.10	0.60	-0.15	-0.14	0.26	0.15	0.28	0.02
July 1 forecast	$\bar{x}$	69.7	63.8	73.5	75.0	89.5	79.4	100.2	86.2	86.3	81.4
	R	53.5	28.6	50.5	45.5	151.8	73.0	151.9	67.7	73.9	161.1
	$\bar{d}$	38.4	13.8	13.8	6.2	9.0	-10.6	1.2	-26.1	-43.8	- 1.1
	r	0.50	0.23	0.46	0.56	-0.08	-0.22	-0.03	0.19	-0.18	0.27
August 1 forecast	$\bar{x}$	55.3	67.4	62.5	77.5	75.1	72.4	75.4	74.1	72.6	70.6
	R	93.8	46.0	65.2	55.9	70.3	95.4	83.1	80.7	89.4	121.6
	$\bar{d}$	23.9	17.4	2.7	8.7	- 5.4	-17.6	-23.5	-38.2	-57.7	-11.9
	r	0.45	0.24	0.11	0.18	-0.30	-0.03	0.40	0.49	-0.09	0.19
Sept. 1 forecast	$\bar{x}$	74.5	98.5	82.9	103.6	83.2	94.0	84.7	74.1	79.2	86.0
	R	108.8	139.9	121.7	133.4	89.3	147.1	97.9	80.7	113.7	193.3
	$\bar{d}$	43.2	48.5	23.1	34.8	2.7	4.1	-14.3	-38.2	-50.9	3.5
	r	0.55	-0.02	-0.44	0.06	-0.13	0.26	0.37	0.49	0.01	-0.05
Farmer average reported harv. yld.	$\bar{x}$	31.3	50.1	59.8	68.8	80.5	89.9	99.0	112.3	130.1	82.5

Empirical Model Adjustment

According to papers by Bence and Runge (1975) and Keener (1978), the model yield must be adjusted by an empirical factor to produce harvested yield. No constant empirical adjustment from model yield to actual farmer yield could be discovered directly from the 1977 Missouri data.

Post-planting and post-harvest interviews were conducted with each operator in an attempt to relate agricultural practices to the empirical adjustment required in the model. The results from this analysis have not been favorable. The variable most highly correlated to yield was plant population ($r = 0.1$). The regression equation selected from a stepwise procedure is:

$$AF = 0.4815 - .00532\ X_1 + 1.58880 X_2 \qquad (15)$$

with $R^2 = 0.216$ and where
AF = empirical adjustment factor
X_1 = historical average yield from field
X_2 = (current plants/acre)/21375.

The devisor employed in X_2 is the average plant population of the research fields from which the model was developed.

Another approach to model adjustment would be to remove the necessity of model adjustment. This could be done by recreating the model from current data regressing directly on the dependent variable of harvested yield. Employing the stepwise regression procedure with either all historical or all current weather data the two regression equations created were, respectively:

$$Y = 111.60 - .945\ W_i \sum_{i=1}^{10} (R_i t_i) - .120\ W_i \sum_{i=1}^{10} (R_i t_i^2) - .002\ W_i \sum_{i=1}^{10} (T_i t_i) \qquad (16)$$

$$Y = 98.268 + 4.150 \sum_{i=1}^{10} (R_i t_i) - .546 \sum_{i=1}^{10} (R_i t_i^2) - .006 \sum_{i=1}^{10} (T_i t_i) \qquad (17)$$

with R^2 equal to .608 and .512.

These R^2 values as well as the models created are evidence that either the original model was not appropriate in 1977 or the estimated parameters used in the original model are not appropriate. There is a high degree of multicolinearity between variables in the original model; thus, it was impossible to fit the entire equation. This multicolinearity provides evidence of overspecification of variables in the model.

A final observation about these two equations is that the weather components are identical in both models, yet only in the historic equation is soil moisture a factor. These two equations will be examined further in the second year of study.

A Large Area Forecasting Application in Illinois, Indiana, Iowa, and Missouri

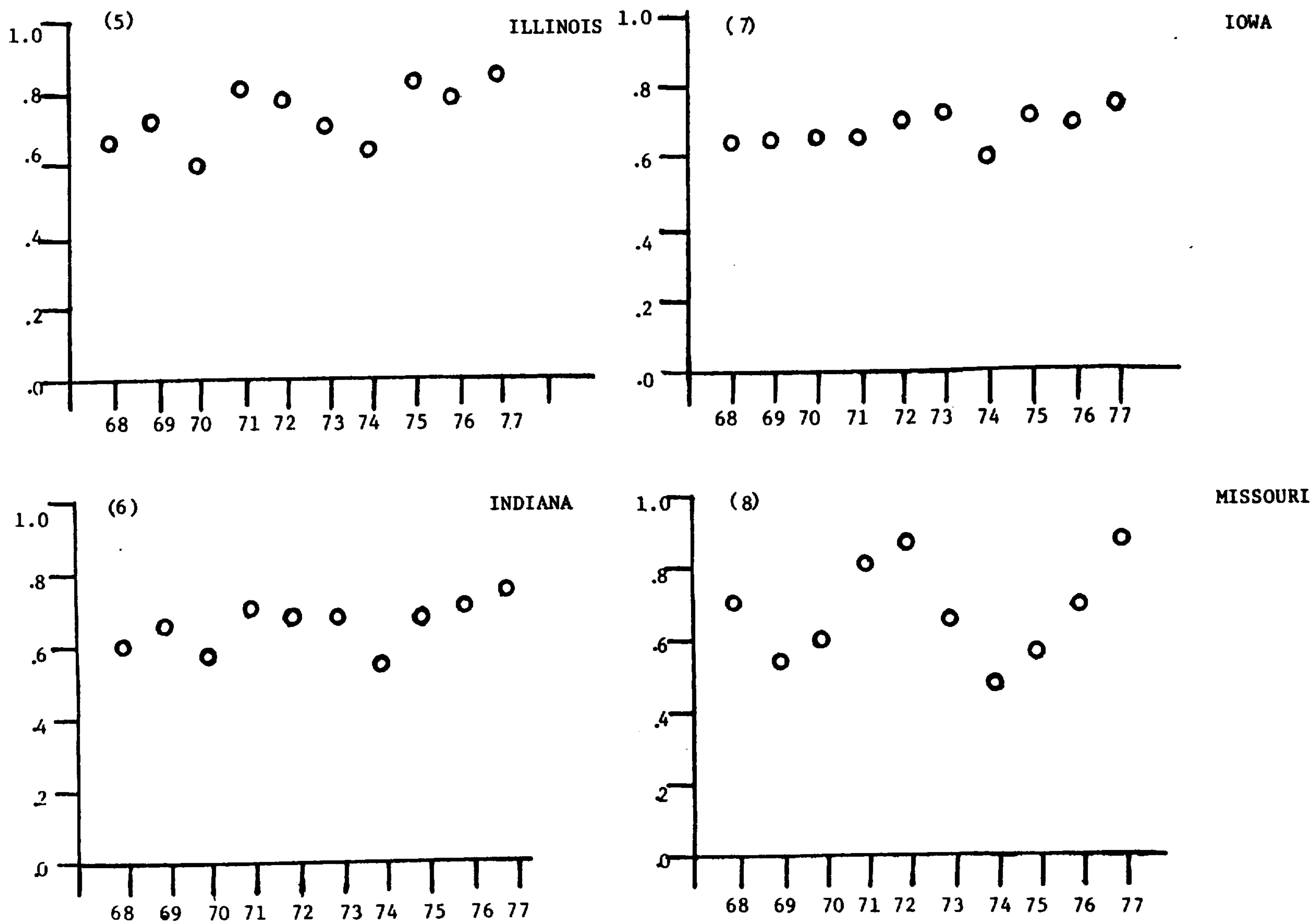
The following section presents some of the results and conclusions from an original paper presented by Keener (1978) to members of the Crops Branch, Methods Staff, and Yield Assessment Section. Some additional results generated by the author are also included. These results present a large area application of the model for the states of Illinois, Indiana, Iowa and Missouri. A comparison of the model calculations with Crop Reporting Board estimates for four states are shown in Table 14.

The first thing that becomes apparent is that the model was developed from experimental plot data where the management was intensive. Thus, the model should not be expected to predict average yields accurately. Since management practices for a large area do not deviate much from year to year, it should be possible to utilize this model to account for weather induced variations. A better way to interpret the relationship between the model calculation and the Crop Board estimate is to examine a ratio of the Crop Board estimate divided by the model estimate or percentage change from previous years. The ratios are shown in Table 14 as well as Figures 5 through 8. From these figures, it becomes apparent that the model has a stable ratio for Indiana and Iowa but does not perform nearly as well

Table 14: Final Crop Reporting Board Estimates and the Unadjusted Model Indication for 1968-1977

STATE	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Illinois										
Board	90.0	102.0	74.0	106.0	110.0	103.0	82.0	116.0	107.0	105.0
Unadj. Model	133.1	137.1	124.1	129.7	138.5	140.1	127.8	139.3	135.4	121.7
Board/Model	.676	.744	.596	.817	.794	.735	.642	.833	.790	.863
Indiana										
Board	88.0	100.0	76.0	101.0	104.0	102.0	73.0	98.0	110.0	102.0
Unadj. Model	142.7	143.7	129.4	144.9	152.2	149.3	136.4	144.4	152.8	135.2
Board/Model	.617	.772	.587	.697	.683	.683	.535	.679	.720	.754
Iowa										
Board	93.0	99.0	86.0	102.0	116.0	107.0	80.0	90.0	91.0	86.0
Unadj. Model	146.1	151.9	131.4	153.0	166.3	145.6	133.0	118.5	131.9	114.9
Board/Model	.637	.652	.654	.667	.698	.735	.602	.759	.690	.748
Missouri										
Board	83.0	68.0	61.0	88.0	91.0	88.0	54.0	63.0	61.0	76.0
Unadj. Model	115.3	123.4	98.1	106.9	102.5	132.9	115.5	108.8	85.7	87.0
Board/Model	.720	.551	.622	.823	.888	.662	.468	.579	.712	.874

FIGURES 5-8: The Ratios Between Crop Board Estimates and Model Predictions for 1968-1977



(variations in ratio) for Illinois and Missouri. In can also be seen that there is a consistent error for all states in 1974. This may be due to a late frost in the fall for that year. The model has no way of accounting for this particular phenomenon. The model did show that even without the frost problems there would have been a decrease in the yield from the previous year. Thus, part of the yield loss could have been caused by factors other than the frost. In 1970, the southern corn leaf blight epidemic struck in Missouri, Illinois and parts of Indiana. Very little damage was recorded in Iowa. This might explain the discrepancies in the model for this year in those states.

Although there are some discrepancies between the model estimate and the Crop Board estimates, in most cases, the model indicates direction of change from the previous year. The ratios for Missouri (Figure 8) seem to fluctuate with no consistent pattern. This makes it difficult to project a ratio for 1978. The data for Illinois (Figure 5) have the same fluctuations as Missouri but the magnitudes of the fluctuations are much less. With the exception of 1974, the Iowa (Figure 7) ratios represent the best case.

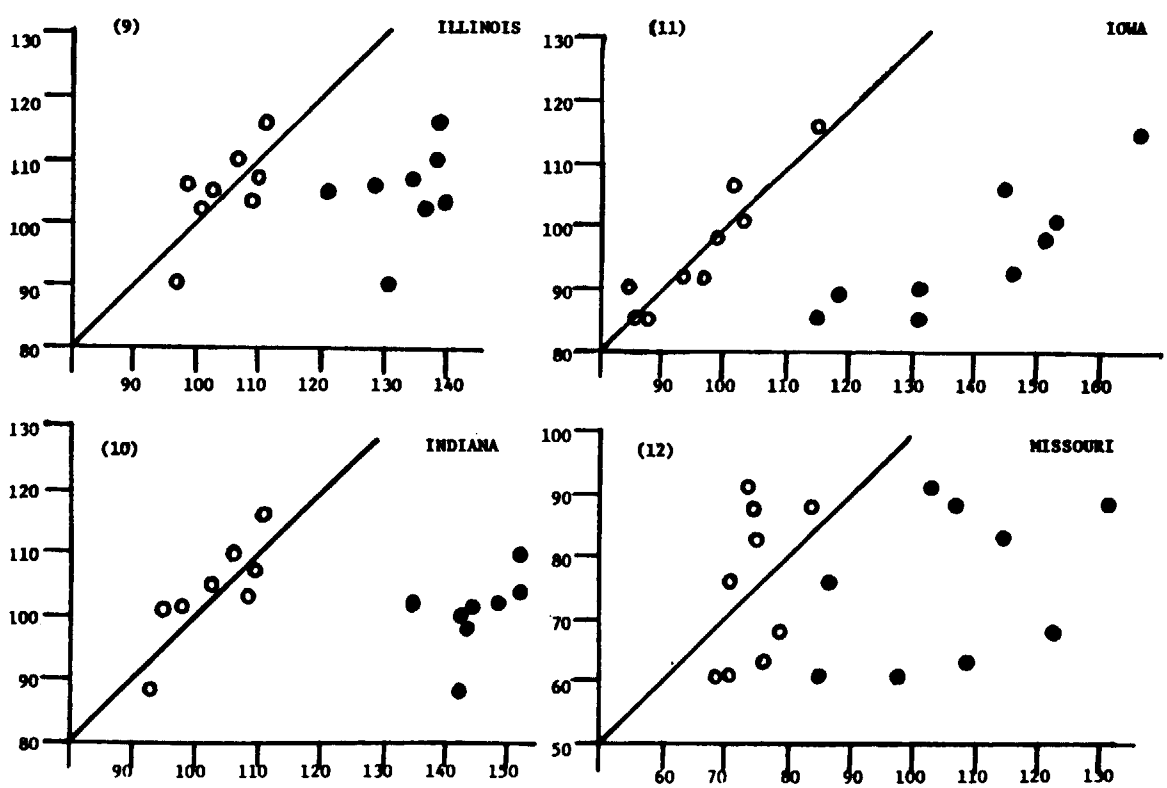
Because of the problems previously mentioned concerning 1974 in all states and 1970 in some states, these years were dropped when the regression lines for Figures 5-8 were calculated. The slopes, intercepts, R^2 values and the years omitted are shown in Table 15. As could be anticipated from the figure, the R^2 values are better for Illinois, Indiana and Iowa than they are for Missouri. While the regression for Illinois, Indiana and Iowa appear to be adequate to project a 1978 adjustment factor, the equation for Missouri appears questionable. The unadjusted yield indication and the adjusted yield indications are charted against Board yield in Figures 9 through 12.

The second objective of this study was to project a Crop Reporting Board indication for 1978 utilizing this model. This year's projections were made in the same manner as were the ten-year estimates. In 1978, the tasseling data and the weather data were gathered by the individual state offices. The soil moisture data was provided by scientists for their states.

Table 15: The Intercepts, Slopes, R^2 Value and Years Omitted from Calculation for Estimating the Yearly Adjustment Factor for Each State

State	Intercept	Slope	R^2	Years Omitted
Illinois	-.2472	.0142	.5838	1970, 1974
Indiana	.0385	.0090	.5567	1970, 1974
Iowa	-.1733	.0120	.7023	1974
Missouri	-.0734	.0109	.0763	1974

FIGURES 9-12: Unadjusted Model Yield (•) and Adjusted Model Yield (o) versus Final Board Yield for 1968 through 1977



In the original presentation by Keener, the adjustment was applied to the model indication producing a Board yield. These results can be found in Table 16. Also in Table 16 will be found results from regression equations applied to three alternative procedures:

1. The unadjusted model indication charted directly against Board yield.

2. The adjusted model indication charted against Board yield.

3. A Board yield produced from the unadjusted model yield and a time variable where the equation is of the form.

$$BY = b_o + b_1 (MY) + b_2 (MY)(Year - 1900).$$

The combined production computed from each method for the four states is also presented.

Table 16: Unadjusted Model Indication, Adjusted Model Indications by Method as of September 1, and Final Board Estimates (bu/acre) for 1978

	Ill. (bu/ acre)	Ind. (bu/ acre)	Iowa (bu/ acre)	MO (bu/ acre)	|Ave dev|	Total Production (bu x 10^6)
Unadj. Model	143	146	151	121	32	4476.2
Univ. Method	123	108	115	92	4.75	3596.9
Method 1	107	101	102	80	8.25	3190.1
Method 2	119	107	115	84	3.50	3530.5
Method 3	119	107	116	80	4.25	3534.2
Board Estimate	111	108	117	87		3482.1

Methods 2 and 3 both produced slight improvement over the procedure outlined by the University. The four state production from either method was within 1.5% of the final Board production. The R^2 values for the method 2 equations were 0.5444 for Illinois, 0.6544 for Indiana, 0.8962 for Iowa, and .1304 for Missouri.

If 1978 model indications and Board estimates are added to the earlier data set, the parameter estimates for methods 2 and 3 do not change in sign and are not significantly different from the previous year. The R^2 values for the method 2 equations improve with 0.5501 for Illinois, 0.7002 for Indiana, 0.9277 for Iowa, and 0.2000 for Missouri.

The adjusted model indications seem to be very good in Iowa, reasonable in Illinois and Indiana, and very suspect in Missouri. The problem in Missouri could be two fold: (1) the soil moisture values for some Missouri soils are in a less effective region and (2) cropping practices cause considerable change in corn acreage, introducing greater amounts of marginal land in some years. For these reasons, the model is deemed inappropriate for Missouri.

CONCLUSIONS

The sensitivity analysis revealed extreme sensitivity to water in the form of both plant available soil moisture at planting and total weekly precipitation. Generally, increases in temperature decreased yield, and later tassel dates decreased yield.

The data collection for current year variables was reasonably satisfactory. Modifications will need to be made in subsequent studies to produce better initial soil moisture data. At site temperature data is not necessary for every field since this variable is fairly uniform over small geographic areas in Missouri. Methods to measure rainfall and estimate tassel date were quite acceptable.

The forecasting capability of the unadjusted model for this small area data set was not acceptable at the field level, but did reproduce a reasonable mean average yield. The best forecasting procedures seemed to be with all historical weather or all current weather. This would suggest July 1 and September 1 forecasts. This is the result of within season variations in the two weather data sets which are not adequately expressed when historical and current weather data are combined for forecasting yields. The R square values for all forecasts were quite low which would suggest that the relationship between current model and the grower yields is poor. There was no consistent relationship in model deviations so that it was not possible to develop an empirical adjustment factor. Studies conducted in 1978 and 1979 should provide more insight into the questions of model stability and adjustment consistency.

In the large area application, the model worked very well in Iowa, reasonably well in Illinois and Indiana, and did not work in Missouri. The problems in Missouri may result from variable soil moisture values at planting and general cropping practices. This model will probably work reasonably well when the cropping practices in a state are fairly stable and initial soil moisture ranges between 7" - 14".

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