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Historical Crop / Climate Relationships in South Dakota

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HISTORICAL CROP/CLIMATE RELATIONSHIPS IN SOUTH DAKOTA

◦1965 to 1982◦

Plant Science Department
South Dakota State University

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16. Abstract
Crop performance and climatic records were collated for high production counties in South Dakota to evaluate the effects of temperature and precipitation on yields. The crops involved were corn, soybeans, sorghum, oats, spring wheat, and winter wheat. Records were compared for the period from 1965 to 1982.

The computer data file for each county includes seven climatic parameters, dates of plant development, adjusted yield and yield rank by year. The crop/climate record for the 17-year period was evaluated in sixteen counties per crop each year. Thus, 272 county x year observat-ions were made for each crop, except for soybeans which involved 12 counties and 204 county x year observations. Multiple regression identify the significant factors influencing yield from a list of fourteen independent variables. The analysis was made on each crop within the desig-nated counties over the 17-year period.

In addition to results from multiple regression, salientclimatic characteristics of years when yields were high or low for each crop are summarized in the attached report "Historical Crop/Climate Relationships in South Dakota - 1965 to 1982". Available county records in South Dakota identified significant climatic stress periods in the phenology of six crops and provides an excellent opportunity for improving yield prediction. A copy of the computer tape containing the data set (Copyrighted by D. G. Kenefick, 1984) has been provided to the sponsoring agency.

Satellite imagery was gathered for seven crop stress situations in South Dakota. Scenes were dated and crops identified as having disease, freeze, or drought conditions. Climatic conditions leading to the stress situations and yield outcome was included in the analysis.

17. Key Words (Suggested by Author(s))
South Dakota, climatic stress, yield influences, corn, soybeans, sorghum, oats, spring wheat, winter wheat, satellite imagery.

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HISTORICAL CROP/CLIMATE RELATIONSHIPS IN SOUTH DAKOTA

1965 to 1982

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Acknowledgments

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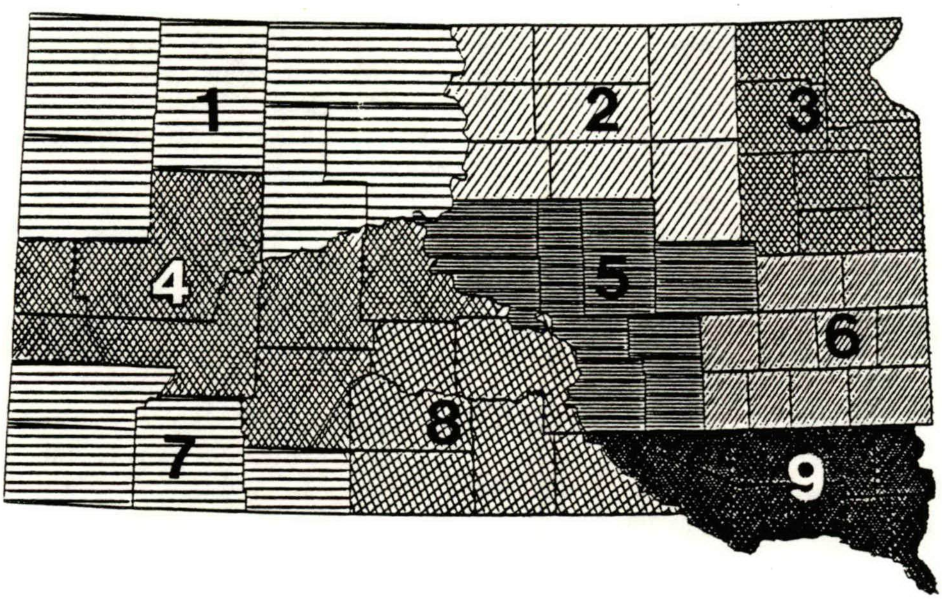
SECTION I
SOUTH DAKOTA CROP REPORTING DISTRICTS



1 NORTHWEST
Spring Wheat

2 NORTH CENTRAL
Corn, Oats, Spring Wheat

3 NORTHEAST
Corn, Oats, Soybeans, Spring Wheat

4 WEST CENTRAL
Winter Wheat

5 CENTRAL
Sorghum, Spring Wheat, Winter Wheat

6 EAST CENTRAL
Corn, Soybeans, Sorghum, Oats

7 SOUTHWEST
Winter Wheat

8 SOUTH CENTRAL
Sorghum, Winter Wheat

9 SOUTHEAST
Corn, Soybeans, Sorghum, Oats

Section 1: Research Approach and Procedures

Weather[1] and crop performance records[2] for South Dakota were analyzed for the period 1965 through 1981 to identify relationships between climate and yield. Performance of six crops was reviewed over this 17-year period; winter wheat, spring wheat, oats, corn, sorghum, and soybeans. Records were examined for 16 counties per crop for each of the 17 years. Selection of counties was made by first determining the four Crop Reporting Districts (USDA-SRS) having the highest harvested acreage in 1965 for the crop selected. Next, the four counties with the highest harvested acreage within each district were identified, thereby providing sixteen widely dispersed counties in South Dakota for studying each crop. Counties so identified by 1965 production records were used to examine climate/yield relationships throughout the study (soybean production was restricted to only three reporting districts in 1965 and therefore only 12 counties were included for this crop).

The average annual county yields were shown to increase for all crops except spring wheat from 1965 to 1981. This increase was attributed to enhanced management practices and cultivar improvement. To remove this bias from the data, yields were adjusted for all crops by regression analysis of county yield records with years. Therefore, "adjusted yields" were used for all comparisons made in this report. Spring wheat yields showed a slight negative slope by regression analysis in some instances, which perhaps can be explained by severe drought conditions in some counties during 1974, 1975, and 1976, influencing yield to a larger extent than production methods.

The climatic data used was calculated from daily measurements from one site in each county. The data considered useful was maximum/minimum air temperature (F) and rainfall. These daily values were used to calculate max/min temperatures, growing degree days to the base 40 and 50 (GDD_{40} and GDD_{50}), precipitation from March 1, precipitation from March 1 including the previous September, October, and November total, and weekly accumulative total for each of these climatic parameters, thereby providing an average weekly max/min temperature and total rainfall in inches per week. March 1 was used as the starting date to compute weekly values for each year and county.

The climatic events which occurred between March 1 and when the crop reached "physiological maturity" were used to compare growth conditions between years for summer annuals. Growing stage data was derived from annual district crop reporting summary. Physiological maturity was arbitrarily designated as follows: for oats and spring wheat when 50% (+ 20%) of the crop in the district had heads turning yellow (stage 4), when 50% ($\mp$ 20%) of the corn was dented

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[1]South Dakota weather records were kindly made available by Professor William Lytle, South Dakota State University.

[2]Crop performance data was obtained from the USDA-SRS Crop Reporting Service, Sioux Falls, S.D.

(stage 4), when 50% (+ 20%) of the sorghum fields had turned color (stage 3), and when 25% (+ 10%) of the lower leaves on soybeans had dropped (stage 4). The growth season for winter wheat was defined as the period from September 1 to when 50% (+ 20%) of the fields turned color during the harvest year (stage 4). Stage 1 always refers to when 50% of the county acreage for a crop is planted. These designations are used in the Appendix and elsewhere in the report.

Growing season precipitation was considered as the amount obtained annually during the principal growth period as determined for each county and crop. For winter wheat this precipitation occurred from the fall to the following summer. However, the amount of water in the soil profile prior to March 1 was considered a variable that could be important for summer annuals also. This reserve soil moisture was estimated by including the total precipitation for September, October, and November of the previous year as a calculation separate from the growth season precipitation. Since December, January, and February precipitation usually occurs while the soil is frozen, it was not considered as an important contribution to water recharge of the profile, and therefore not considered useful in crop production. Rather, it was assumed that most of this water resulted in runoff.

The computer data file for this study contains a weekly record of nine climatological variables for each selected county interfaced with comparable crop growth stage data for the 17-year period. Additionally, the file contains a ranking of adjusted average yield for each crop by year within each county (1 = highest and 17 = lowest).

Two general approaches were used to assess the data: 1) A step-wise multiple regression of district-wide data was used to determine significant regression coefficients which explained important variables contributing to yield. The multiple regression analyses were conducted using the SAS software package with the maximum R^2 option of the stepwise procedure. 2) Important climatic variables were evaluated by visually comparing climatic inputs of the four highest yielding years for a crop within a county compared to the five lowest yielding years.

Overview of Data Set. In limited precipitation areas, such as South Dakota, rainfall distribution at critical stages of crop growth was assumed to be an important influence on production. A cursory comparison of all yield data with the associated growing season and the previous fall precipitation, showed no consistent relationship between total rainfall and crop performance within counties, which provided support for this assumption. The year 1976 was one exception in which uniformly low total growing season precipitation for all crops seriously impaired yield. By contrast, 1974 frequently had double the 1976 total rainfall amounts for comparable crops and counties and yet ranked with 1976 as a poor crop production year in South Dakota (Table 1).

Data for 1975 also shows a high proportion of corn and sorghum producing counties experienced drought conditions as did 44% of the spring wheat producing counties (Table 1). Yields reported for oats and spring wheat were almost completely in the low class for 1966. However, 37% of the sorghum and 67% of the soybean producing counties were ranked in the high class in 1966. 1967 showed the opposite tendency, compared to 1966, with 87% of the sorghum and 67% of the soybean counties in the low class and 44% of the spring wheat counties in the high yield class. These comparisons illustrate some significant climatological effects upon cool season versus warm season crops.

1971 was generally a good production year for only oats and spring wheat, whereas 1969 favored corn, sorghum, and soybean production. 1972 and 1979 production records indicated evidence for consistently good spring wheat production and excellent corn, sorghum, and soybean yields in South Dakota.

Evaluation Procedures. Several interpretations could be given to the summary shown in Table 1:

1. The high/low yield summary reflects the climatic pattern of the predominant production districts where a crop is grown in South Dakota, and tends to validate the climatic data derived from one measurement site in each county. Selection of the input data tended to minimize the effects of localized weather conditions.

    a) Sixteen widely dispersed counties (four from each district) were selected for each crop, reducing the impact for localized weather conditions on yield.

    b) The reported average county yield data was obtained from 60 to 100 observations, the results of which integrated the effects of climate over the entire county. County yield estimates had a variation of ± 5%.

    c) Only the extremes were used from the yield ranking results. Additionally, Table 1 only shows years when more than 6 counties and when two crops received either a high or low ranking, thus reducing chances for spurious associations.

2. Some years clearly showed uniform reduction in yields for all crops (1974 and 1976), some years favored cool compared to warm season crops (1967, 1969, 1971, 1972) and some uniformly good production for all crops (1978, 1979). Thus, it appears that readily available climatic and crop yield records at the county level, could be used to discern critical stages of development in relation to important climatic events.

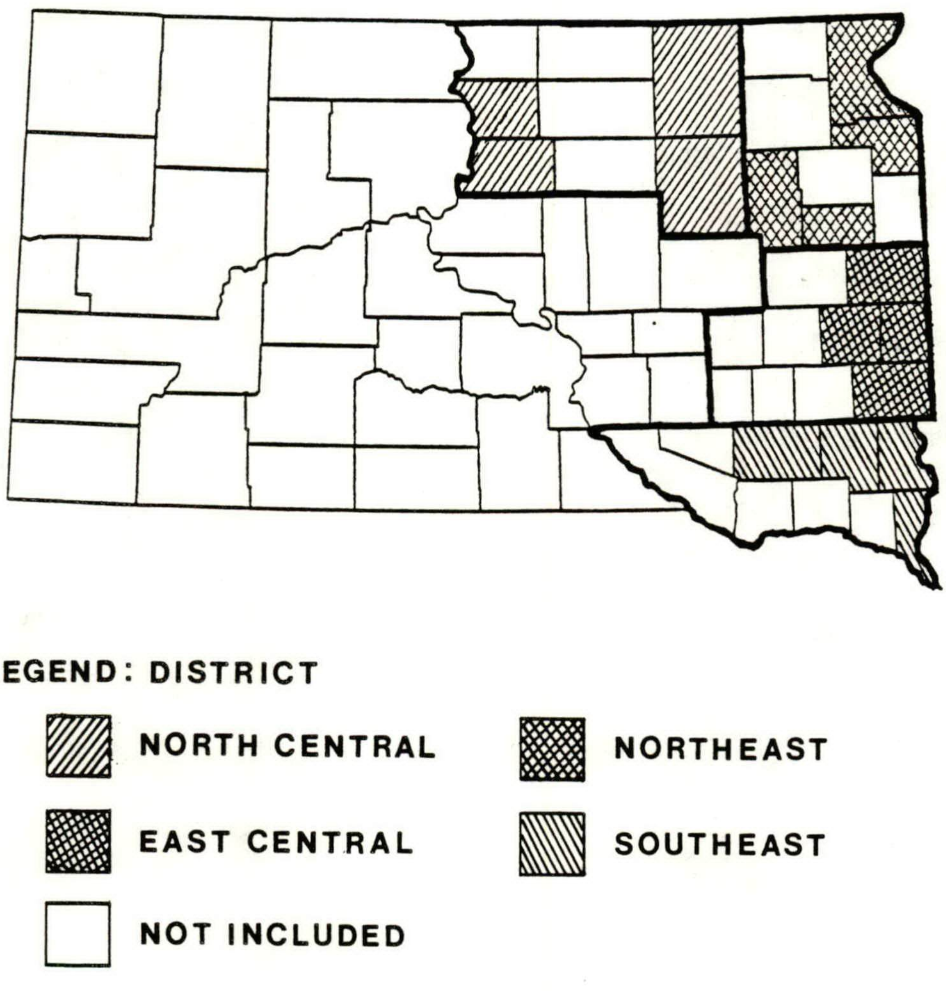
Table 1. Percent of Counties[1] in High or Low Yield Class by Year for Six Crops in South Dakota Between 1965 and 1982.

Year	Yield[2]	Cool Season			Warm Season		
		Oats	Sp Wheat	W Wheat	Corn	Sorghum	Soybeans
1965	Low		69	100		44	
1966	Low	87	94				
	High					37	67
1967	Low					87	67
	High		44	63			
1969	High				56	56	50
	Low			63			
1970	Low	37					50
1971	High	81	94	81			
1972	High		50	75	87	63	58
1973	Low	37					
	High		56			50	
1974	Low	63	94		100	100	92
1975	Low		44		87	75	
1976	Low	94	87	75	100	87	100
1977	High	63	50			50	
1978	High	37			56	63	50
1979	High	63	44		100	50	75
	Low			81			
1980	Low		50			69	

[1]Adjusted average yield of each crop was ranked within county by year from 1 to 17. Number of counties for each crop and year was 16, except for soybeans which had 12.

[2]High yield class was designated as the highest four production years and the low yield class was the five lowest years for each county. Values arbitrarily selected from the data set were those involving more than 6 counties per crop per year and only when two or more crops were listed per year in either or both yield classes.

SECTION II
CLIMATIC IMPACTS ON CORN PRODUCTION IN SIXTEEN COUNTIES OF SOUTH DAKOTA



Section II: Climatic Impacts on Corn Production in Sixteen Counties of South Dakota Between 1965 and 1982

The influence of independent variables (Appendix G) on yield are described by the equation:

$$YIELD = Intercept + \beta_1 \text{ (variable 1)} +$$

$$\beta_2 \text{ (variable 2)} \text{ --------- } + \beta_{14} \text{ (variable 14)}.$$

A stepwise regression analysis of corn yields was made using 14 independent variables (Appendix G), including all years and crop reporting districts (Appendix A), in an attempt to sort out primary variables influencing corn production in South Dakota (Table 2.0). Crop Reporting Districts (CRD) were entered as "dummy" variables and appeared in steps 2 (CRD-9) and 3 (CRD-6) explaining an additional 7% and 11% of the variability, respectively.

The most significant climatic variables identified in Table 2.0 for corn production over the 17-year period were July precipitation (Step 1-19%), August precipitation (Step 4-3%) August high temperature (Step 5-3%), and September low temperature (Step-3%). The projected effect of an inch of rain in July on corn yield was 3.31 bushel per acre, 1.90 bushel if received in August, a loss of 0.5 bushel per acre per degree high August temperature and a gain of .49 bushel per acre per degree September low temperature. This gain in yield by low September temperature is not consistent with actual experience and reflects a statistical detail not resolved here.

Table 2.0. Maximum R-Square Improvement Stepwise Regression Showing Corn Yield Variables in Four South Dakota Crop Reporting Districts Between 1965 and 1982.

Variable	Final β Value	R^2 Upon Entry
1. July precipitation	3.31	.19
2. CRD 9*	13.02	.26
3. CRD 6*	12.20	.37
4. August precipitation	1.90	.40
5. August high temperature	-.50	.43
6. September low temperature	.49	.46
Intercept	52.73	

*Crop Reporting Districts (CRD) were entered as "dummy" variables in the multiple regression analysis; CRD 9 and CRD 6 represent the SE and EC districts.

Three years when corn yields ranked in the top four yield classes in South Dakota were 1969, 1972, and 1979 (Table 1). Comparing the effects of climatic stress on corn yields, it was assumed that these years not only provided the most favorable growth conditions, but since high yields existed consistently in most counties of all districts for these years (Table 2.1), good agreement was established between yield and consistently favorable climatic conditions among districts. A large number of counties, designated within a year as either in the high or low production class, reinforced the assumption that climatic data assembled from one site in each county is somewhat representative of weather events in that county.

The average precipitation amounts for the districts selected in the corn study during three high production years are compared in Table 2.1. The years 1969, 1972, and 1979 differ across all districts in the amount of rain occurring the previous fall. 1972 had the highest amount ranging from 7.2 to 9.8 inches, followed by 1969 with 6.2 to 9.6 and 1979 with 1.5 to 3.3 inches. Generally, 1972 received the most rainfall during the growing season and previous fall, indicating ample moisture for the corn crop through critical growth stages for 1972.

Table 2.1 Inches Average Seasonal Precipitation by Crop District in Three Years When Corn Yields were Ranked in the Four Highest Classes in Nine or More Counties Each Year.

	1969		1972		1979	
District	1968 Fall	Growing Season	1971 Fall	Growing Season	1978 Fall	Growing Season
North Central*	-	-	8.1	16.1(3)	1.5	15.3
North East*	6.2	15.3(2)	9.8	20.2(3)	3.0	17.4
East Central*	8.7	16.2	9.6	22.0	3.3	22.8
South East*	9.6	18.0(3)	7.2	21.8	3.2	20.6
Seasonal Average	8.2	16.5	8.7	20.0	2.7	19.0

*Values in parenthesis indicate when the number of counties contributing to the average was fewer than four per district and the actual number involved.

In contrast to the reported high corn production years shown in Table 2.1, Table 1 identifies three years which uniformly showed low yields; 1974, 1975, and 1976. The all-district average total previous fall and the growing season precipitation values for these years are shown in Table 2.2. The average previous fall rainfall amounts for 1974 and 1976 (Table 2.2) was higher than shown for the comparable previous fall value in the high production year 1979 (Table 2.1). However, the fall of 1974 (1975 growing season) was the driest of all fall values in both tables. Total growing season rainfall for both 1974 and 1976 was obviously below the amount needed for good corn production, despite the fact that in the EC and SE districts the average 1973 fall precipitation (Table 2.2) approached that received in the fall of 1968 (Table 2.1). Specifically, one might suggest that 1.2 inches more rain in the growing season of 1969 (Table 2.1) than in 1974 (Table 2.2) in the EC district accounted for yields in the high class (1969) as opposed to the low class in 1974, since the previous fall precipitation was about equal both years. But yield differences may also reflect a more favorable rainfall distribution in 1969.

The importance of rainfall distribution, in contrast to total amounts, are suggested by comparisons of values for 1975 (Table 2.2) with those of high production years shown in Table 2.1. Within district averages for growing season precipitation for 1969 (high yield) were all lower than in 1975 (low yield), yet these years fell in opposite yield classes. The year 1969 is particularly interesting in that excellent corn yields were obtained with a minimum amount of growing season rainfall. An examination of rain distribution by date in 1969, of data shown later, may illustrate critical growth periods for corn where moisture is needed.

A marked distinction between 1969 and 1979 was an average of 5.5 inches of precipitation over all districts in the previous fall (Table 2.1). The fall of 1978 had an average of 2.7 inches versus 8.2 inches in 1968 (Table 2.1). In contrast, 1979 averaged 19.0 inches of rain for all districts during the growing season with only 16.5 in 1969. Inspection of these data indicate that 1968 fall precipitation may have compensated for a shortage of about 2.5 inches rainfall when comparing the growth seasons of 1969 and 1979.

The years 1969 and 1979 were statistically examined in detail as a means to describe the relationship between amount and the distribution of precipitation for optimum corn production in South Dakota. Less favorable climatic conditions leading to stress will be cited later and evaluated against these "ideal" conditions.

Fourteen climatic variables (Appendix G) that could impinge on corn yields in 1969 and 1979, were compared by stepwise regression combining data of four reporting districts for each year. The "best" regression fit for these two years are shown in Table 2.3.

Table 2.2 Inches Average Season Precipitation by Crop District in Three Years When Corn Yields Were Ranked in the Five Lowest Classes in Fourteen or More Counties Each Year.

	1974		1975		1976	
District	1973 Fall	Growing Season	1974 Fall	Growing Season	1975 Fall	Growing Season
North Central*	5.3	11.0	0.7	14.9	2.1	6.3
North East*	4.0	12.3	1.8	16.4	4.1	5.4
East Central*	8.7	15.0	0.9	19.6(2)	4.9	8.4
South East*	9.0	13.9	1.9	21.3	5.9	10.5
Seasonal Average	6.7	13.1	1.3	18.1	4.3	7.7

*Values in parenthesis indicate when the number of counties contributing to the average was fewer than four per district and the actual number involved.

Table 2.3. Maximum R-Square Improvement Stepwise Regression Evaluating Yield Variables for Corn Production in 1969 and 1979.

Variable	1969 Final β Value	R^2 Upon Entry
1. Fall precipitation	2.91	.65
2. May low temperature	.52	.80
3. August precipitation	6.73	.87
4. May precipitation	-2.69	.90
5. July precipitation	2.42	.92
6. August high temperature	-.58	.94
Intercept	44.45	

Variable	1979 Final β Value	R^2 Upon Entry
1. May precipitation	6.06	.59
2. CRD 9*	16.82	.79
3. May low temperature	2.21	.83
4. September low temperature	-1.42	.86
5. July high temperature	-1.33	.88
Intercept	116.66	

*Crop Reporting Districts (CRD) were entered as "dummy" variables in the multiple regression analysis; CRD 9 represents the SE district.

The stepwise maximum R^2 regression approach was used to identify variables in 1969 and 1979 which contributed the greatest in explaining yield variation. Results given in Table 2.3 show that 65% of yield variation for corn was explained by previous fall precipitation in 1969, as might be anticipated from data shown in Table 2.1. By contrast, this variable did not enter the regression model for 1979 (Table 2.3). Also, in 1969, low May temperature was the second step variable contributing an additional 15% variation, followed by August precipitation (7% additional), May precipitation depressed yield, accounting for an additional 3% variation with July rainfall adding 2% and August high temperature accounting for 2% more variation and causing yield depression.

The year 1979 was characterized by different growing season climatic circumstances than 1969 (Table 2.3). May precipitation accounted for 59% of yield variation. Crop Reporting District 9 (SE South Dakota) appeared in the model as a "dummy" variable accounting for an additional 20% variation. As in 1969, May low temperature improved yield in 1979 (an additional 4% variation). Each degree F for low September temperature depressed yield 1.4 bushel per acre (Step 4) and each degree F July high decreased yield 1.3 bushel per acre. The positive influence of May low temperature on yield in 1969 and 1979 was attributed to interactions not elucidated further by analysis.

When the results shown in Table 2.3 were compared with Table 2.1, the importance of July precipitation in 1969 and 1979 was not as apparent as when all 17 years were included in the analysis. The stepwise R-square improvement approach suggested that rainfall was not highly variable in 1969 and 1979 but adequate during the July period to account for high yield characteristic of these years.

The maximum and minimum air temperature plots, weekly precipitation, and the progression of corn development in one representative county for each crop reporting district in 1979 are shown in Figs. 2.0 through 2.3. Characteristically for 1979, steady weekly precipitation occurred from March 1 through the week ending June 20. The next 4-week period was essentially without rain in all districts, with about 1 inch falling the week ending July 25. It appears that in 1979, at these locations, rainfall in July could have been an exception to results shown in Table 2.0, if one regards an inch of rain during July to be inadequate. However, if substantial amounts fell between March 1 and June 20, as actually occurred in 1979 with 12 to 14 inches in this interval, then ample residual soil moisture prior to July apparently minimized water stress in 1979. Yield rank was consistently high for all districts in 1979.

Fig. 2.4 compares cumulative precipitation planting (P) dates and tasseling (T) dates in Lincoln County for 1969, 1972, and 1979. Early season precipitation in 1972 and 1979 apparently carried the crop through the critical July period, identified in Table 2.0 as the first entry, but entered as step 5 in Table 2.3.

Rainfall distribution in 1969 was markedly different from 1972 and 1979 showing lower amounts between March 1 and June 13 (Fig. 2.4), with significant weekly amounts falling thereafter through the week ending July 18. It is apparent that substantial rain which fell in the fall of 1968 was an important factor during the dry spring of 1969, contributing to high productivity. This distinction is apparent when comparing results of 1969 against all other high production years, which suggests that fall precipitation typically was not a contributing factor in corn yield variation in South Dakota between 1965 and 1980 (Appendix A).

Figs. 2.5 through 2.8 show cumulative precipitation during the corn growing season among two high yield years (1969, 1979) and a low yield year (1975) in four Eastern South Dakota counties. These figures also indicate when 50% of the crop was planted (P), and when it was 50% tasseled (T) in each county. They consistently show higher total rainfall and more early season rain in 1979 compared to 1969. The apparent benefit of July rains in 1969 likely explain the high yield results (Table 2.0) whereas stored soil moisture in 1979, prior to July, and subsequent rains after July 25 is attributed to the high rank in 1979.

An explanation for the consistently low yield rank in 1975 is more difficult, when based only upon amount and distribution of precipitation. The pattern of cumulative rainfall for 1975 was very similar to 1979 in Hamlin (Fig. 2.5), Union (Fig. 2.7), and Roberts (Fig. 2.8) county. It was somewhat lower in the early season for 1975 compared to 1979 in Minnehaha (Fig. 2.6), but exceeded 1969 except for the July amounts. Perhaps low yield in 1975 could be explained in some cases by inadequate July rainfall and a lower soil moisture reserve than in 1979. The possibility of temperature effects in 1975 could also account for low yield responses.

An examination of the cumulative average maximum temperature during August showed 1975 and 1979 to be similar. However, the average maximum weekly temperature between the weeks ending July 4 and August 8 was consistently higher in 1975 than in 1979 (Table 2.4). This difference was most obvious in the week of July 4 in all locations and more pronounced the week of August 1, when average values were as much as 15°F higher in 1975 (Minnehaha County).

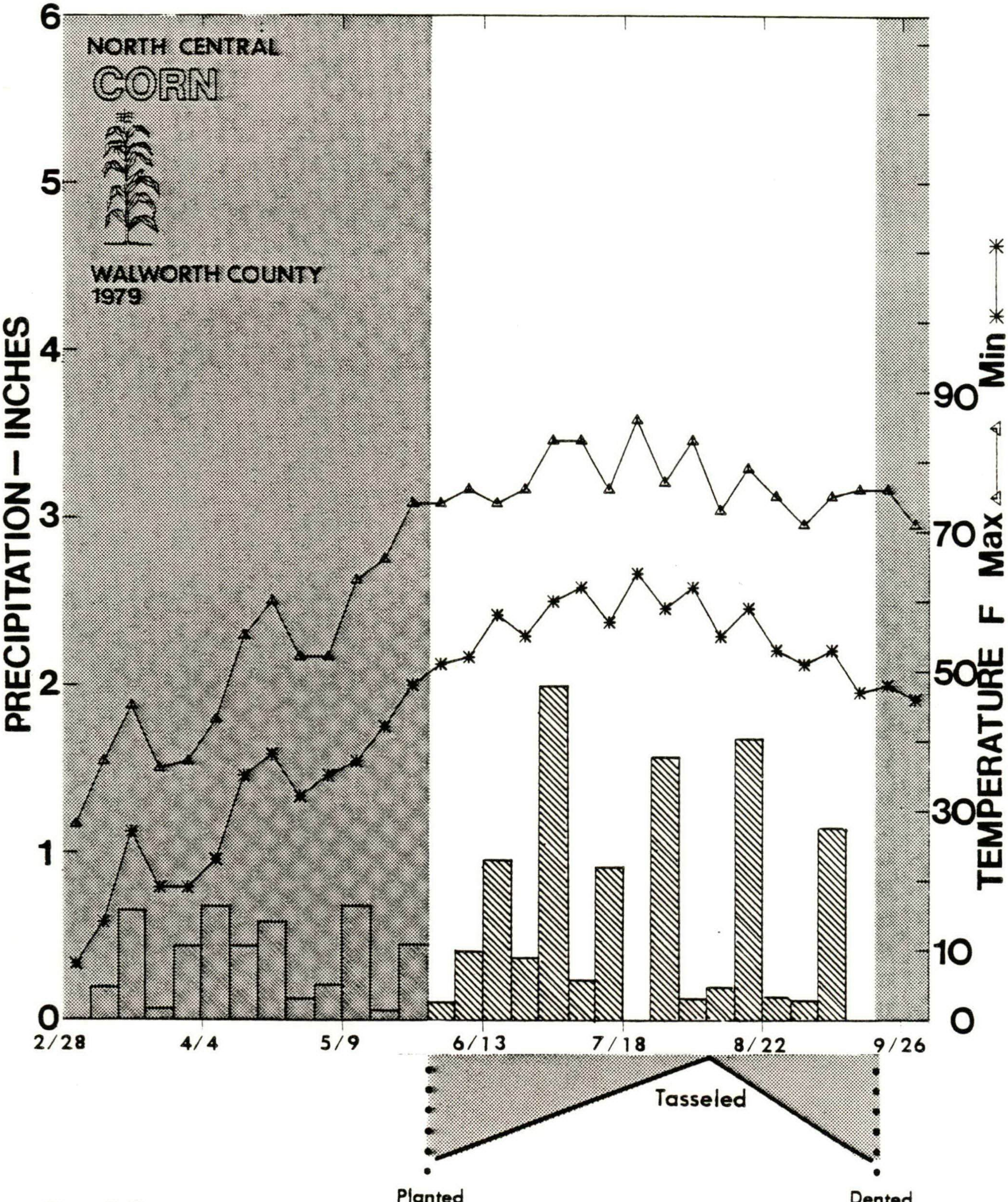
Based upon weekly averages, it is difficult to discern if a single hot day in July was responsible for yield loss during a critical developmental stage in corn. The most intense hot spell in 1975 occurred the week ending August 1, which was also a week of high rainfall at some locations (Figs. 2.5, 2.6, and 2.7).

Table 2.4. A Comparison of the Average Maximum Weekly Air Temperature (F°) During July in 1975 and in 1979 in Four Eastern Corn Growing Counties of South Dakota.

	Hamlin		Minnehaha		Lincoln		Union	
Dates	1975	1979	1975	1979	1975	1979	1975	1979
7/4	92	87	94	85	92	89	89	85
7/11	85	83	88	84	86	83	86	81
7/18	90	82	93	84	90	85	88	87
7/25	89	88	91	87	88	86	85	87
8/1	92	80	95	80	91	81	90	81
8/8	72	88	87	85	84	87	85	90

The combination of high temperatures and rain might suggest storm conditions and crop damage. However, the Federal Crop Insurance records for 1975 in Eastern South Dakota show drought as the primary indemnity payment for corn. High temperature, limited rainfall, or a combination of these factors in July, 1975, appear as likely explanations for yield loss. With a closer inspection of records, it may be possible to discern more specific information about yield influences from this data since rainfall patterns were very similar in 1975 and 1979.

Precipitation events in the one month preceding tasseling, appear important for influencing corn production in South Dakota. It would appear that in a limited rainfall area such as South Dakota, adequate precipitation is essential in July and perhaps not a high probability occurance. However, it is less likely to occur in both July and August. Low temperatures together with short seasons likely account for the lower corn yields in South Dakota compared to high producing states. Tasseling at this latitude usually occurs about 40 days after the photoperiod begins to decline each year, with ear filling and crop dry-down occurring when radiant energy is beyond optimal levels.


NORTH CENTRAL
CORN
WALWORTH COUNTY
1979
PRECIPITATION — INCHES
TEMPERATURE F Max Min
0
1
2
3
4
5
6
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10
30
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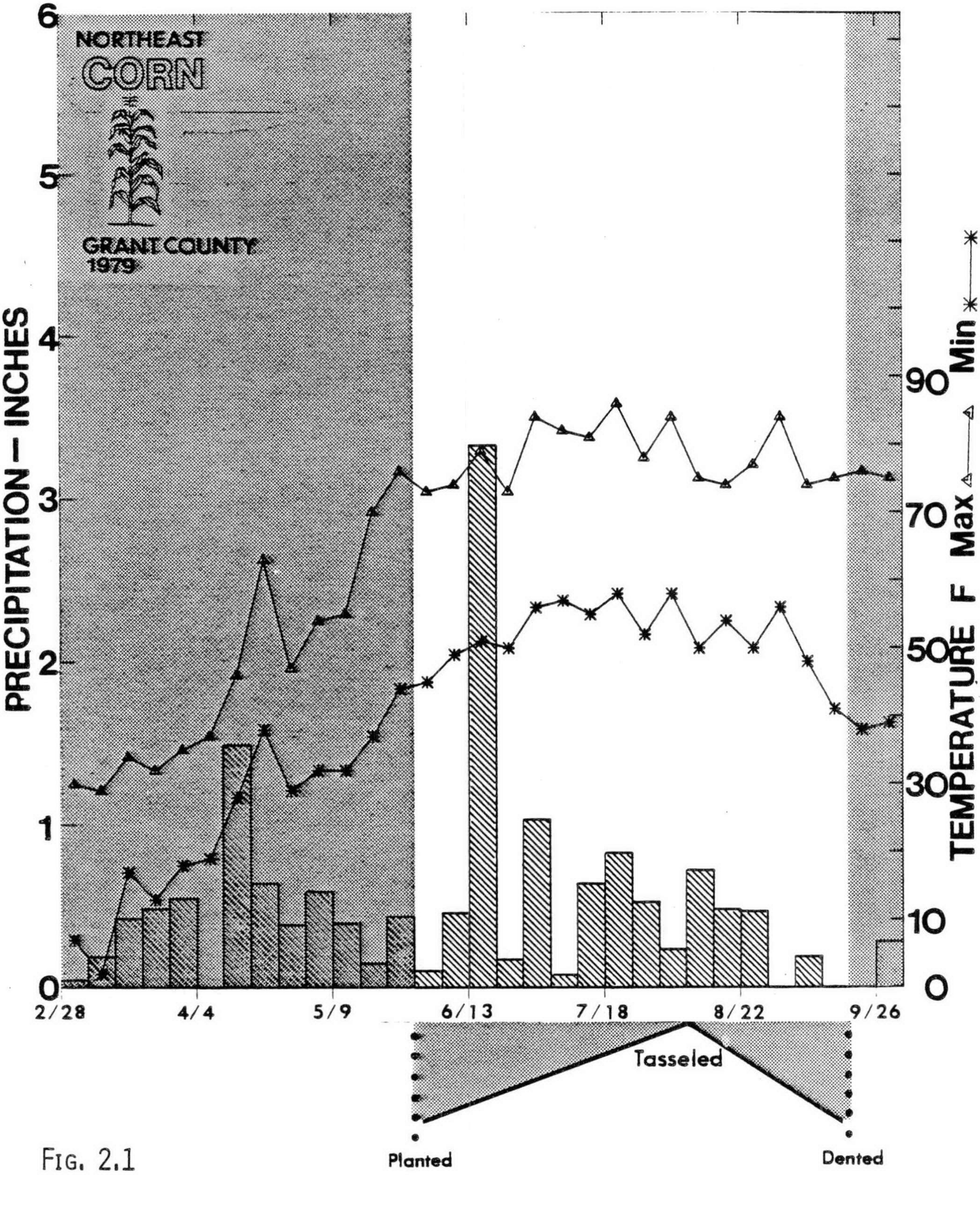
8/22
9/26
Tasseled
Planted
Dented

FIG. 2.0



NORTHEAST
CORN
GRANT COUNTY
1979
PRECIPITATION – INCHES
TEMPERATURE F Max Min
6
5
4
3
2
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0
90
70
50
30
10
0
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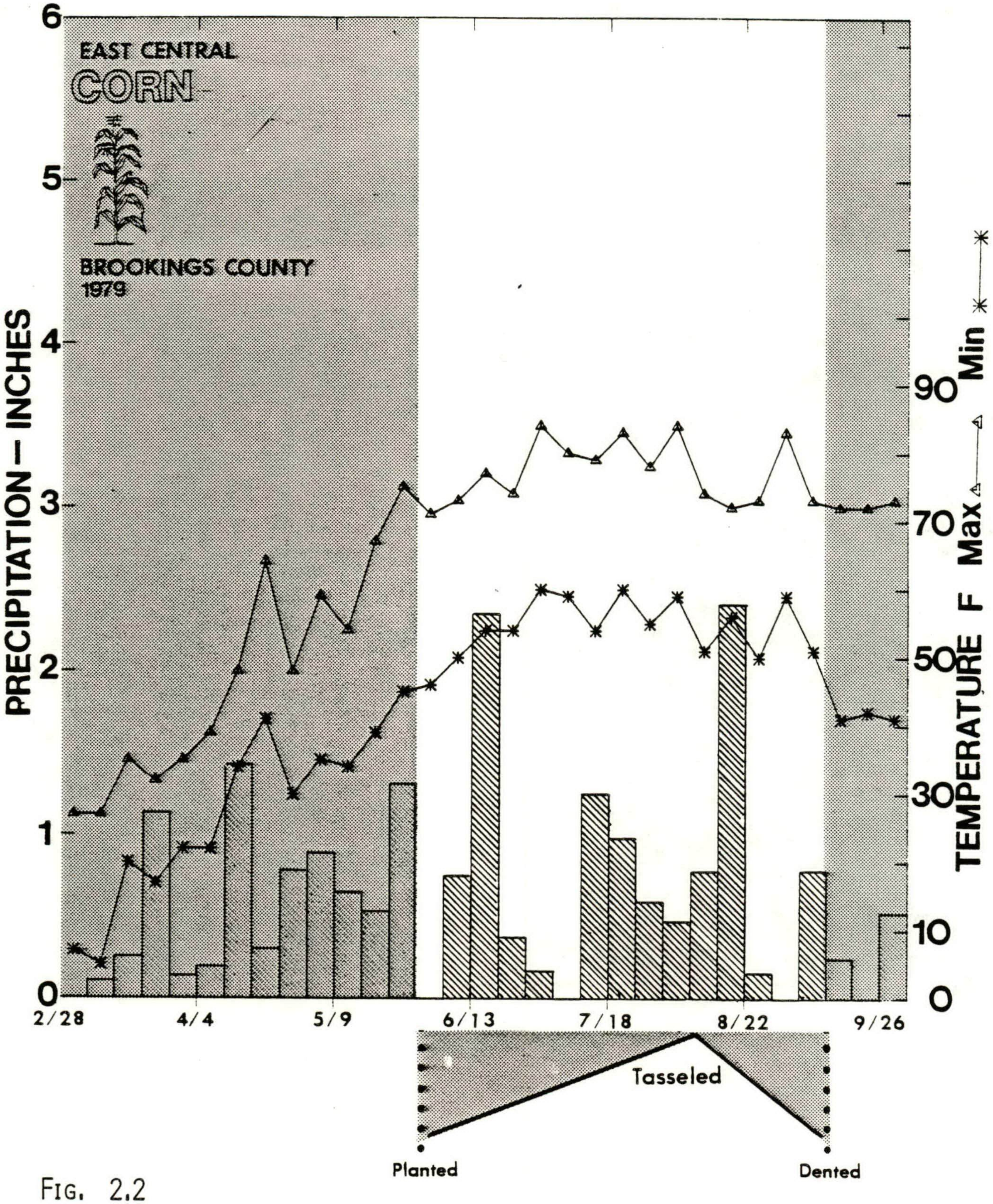
7/18
8/22
9/26
Tasseled
Planted
Dented

FIG. 2.1


EAST CENTRAL
CORN
BROOKINGS COUNTY
1979
PRECIPITATION – INCHES
TEMPERATURE F Max Min
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5
4
3
2
1
0
90
70
50
30
10
0
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Tasseled
Planted
Dented

FIG. 2.2

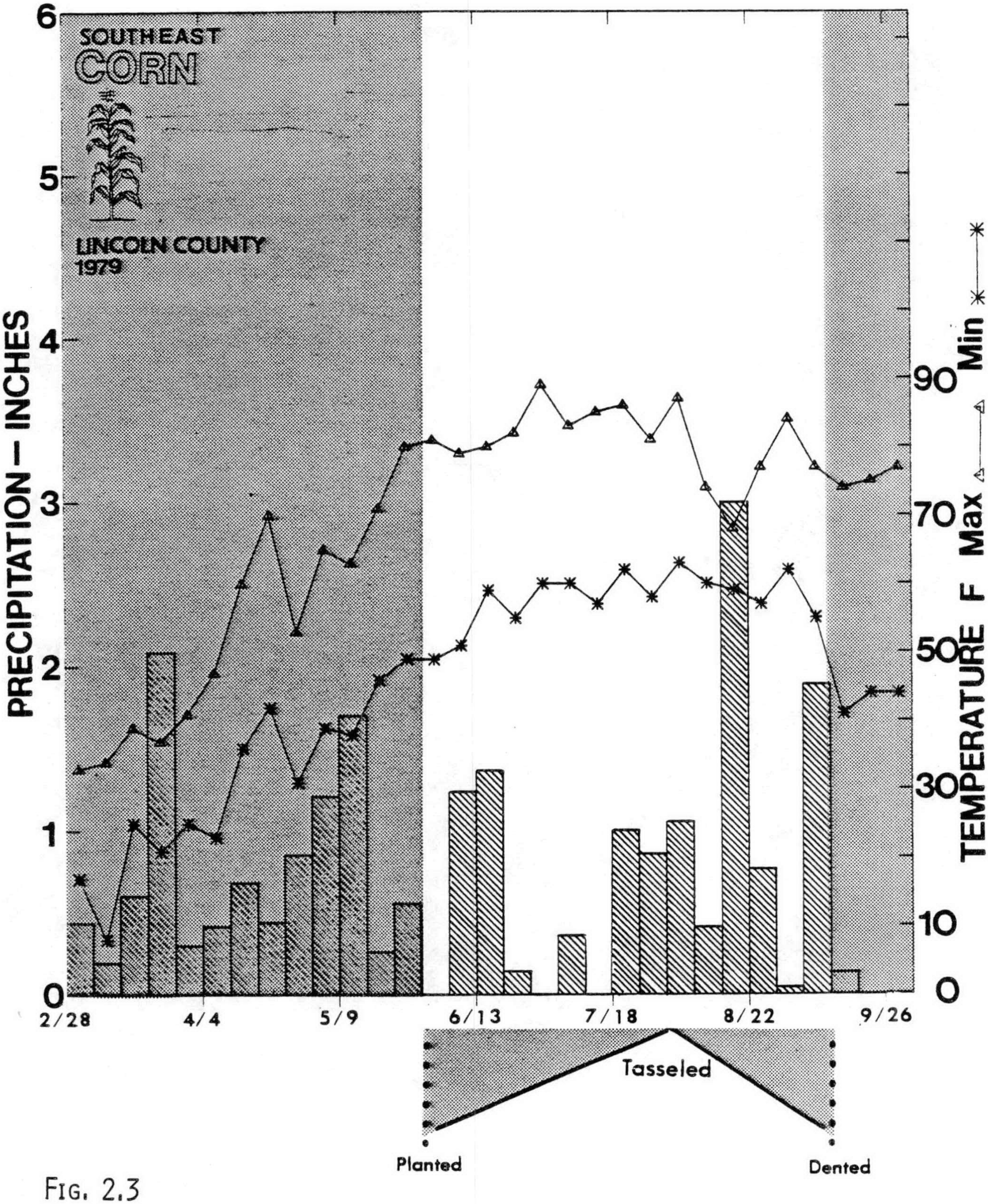

SOUTHEAST
CORN
LINCOLN COUNTY
1979
PRECIPITATION – INCHES
TEMPERATURE F
Max
Min
0
1
2
3
4
5
6
10
30
50
70
90
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Tasseled
Planted
Dented

FIG. 2.3

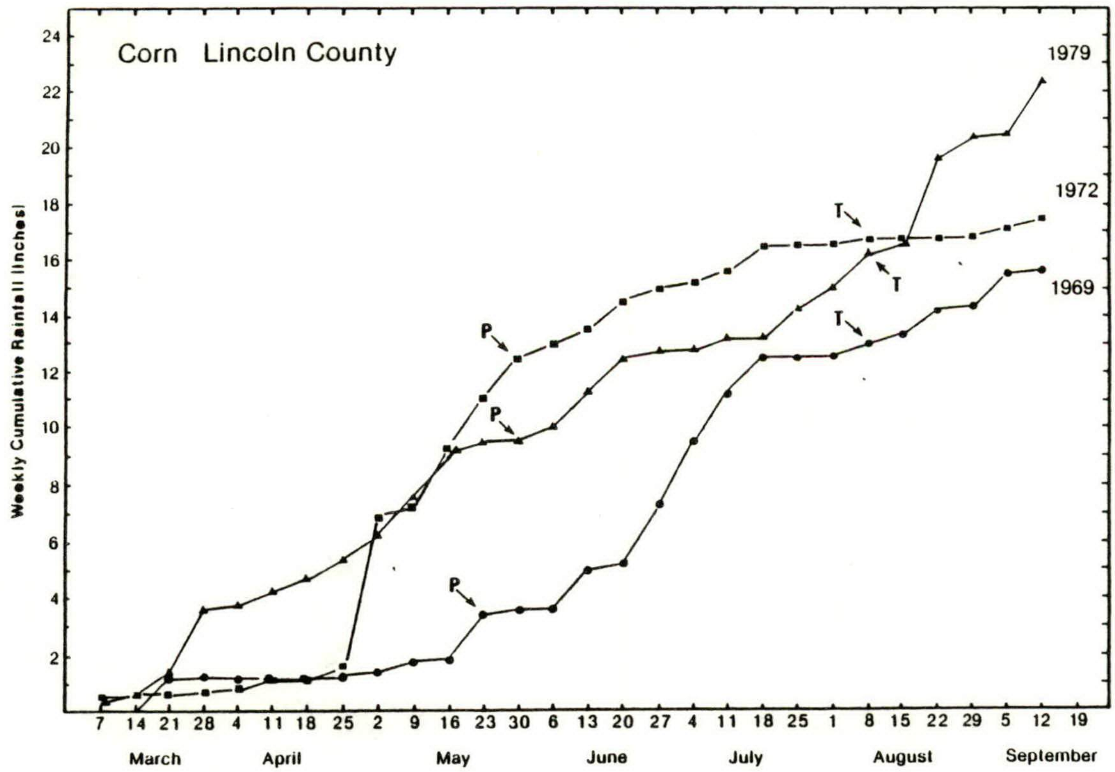

Corn Lincoln County
Weekly Cumulative Rainfall (inches)
1979
1972
1969
P
T
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 2.4

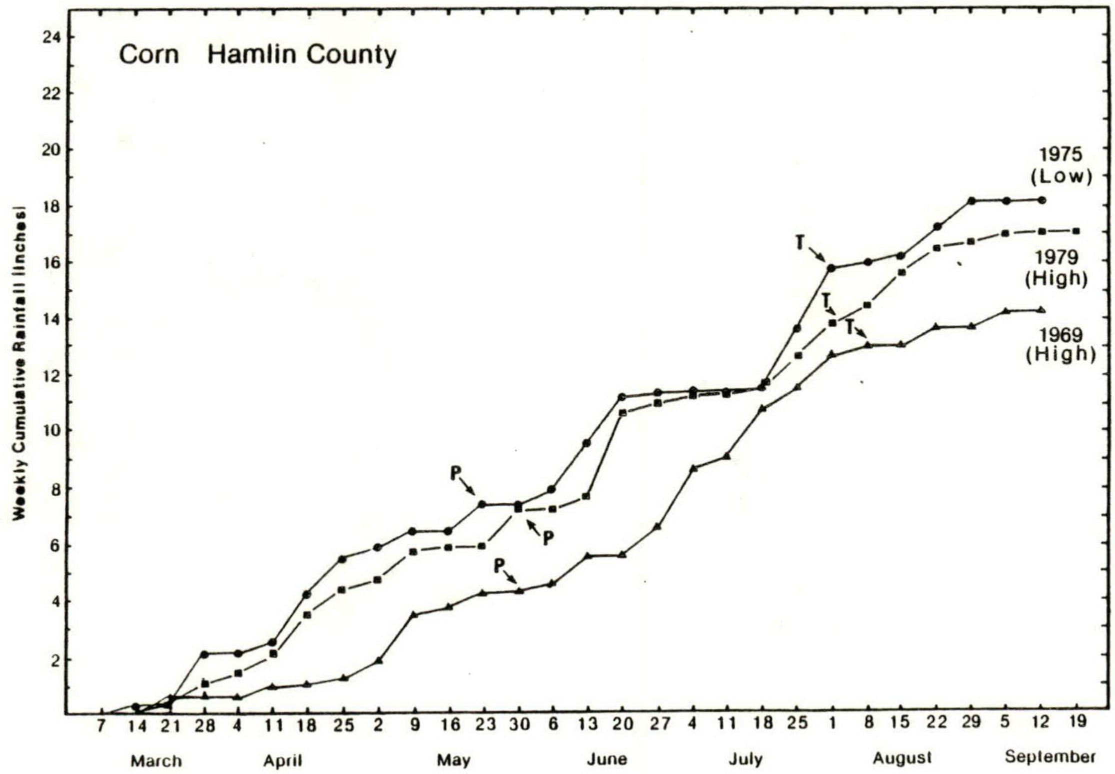

Corn Hamlin County
Weekly Cumulative Rainfall (inches)
1975
(Low)
1979
(High)
1969
(High)
P
T
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 2.5

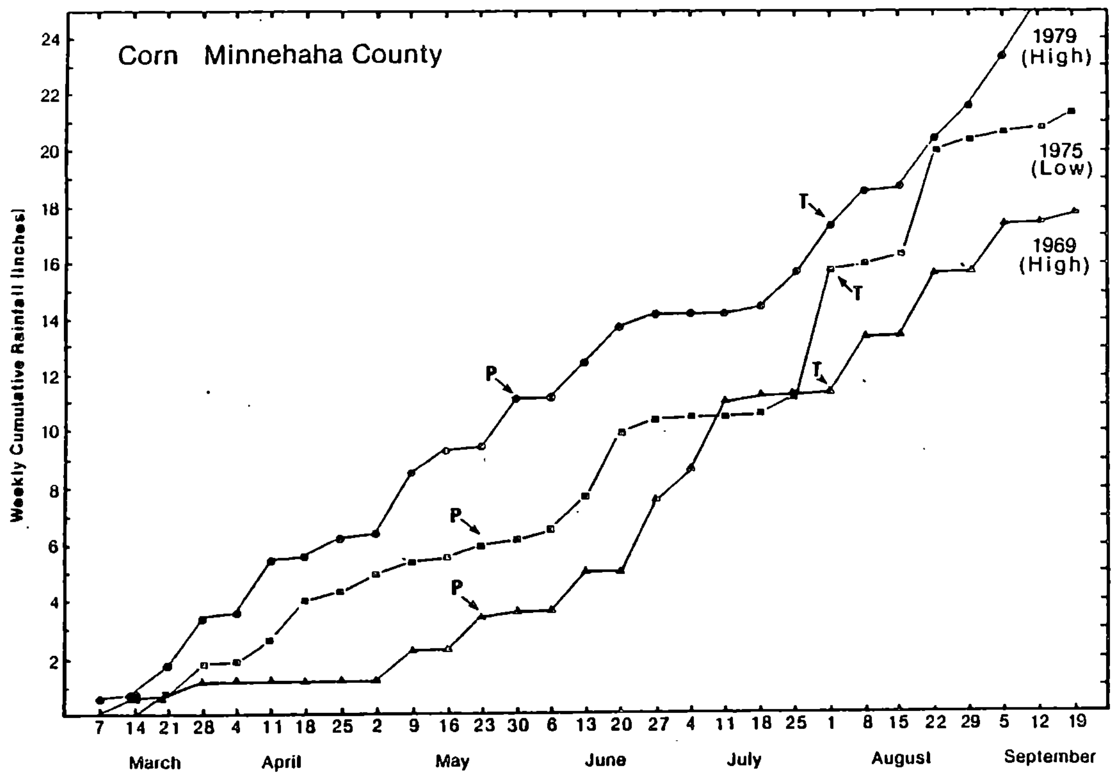

Corn Minnehaha County
Weekly Cumulative Rainfall (Inches)
1979 (High)
1975 (Low)
1969 (High)
P
T
March
April
May
June
July
August
September

FIG. 2.6

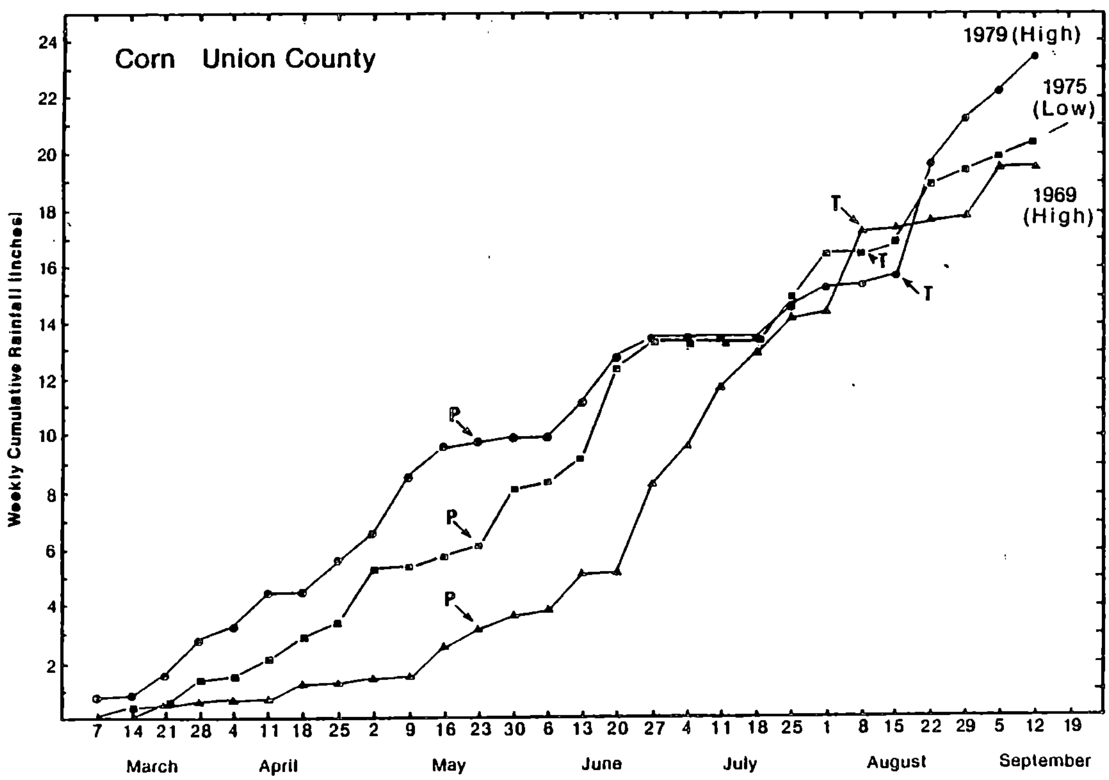
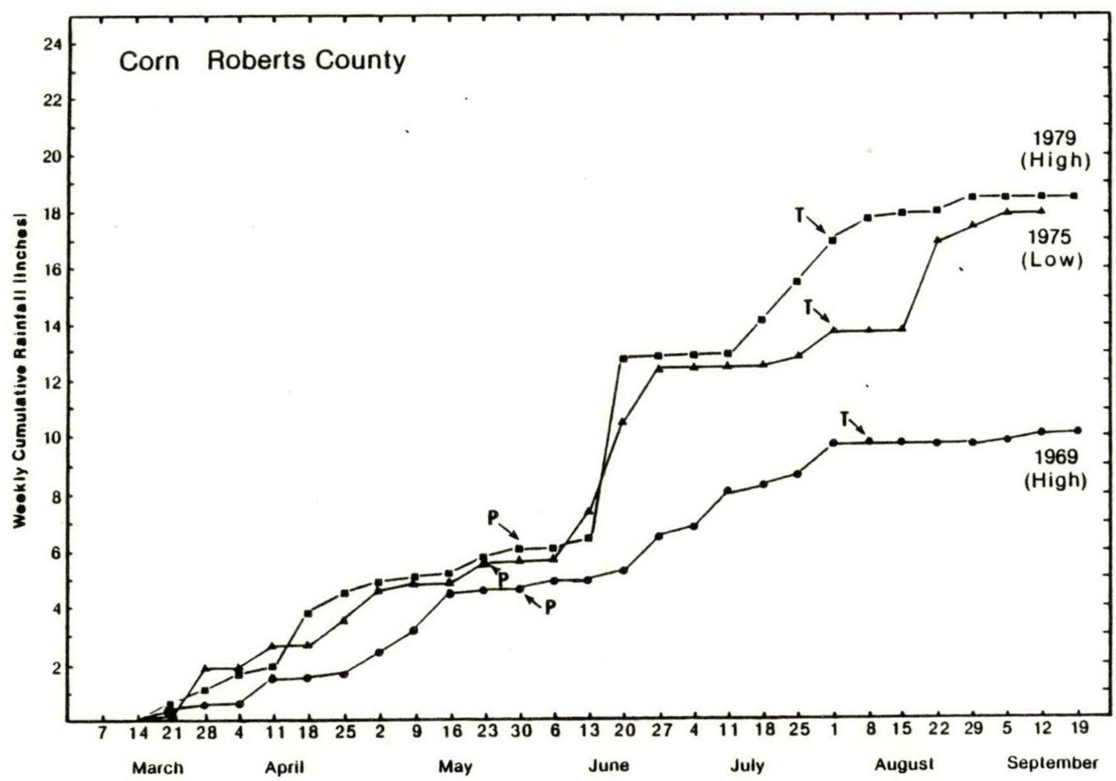

Corn Union County
Weekly Cumulative Rainfall (Inches)
1979 (High)
1975 (Low)
1969 (High)
P
T
March
April
May
June
July
August
September

FIG. 2.7

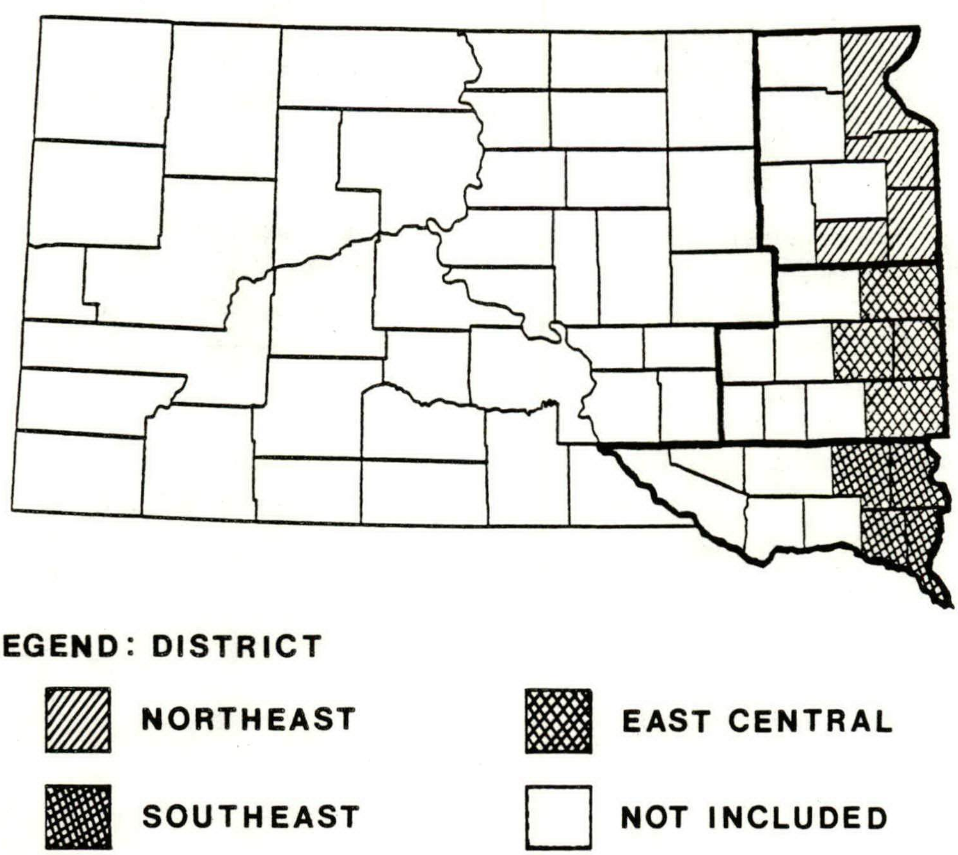


Corn Roberts County
Weekly Cumulative Rainfall (inches)
24
22
20
18
16
14
12
10
8
6
4
2
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September
1979
(High)
1975
(Low)
1969
(High)
T
T
T
P
P
P

FIG. 2.8

SECTION III

CLIMATIC IMPACTS ON SOYBEAN PRODUCTION IN TWELVE COUNTIES OF SOUTH DAKOTA



Section III: Climatic Impacts on Soybean Production in Twelve South Dakota Counties Between 1965 and 1982

Harvested acreage records for soybeans in 1965 showed three crop reporting districts involved in cultivation of this crop. The 12 counties selected within these districts border on the eastern edge of South Dakota. As typical for soybean production, these counties also have a high proportion of acreage planted to corn. However, the phenology of soybeans is different from corn and it was expected that critical climatic events for good soybean production may not always be coincident with good corn production years (Table 1). The production relationship between these two crops within an area having common climatic records should reveal something about the differential responses of corn and soybeans.

A stepwise regression, using maximum R-square improvement analysis, compared soybean yields with climate for all districts during the period 1965 to 1982. Fourteen variables (Appendix G) were entered into the regression equation and results of the first seven and most significant variables are shown in Table 3.0.

Table 3.0. Maximum R-Square Improvement Stepwise Regression Evaluating Soybean Yield Over-all Districts During the Period 1965 to 1981.

Variable	Final β Value	R^2 Upon Entry
1. CRD 9*	5.11	.16
2. August precipitation	1.14	.25
3. July precipitation	.89	.36
4. May precipitation	.69	.40
5. CRD 6*	2.79	.44
6. Weeks < .10 inch rain in June	-1.22	.48
7. September low temperature	.22	.51
Intercept	3.37	

* CRD 9 and CRD 6 represent Crop Reporting District (CRD) for the SE and CE, respectively, and were two "dummy" variables with above average yields.

The SE Crop Reporting District (CRD 9) usually has higher yields than other districts and 16% of the variation in soybean yields were explained by this "dummy" variable. The variable next in importance was August precipitation accounting for an additional 11% variation. July precipitation was the third variable describing an additional 11% variation. May precipitation, CRD 6, and weeks less than 0.10 inch rain in June each contributed an additional 4%, explaining 48% of variation for the first six variables. September low temperature raised the R^2 value to 51% accounting for seven variables.

Three years when yield rank of soybeans was in the high yield class for the largest number of counties are compared in Table 3.1. As with corn production (Table 2.1), 1972 and 1979 were also rated high for high soybean production, with 1979 consistently having the most uniformly favorable climatic conditions for all three districts. Average growing season precipitation was highest in 1979, followed by 1972 and 1966. Previous fall precipitation was highest in 1971, followed by 1965 and 1978. As with corn production in 1979, rainfall amounts of 18 to 22 inches during the growing season appeared ample for the yields obtained, even with 3 inches or less of previous fall moisture. A comparable situation existed in 1972, but with approximately 6 inches more fall precipitation. The year 1966 (Table 3.1) is the exception to results shown in Table 2.1 for corn, replacing 1969. There were somewhat similar precipitation amounts in the fall of 1965 and 1968 and during the subsequent growth seasons.

Table 3.1. Inches Average Seasonal Precipitation by Crop District in Three Years When Soybean Yields were Ranked in the Four Highest Classes in Seven or More Counties.

District	1966		1972		1979	
	1965 Fall	Growing Season	1971 Fall	Growing Season	1978 Fall	Growing Season
North East*	6.4	15.4	10.4	22.5(1)	3.2	17.7
East Central*	-	-	9.6	21.5	3.1	25.6(1)
South Central*	8.5	16.7	7.7	18.9(2)	2.9	22.0
Seasonal Average	7.5	16.0	9.2	20.9	3.1	21.8

*Values in parenthesis indicate when the number of counties contributing to the average was fewer than four per district and the actual number involved.

An average of 7.5 inches of precipitation fell in the fall of 1965 in the NE and SE districts (Table 3.1). Compared to other years (Appendix B), 1966 had higher than normal soil moisture at the start of the growing season. The extent to which crops benefited from this fall moisture is problematic, particularly when viewing the low yield rank of 1966 for spring grains (Table 1).

In contrast to high soybean production years, 1967, 1974, and 1976 were ranked in the low yield class (Table 1). The total previous fall and growing season precipitation for these years and the averages across districts is in Table 3.2. The largest amount of total precipitation was recorded in 1974, with averages of 7.5 inches in the fall of 1973 and 14.3 inches in the growing season. However, all values were low and inadequate; total rainfall likely accounted for low production during these years.

Table 3.2. Inches Average Seasonal Precipitation by Crop District in Three Years When Soybean Yields were Ranked in the Five Lowest Classes in Eight or More Counties.

District	1967		1974		1976	
	1966 Fall	Growing Season	1973 Fall	Growing Season	1975 Fall	Growing Season
North East*	3.4	12.5(3)	4.1	13.3	3.8	5.4
East Central*	5.5	14.7	9.7	15.6(3)	4.9	5.3
South East*	8.1	12.6(1)	8.8	13.9	5.7	10.1
Seasonal Average	5.7	13.3	7.5	14.3	4.8	7.9

*Values in parenthesis indicate when the number of counties contributing to the average was fewer than four per district and the actual number involved.

Weekly precipitation, maximum/minimum air temperature plots are described for 1979 in Section II (Figs. 2.0 through 2.3). Soybean production also ranked high in 1979 and precipitation distribution for this year is compared with both high and low years later in this section. The year 1966 for Roberts County (NE District), and Lincoln County (SE District) and 1969 for Moody County (EC District) were selected as representative of climatic conditions contributing to high soybean yields. Results shown in Fig. 3.0, 3.1, and 3.2 compare the maximum/minimum air temperature and weekly precipitation of these locations by year to developmental stages of soybeans.

The climatic record for Roberts County as related to soybean production is shown in Fig. 3.0; about 50% of the crop was planted by May 30, 50% blooming by July 18, and about 50% podded by August 1. Good moisture conditions existed for planting and germination with two 1-inch rains between June 20 and July 18. However, it appears that rains totaling more than 2.5 inches occurred each week for the weeks ending August 15 and 22, which contributed to the high yield rank of soybeans for 1966 in Roberts County (Appendix B). This is consistent with multiple regression results shown in Table 3.0.

Lincoln County data was selected as representative of the SE District for 1966 (Fig. 3.1). Over 50% of the acreage was planted by May 30, 50% was in bloom by July 18, and over 50% had podded by August 8, a pattern very similar to Roberts County (Fig. 3.0). However, Lincoln County records showed more frequent rain and greater amounts in May, less total in June, more in July, but less in August when compared to Roberts County. This variance from results shown in Fig. 3.0 apparently did not adversely influence soybean yields in 1966 for Lincoln County, where the adjusted average was 31 bushel/acre. Total growing season rainfall was the lowest (13.4 inches) in Lincoln County when compared to the other three counties in the SE District (Appendix B), which suggests that the rain received at this measurement site may have been below actual amounts in the county. However, it is expected that the frequency of rains over the entire county is accurately portrayed in Fig. 3.1 and provides an approximation of favorable rain distribution for the growth of soybeans.

The year 1966 was not classed as a high yield year in the EC District (Appendix B). Climatic comparisons were made earlier in this Section between 1966 and 1969. Based on these similarities, the records for Moody County in 1969 were selected as representative of a good production year in the EC District (Fig. 3.2). Similar to the situation described above for Lincoln County in 1966, the total growing season precipitation in 1969 for Moody County is the lowest (13.8 inches) of the four counties in this district (Appendix B). Again, this rainfall level may not have been typical of the entire county in 1969, but it may also suggest that soybeans do well with this amount of water.

About 50% of the Moody County acreage was planted by June 6, 1969; bloom occurred over an extended period in July with over 50% of the acreage podded by August 15. Rainfall was frequent and apparently adequate in May and June. Two other counties (Brookings and Minnehaha) examined in the EC District had one or more inches of rain happening the week of June 27 than Moody County and typically had more precipitation and later in August compared to Moody County (data not shown).

The information in Table 3.0 is supported by the data plotted in Figs. 3.0, 3.1, and 3.2, pointing to the importance of August and July rainfall for soybean production in South Dakota. The cumulative precipitation patterns, planting (P) and podding (Pd) dates of the three high ranked years 1966, 1972, and 1979 in Hamlin County are compared in Fig. 3.3. The total growing season precipitation is comparable in 1966 and 1979 although the annual amounts were derived by a different distribution pattern. As with corn production, the amounts in 1972 exceeded both 1966 and 1979 in total growing season precipitation. In addition, ample amounts fell in July and August to augment a favorable production year for soybeans in South Dakota. A similar comparison (Fig. 3.4) was found for Turner County (SE District) with total rainfall amounts being higher, but with the same relative relationship between years.

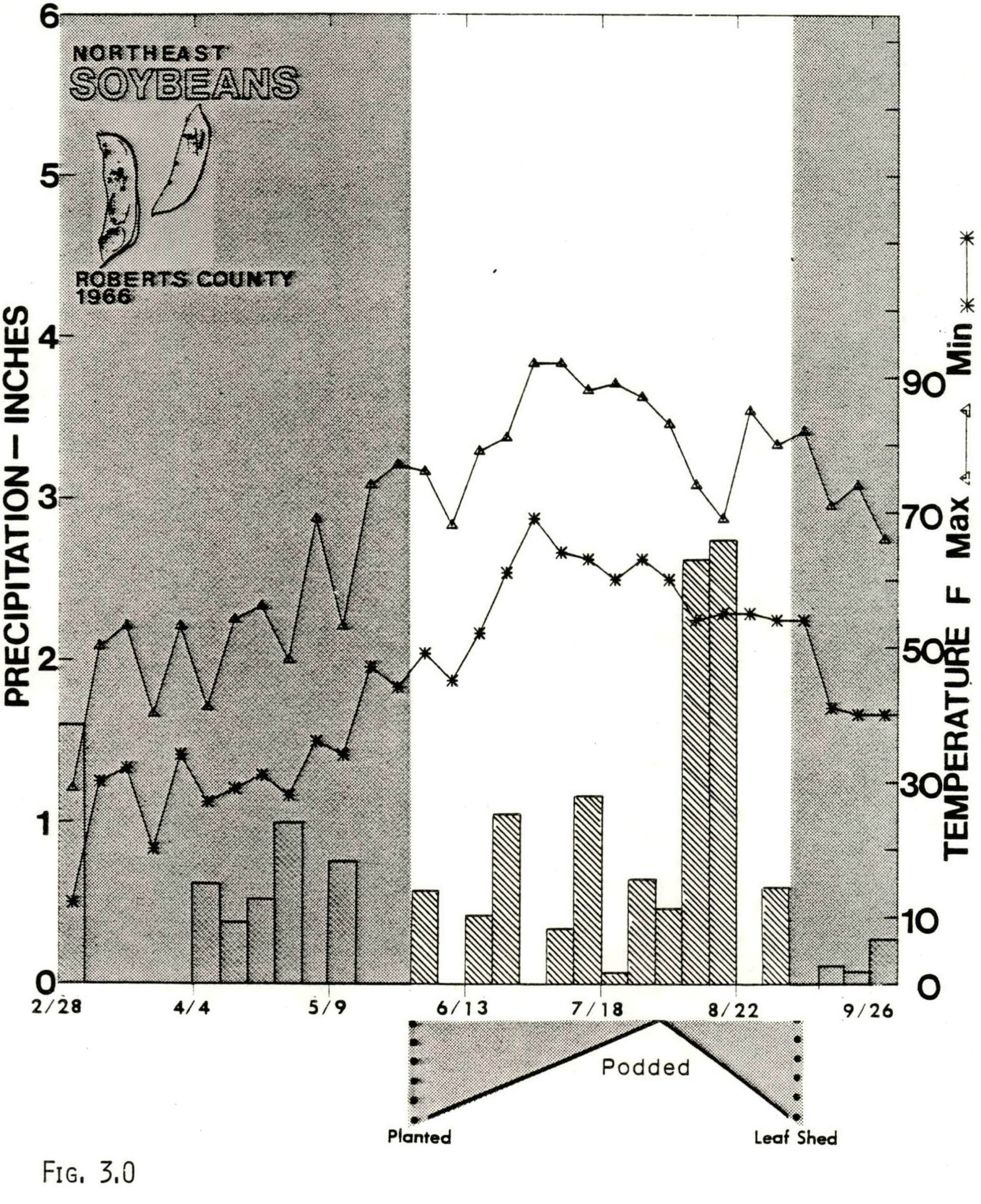
Plots of cumulative precipitation during the growing season in Deuel County are shown in Fig. 3.5 for two high production years (1966 and 1979) compared with a low production year in 1974. Rainfall amounts were comparable through June 20 in both 1974 and 1979, but lagged behind after July 18 in 1974. However, 1974 received more rain than 1966 until August 22 (Fig. 3.5), yet ranked lower by comparison (Appendix B).

Water stress in crop production can be imposed by two primary influences: 1) limited total water available for the growing season, and 2) an unfavorable distribution pattern of rain in relation to crop development. Inadequate rainfall occurred in 1976, which depressed yield of all crops and which was uniformly scant over all South Dakota (Table 1). Another year, 1974, was also classed as a low production year for soybeans, but tended to be more favorable for oat production as indicated by fewer counties in the low yield group in the EC and SE Districts, with Minnehaha, Hutchinson, and Turner counties appearing in the high oat yield class in 1974 (Appendix D). Localized precipitation and timeliness of the events benefited the oat crop in some instances but not always soybean production (Table 1).

Results shown in Table 3.0, regarding the importance of July and August precipitation in soybean production, are also illustrated by data from Lake County comparing 1969 and 1975 (high years) with 1974, a low yield year (Fig. 3.6). Between June 13 and August 8, the year 1974 had the least precipitation (2.6 inches) followed by 1969 (3.7 inches) and 1975 (6.9 inches). High temperature during July 1975 for corn production (Table 2.4) was apparently a critical factor in soybean yields also.

A comparison of precipitation data from Hamlin, Lake, and Union counties in 1975 (Appendix B) indicate the importance of precipitation during the July and August period (Fig. 3.7). Two inches less rain during mid-June in Hamlin County apparently prevented good use of about 4 inches that occurred after July 18, as indicated by an adjusted county average yield of 15 bushel per acre in Hamlin County compared to 21 bushel in Union and 24 bushel per acre in Lake County (Appendix B).

The first six variables explained 46% of the corn (Table 2.0) and 48% of the soybean (Table 3.0) yield variation. Four of the six independent variables were shown to be climatic influences on corn and soybean yields. July precipitation was shown to be most important in corn production (Step 1) whereas August precipitation entered the model as Step 2 in soybean production. May rainfall appeared as Step 4 for soybean yields, but was absent in Table 2.0 for corn. August high temperature curtailed corn yields (Table 2.0), but was not an entry for soybeans. These results do suggest differences between corn and soybean responses to climatic variation.



NORTHEAST
SOYBEANS
ROBERTS COUNTY
1966
PRECIPITATION – INCHES
TEMPERATURE F Max Min
6
5
4
3
2
1
0
90
70
50
30
10
0
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Podded
Planted
Leaf Shed

FIG. 3.0

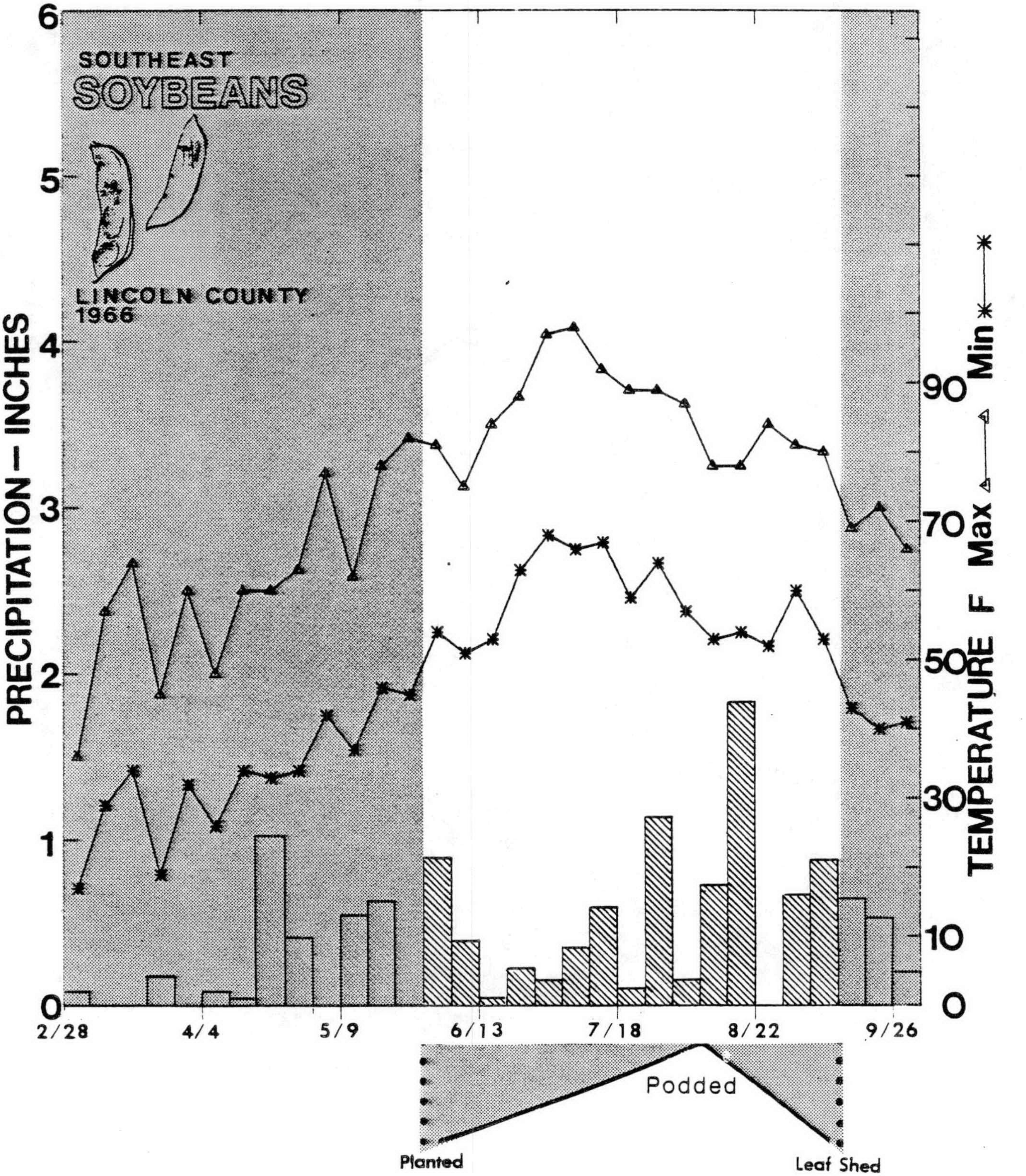
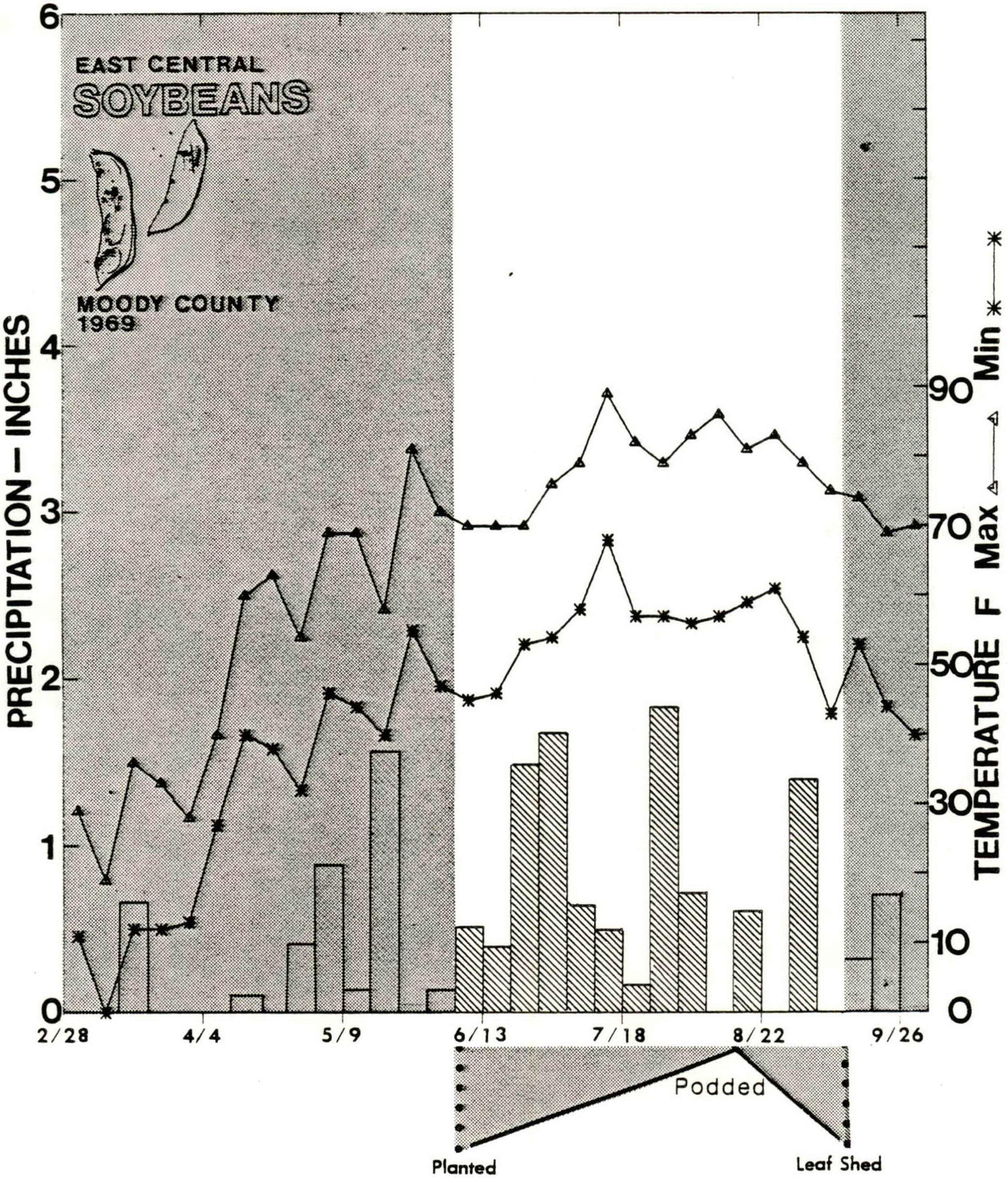
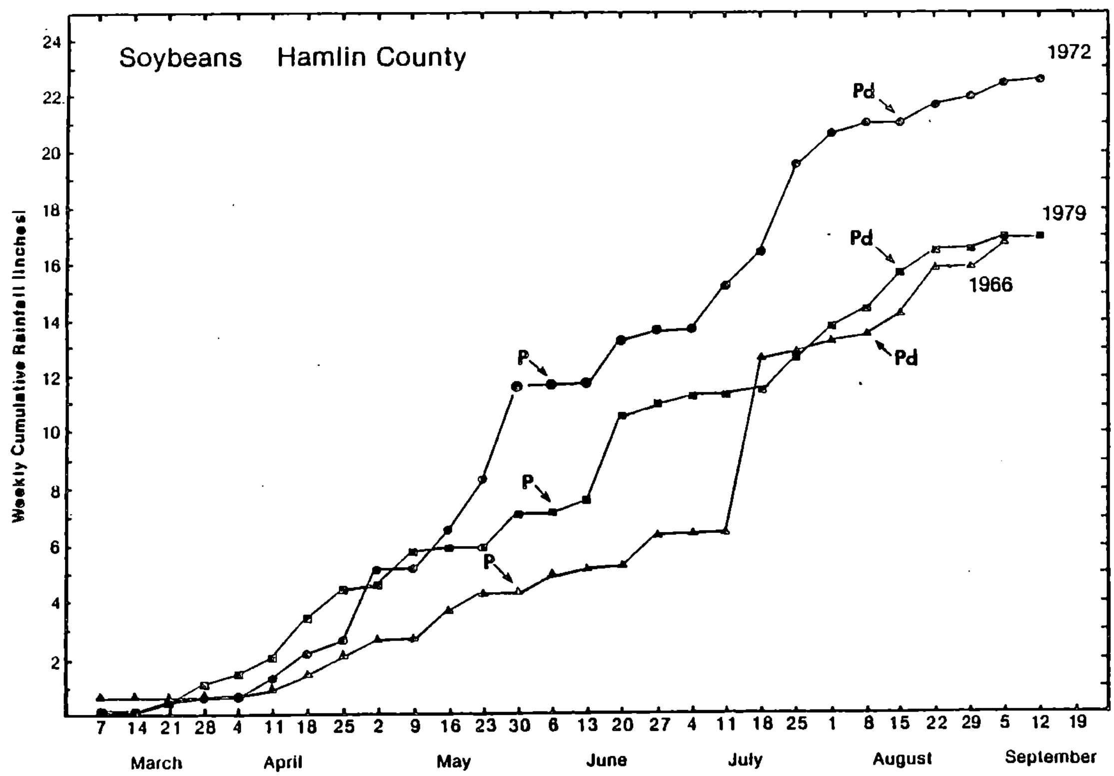

SOUTHEAST
SOYBEANS
LINCOLN COUNTY
1966
PRECIPITATION — INCHES
TEMPERATURE F Max Min
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Podded
Planted
Leaf Shed

FIG. 3.1



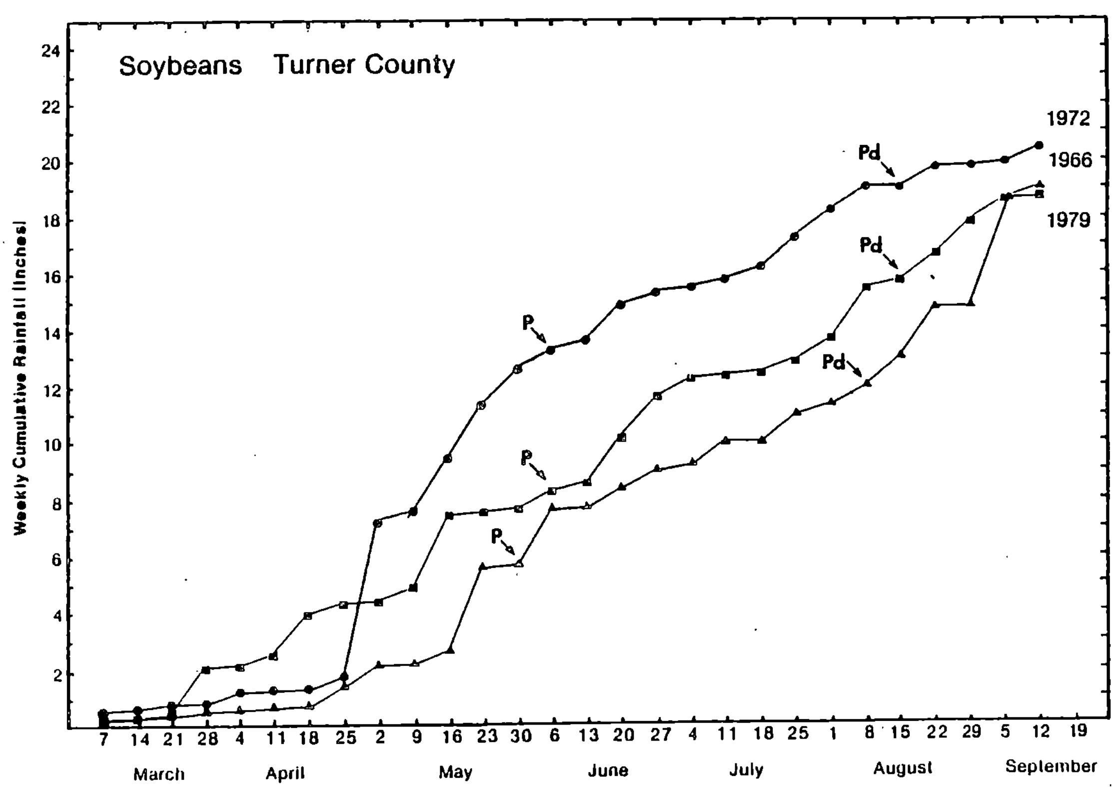
EAST CENTRAL
SOYBEANS
MOODY COUNTY
1969
PRECIPITATION — INCHES
TEMPERATURE F Max Min
6
5
4
3
2
1
0
90
70
50
30
10
0
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Podded
Planted
Leaf Shed

FIG. 3.2



Soybeans Hamlin County
1972
1979
1966
Pd
P
Weekly Cumulative Rainfall (inches)
24
22
20
18
16
14
12
10
8
6
4
2
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 3.3



Soybeans Turner County
1972
1966
1979
Pd
P
Weekly Cumulative Rainfall (inches)
24
22
20
18
16
14
12
10
8
6
4
2
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 3.4

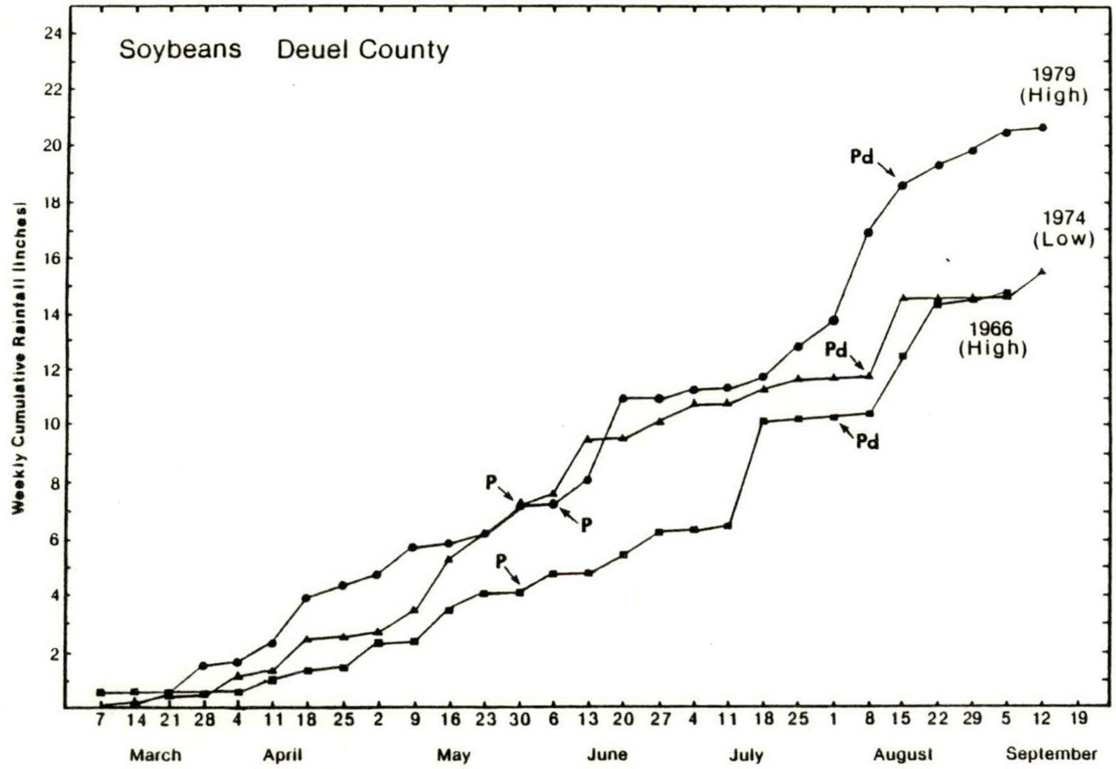

Soybeans Deuel County
1979 (High)
1974 (Low)
1966 (High)
Pd
P
Weekly Cumulative Rainfall (inches)
2 4 6 8 10 12 14 16 18 20 22 24
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March April May June July August September

FIG. 3.5

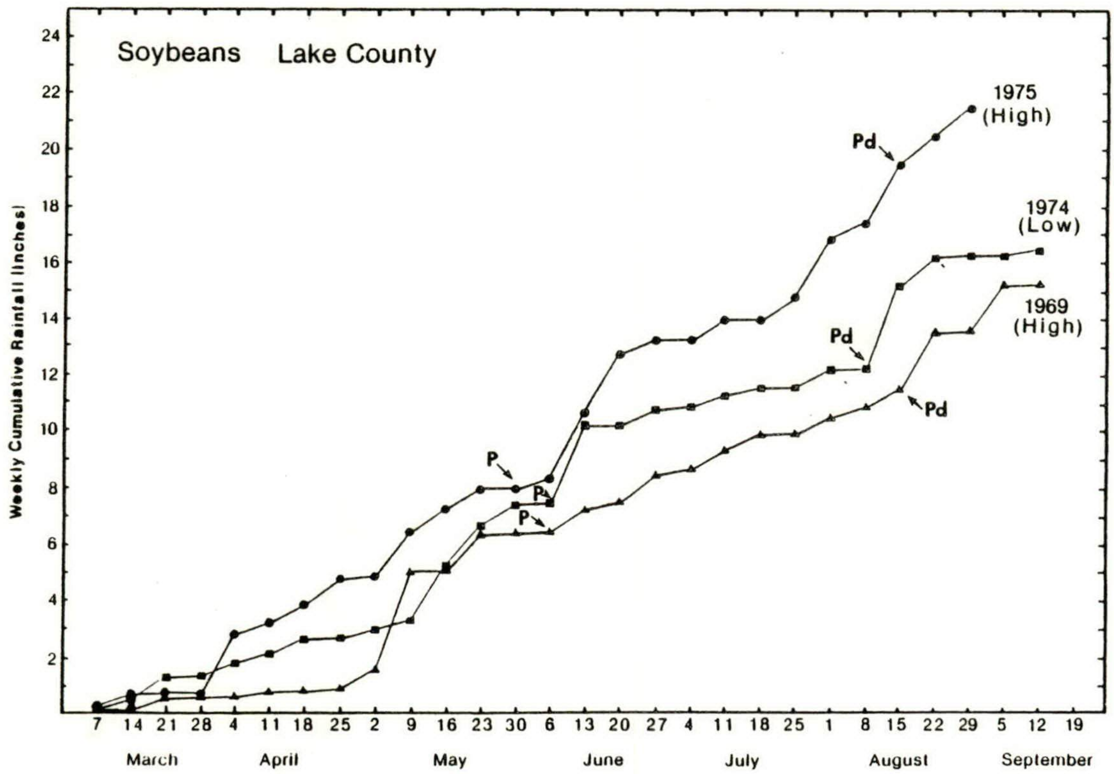
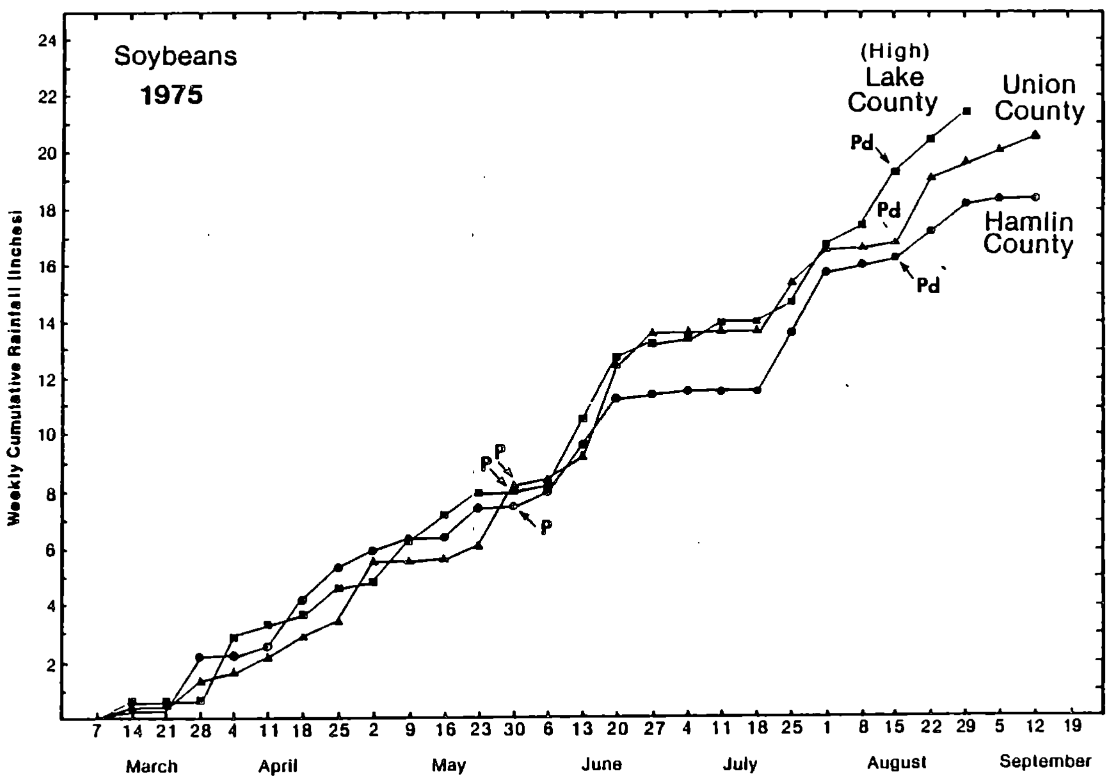

Soybeans Lake County
1975 (High)
1974 (Low)
1969 (High)
Pd
P
Weekly Cumulative Rainfall (inches)
2 4 6 8 10 12 14 16 18 20 22 24
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March April May June July August September

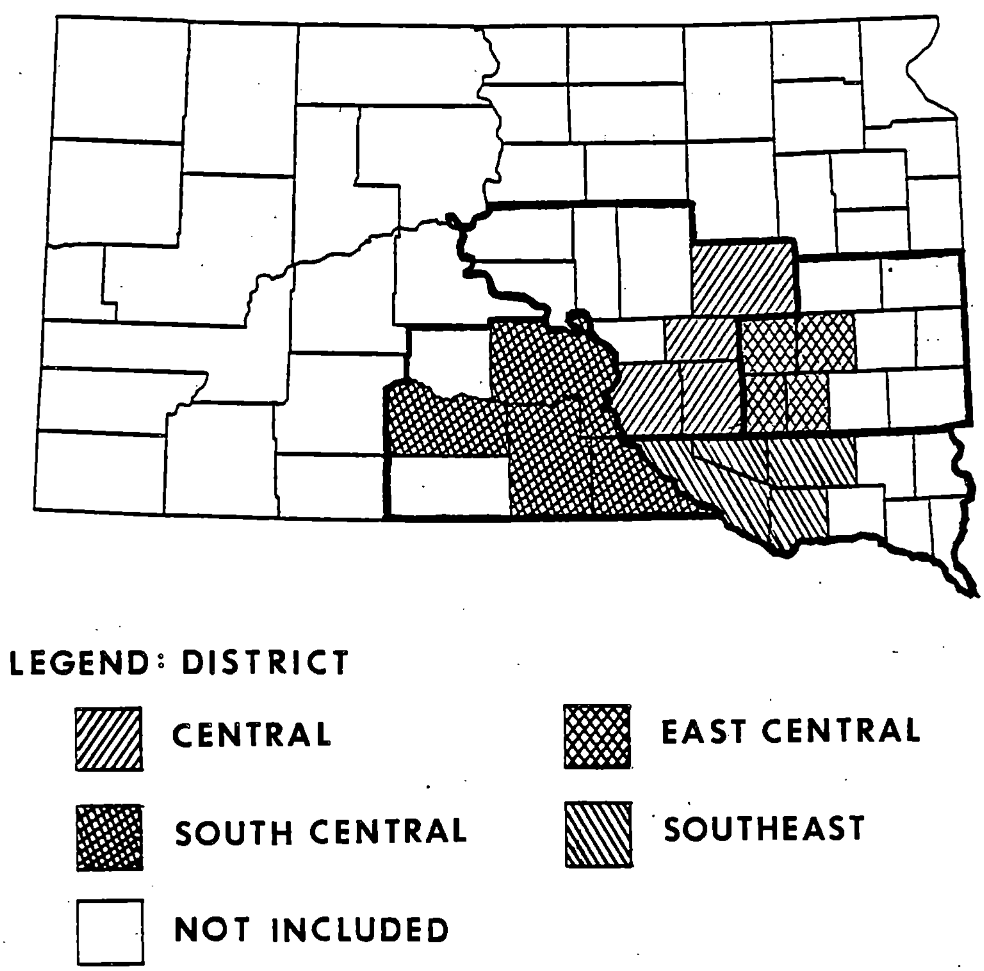
FIG. 3.6



Soybeans
1975
(High)
Lake
County
Union
County
Hamlin
County
Pd
Pd
Pd
P
P
P
Weekly Cumulative Rainfall (Inches)
24
22
20
18
16
14
12
10
8
6
4
2
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 3.7

SECTION IV
CLIMATIC IMPACTS ON SORGHUM PRODUCTION IN SIXTEEN COUNTIES OF SOUTH DAKOTA



Section IV: Climatic Impacts on Sorghum Production in Sixteen Counties of South Dakota Between 1965 and 1982

Four districts, identified for comparing climatic events to phenology and production of sorghum are located in the south central and southeast counties of South Dakota. The six most prominent factors contributing to yield variation of sorghum in these districts during the 17-year period are shown in Table 4.0. Crop Reporting Districts (CRD) were entered as "dummy" variables to determine location effects. Locations entered as the second and third step variables. The negative adjusted yield value for CRD 8 was attributed to an actual zero yield recorded in Mellette County in 1976 and is believed to be the reason for the -24.18 bushel per acre "adjusted" yield resulting from regression analysis (Table 4.0). The stepwise regression analysis (Table 4.0) identified an additional 17 and 11% variation in sorghum yield for CRD 9 and CRD 8, respectively.

The climatological factors contributing to yield variation were amount of July precipitation as step 1 (30%), weeks less than 0.10 inch rain in July as step 4 (an additional 2%), amount of August precipitation (an additional 5%) as step 5, and September low temperature as step 6 (an additional 1%).

Table 4.0. Maximum R-Square Improvement Analysis Developed by Stepwise Regression for Determining Factors Contributing to Sorghum Yield Variation in South Dakota Between 1965 and 1982.

Variable	Final β Value	R^2 Upon Entry
1. July precipitation	3.06	.30
2. CRD 9*	8.69	.47
3. CRD 8*	-24.18	.58
4. Weeks < 0.10 inch rain in July	-3.85	.60
5. August precipitation	1.61	.65
6. September low temperature	.38	.66
Intercept	12.89	-

*Crop Reporting Districts (CRD) entered regression analysis as "dummy" variables. CRD 9 and CRD 8 represent the SE and SC districts, respectively.

During the 17-year period covered by this study, rain during July was the most significant variable in sorghum production. For each additional inch of July precipitation, a gain of 3.06 bushel per acre could be realized (Table 4.0). By contrast, for each week during July where rainfall was less than 0.10 inch, a 3.85 bushel per acre yield reduction could be expected. August precipitation was likewise important as shown by an estimated 1.61 bushel per acre increase for each inch of rain. September low temperature had a positive influence on sorghum yields for an unidentified reason.

Three years most consistently ranked in the high yield class for sorghum were 1969, 1972, and 1978 (Table 1). Table 4.1 contains a list by district of the total precipitation during the previous fall and the growing season for each of these years as a means to characterize total moisture requirements for high sorghum production in South Dakota.

Table 4.1. Inches Average Seasonal Precipitation by Crop Reporting District in Three Years when Sorghum Yield were Ranked in the Four Highest Classes in at Least Nine Counties Each Year.

	1969		1972		1978	
District	1968 Fall	Growing Season	1971 Fall	Growing Season	1977 Fall	Growing Season
Central*	5.1	13.3(2)	8.2	20.5(2)	5.7	14.1(2)
East Central*	6.1	12.7(3)	8.4	19.2(1)	8.3	16.0(2)
South Central*	-	-	6.3	19.0	4.4	14.7(2)
Southeast*	7.7	15.8	7.1	23.1(3)	6.3	17.9
Seasonal Average	6.3	13.9	7.5	20.5	6.2	15.7

*Values in parenthesis indicate when the number of counties contributing to the average was fewer than four per district and the actual number involved.

One characteristic common to 1969, 1972, and 1978 is that the previous fall precipitation amounts, averaged across the four districts, were all over 6 inches, well above a typical September, October, November period in South Dakota (Appendix C). However, previous fall precipitation did not appear as a significant variable in multiple regression analysis (Table 4.0).

Average growing season precipitation, across all districts (as shown in Table 4.1), ranged from a low of 13.9 inches in 1969, to 15.7 in 1978, to a high of 20.5 inches in 1972. No counties of the SC District qualified for the high yield class in 1969, where growing season precipitation ranged from 9.7 to 13.6 inches and averaged 10.9 inches (Appendix C). It is assumed that the amounts shown for other districts in 1969 represents a lower limit for good sorghum production and also suggests that rainfall occurred at opportune periods. By contrast, total growing season amounts averaged 2 inches higher in 1978 than 1969 and the 1972 rainfall was better than 5 inches above that in 1978.

Precipitation totals for 1967, 1974, and 1975, three years which were ranked in the low yield class in South Dakota, are recorded in Table 4.2. The all-district previous fall (1973) average in 1974 was about 2 inches above the 1968 and 1977 fall values in Table 4.1. However, total growing season rain averaged a lower value for all 16 counties in 1974 (12.5 inches) than in 1969

(13.9 inches, Table 4.1) and could account for the low yield rank for 1974. From the standpoint of total growing season precipitation, the over-district average for the poor production years of 1967 and 1975 (Table 4.2) exceeds that of 1969 and approaches that of 1978 (Table 4.1). Previous fall precipitation appears as a distinction between high and low yield years, but this factor was not an entry into the variables listed in Table 4.0, indicating that it was not as important a factor as some others in accounting for sorghum yield variation during the 1965 to 1982 period.

The weekly precipitation, maximum/minimum air temperature, and developmental stages of the sorghum crop in 1969 and 1973, two high production years, are shown in Figs. 4.0 through 4.3. The years selected were low to mid-range in total precipitation. A county was chosen to represent each of three districts in 1969 (Figs. 4.0, 4.1, and 4.2). Characteristic of 1969, adequate amounts of precipitation prevailed during the summer months favoring late season crops. The year 1973 was an unusual year (Fig. 4.3) in that it was identifed as a high production year for spring wheat and sorghum (Table 1). Rainfall distribution was apparently unique for these crops in the SC counties chosen for the study, as indicated in Fig. 4.3 for sorghum.

Table 4.2. Inches Average Seasonal Precipitation by Crop Reporting District in Three Years When Sorghum Yields Were Ranked in the Five Lowest Classes in at Least Twelve or More Counties Each Year.

	1967		1974		1975	
District	1966 Fall	Growing Season	1973 Fall	Growing Season	1974 Fall	Growing Season
Central	4.5	15.4(3)	6.8	12.9	0.75	13.9(2)
East Central	3.4	15.3	8.4	11.7	0.7	14.9(3)
South Central	4.0	12.7	7.4	12.5	1.3	13.8(3)
South East	2.4	16.9(3)	10.5	12.8	1.3	15.9
Seasonal Average	3.6	15.1	8.3	12.5	1.0	14.5

*Values in parenthesis indicate when the number of counties contributing to the average was fewer than four per district and the actual number involved.

A comparison of three high production years in Beadle County, 1966, 1969, and 1978 (Fig. 4.4) shows similar amounts of rainfall among years in early April with variation no greater than 2.5 inches throughout the season. The plots indicate planting (P) and heading (H) dates for each year. Cumulative rainfall for 1966 lagged behind 1969 and 1978 from early June until August 15. Thereafter, amounts in 1966 increased and exceeded the other two years by about 1.5 inches after August 15.

The years selected for high yield ranks in Bon Homme County were 1969, 1972, and 1978 (Fig. 4.5). 1972 exceeded the other two years by as much as 7.5 inches on June 20, an amount nearly equaling the total seasonal for 1969 and

1978. Rainfall distribution patterns in 1969 and 1978 were similar, but with higher rainfall occurring in both early and late season periods in 1978. All three years had the common trait needed, as suggested in Table 4.0, that of ample and persistent rainfall in July and August.

Precipitation in Hanson County for 1969, a high production year, is compared with 1967 and 1975, low ranked years, in Fig. 4.6. Between June 20 and August 22, 1969, about 6.2 inches of rain were recorded compared to about 3.5 in 1975 and 2.7 in 1967 for the same critical period. Whereas total rainfall was nearly equal in 1969 and 1975, apparently the important difference was in mid- to late-summer rains.

The cumulative precipitation pattern in Douglas County in 1969 (high rank) is compared with 1967 and 1974 (low ranked years) in Fig. 4.7. All three years had similar total growing season precipitation and high amounts were also received by June 20 in both 1967 and 1974. However, between July 11 and August 8, 1969, about 4.5 inches fell, compared to about 1.2 inches in 1967 and 3.1 inches in 1974. One-half inch was recorded the first week in August 1974, contributing to the 3.1 inch total, but apparently too late for a good response by sorghum. The rains after August 1, 1974, may have arrived too late to support good yields.

Precipitation in Hutchinson County for 1966 (high yield) and 1968 and 1974, low production years, is plotted in Fig. 4.8. No appreciable rainfall was received during the month prior to the week ending July 11, 1966. Between July 11 and August 22, about 7.2 inches fell in 1966, about 4 inches in 1968 and about 3.7 in 1974. These results reinforce the data in Table 4.0 indicating the importance of July and August rains for sorghum production.

For the years and locations compared for sorghum production in South Dakota, at least 4 to 7 inches is required from mid-July to mid-August for good sorghum yields. Considerable variation in cumulative precipitation can occur prior to July 1 without much influence on yield, provided that ample late summer rains occur.

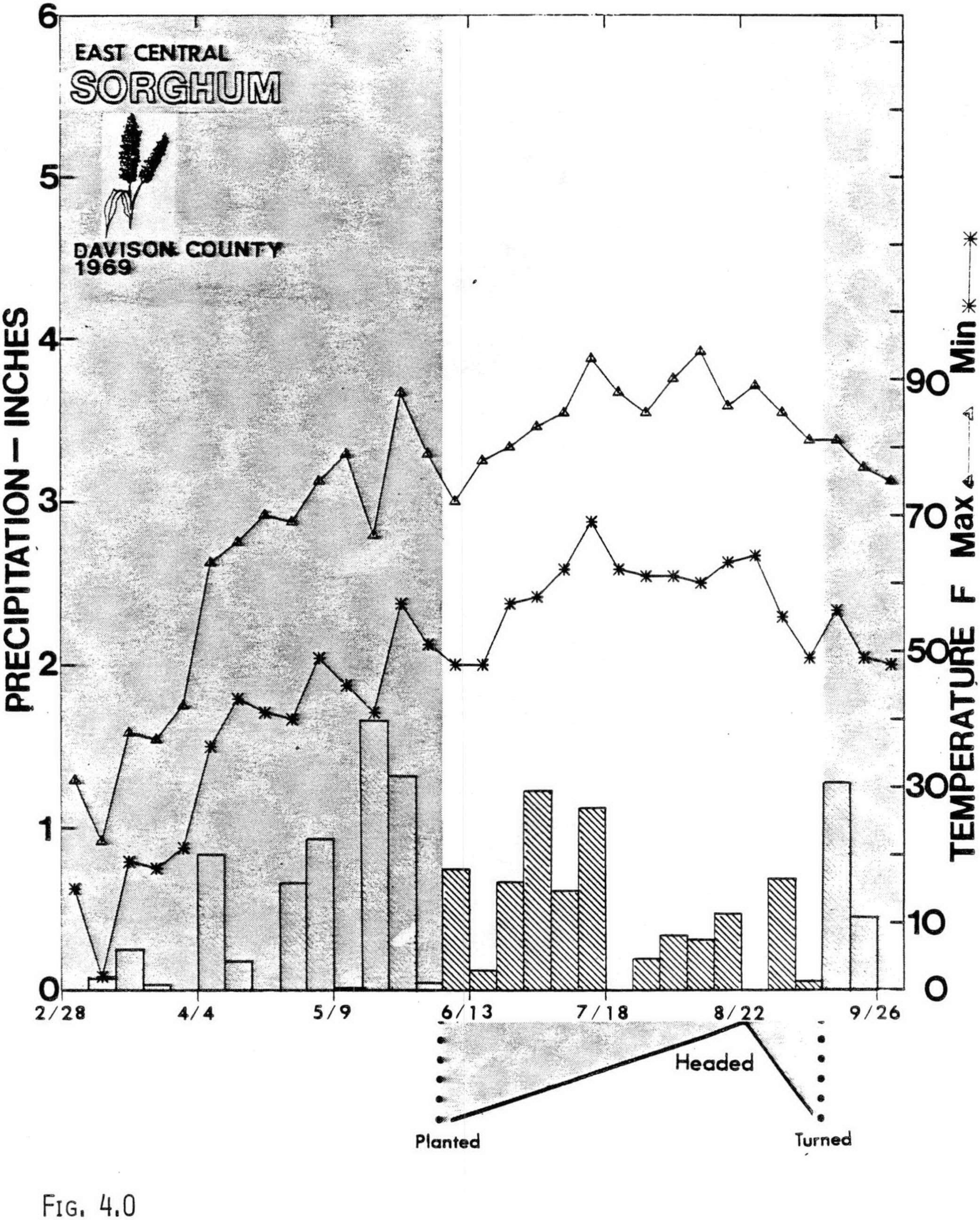

EAST CENTRAL
SORGHUM
DAVISON COUNTY
1969
PRECIPITATION – INCHES
TEMPERATURE F Max Min
0
1
2
3
4
5
6
0
10
30
50
70
90
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Headed
Planted
Turned

FIG. 4.0

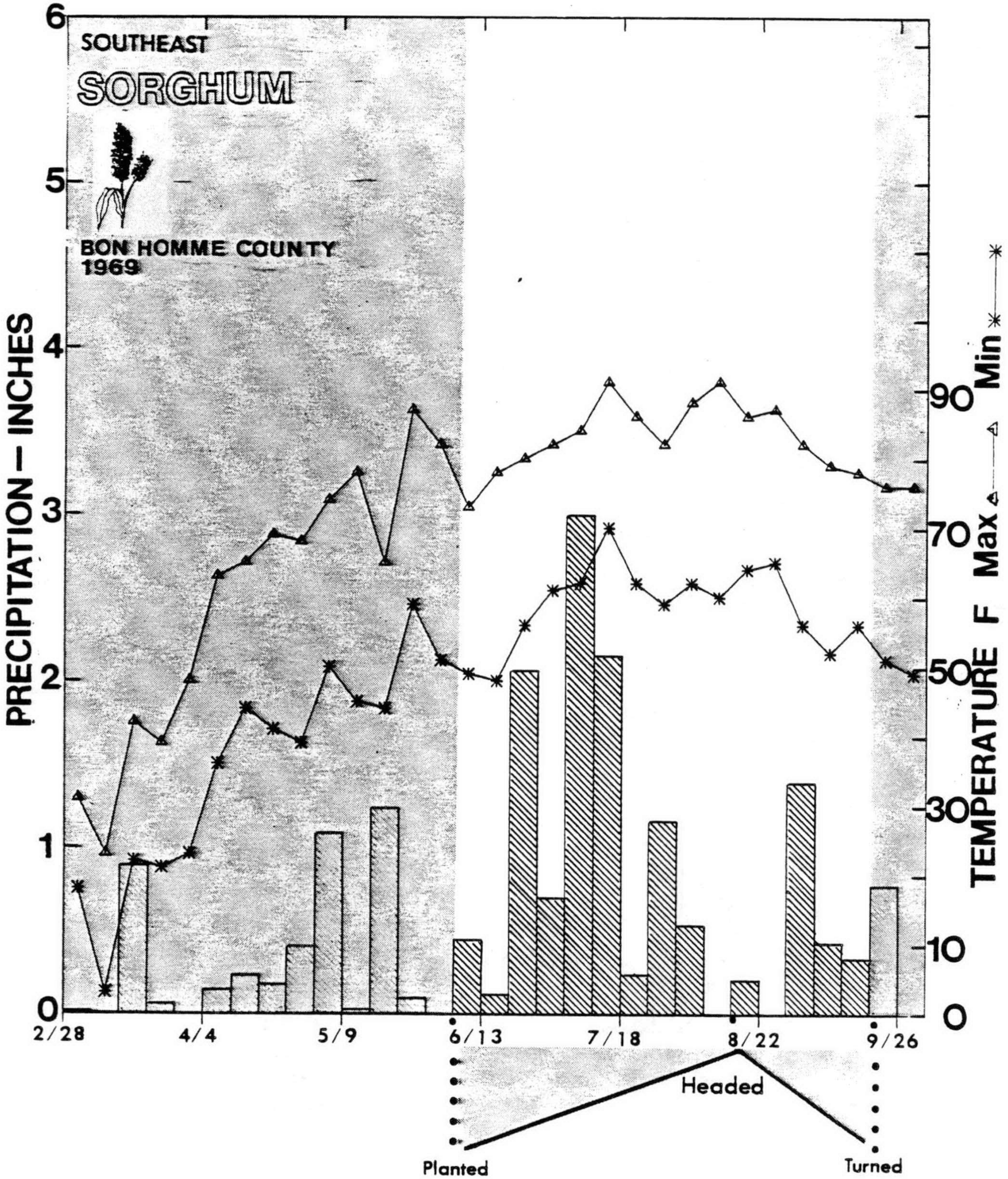

SOUTHEAST
SORGHUM
BON HOMME COUNTY
1969
PRECIPITATION – INCHES
TEMPERATURE F Max Min
0
1
2
3
4
5
6
0
10
30
50
70
90
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Headed
Planted
Turned

FIG. 4.1

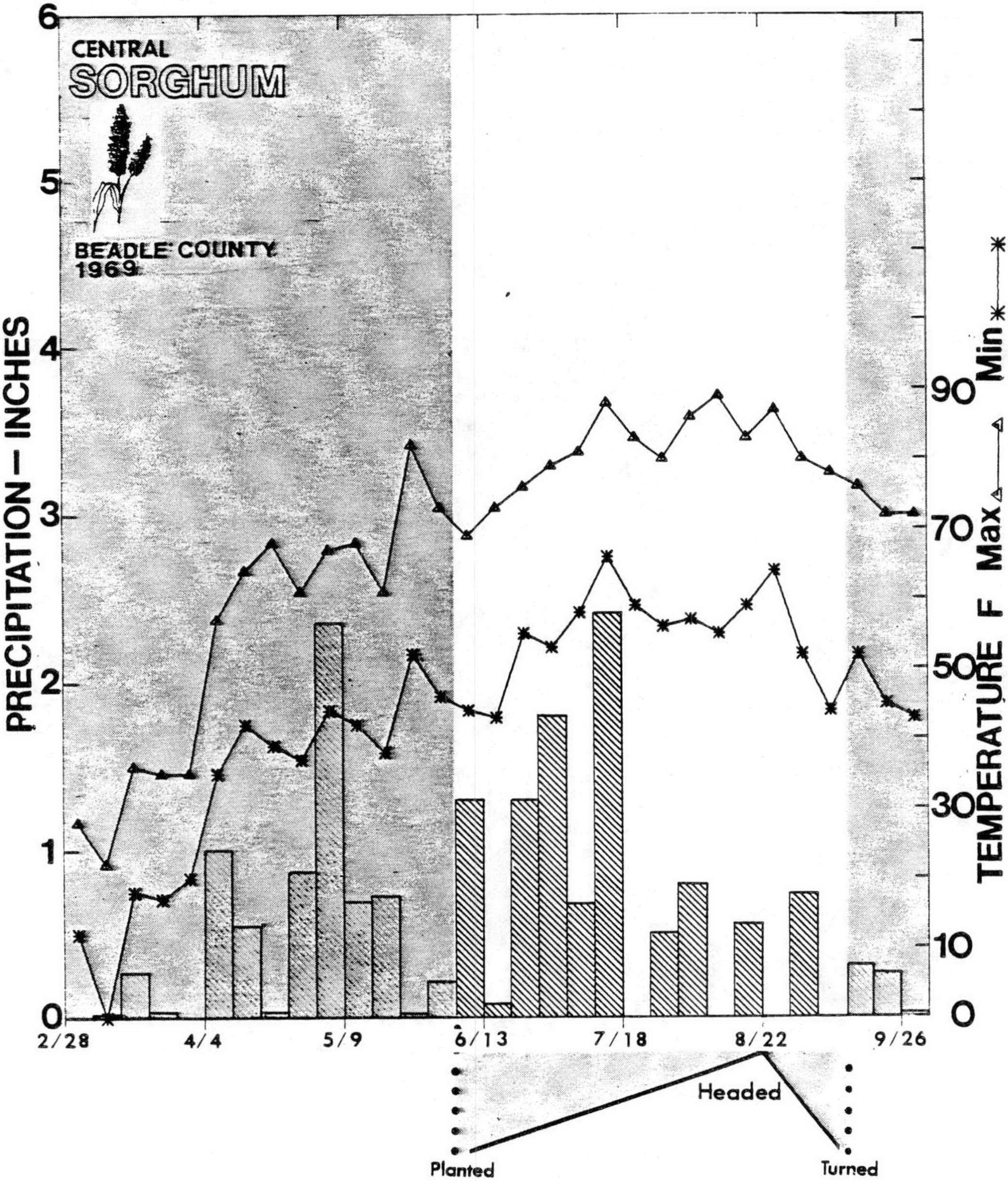

CENTRAL
SORGHUM
BEADLE COUNTY
1969
PRECIPITATION — INCHES
TEMPERATURE F Max Min
0
1
2
3
4
5
6
0
10
30
50
70
90
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Headed
Planted
Turned

FIG. 4.2

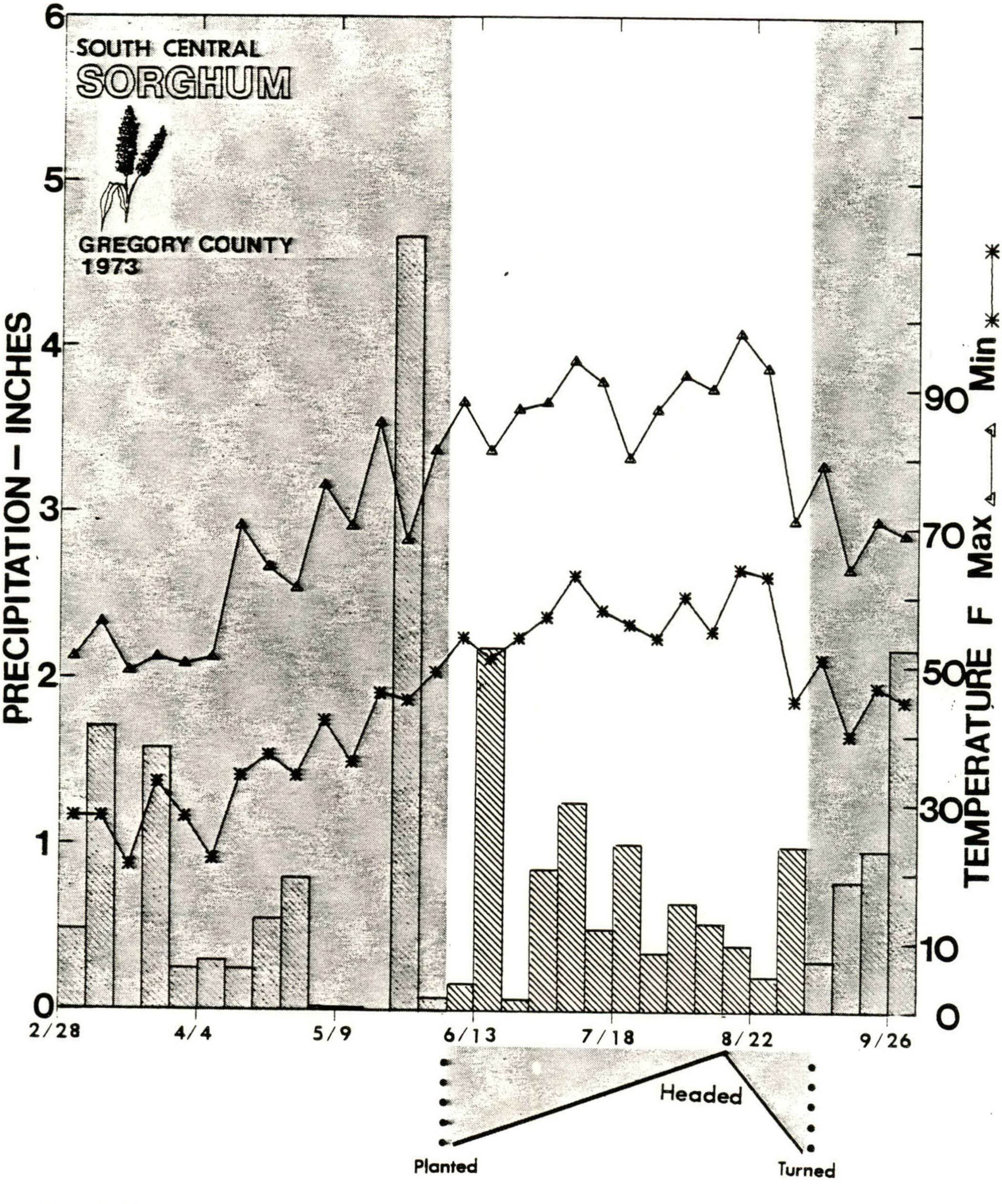

SOUTH CENTRAL
SORGHUM
GREGORY COUNTY
1973
PRECIPITATION – INCHES
TEMPERATURE F Max Min
0
1
2
3
4
5
6
0
10
30
50
70
90
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Planted
Headed
Turned

FIG. 4.3

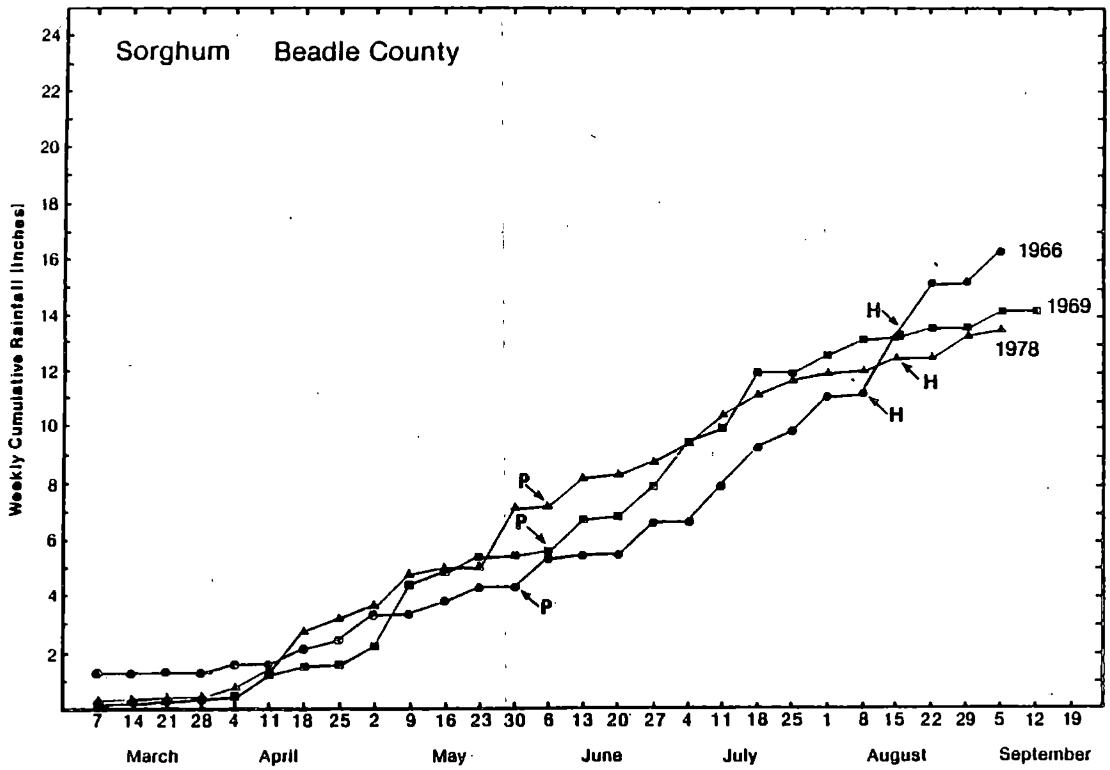

Sorghum Beadle County
Weekly Cumulative Rainfall (Inches)
1966
1969
1978
P
H
March
April
May
June
July
August
September

FIG. 4.4

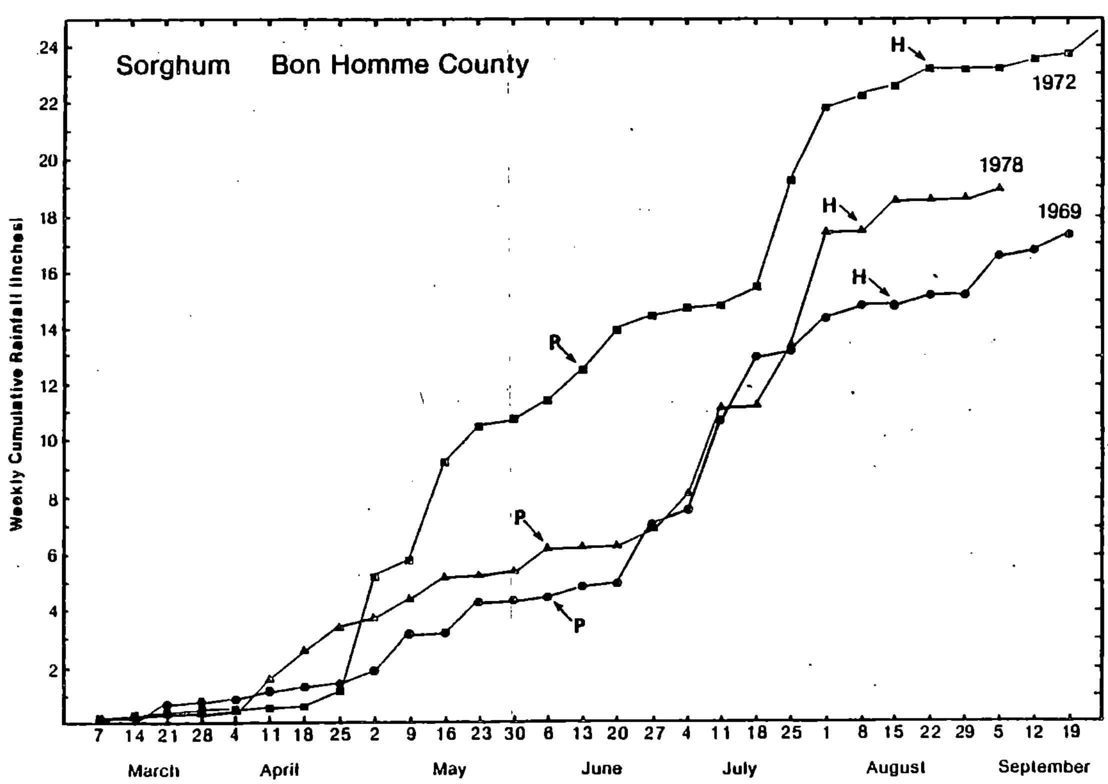

Sorghum Bon Homme County
Weekly Cumulative Rainfall (Inches)
1972
1978
1969
P
H
March
April
May
June
July
August
September

FIG. 4.5

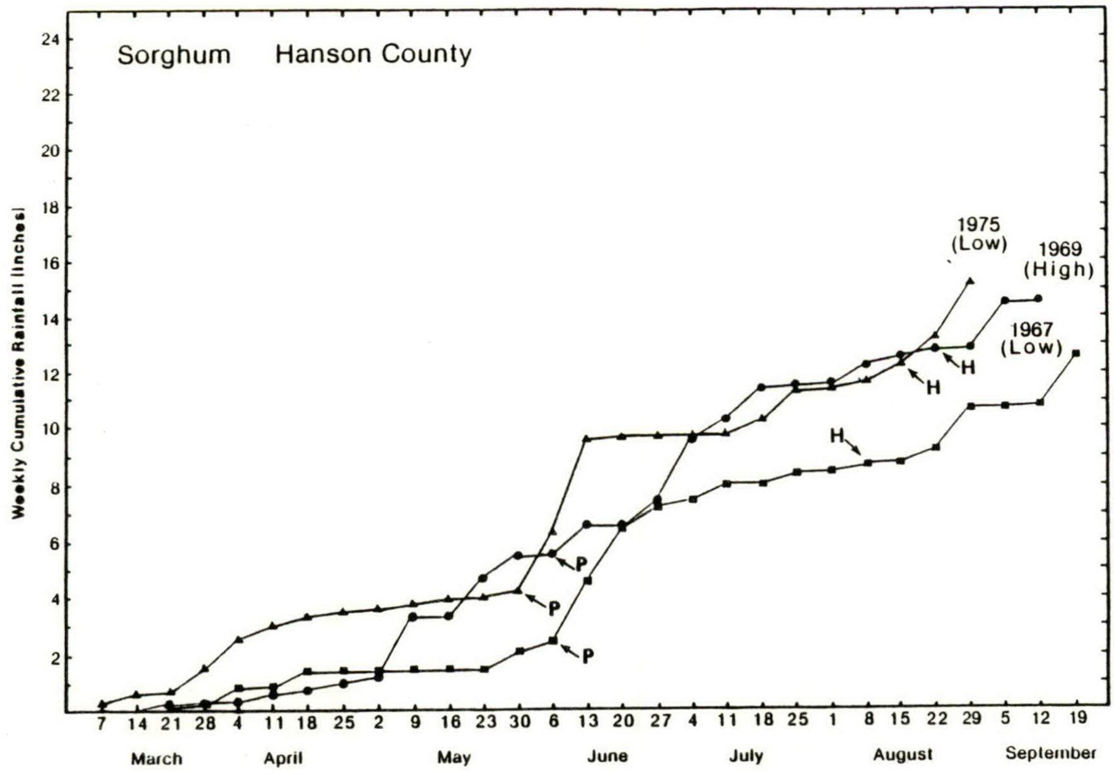

Sorghum Hanson County
Weekly Cumulative Rainfall (inches)
24
22
20
18
16
14
12
10
8
6
4
2
1975
(Low)
1969
(High)
1967
(Low)
H
H
H
P
P
P
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 4.6

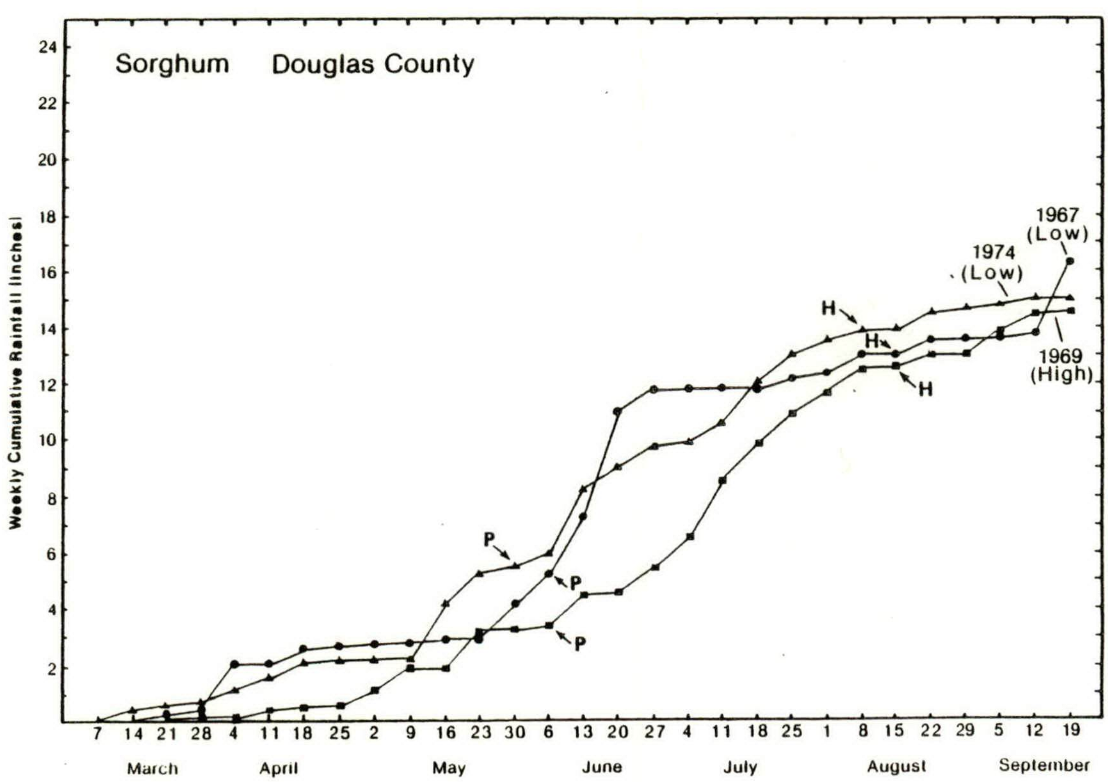
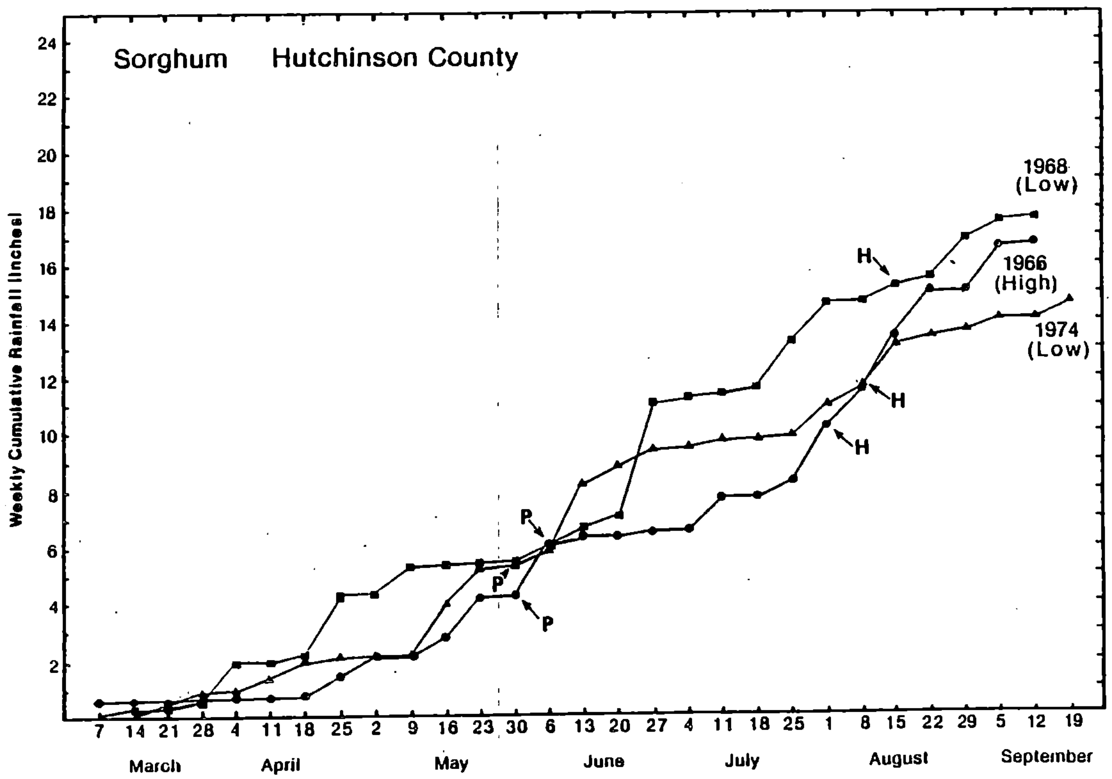

Sorghum Douglas County
Weekly Cumulative Rainfall (inches)
24
22
20
18
16
14
12
10
8
6
4
2
1967
(Low)
1974
(Low)
1969
(High)
H
H
H
P
P
P
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

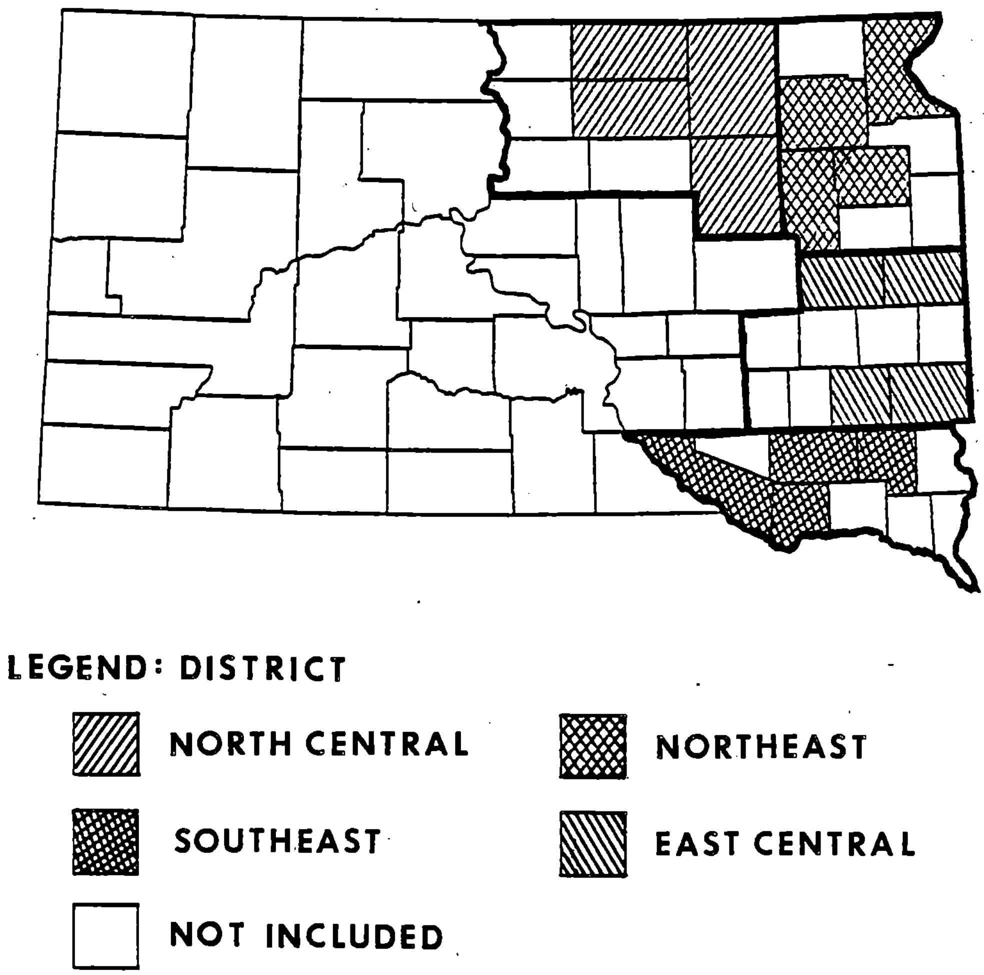
FIG. 4.7



Sorghum Hutchinson County
Weekly Cumulative Rainfall (Inches)
24
22
20
18
16
14
12
10
8
6
4
2
1968
(Low)
1966
(High)
1974
(Low)
H
H
H
P
P
P
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 4.8

SECTION V
CLIMATIC IMPACTS ON OATS PRODUCTION IN SIXTEEN COUNTIES OF SOUTH DAKOTA



Section V: Climatic Impacts on Oat Production in Sixteen Counties of South Dakota Between 1965 and 1982

The six independent variables identified by stepwise regression explained 30% of the oat yield variation over all years and districts (Table 5.0). CRD 6 and 3 entered the regression model at steps three and five, respectively, as "dummy" variables. The most pronounced climatic variable in oat production was June precipitation, where each inch of rain received increased yield by 2.22 bushel per acre above the intercept. Next in importance was May precipitation (1.21 bushel/acre), July precipitation (1.16 bushel per acre) and May low temperature (0.22 bushel per degree).

The three years consistently showing the highest oat yields in South Dakota were 1971, 1977, and 1979 (Table 1). The highest average growing season precipitation across all districts occurred in 1977 (13.2 inches) followed by 1979 (12.4 inches), and 1971 (11.6 inches) as shown in Table 5.1. Previous fall amounts for 1977 and 1979 were about the same (2.3 to 2.5 inches). However, during the fall of 1970 an average of 6.3 inches fell, or about four inches more than either 1976 or 1978. Whereas about two inches less rain fell in the 1971 growing season compared to 1977 and an inch less than in 1979, perhaps some benefit was gained from the larger amounts of precipitation in the fall of 1970.

Table 5.0. Maximum R-Square Improvement Analysis Developed by Stepwise Regression for Determining Factors Contributing to Oat Yield Variation in South Dakota Between 1965 and 1982.

Variable	Final β Value	R^2 Upon Entry
1. June precipitation	2.22	.10
2. May precipitation	1.21	.18
3. CRD 6*	6.67	.23
4. July precipitation	1.16	.27
5. CRD 3*	3.63	.29
6. May low temperature	.22	.30
Intercept	17.57	--

*CRD 6 and CRD 3 entered as "dummy" variables for the EC and NE Crop Reporting Districts, respectively.

Weekly precipitation, maximum/minimum air temperature and the developmental stages of the oat crop for 1971 are shown in Figs 5.0 through 5.3 in counties representing each of the four crop reporting districts studied. Only trace amounts of precipitation were recorded between March 1 and April 18, except in the EC and SE districts, which probably resulted in rapid soil warming when air temperatures approached 70 F in mid-April. These climatic conditions resulted in earlier planting in 1971 then most other high yield years (Appendix D). Timely rains after planting hastened germination and adequate rainfall likely occurred during May and June (Table 5.0) which was needed to sustain excellent oat production conditions in 1971 (Figs. 5.0, 5.1, 5.2, 5.3).

Table 5.1. Inches Average Seasonal Precipitation by Crop Reporting District in Three Years When Oat Yields Were Ranked in the Four Highest Classes in Ten or More Counties Each Year.

	1971		1977		1979	
District	1970 Fall	Growing Season	1976 Fall	Growing Season	1978 Fall	Growing Season
North Central*	5.6	11.9	-	-	1.4	11.5(3)
North East*	6.3	12.1	2.0	14.2(3)	2.8	12.5(2)
East Central*	6.6	11.0(1)	2.2	12.6(3)	3.0	13.2(2)
South East*	6.5	11.5	2.6	13.2	3.0	12.4(3)
Seasonal Average	6.3	11.6	2.3	13.3	2.5	12.4

*Values in parenthesis indicate when the number of counties contributing to the average was fewer than four per district and the actual number involved.

The cumulative precipitation between March 1 and when the oat crop reached physiological maturity during each of the years 1971, 1977, and 1979 are shown for Clark County in Fig. 5.4. Planting (P) and heading (H) dates show when 50% of the district acreage was completed each year. The cumulative rainfall reached the 2" inch level by March 14 in 1977, April 4 in 1979, but not until May 2 in 1971. However, from May 2, 1971 until July 18, the time when heads turned color in 50% of the county acreage, 10.8 inches of rain accumulated. In contrast, intervals of very little rain occurred in 1977 and 1979 during critical periods (Table 5.0), but apparently ample reserve soil moisture existed to maintain high yield potential.

A somewhat similar situation existed in Hutchinson County (SE District, Fig. 5.5) when comparing these three years. However, slightly more precipitation occurred during March in all years and weekly precipitation was more frequent in Hutchinson County among all years until the oat crop reached physiological maturity. Whereas the fall period of 1970 received more precipitation than other years in this comparison (Table 5.1), it is questionable that this previous fall precipitation benefited the 1971 crop significantly compared to 1977 and 1979.

The precipitation amounts for three years when crop yields were consistently in the low class are shown in Table 5.2. The average previous fall precipitation was high for these three years, compared to typical values in South Dakota (Appendix D), with the fall of 1975 receiving the lowest amount, an average of 4.5 inches across four districts. Fall 1965 and 1973 precipitation amounts averaged 5.7 inches, or 0.6 inches less than the 1970 fall (Table 5.1), when 1971 oat yields ranked high.

Shortage of total precipitation between March 1 and when the crop reached physiological maturity was likely the limiting factor for all years listed in Table 5.2. In particular, rainfall amounts during the growing season of 1966 and 1976 were inadequate to sustain high productivity. Actually, the growing season rainfall over all districts averaged 10.4 inches in 1974, only 1.2 inches below the overall average in 1971 (Table 5.1). Beside total amount, precipitation distribution is a contributing factor to good yield and perhaps 1974 typifies this poor distribution situation.

Table 5.2. Inches Average Seasonal Precipitation by Crop Reporting District in Three Years When Oat Yields Were Ranked in the Five Lowest Classes in Ten or More Counties Each Year.

	1966		1974		1976	
District	1965 Fall	Growing Season	1973 Fall	Growing Season	1975 Fall	Growing Season
North Central	5.1	8.7	6.5	10.3	2.2	5.3
North East*	5.9	9.4(3)	4.8	9.0	4.1	4.3
East Central*	6.1	8.2	4.6	10.3(1)	5.1	6.2
South East*	5.7	7.3(3)	6.9	11.9(1)	6.6	6.8(3)
Season Average	5.7	8.4	5.7	10.4	4.5	5.7

*Values in parenthesis indicate when the number of counties contributing to the average was fewer than four per district and the actual number involved.

The data base for yield was obtained from a county-wide estimate whereas weather records used in all comparisons were collected at one station and may not be as representative of the county as was crop information. This limitation for the precipitation data is particularly critical where rainfall from localized showers can be highly variable. However, rainfall periodicity and amounts, when assembled for several adjacent counties and when it is verified by such comparisons, tend to substantiate certain climatic events. We believe this assumption to be particularly valid for years consistently in the high or low yield class (Table 1) and when total precipitation suggests that yields should not be adversely affected. Certain years appear in both the high and low yield class in different areas of the state; for example, 1968, 1975, and 1978 (Appendix D), indicating regional shower activity did occur.

Weekly cumulative precipitation in Edmunds County for 1966 and 1974, classed as low yield years, and 1971 a high yield year in Edmunds County is compared in Fig. 5.6. By May 23, rainfall amounts totaled 4.5 inches higher in 1974 than 1971 or 1966. The cumulative difference was less than an inch by June 27. These data illustrate the importance of May and June precipitation as shown in Table 5.0. The lack of rain during these months in 1966, plus the limited total rainfall likely reduced yield potential (Table 5.2).

Two situations in McCook County (1966 and 1968), where yields were low compared to 1971 a high ranked year, are illustrated in Fig. 5.7. Between May 23 and June 27 about 1.5 inches were recorded in 1966, followed by another inch up to yellowing of the heads. During the same period the amounts in 1971 were about 3.5 inches and 2.7, respectively. The rainfall pattern in 1968 was different in that the total amount equaled that in 1971, but about 1.2 inches fell between May 9 and June 20, followed by about 5.0 inches up to July 4. It appears that a ceiling on oat yield potential was established by June 20, 1968 and that rains between June 6 and June 20 in 1971 made a significant difference in yield between the two years (1968 and 1971).

Statistical analysis of several possible variables contributing to oat yields for all sixteen counties over 17 years (Table 5.0), suggest that a certain degree of confidence can be placed in conclusions from these isolated examples (Figs. 5.4 through 5.7). Periods of low rainfall during May and June adversely affect oat yields in South Dakota. Perhaps some benefit is derived from ample previous fall precipitation as in 1971 (Table 5.1), but from results of isolated district situations (Table 5.2; for example SE) in 1974, total fall and growing season amounts seemed comparable to 1971 results (Table 5.1). Certainly high temperatures influence oat yield, but this variable did not enter the regression equation (Table 5.0).

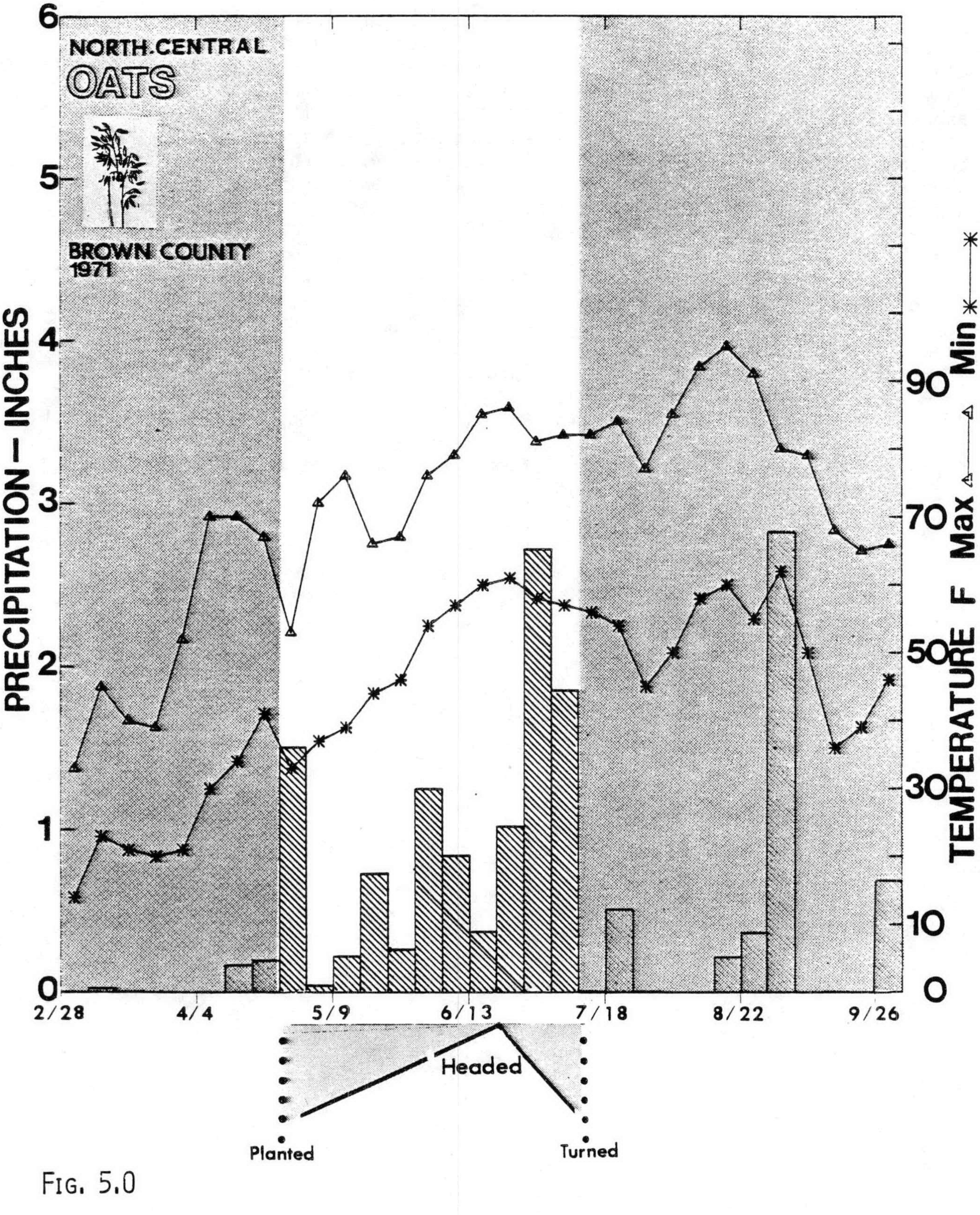

NORTH CENTRAL
OATS
BROWN COUNTY
1971
PRECIPITATION – INCHES
TEMPERATURE F Max Min
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Headed
Planted
Turned

FIG. 5.0

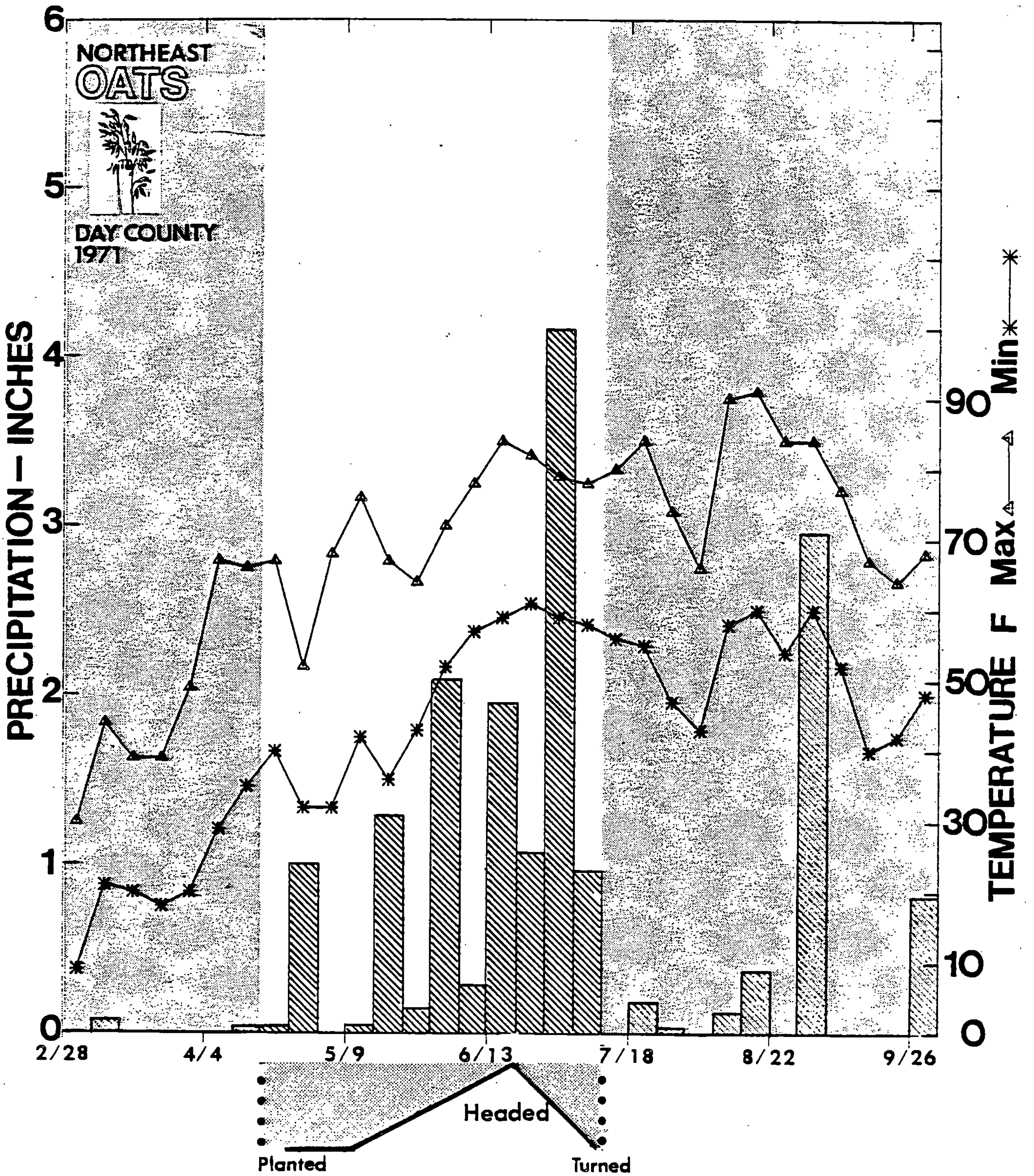
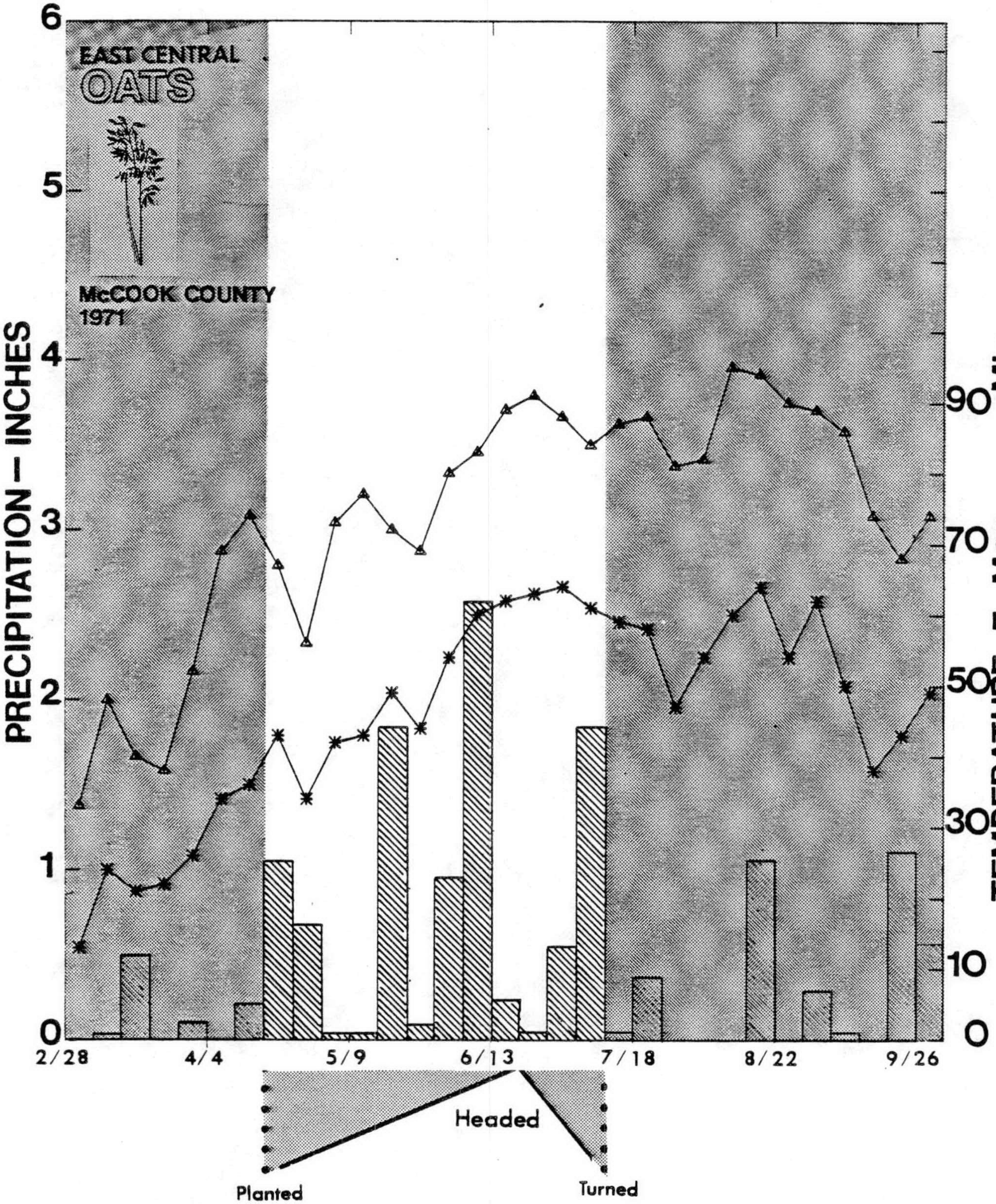

NORTHEAST
OATS
DAY COUNTY
1971
PRECIPITATION — INCHES
TEMPERATURE F Max Min
0
1
2
3
4
5
6
10
30
50
70
90
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Planted
Headed
Turned

FIG. 5.1



EAST CENTRAL
OATS
McCOOK COUNTY
1971
PRECIPITATION – INCHES
TEMPERATURE F Max Min
6
5
4
3
2
1
0
90
70
50
30
10
0
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Headed
Planted
Turned

FIG. 5.2

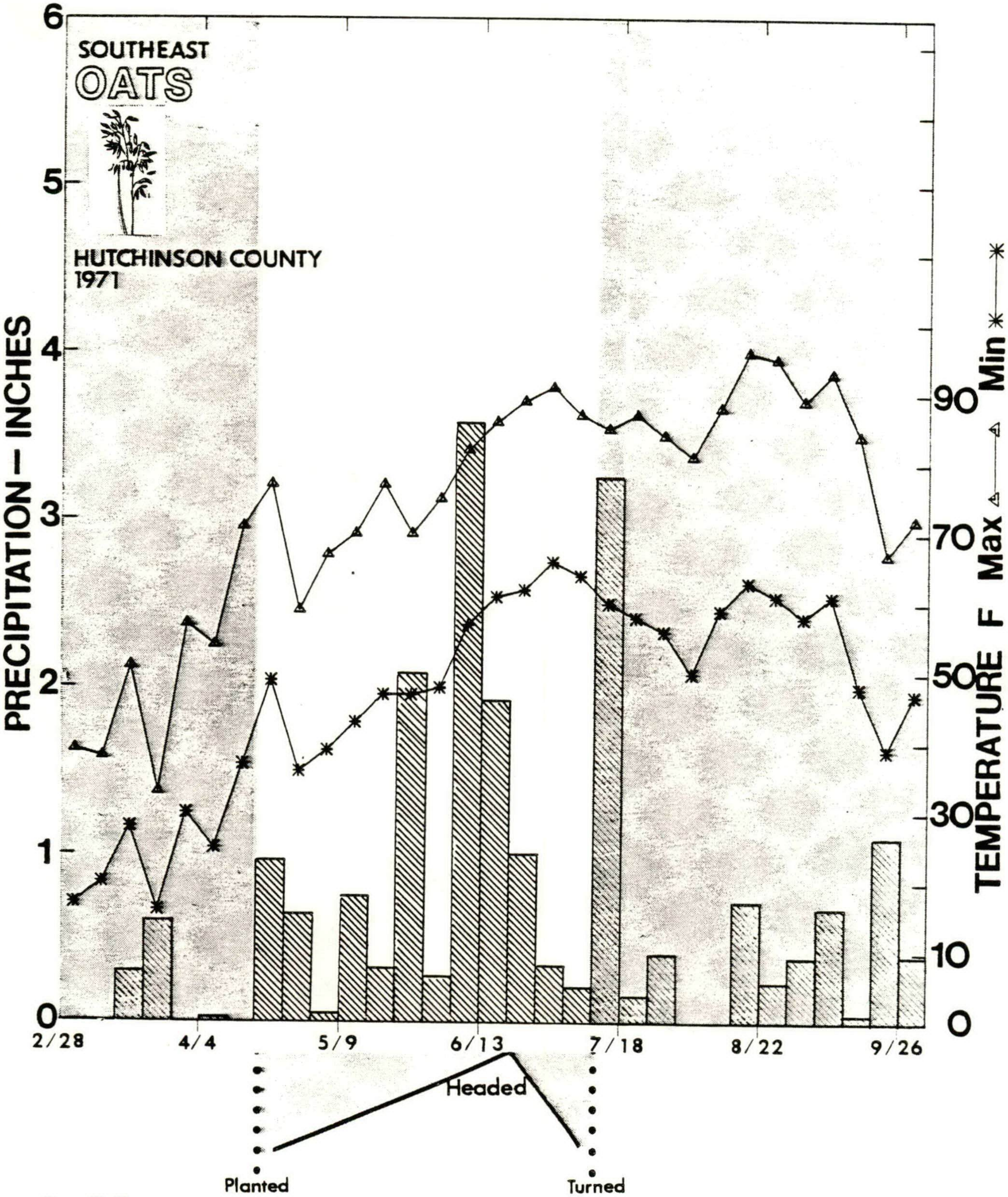
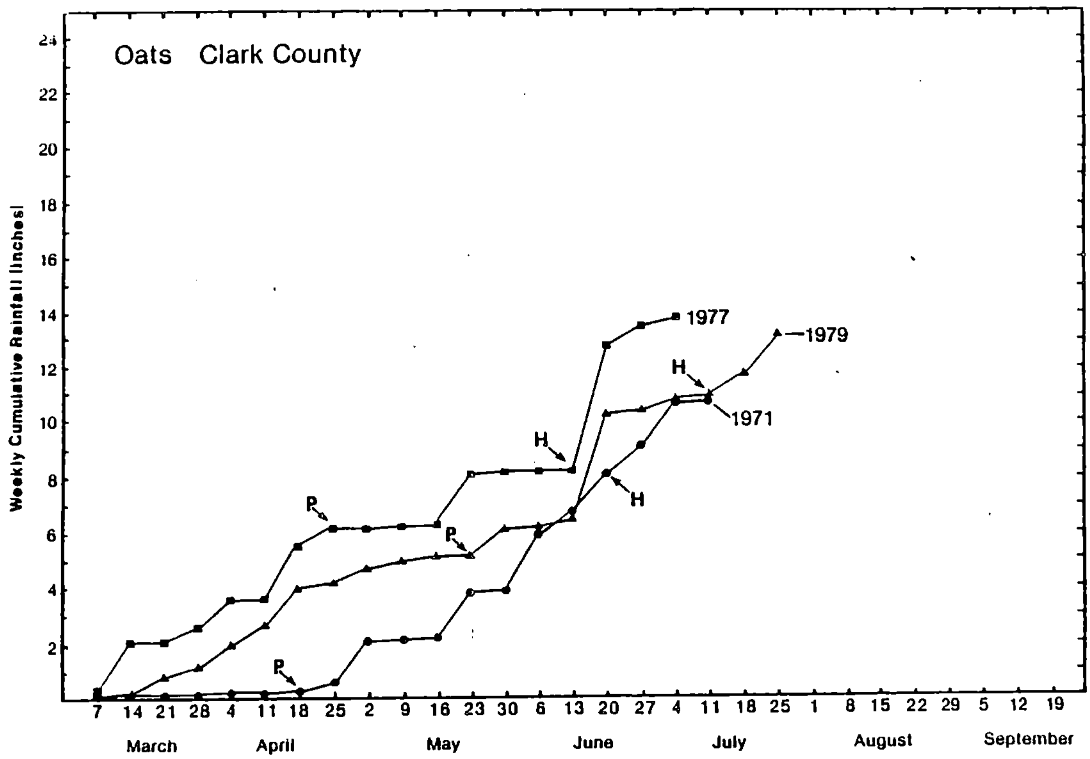
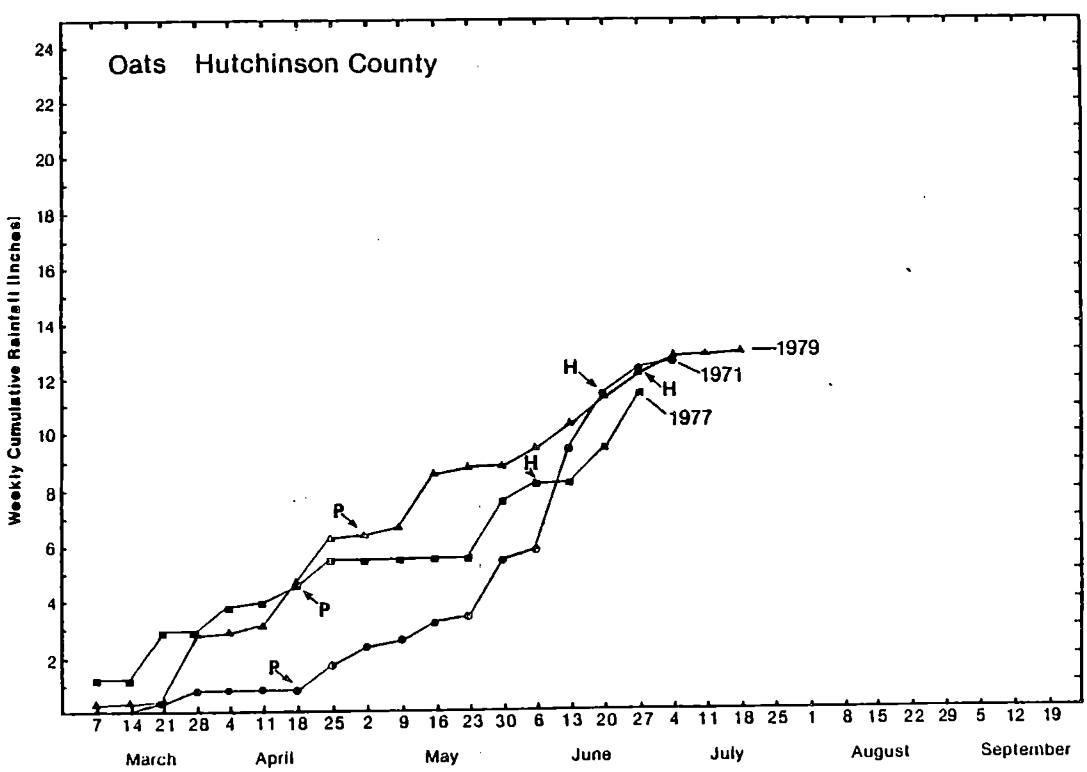

SOUTHEAST
OATS
HUTCHINSON COUNTY
1971
PRECIPITATION – INCHES
TEMPERATURE F Max
Min
0
1
2
3
4
5
6
10
30
50
70
90
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Headed
Planted
Turned

FIG.5.3



Oats Clark County
Weekly Cumulative Rainfall (Inches)
24
22
20
18
16
14
12
10
8
6
4
2
1977
1979
1971
H
P
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 5.4



Oats Hutchinson County
Weekly Cumulative Rainfall (Inches)
24
22
20
18
16
14
12
10
8
6
4
2
1979
1971
1977
H
P
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 5.5

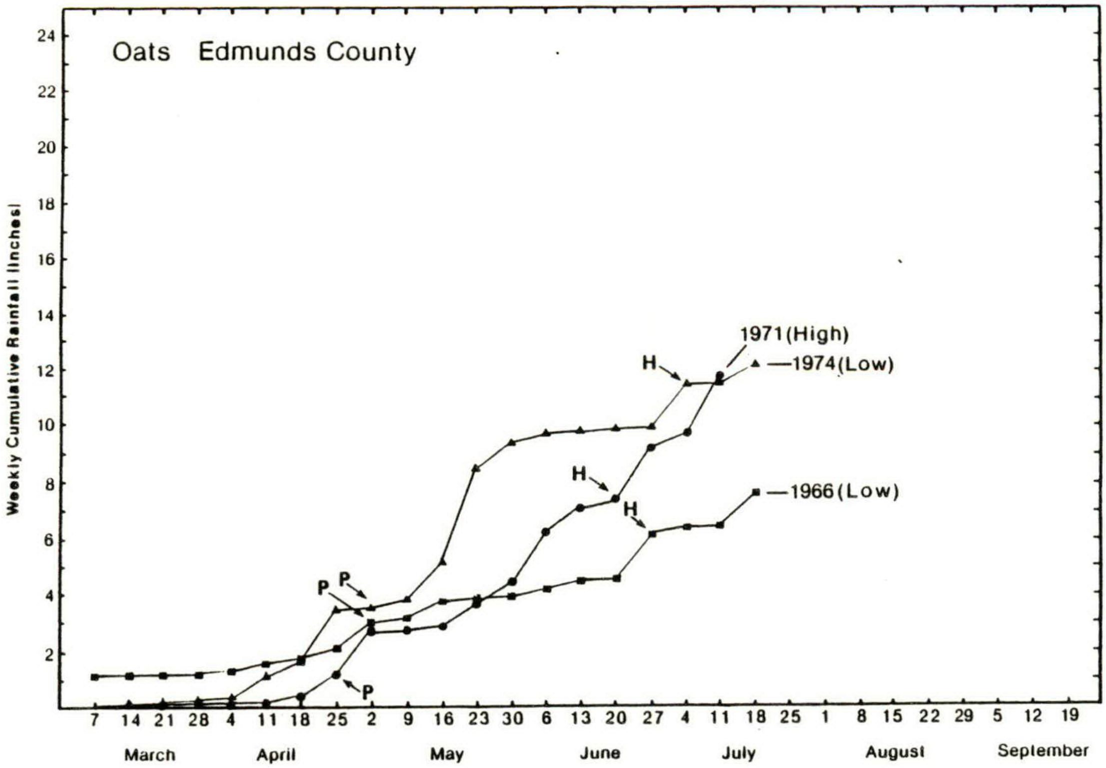

Oats Edmunds County
Weekly Cumulative Rainfall (inches)
24
22
20
18
16
14
12
10
8
6
4
2
1971(High)
H
—1974(Low)
H
H
—1966(Low)
P
P
P
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 5.6

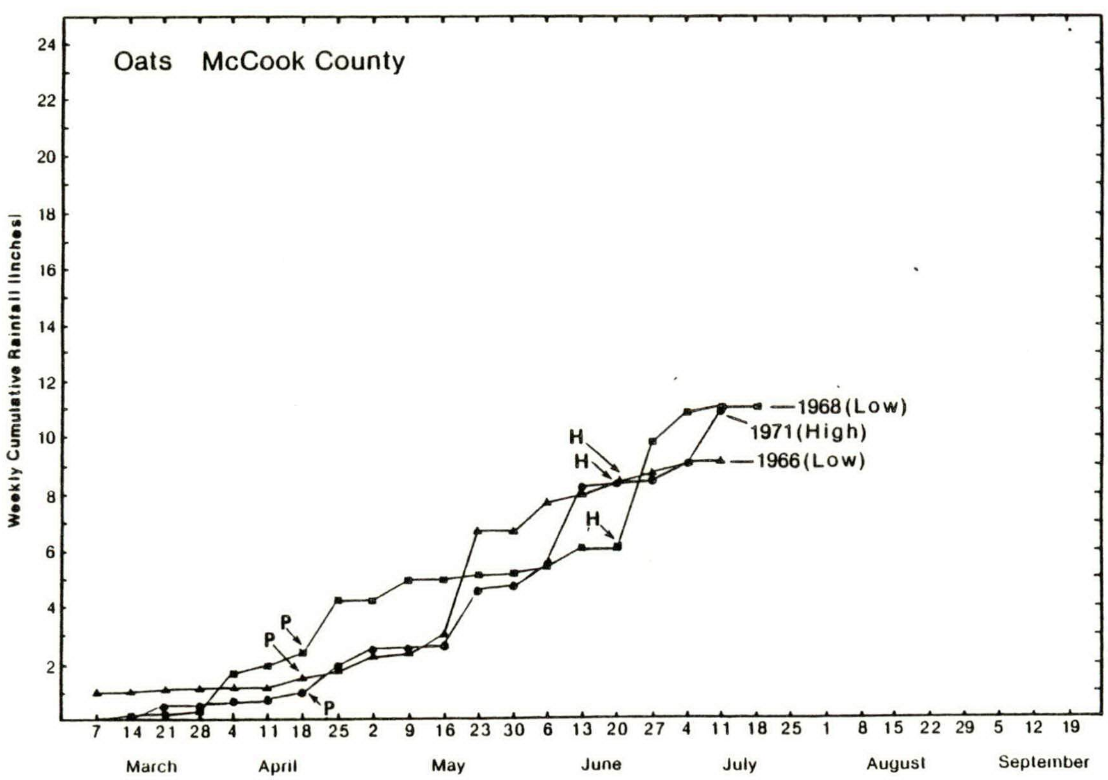
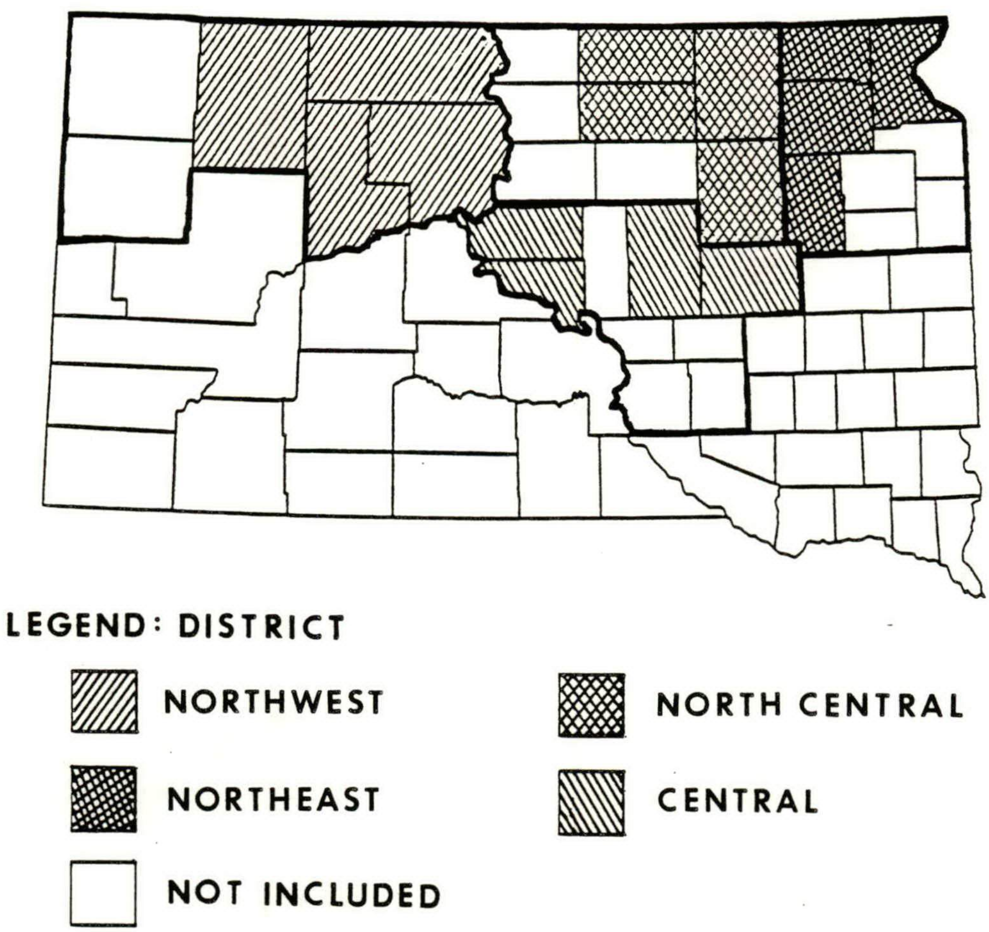

Oats McCook County
Weekly Cumulative Rainfall (inches)
24
22
20
18
16
14
12
10
8
6
4
2
—1968(Low)
1971(High)
—1966(Low)
H
H
H
P
P
P
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 5.7

SECTION VI
CLIMATIC IMPACTS ON SPRING WHEAT PRODUCTION IN SIXTEEN COUNTIES OF SOUTH DAKOTA



Section VI: Climatic Impacts on Spring Wheat Production in Sixteen Counties of South Dakota Between 1965 and 1982

The sixteen counties selected for climatic stress evaluation of spring wheat are located in the three Crop Reporting Districts across northern South Dakota and the Central District, which is bordered on the west by the Missouri River. In contrast to most other cultivated crops grown in South Dakota, large acreages of spring wheat are planted from the east to west borders of the state. Therefore, wide climatic variation exists within and between years which influenced production.

The six independent variables identified by stepwise regression, over the 17-year period of the study and the four districts explained 35% of the yield variation (Table 6.0). CRD 3 appeared first in the regression model as a "dummy" variable indicating a yield of about 4.2 bushel per acre advantage for this crop reporting district.

Table 6.0. Maximum R-Square Improvement Analysis Developed by Stepwise Regression for Determining Factors Contributing to Spring Wheat Yield Variation in South Dakota Between 1965 and 1982.

Variable	Final β Value	R^2 Upon Entry
1. CRD 3 "dummy"*	4.17	.13
2. Weeks < 0.1 inch rain in June	-1.66	.22
3. July high temperature	-.22	.29
4. May precipitation	.65	.31
5. May low temperature	.20	.34
6. June precipitation	.52	.35
Intercept	24.89	--

*Crop Reporting Districts (CRD) listed as "dummy" variables and CRD 3 (NE District) entered the "best" regression model yielding 4.2 bushel higher than other districts.

The sequence of entries into the regression model was found to be different for spring wheat than for oats (Table 5.0). Two explanations which may account for the apparent differences in the "best" model for spring wheat and oats: (1) as the data set was assembled, the oat study includes the EC and SE Districts whereas the spring wheat set includes the NW and Central districts, districts which represent a diversity of climatic conditions in South Dakota, (2) in the NC and NE districts, common to both cereals in this study, the 10-year average shows spring wheat to be planted about a week earlier than oats, which may change the order of important climatic events for each crop. It is assumed that the primary influence on planting decisions is the higher economic value of spring wheat. It is believed that these two factors influenced the regression results rather than different physiological requirements in the crops. Spring wheat was the only crop showing a negative slope in a few counties when the "adjusted yield" values were calculated from the regression of yield vs. years.

The second most significant variable contributing to spring wheat yield variation was the frequency of weekly June rains amounting to less than 0.1 inch. This variable depressed yields by a significant 1.66 bushel per acre, yet did not enter the model for oats (Table 5.0).

Table 6.1. Inches Average Seasonal Precipitation by Crop Reporting District in Three Years When Spring Wheat Yields Ranked in the Four Highest Classes in Eight or More Counties Each Year.

District	1971		1973		1977	
	1970 Fall	Growing Season	1972 Fall	Growing Season	1976 Fall	Growing Season
North West	4.4	11.7	2.7	10.3	-	-
North Central*	4.5	11.9	1.3	6.6(1)	1.8	10.6(3)
North East*	5.9	12.2	1.5	9.1(2)	1.5	12.8(3)
Central*	4.1	9.4(3)	4.4	7.5(2)	2.1	11.2(2)
Seasonal Average	4.7	11.3	2.5	8.4	1.8	11.5

*Values in parenthesis indicate when the number of counties contributing to the average was fewer than four per district and the actual number involved.

The climatic factors contributing to yield variation in spring wheat included high July temperature (Table 6.0). High July temperature could potentially depress yields 0.22 bushel per acre per degree F. Each inch of rainfall in May contributed 0.65 bushel increase per acre and May low temperature added 0.20 bushel per acre (Table 6.0). The final entry identified was June precipitation, which increased yield by about 0.5 bushel per acre for each inch of rain received.

According to Appendix E and the scheme used in Table 1, 1971, 1972, 1973, and 1977 were classed as high production years for spring wheat. During these years 50% or more of the counties were identified as having an average yield in the highest four ranks. The year 1972 was ranked high also for warm season crops (Table 1), indicating ample amounts of both early and late summer precipitation. Climatic characteristics of 1972 were outlined in Chapters 2, 3, and 4. The precipitation amounts for 1971, 1973, and 1977 as related to spring wheat growing districts are listed in Table 6.1 for the four districts studied.

Comparing the average precipitation amounts for all districts (Table 6.1), 1971 and 1977 values were similar for the growing season, but the average for fall 1970 was about 3 inches higher than the fall of 1976. This difference in previous fall precipitation did not appear to significantly influence spring wheat yields (Appendix E). The average growing season rainfall for all districts in 1973 was about 3.0 inches less than 1971 and 1977. The range between districts was 6.6 inches (NC) to 10.3 (NW) for 1973. The previous fall precipitation average of 2.5 inches in 1972 was intermediate between 1970 and 1976.

The rainfall amounts by districts for three years, when yields ranked in the lowest class, 1966, 1974, and 1976 are listed in Table 6.2. Based upon average values for all districts, 1966 and 1974 amounts were higher during the previous fall and the growing season (Table 6.2) than shown for 1973 (Table 6.1). Rainfall distribution differences within each year likely account for the wide variation in spring wheat yields between these years.

Table 6.2. Inches Average Seasonal Precipitation by Crop Reporting District in Three Years When Spring Wheat Yields Ranked in the Five Lowest Classes in Fourteen or More Counties.

	1966		1974		1976	
District	1965 Fall	Growing Season	1973 Fall	Growing Season	1975 Fall	Growing Season
North West*	3.7	10.7	6.7	7.1(3)	1.5	10.3(2)
North Central	4.4	8.7	6.3	10.5	3.7	4.3
North East	5.6	9.6	4.7	8.7	3.9	4.1
Central	4.6	6.8	4.5	9.3	3.1	3.9
Seasonal Average	4.6	8.9	5.5	8.9	3.1	5.7

*Values in parenthesis indicate when the number of counties contributing to the average was fewer than four per district and the actual number involved.

The weekly cumulative precipitation, maximum/minimum air temperature and the developmental stages of the spring wheat crop for 1971 are shown in Figs. 6.0 through 6.3. Consistent with data provided in Table 6.0, May and early June precipitation usually occurred at weekly intervals in all districts as characteristic of a high production year, and persisted through June 27 when the crop was 50% headed throughout the state (Figs. 6.0, 6.1, 6.2, and 6.3).

The cumulative weekly precipitation amounts during the growing season in high yield years, 1971, 1972, and 1973, in Corson County (NW District) are shown in Fig. 6.4. The year 1972 appeared as a high production year in the NW District and is compared with 1971 and 1973 identified in Table 6.1. Rainfall distribution for 1971 and 1972 growing season was nearly identical until May 30. The fall months preceding these years were also similar in amounts of rain received (Appendix E), with an average of 4.4 and 5.8 inches in 1970 and 1971, respectively. Spring rains occurred the week after April 18 in 1971 and April 25 in 1972 immediately after which 50% of the county acreage was planted

(Appendix E) and precipitation steadily cumulated through May and June. The year 1971 differed from 1972 in that about 3 inches more rain fell between May 30 and when the crop reached physiological maturity. The rainfall pattern for 1973 differed from both 1971 and 1972 in that about 3 inches more cumulated before April 18 in 1973 and then about a 4-week period lapsed in May without precipitation. The need for May rains, as suggested in Table 6.0, apparently was met by the early season precipitation in 1973.

Cumulative precipitation amounts for three high production spring wheat years, 1971, 1973, and 1977 in Roberts County (NE District) are plotted in Fig. 6.5. Similar to Corson County (Fig. 6.4), more early rain was received in 1973 than in 1971 in Roberts County (Fig. 6.5), but amounting to only an inch difference by May 16. In both 1971 and 1973 only small amounts fell as of May 23, after which about 3 inches was recorded in 1971 and about 3 inches a week later in 1973. Similarly, a period of two to three rainless weeks occurred in June followed by increments of about 2.5 (1973) to 4.5 inches (1971) from mid-June to early July. Apparently these were critical rains for spring wheat, which contributed to a high county average yield. In the year 1977, records showed higher precipitation amounts early, compared to 1971 and 1973, and sustained this difference through May and most of June.

The weekly cumulative precipitation profiles of 1971 (high yield) are compared with 1966 and 1974, two low production years in Brown County (NC District) in Fig. 6.6. Brown County had nearly identical precipitation amounts for the previous fall and growing season in 1971 and 1966, but vastly different production ranks (Appendix E). However, in 1966 only about 2.5 inches of rain fell between May 2 and June 20. Actually, only about 3.5 inches fell during this period in 1971 but it accrued more rapidly in 1971 as June 20 approached. Because precipitation events and amounts appeared similar after June 20 for both 1966 and 1971, and diseases were not a factor[1], differences in yield rank must be attributed to events before this date. In 1974, also a low production year in South Dakota (Table 1), a dry period occurred between mid-May and late June which is critical for spring wheat (Table 6.0). However, total rainfall could also have been limiting in 1974.

Some interesting comparisons exist among cumulative rainfall amounts for Hand County (Central District) records for 1966, 1971, and 1974 (Fig. 6.7). The low rank for 1966 can be explained by either low amounts during May and June, low total precipitation, or both. However, 1974 had a marked precipitation increase starting on May 16, which exceeded the 1971 amounts by 2 to 4 inches up to June 20. Between June 27 and July 4, 1971, about 2 inches fell with less than 1 inch between these dates in 1974. Heading was earlier by one week in 1971 (June 20) compared to 1974 (June 27) and the average maximum weekly temperature approached 95 F in 1974 compared with 90 F in 1971 during early July. The above factors likely all contributed to the low yield in 1974.

Comparisons between the results in Table 5.0 for oats and Table 6.0 for spring wheat indicate a different order of entry for the independent variables. June, May, and July precipitation entered as Step 1, 2, and 4, respectively, for oat production compared to May and June precipitation as Step 4 and 5,

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[1]United States Department of Agriculture Miscellaneous Publication No. 1363, 1978.

respectively, in spring wheat yield analysis. Direct comparisons may not be advisable for oat and spring wheat production as was done between corn and soybeans (Section III) because of a lack in district correspondence for the two crops. The possible significance of a difference in variable entry levels into regression analysis could be tested by another analysis for each crop, using only counties common to both crops.

Total rainfall amounts (NC and NE Districts) needed for high production in both crops are similar (Tables 5.1 and 6.1). A limited comparison, by manual plots, between two different years in one county has shown rainfall distribution to be similar for high production of both oats and spring wheat. For example, Roberts County (1967 - spring wheat and 1969 - oats) and Day County (1967 - spring wheat and 1971 - oats) show very similar precipitation patterns for yield rankings. Preliminary evidence indicates that climatic requirements shown in Tables 5.0 and 6.0 between these crops cannot be identified with their developmental needs.

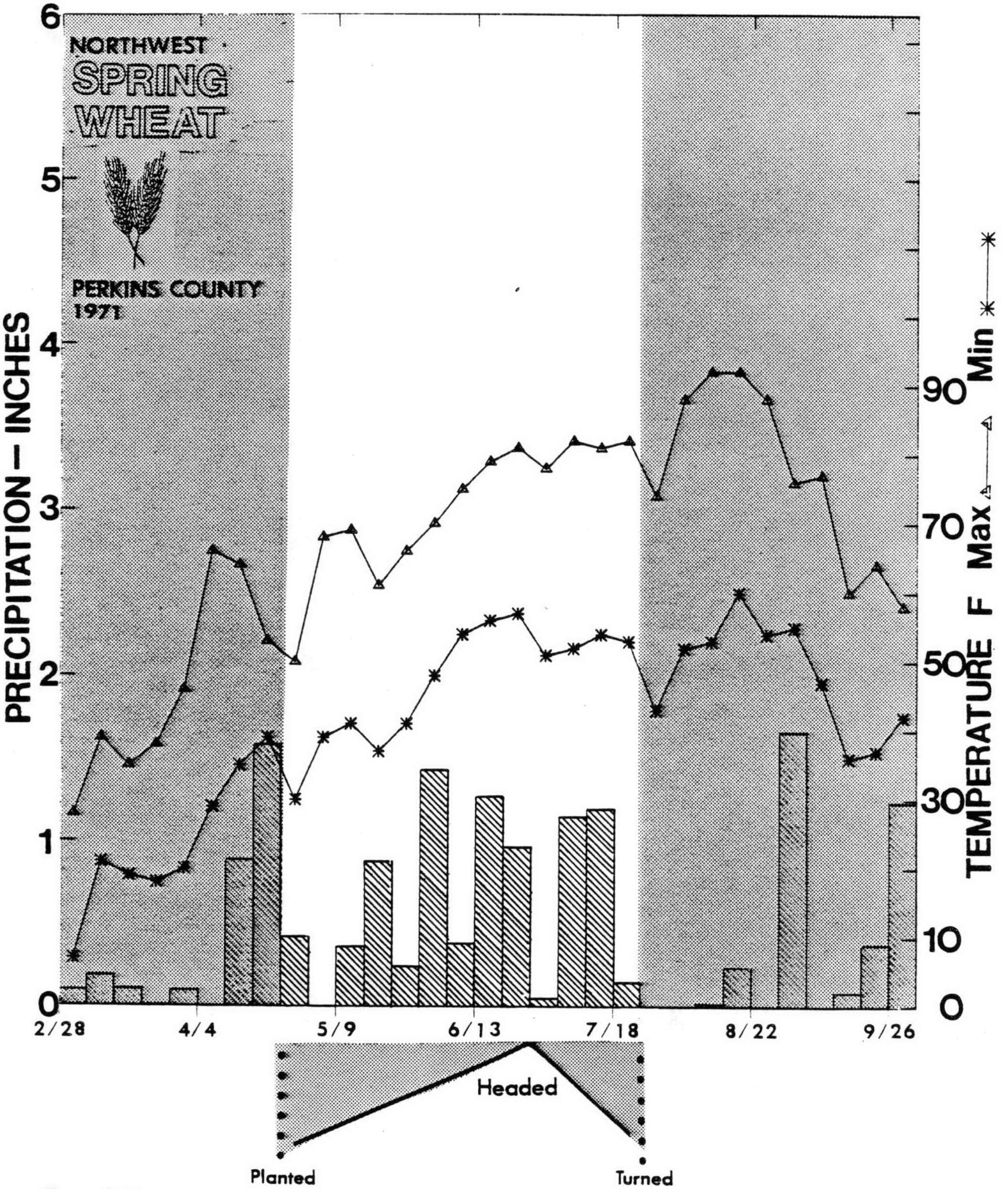

NORTHWEST
SPRING
WHEAT
PERKINS COUNTY
1971
PRECIPITATION — INCHES
TEMPERATURE F Max Min
0
1
2
3
4
5
6
10
30
50
70
90
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Headed
Planted
Turned

FIG. 6.0

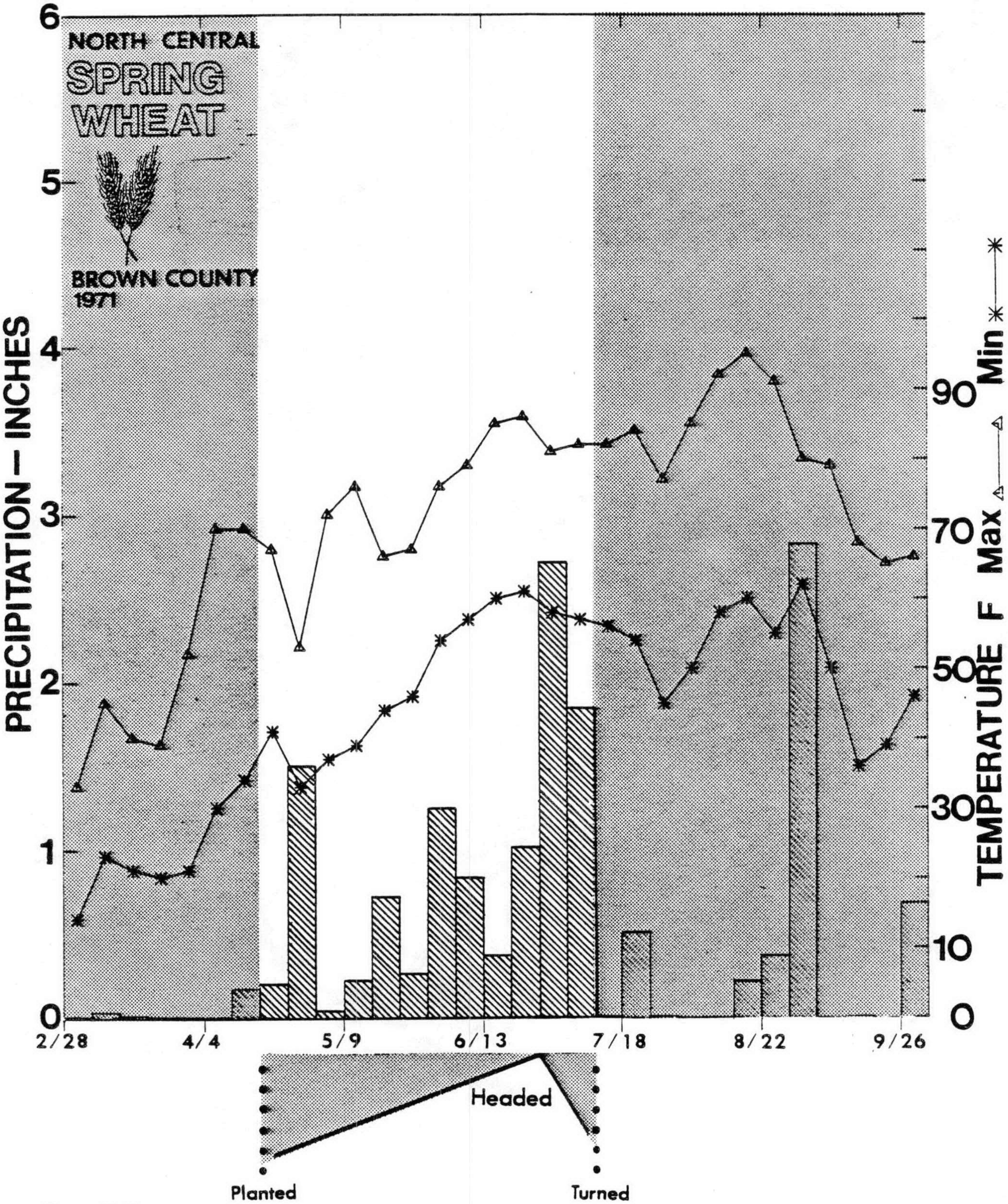

NORTH CENTRAL
SPRING
WHEAT
BROWN COUNTY
1971
PRECIPITATION — INCHES
TEMPERATURE F Max Min
6
5
4
3
2
1
0
90
70
50
30
10
0
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Headed
Planted
Turned

FIG. 6.1

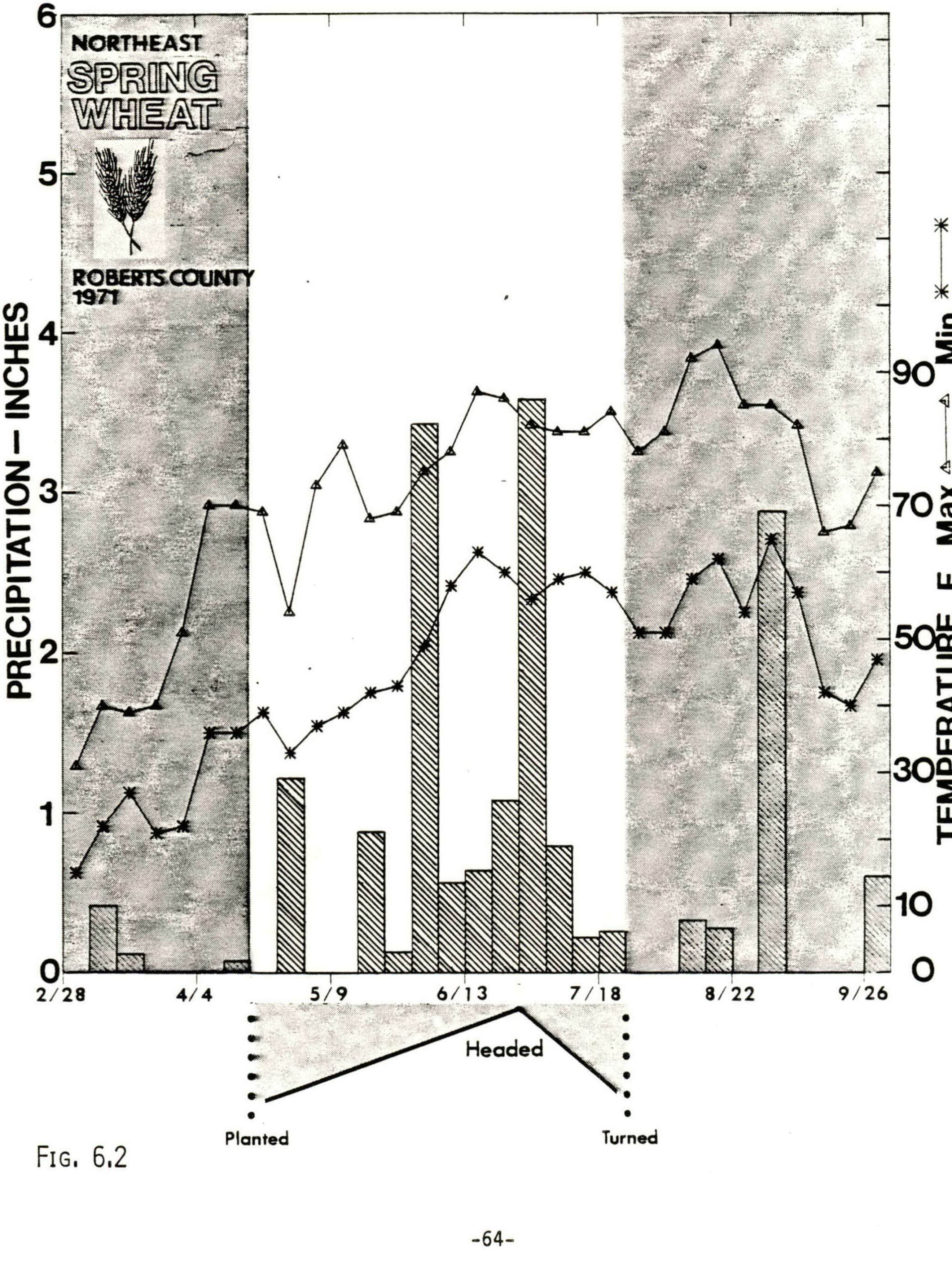

NORTHEAST
SPRING WHEAT
ROBERTS COUNTY
1971
PRECIPITATION – INCHES
TEMPERATURE F Max Min
6
5
4
3
2
1
0
90
70
50
30
10
0
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Headed
Planted
Turned

FIG. 6.2

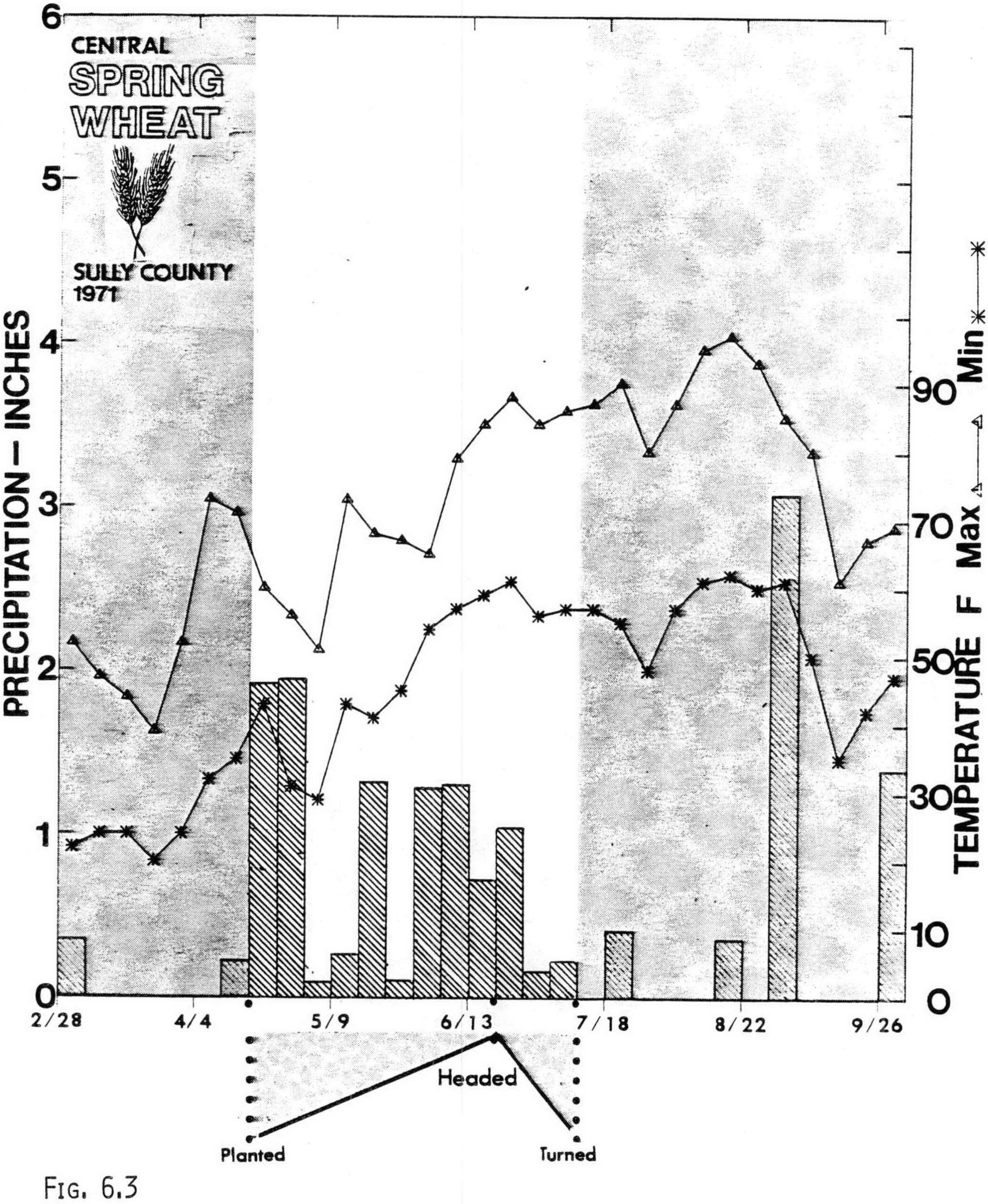
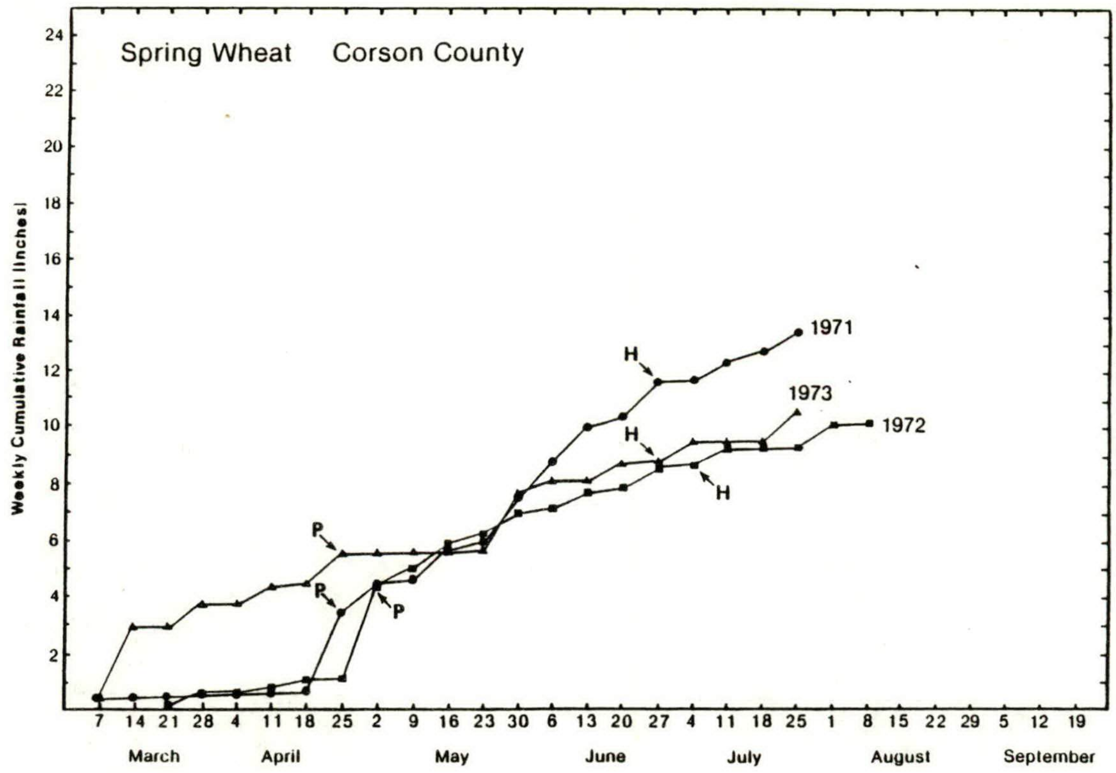
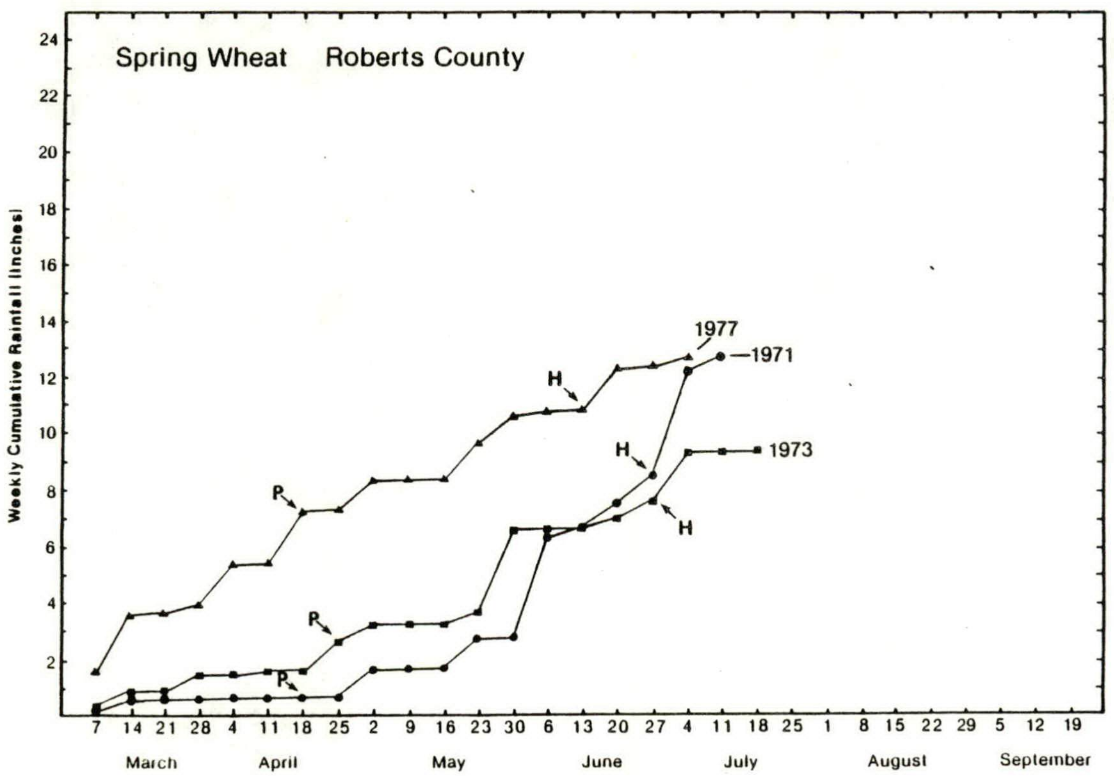

CENTRAL
SPRING
WHEAT
SULLY COUNTY
1971
PRECIPITATION – INCHES
TEMPERATURE F Max Min
6
5
4
3
2
1
0
90
70
50
30
10
0
2/28
4/4
5/9
6/13
7/18
8/22
9/26
Headed
Planted
Turned

FIG. 6.3



Spring Wheat Corson County
Weekly Cumulative Rainfall (Inches)
24
22
20
18
16
14
12
10
8
6
4
2
1971
1973
1972
H
H
H
P
P
P
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 6.4



Spring Wheat Roberts County
Weekly Cumulative Rainfall (Inches)
24
22
20
18
16
14
12
10
8
6
4
2
1977
—1971
1973
H
H
H
P
P
P
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 6.5

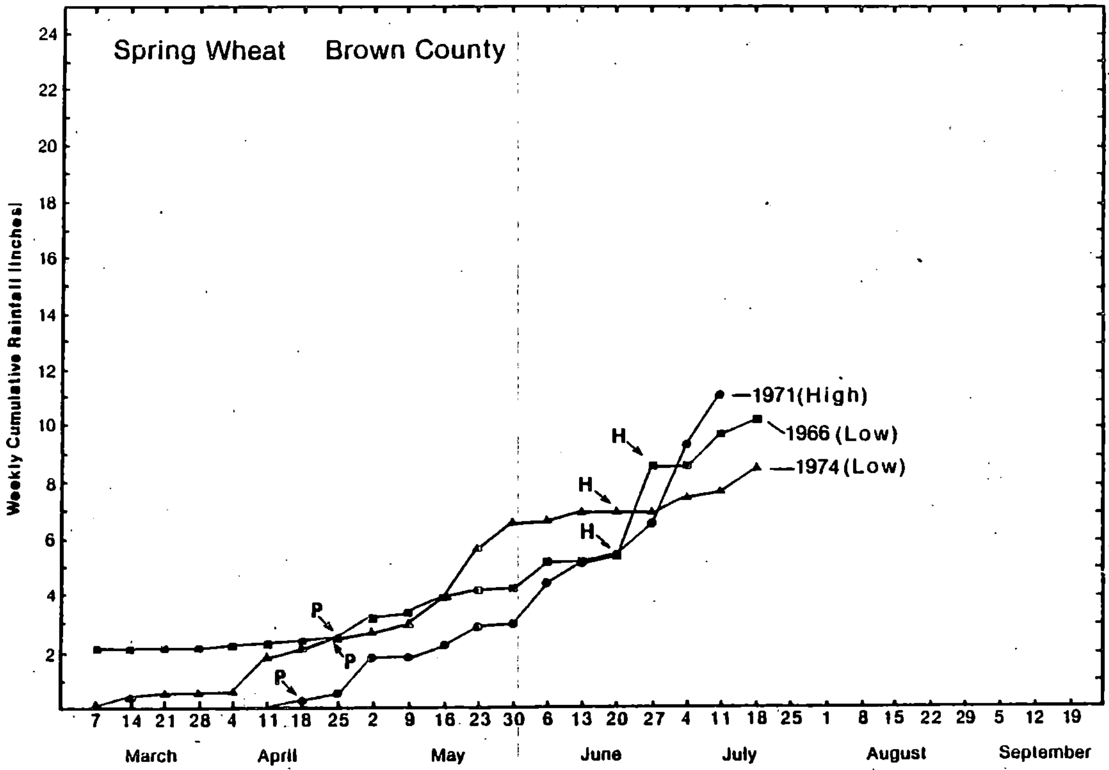

Spring Wheat Brown County
Weekly Cumulative Rainfall (Inches)
24
22
20
18
16
14
12
10
8
6
4
2
—1971(High)
1966 (Low)
—1974(Low)
H
H
H
P
P
P
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 6.6

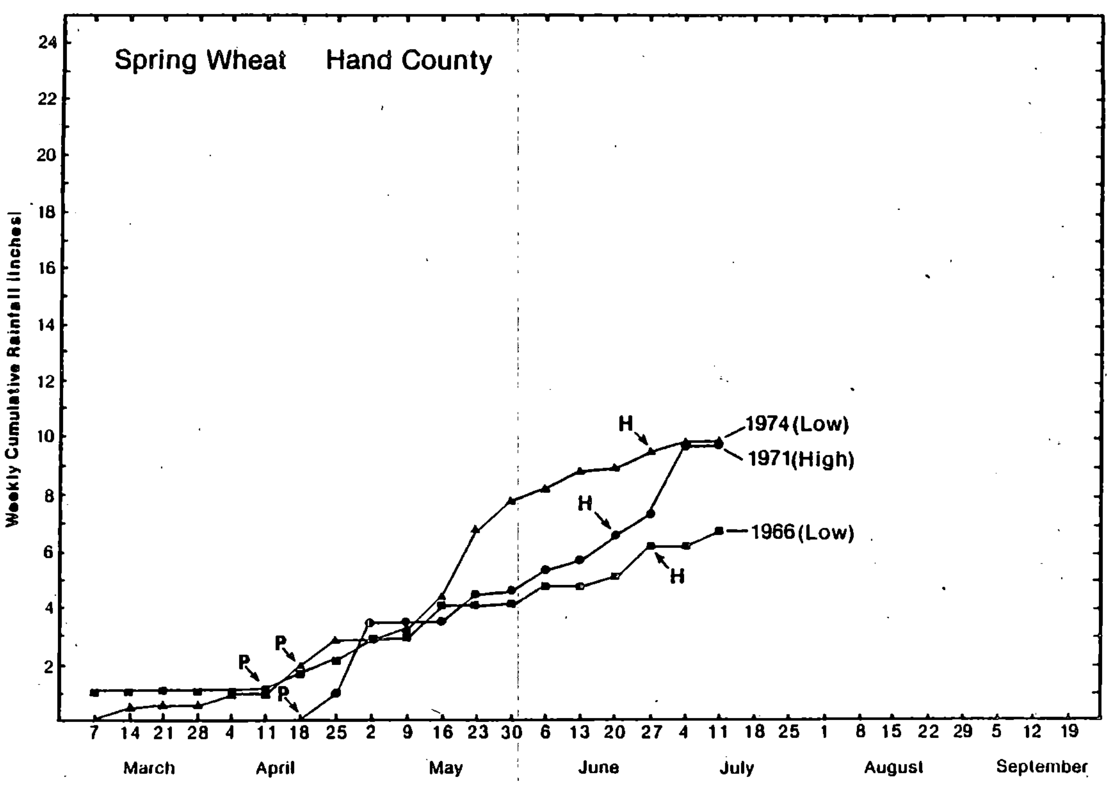
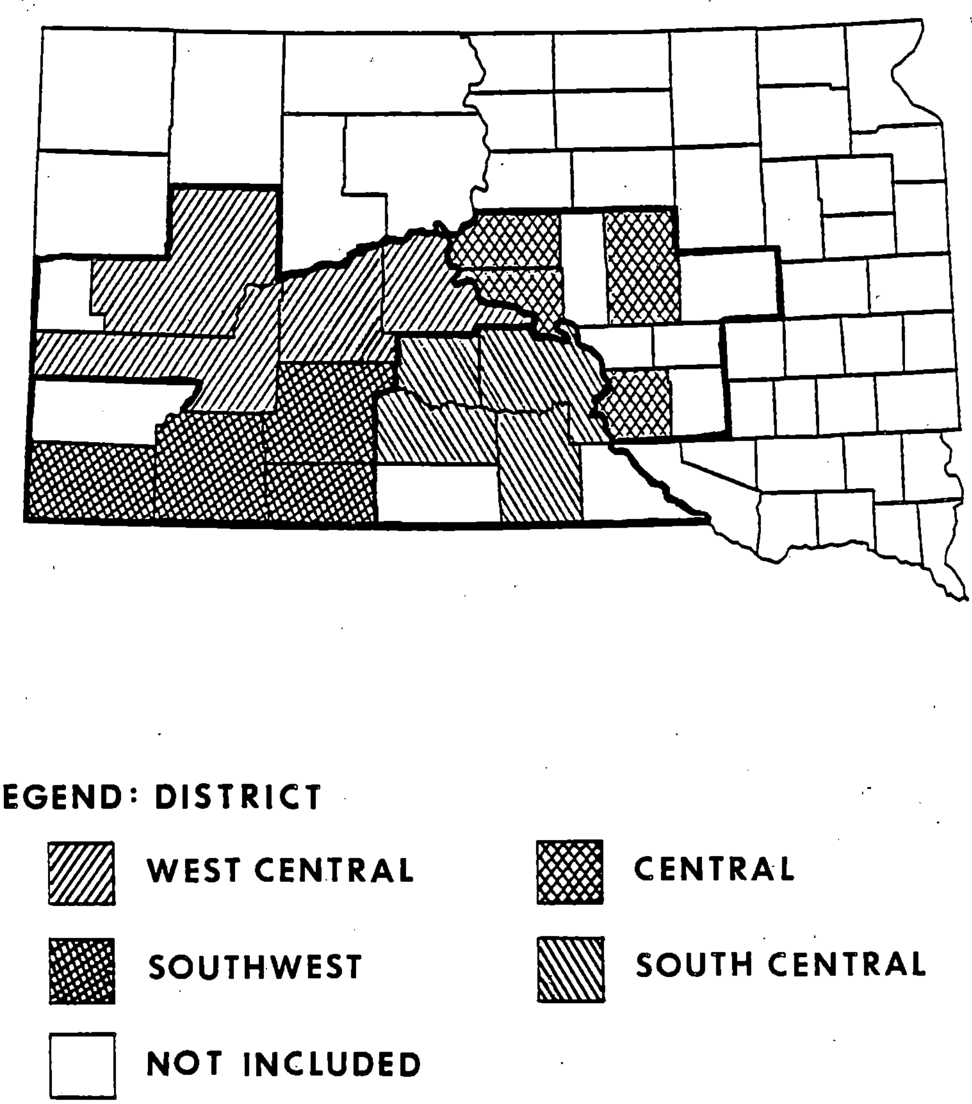

Spring Wheat Hand County
Weekly Cumulative Rainfall (Inches)
24
22
20
18
16
14
12
10
8
6
4
2
1974(Low)
1971(High)
—1966(Low)
H
H
H
P
P
P
7 14 21 28 4 11 18 25 2 9 16 23 30 6 13 20 27 4 11 18 25 1 8 15 22 29 5 12 19
March
April
May
June
July
August
September

FIG. 6.7

SECTION VII

CLIMATIC IMPACTS ON WINTER WHEAT PRODUCTION IN SIXTEEN COUNTIES OF SOUTH DAKOTA



Section VII. Climatic Impacts on Winter Wheat Production in Sixteen Counties of South Dakota Between 1965 and 1982.

About one million acres of winter wheat are planted in South Dakota each year. The traditional production area is confined to the approximate south-western quarter of the state. Freeze survival is a primary determinant of the growing area, however, limited rainfall in this part of the state may also impose yield limitations. Typically, this crop is grown in a wheat/fallow rotation. A significant yield advantage exists for winter wheat compared to spring wheat provided that good stands remain in the spring. This yield enticement is a continued incentive for expanding the winter wheat area in South Dakota. Spring and winter wheat cultivation co-exist primarily in the Central and the Northwest Crop Reporting Districts.

Six of fourteen independent variables (Appendix G) were identified by step-wise regression, which explained 26% of the yield variation during the 17-year period studied in the selected 16 counties (Table 7.0). May precipitation was the first variable appearing in the analysis contributing 6% variation. Low February temperature was the second variable to enter the analysis, explaining an additional 5% variation. November precipitation entered as the third variable accounting for another 5% variation. June precipitation caused an additional 1% variation. The fifth variable entering was CRD-5, a "dummy variable", explaining 4% more variation. Low April temperature entered as the sixth variable accounting for 5% of the variation. The physiological implication of these variables will be discussed later in this section.

Table 7.0. Maximum R-Square Stepwise Regression Showing Variables Affecting Winter Wheat Yield in Four South Dakota Crop Reporting Districts Between 1965 and 1982.

Variable	Final β Value	R^2 Upon Entry
1. May precipitation	.69	.06
2. February low temperature	.23	.11
3. November precipitation	5.09	.16
4. June precipitation	.94	.17
5. CRD-5*	-3.12	.21
6. April low temperature	-.14	.26
Intercept	23.11	--

*Crop Reporting Districts (CRD) listed as "dummy" variables in the multiple regression analysis, CRD 5 represents the central control district.

High production years for winter wheat (Table 7.1) tended to be different than those listed for spring wheat (Table 6.1). The average heading date (50% of a district wheat acreage headed) for winter wheat compared to spring wheat during the period 1970-1979 was June 7 versus June 25, respectively (South Dakota Crop Reporting Service). Therefore, plant growth and development for these two crops in relation to rainfall patterns would expectedly be different. However with winter wheat final yield frequently is determined also by plants remaining after the freezing season, whereas spring wheat yield is largely influenced by precipitation. Finally, the winter wheat production area is sufficiently separated from the spring wheat area that annual weather patterns are different and crop response likely reflect these location differences.

Table 7.1 shows three winter wheat production years in South Dakota when yields were high in all districts; 1968, 1971, and 1972. The approach of identifying level of production by arbitrarily limiting year entries in Table 1.0 to only those involving two or more crops resulted in the exclusion of 1968. Winter wheat was the only crop with consistently high yields in 1968 as shown by 12 of 16 winter wheat counties in this class (Appendix F). Total growing season rainfall requirements for winter wheat tend to be intermediate between spring wheat (Table 6.1) and oats (Table 5.1) when comparing the three high production years for each crop. However, the opportunity to identify a "water efficient" year for winter wheat may also be statistically illusive, because problems of freeze injury in some years could limit otherwise favorable climatic conditions. The evaporative loss is likely greater in the winter wheat growing Missouri plateau area of western South Dakota, with higher temperatures and more air movement. The year 1972 showed the lowest seasonal average of growing season rainfall (10.4) of the three high years (Table 7.1) followed by 1971 (10.6 inches) and 1968 (12.3 inches).

Table 7.1. Inches Average Seasonal Precipitation by Crop Reporting District in Three Years When Winter Wheat Yields Ranked in the Four Highest Classes in Twelve or More Counties Between 1965 and 1982.

	1968		1971		1972	
District	1967 Fall	Growing Season	1970 Fall	Growing Season	1971 Fall	Growing Season
West Central*	1.8	10.0 (3)	2.6	10.3	5.5	11.1 (2)
Central*	2.2	13.8 (2)	4.3	10.5	7.5	8.9 (2)
Southwest*	2.1	11.2	3.3	11.7 (3)	4.2	10.4
South Central*	2.6	14.4 (3)	2.8	9.9 (2)	7.2	11.2
Seasonal Average	2.2	12.3	3.3	10.6	6.3	10.4

*Values in parenthesis indicate when the number of counties contributing to the average was fewer than four per district and the actual number involved.

Regression analysis, shown in Table 7.0, indicates the importance of November precipitation in winter wheat production. Previous fall precipitation did not enter the regression analysis with the other crops in this study, with the exception of corn for 1969 (Table 2.3). Table 7.1 shows that the high production years for winter wheat all received an average of at least 2.2 inches of previous fall moisture. The significance of November precipitation in particular, and adequate total fall precipitation in general, is evident from the statistical analysis and by inspection of high production year records (Appendix F).

Winter wheat yields were consistently high in South Dakota for 1971, indicating that climatic conditions were favorable for winter survival and subsequent spring growth. The weekly precipitation, average maximum/minimum air temperature and developmental stages of winter wheat for 1970/71 are shown for four counties (Fig. 7.0 through 7.3) representing the districts listed in Table 7.1. Characteristically, all counties received almost weekly precipitation during the fall of 1970 and this pattern persisted into early December of that year. Snowfall was also recorded through the winter months, however, these recordings do not reflect snow cover in wheat fields. Weather data are collected at sites protected from wind. Typically, wheat fields in South Dakota are snow covered only for short intervals but if coincident with low temperature periods, can be significant in the survival of the crop.

The average weekly maximum/minimum air temperature provide some basis for comparing the temperature differences between locations and years. The 1970-71 growing season for winter wheat shows the lowest temperature was the week ending January 16, 1971, with a rather pronounced upward inflection of both the maximum and minimum temperature curves after this date. Other comparison between years show a diversity of temperature conditions with extended periods of minimum air temperature from December 5 to March 28 (1964-65, Figs. 7.7, 7.8) or a mild winter followed by a single week with a below zero average (February 20, 1967, data not included) or a late cold period into mid-February 1979.

Soil temperature records were not available in winter wheat fields for South Dakota until the growth season of 1978-79. Therefore, the relation of winter wheat survival to climate can only be approximated for years prior to 1978-79, by the use of air temperature records. In the approximation process it is important to emphasize that both diurnal and seasonal temperature fluctuation is dampened by the soil and the variation of water content in soil. As will be shown later, two issues of critical importance in winter wheat survival are: (1) the soil temperature at crown depth and (2) that point in the season when the minimum soil temperature curve reaches the lowest downward inflection. Because of heat capacity of the soil, the time when soil temperature gets to the lowest point annually in South Dakota, at the 2.5 inch depth (crown depth), is usually about 15 days beyond the lowest point in seasonal air temperature. Typically, soil temperatures at crown depth in wheat fields reach a minimum between the last week in January and the first week of February.

The lowest temperature at which winter wheat will survive is about +5 to 0 F. However, as shown by Metcalf, et al. (2), the lethal temperature (LT) is dependent upon moisture content of the crown tissue. The LT_{50} (temperature at which 50% of a plant population is killed) is the lowest when crown moisture content is between 55 and 65% water in wheat (capable of withstanding the greatest freeze stress).

Fowler and Carles (1) have investigated the relationship between crown water content and the progression of plants into the winter season and found that water content declines with the onset of cool fall temperatures. Results provided by Tyler, et al. (3) indicate that dry matter content also increases in cereal tissue during cold acclimation. Obviously, as wheat plants make the transition from rapid growth of early fall to slowed metabolism of late fall, tissue water content diminishes.

A diagram of the proposed dehydration/hydration cycle is shown in Fig. 7.4. The curve depicts the water content of crown tissue as plants make the transition between an active growth state at about 85% water into a quiescent state of growth at the desirable 55 to 65% water content. The optimal crown moisture content for the lowest LT_{50} should theoretically be attained at that time when soil temperature in the crown region is at the lowest point in the season (late January/early February). Obviously, this match depends on precipitation received, when it occurs, and evaporative loss.

Should fall precipitation be inadequate, so that the tissue water content drops (dehydration phase) below the optimum 55 to 65% mid-winter level (Fig. 7.5), wheat will likely be killed at a higher LT_{50} according to Metcalf, et al. (2). The period when crown temperature reaches the lowest point in winter is described here as the <u>first critical</u> survival stage. The <u>second critical</u> survival stage for winter wheat in South Dakota is after the upward inflection of the soil temperature curve, at which time the hydration phase begins. This critical period can extend into mid-April as diagramed in Fig. 7.6, or the time when the last lethal freeze occurs. Typically, the conditions occurring in South Dakota which results in kill during this stage is a period of unseasonable high temepratures after mid-February causing snow to melt and soil to thaw, which is then followed by a severe freeze. If temperatures are high enough for 3 to 5 days in duration, and if sufficient water is available for tissue hydration (signs of growth may or may not exist), then wheat plants are vulnerable to freeze kill because the LT_{50} is increased (2). Obviously, these climatic conditions can be threatening until the dangers of the soil freezing are over. But as the late winter/early spring period advances, the conditions favoring growth improve and a concurrent increase in LT_{50} takes place.

This dehydration/hydration cycle is coincident with seasonal climatic changes, but it only provides a physical explanation of factors influencing winter wheat survival. For example, the known variations which exist among cultivars can only be partially explained by these climatic changes. Winter wheat cultivars can be differentiated by their LT_{50} after cold acclimation when crown moisture content is carefully controlled (2). This biological variation in cold hardening or acclimation of winter cereals continues to be an active research topic. However, it is well established that plants in active stages of growth (85% water) are least capable of enduring freezing temperatures. The converse is also true, that plants at 55 to 65% water are not capable of active growth and perhaps will not survive long in this dehydrated state. Thus, both temperature and precipitation have a controlling influence on biological responses in winter wheat. Adequate water is necessary to maintain winter wheat through <u>critical stage one</u>, however, a deficiency of water may be beneficial during early stages of <u>critical stage two</u>.

The procedure used to assess the annual freeze loss of winter wheat in South Dakota was to examine the indemnity payment records of the Federal Crop Insurance (FCI). The purpose was to first identify serious loss years and then examine climatic characteristics of those years. Since all winter wheat growing counties are not covered by the FCI program, there was not complete correspondence between the sixteen counties shown in Appendix F and those used to identify the loss years shown in Table 7.2. However, to document as completely as possible the extensiveness of high freeze indemnity years, all winter wheat counties in South Dakota listed by FCI were used to rank freeze loss years. Once high loss years were identified, only climatological data from those counties were compared that are in the four crop reporting districts listed in Table 7.2.

The four years identified by FCI for the highest freeze indemnity payments were 1965, 1977, 1978, and 1979. Within this group, 1965 and 1979 showed average previous fall precipitation amounts of 0.7 and 1.4 inches, respectively, below the fall amounts listed in Table 7.1. Records showed an average of 2.3 and 6.9 inches in the fall preceding 1977 and 1978, respectively. It is speculated that results of the four years shown in Table 7.2 suggest the effects of two different lethal periods for winter wheat in South Dakota: 1) in 1965 and 1979 freeze stress occurred prior to or during the first critical period (Fig. 7.5); 2) in 1977 and 1978 primary stress occurred after the first critical period (Fig. 7.6). Surveys in the spring of 1978 and 1979 resulted in observations on plant response and actual field conditions (Appendix H). For example, in early March 1978 county agent reports indicated uniform greening of the crop statewide, but by April 15 over 50% of the crop was lost. In 1979 a similar degree of freeze loss occurred, but the crop never greened-up in the spring.

Table 7.2. Inches Average Seasonal Precipitation by Crop Reporting District in Four Years When Indemnity Records Showed Freeze Loss of Winter Wheat in Eight or More Counties Listed in the Federal Crop Insurance Records (FCI)*.

	1965		1977		1978		1979	
District	1964 Fall	Growing Season	1976 Fall	Growing Season	1977 Fall	Growing Season	1978 Fall	Growing Season
West Central**	0.3	9.3 (2)	--	--	--	--	1.5	7.9
Central**	0.5	10.0 (3)	1.7	9.1 (1)	6.9	10.0 (3)	1.1	9.5 (2)
South West**	1.0	9.9 (1)	2.9	15.2 (1)	--	--	1.5	10.9 (1)
South Central**	1.0	11.8	--	--	--	--	1.4	8.6 (3)
Seasonal Average	0.7	10.3 (10)	2.3	12.1 (2)	6.9	10.0 (3)	1.4	9.2 (10)

* Thirteen counties were identified as participants in FCI as a means of ranking years for severity of loss; however, data is summarized from four districts and therefore excludes winter wheat counties listed by FCI but outside districts shown in the table. Blank spaces indicate that FCI payments were made but yield for that year and county did not fall in either the high or low yield class (Appendix F).

**Values in parenthesis indicate when the counties contributing to the average were fewer than four per district and the actual number involved.

Figs 7.7 through 7.11 compare the maximum/minimum air temperature in Bennett and Stanley counties in four years when freeze losses were high (Table 7.2). Table 7.3 summarizes these comparisons by tabulating the number of weeks at each location and each year when the average temperature fell into specific temperature ranges. These data indicate that Stanley County is usually colder than Bennett as shown in the higher frequency of weeks below freezing.

Table 7.3. Number of Weeks* When the Average Weekly Air Temperature was Below Freezing Between November 1 and April 25, as a Means to Compare Four High Freeze Loss Years with a High Yield Year.

	Stanley County			Bennett County		
	0 to 33°F		Below 0°F	0 to 33°F		Below 0°F
Temperature Range	Max	Min	Min	Max	Min	Min
Year						
1964-65	14	17	3	6	20	1
1978-79	15	15	7	10	18	4
1976-77	8	19	3	4	20	2
1977-78	14	15	6	10	21	0
		High Yield Year				
1971-72	13	19	4	3	21	1

*See Figs. 7.7 through 7.11

Based on the assumption that low annual air temperatures correspondingly result in low soil temperature, some approximations can be made among the years listed in Table 7.3 as to intensity of cold and when winterkill may have occurred. Results in Table 7.3 suggest that air temperatures were the lowest, of the four high loss years, in 1978-79 as indicated by the number of weeks when the temperature was below zero (Stanley - 7 weeks and Bennett - 4 weeks). Also, the record showed 1978-79 to rank with 1977-78 in number of weeks when the minimum temperature was in the 33 to 0°F range. However, since the fall of 1978 received less rain than in 1977 (Table 7.2) it is expected that soil temperatures were closer to actual air temperature in mid-winter of 1978-79 (colder) as compared to 1977-78.

By this analysis (Table 7.3), the intensity of freezing temperatures appear less severe in 1964-65 and 1976-77 than the other two high loss years (Table 7.2). However, wheat losses in 1964-65 can likely be associated with the dry fall condition as in 1978-79. Whereas temperatures were not as low in 1964-65, they extended over a greater period of the winter season intensifying the dehydration process (Fig. 7.7 and 7.8). It is believed that high losses in the years 1964-65 and 1978-79 can be explained as occurring at the first critical stage, described by Fig. 7.5, with combination of tissue dehydration and low temperature causing plant loss. The LT_{50} of plants increased, contributing to the adverse freezing conditions.

To repeat, the LT_{50} is between +5 and 0°F at an optimum 55 to 65% water in tissue. If the tissue water content is above or below 55 to 65%, plant death occurs at a temperature higher than +5 to 0°F. However, even at optimum water content, winter wheat plants will be killed below 0°F.

A contrasting situation to 1964-65 1978-79 (Table 7.2) existed in 1976-77 and 1977-78, both years having higher average precipitation in the fall growth period. The year 1976-77 predates some of the recent efforts to describe climatic conditions associated with freeze survival of winter wheat in South Dakota (Appendix H). However, by comparison to other years in Table 7.3, including 1971-72; a high yield year, 1976-77 can be regarded as a mild year with an earlier and shorter low temperature period than 1977-78 (Fig. 7.9 and 7.10). An intensive grower field inspection program was initiated in the fall of 1977 and a soil temperature measurement program was started in grower fields in the fall of 1978 (Appendix H). It is proposed that some of the climatic similarities between 1976-77 and 1977-78 (Tables 7.2 and 7.3) indicate that freeze stress in these two years occurred in the second critical stage as shown in Fig. 7.6.

During the period from February 13 to March 14, 1977, the records show that eight of the sixteen counties received between 2.3 and 6.5 inches of precipitation. The remaining eight counties received between 0.6 and 1.4 inches, in most cases between February and March 14. During the three weeks between March 14 and April 4 the weekly average minimum temperature dropped to the 20-24°F range in the majority of these counties (data not shown). It is suggested that a lethal freeze occurred during this period; lethal because of the level of tissue hydration and elevation of the LT_{50}.

Precipitation distribution was slightly different in 1978, with low amounts recorded between February 13 and March 14. However, during the week ending April 18, amounts between 1 and 2.7 inches were recorded in ten of sixteen counties and all received at least 0.6 inches (data not shown). The week ending April 25 had an average minimum temperature of about 20°F for most counties. Field inspections during the spring of 1978 provided evidence of April 12 and 20 being critical dates for winter wheat loss (Appendix H). Section VIII also describes satellite imagery data confirming a spring green-up period followed by crop loss.

Table 7.3 and Fig. 7.11 show temperature data for the year 1971-72, a high yield year and presumably high survival, which approached the low thermal values for 1977-78 and 1978-79. Apparently, fall precipitation in 1971 (overall average of 6.3 inches - Table 7.1) was adequate to prevent winterkill during the first critical period and sparse enough in late winter and early spring to prevent damage during the second critical stage. During the period February 13 through April 4 most county records showed less than 0.4 inches per week and a few with up to 0.7 inches for a single week (data not shown). Precipitation that occurred after April 4, 1972 was apparently beyond a period of lethal freezes. Fig. 7.0 through 7.3 show a similar result for 1970-71, another high yield year for winter wheat, which is characterized by low precipitation in late winter.

Starting in the spring of 1982, soil temperature measurements were augmented with an assessment of plant survival in grower fields. Mid-February was selected as an appropriate sampling time since it follows the lowest soil temperature period. Any reduction in surviving plants at this date could be attributed to this first critical period, which combines the influence of fall precipitation and the period of lowest inflection of the soil temperature curve.

On January 10, 1982, air temperature dropped to -30°F in Gettysburg after a series of below zero minimum air temperature readings (Table 7.4). In addition to low temperature on January 10, wind speeds in excess of 50 mph were reported and a chill factor of about -100°F. For about a four-hour period, minimum temperature at the 3-inch depth reached -2°F and then started an upward trend. Instrument failure at Gettysburg eliminated further data collection at this site. However, results at Martin showed a further drop to 9°F in 3-inch soil temperature on January 22, 1982. This was the lowest downward inflection of minimum temperature at the 3-inch soil depth (about crown region). Presumably temperatures would have dropped again on this date in Gettysburg, perhaps reaching a similar or lower point to that on January 10.

Table 7.4. Minimum Temperatures (F°) in Winter Wheat Fields* at Two Locations in South Dakota in 1981-82.

	Gettysburg			Martin		
Date	Air	3" Soil	6" Soil	Air	3" Soil	6" Soil
Jan. 1	-16	11	18	1	18	23
2	-17	11	18	1	20	24
3	-17	11	18	-3	17	23
4	-10	11	18	6	11	21
5	-12	11	20	-4	14	22
6	-20	8	18	-24	18	22
7	-20	7	16	-12	18	18
8	-11	12	18	-5	22	23
9	-25	3	15	-18	18	20
10	-30	-2	12	-27	11	18
11	-21	2	11	-14	11	16
12	-17	6	13	-10	14	18
13	-10	7	14	-3	14	18

*Air temperature was measured 36" above the soil surface and also at soil depths of 3" and 6" below plants in the furrow, all at 1 hour intervals.

Despite the existence of seemingly severe mid-winter stress conditions in Sully, Potter (Table 7.4), and Dewey counties in 1982, plant survival remained adequate at Onida, Gettysburg, and Eagle Butte locations within these counties (Table 7.5). Usually 40% survival is considered an adequate stand for an economic return in South Dakota winter wheat production.

However, some of the 1982 crop was eliminated by freeze injury. With the onset of spring, it was discovered that essentially all winter wheat in Potter, Sully, Ziebach, and Dewey counties was killed after February 15, 1982. In Appendix I, a comparison is made of air temperature at 10 location in South Dakota during the second critical period. The warm 8-day period between February 14 and 22 (air temperatures as high as 75°F) likely initiated the growth process. It is proposed that the freezing temperatures on February 24 and 25 (lowest at Gettysburg and Onida - Appendix I) destroyed the crop in Potter, Sully, Dewey, and Ziebach counties. Plant death likely occurred at this second critical stage as in 1976-77 and 1977-78.

Table 7.5. Summary of Winter Wheat Survival Results* of Plants Taken from Grower Fields in Various Locations in South Dakota in Mid-February, 1982.

Location	Stage of Growth	Plts. Sampled	% Survival
Sampled on 2/14/82			
Onida - 3 m S	2-3 Tillers	19	68
Gettysburg - 4 m W and 10 m N	2-3 Tillers	19	74
Eagle Butte - 17 m East	6-8 Tillers	13	92
Eagle Butte	4-6 Tillers	17	82
Hayes - 2 m W	6-8 Tillers	16	100
Wall - 8 m NW	4-5 Tillers	24	100
Sampled on 2/15/82			
Martin - 9 m W and 4 m N	3-4 Tillers	18	100
Murdo - 1 m E	6-8 Tillers	18	88
Presho - 2 m N	6-8 Tillers	17	88

*Plant survival was evaluated in the laboratory by removing roots and trimming leaves to 1 inch above crown, washing and permitting regrowth in a plastic bag for five days at 77°F.

The 1982-83 winter wheat crop was excellent in South Dakota, with record yields attained. Favorable fall moisture conditions existed (greater than 2.5 inches in September, October, and November) followed by a mild winter (stage one) with an ideal late winter/early spring regrowth period (stage two). A plant survival evaluation was made on February 23 and 24, 1983, similar to that in 1982 (Table 7.5), where ratings ranged between 80 and 100% (data not shown).

A repeat comparison of the minimum soil temperature and plant survival survey was made in 1983-84. A wind chill of about -70°F was experienced on December 23 and 24, 1983. Snow cover existed in most areas of the state except in the Potter, Sully, and Dewey county region. Minimum temperatures at the 2.5 inch soil depth reached the critical level on December 23 and 24 at Gettysburg and Pierre (Appendix J). Results as of February 20, 1984 showed about 40% survival (Stage 1) in the Gettysburg and Onida areas, whereas wheat samples from all other areas showed excellent regrowth. The possibility of additional stand reduction in stage two was not evaluated as this report went to press.

The impact of freeze loss on winter wheat yield in certain years (Table 7.2) reduced the chances of evaluating the direct effects of drought in those years. FCI records aided in identifying years where low growing season precipitation caused yield to plunge into the lowest class (Table 7.6). Previous fall precipitation was lowest in 1969 (average 1.9 inches), but adequate in 1966 and 1970. Total growing season precipitation was extremely low in 1966 and 1969, but appeared ample in 1970. Apparently rainfall was not favorably distributed in 1970.

Table 7.6. Inches Average Seasonal Precipitation by Crop Reporting District in Three Years* When Winter Wheat Yields Ranked in the Five Lowest Classes in Six or More Counties Between 1965 and 1982.

	1966		1969		1970	
District	1965 Fall	Growing Season	1968 Fall	Growing Season	1969 Fall	Growing Season
West Central**	2.3	7.2 (3)	1.5	7.3 (2)	2.3	12.9 (1)
Central**	4.6	5.6 (3)	--	--	4.8	12.7 (1)
South West**	3.5	5.0 (1)	1.4	6.9	2.7	8.7 (2)
South Central**	4.9	7.5 (2)	2.8	5.1	3.1	10.6 (2)
Seasonal Average	3.8	6.3	1.9	6.4	3.2	11.2

*Years when indemnity payments due to freeze loss were low, as shown in FCI records (see Table 7.2), and yield depression was therefore attributed to drought.

**Values in parenthesis indicate when the number of counties contributing to the average was fewer than four per district and the actual number involved.

Three of the five climatic factors listed in Table 7.0 are associated with periods when freezes can occur. Additional analysis is necessary, perhaps by inspection of interactions, to determine why low February temperature has a positive influence on yield.

An inch of precipitation in November is estimated to increase yield by 5.09 bushel per acre. It is believed that November precipitation is beneficial for maintaining wheat through the first critical survival stage (Fig. 7.5). Inspection of several high/low survival years (Tables 7.1 and 7.2) suggest that at least 2.0 to 2.5 inches of rain in September, October, and November is needed in South Dakota to avoid the situation suggested in Fig. 7.5.

Low April temperature (Table 7.0) has a negative influence on winter wheat yields in South Dakota. The influence of this variable is consistent with the discussion related to Fig. 7.6 and the second critical survival period.

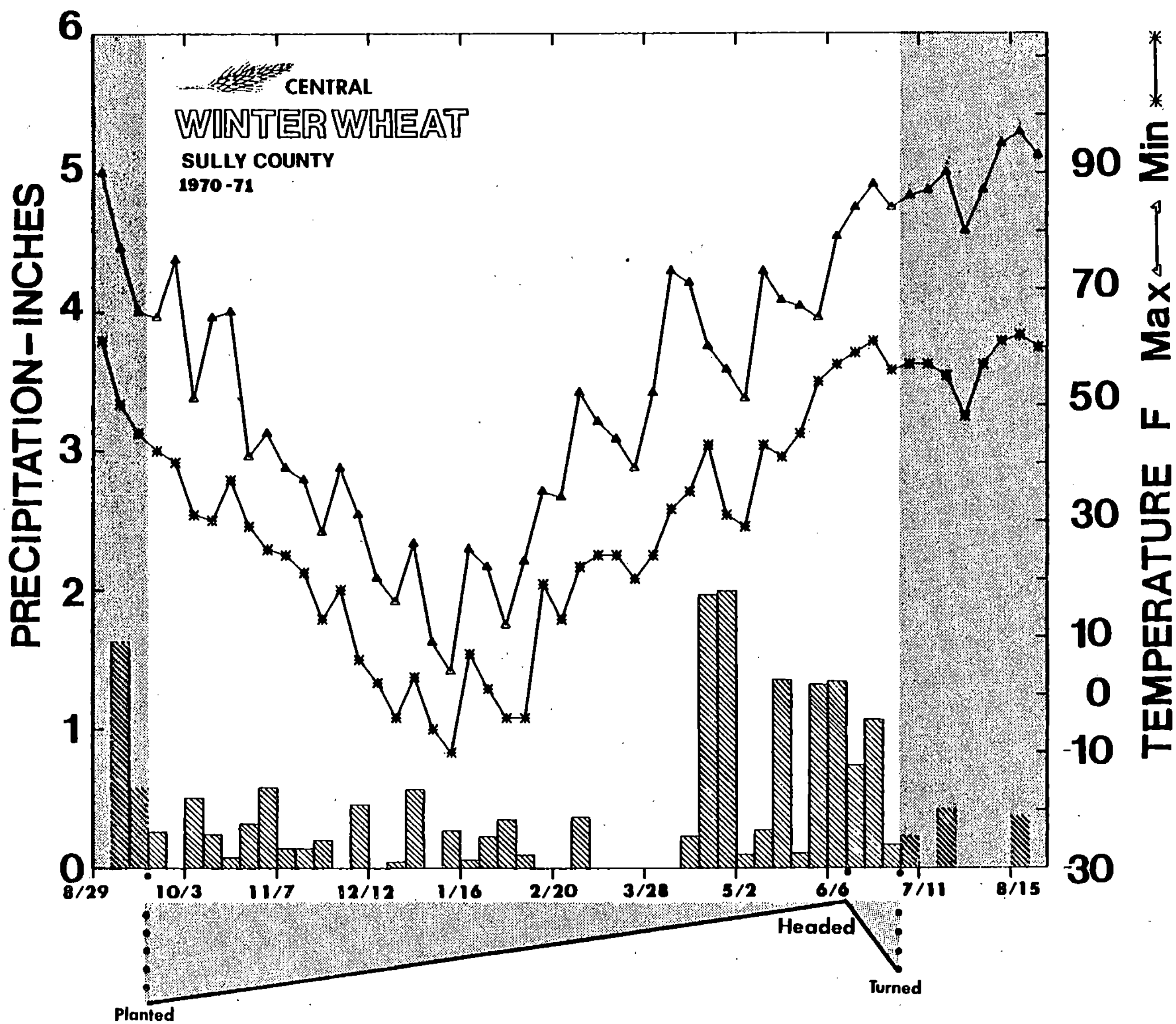
These ideas are advanced as working models to describe factors influencing freeze survival in winter wheat. They are not intended as the only explanations to freeze loss because other climatic conditions do prevail which can account for freeze injury. However, these two situations do frequently exist in South Dakota.

References

1. Fowler, D. B. and R. J. Carles. 1979. Growth, development, and cold tolerance of fall-acclimated cereal grains. Crop Sci. 19:915-922.

2. Metcalf, E. L., C. E. Cress, C. R. Olein, and E. H. Everson. 1970. Relationship between crown moisture content and killing temperature for three wheat and three barley cultivars. Crop Science 10:362-365.

3. Tyler, N. J., L. V. Gusta, and D. B. Fowler. 1981. The effect of a water stress on the cold hardiness of winter wheat. Can. J. Bot. 59:1717-1721.



CENTRAL
WINTER WHEAT
SULLY COUNTY
1970-71
PRECIPITATION-INCHES
0
1
2
3
4
5
6
TEMPERATURE F Max Min
-30
-10
0
10
30
50
70
90
8/29
10/3
11/7
12/12
1/16
2/20
3/28
5/2
6/6
7/11
8/15
Planted
Headed
Turned

FIG. 7.0

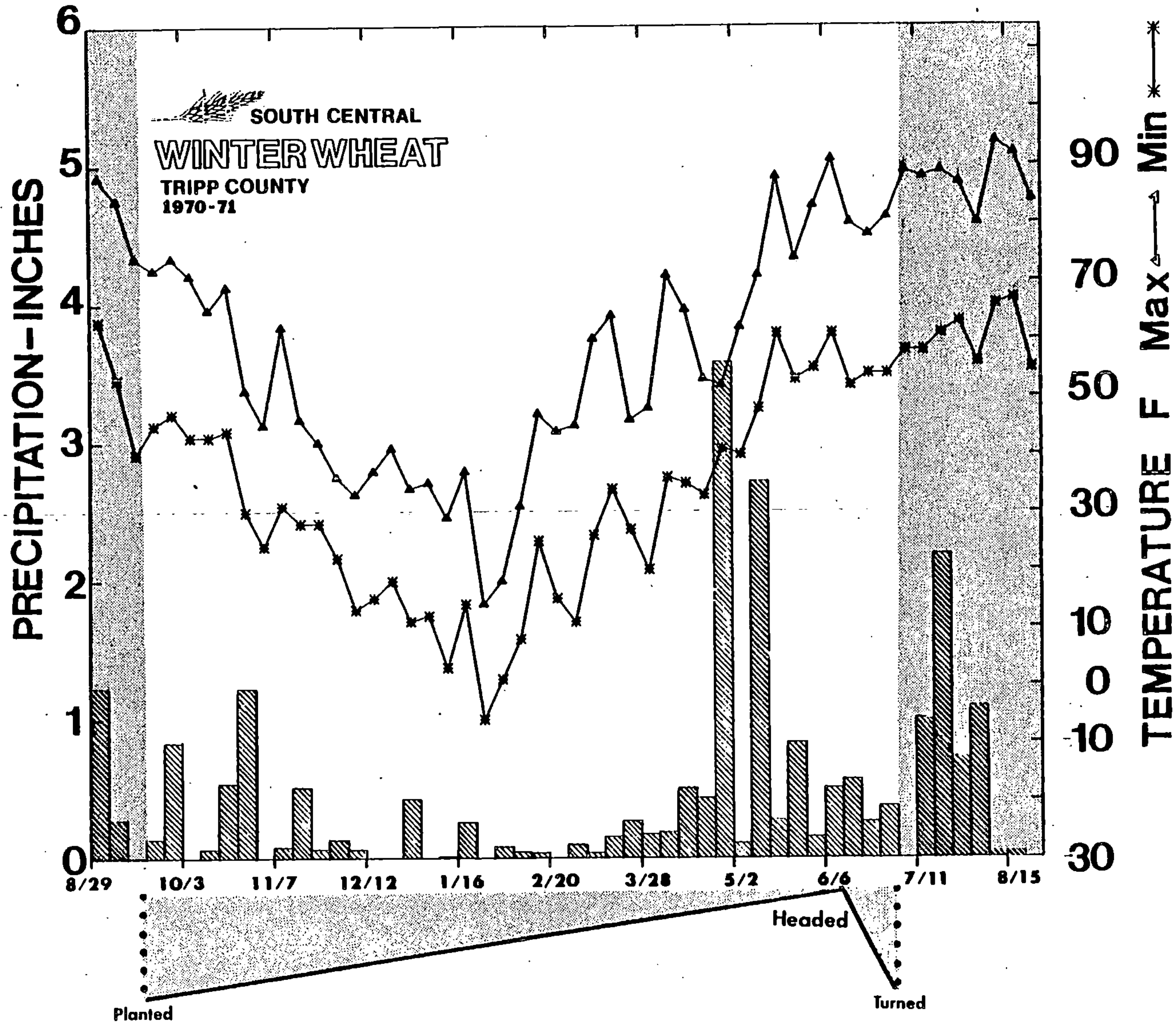
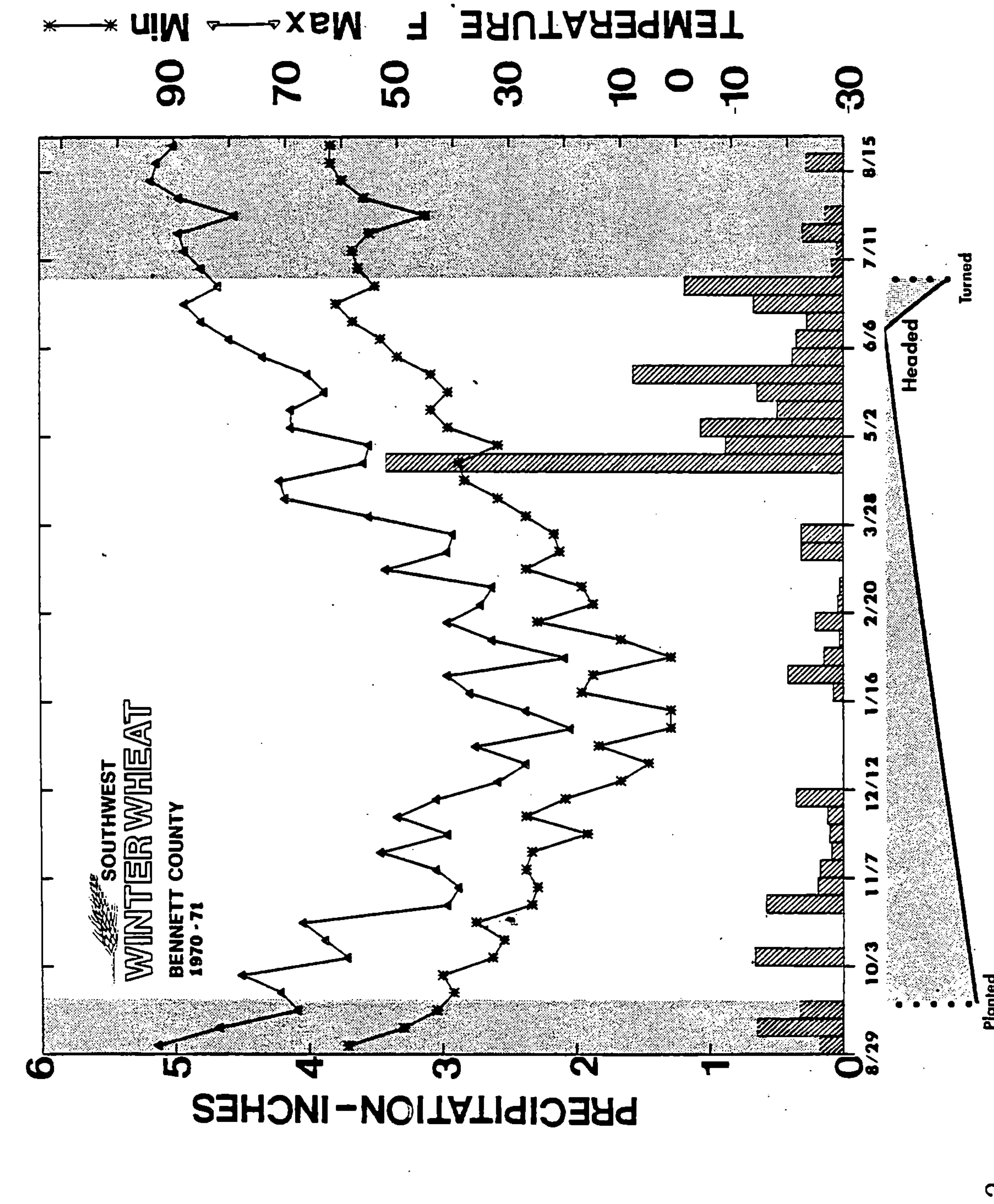
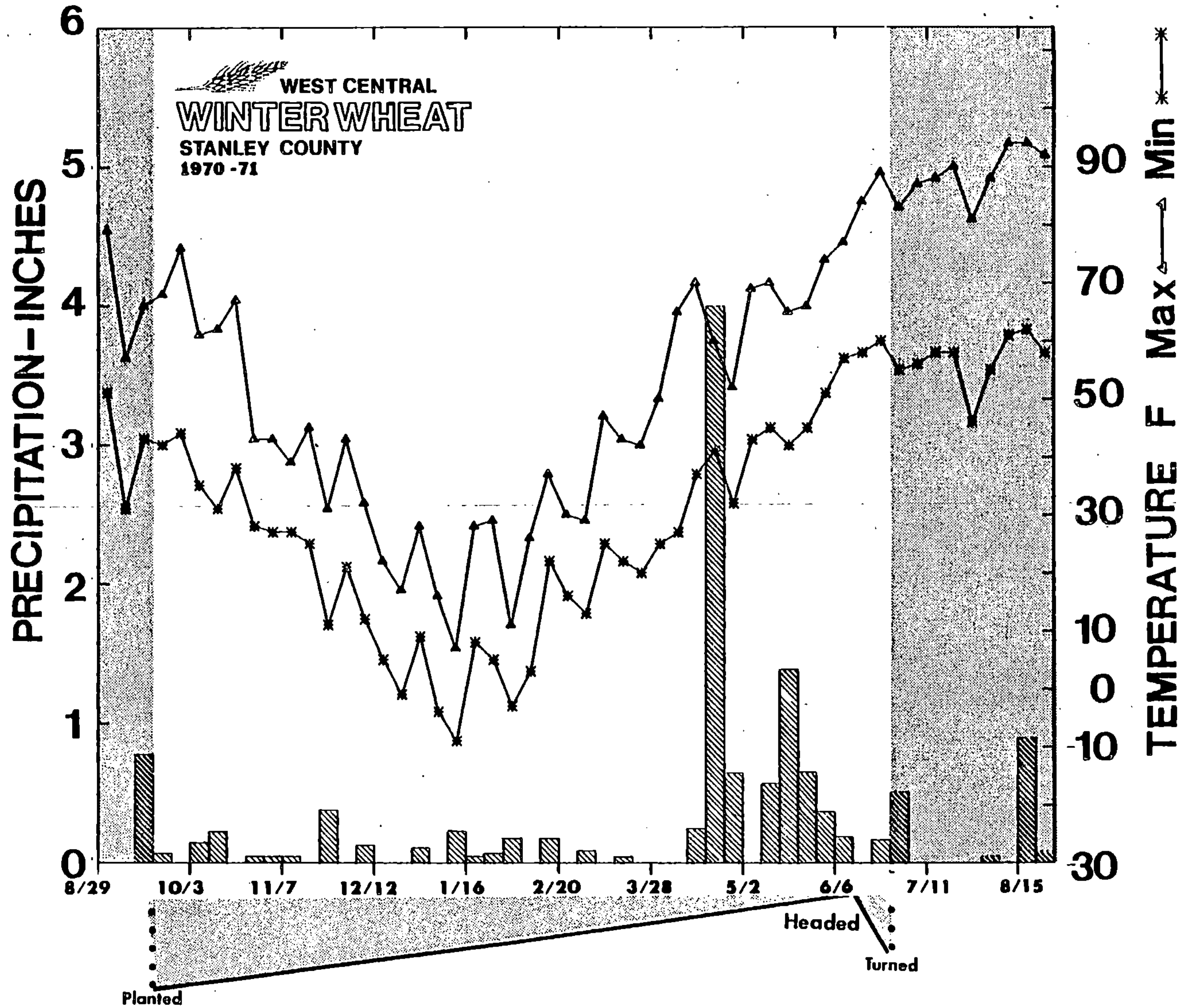

SOUTH CENTRAL
WINTER WHEAT
TRIPP COUNTY
1970-71
PRECIPITATION-INCHES
6
5
4
3
2
1
0
TEMPERATURE F Max Min
90
70
50
30
10
0
-10
-30
8/29
10/3
11/7
12/12
1/16
2/20
3/28
5/2
6/6
7/11
8/15
Planted
Headed
Turned

FIG. 7.1



SOUTHWEST
WINTER WHEAT
BENNETT COUNTY
1970-71
PRECIPITATION - INCHES
TEMPERATURE F Max Min
6
5
4
3
2
1
0
90
70
50
30
10
0
-10
-30
8/29
10/3
11/7
12/12
1/16
2/20
3/28
5/2
6/6
7/11
8/15
Planted
Headed
Turned

FIG. 7.2



WEST CENTRAL
WINTER WHEAT
STANLEY COUNTY
1970 -71
PRECIPITATION-INCHES
TEMPERATURE F Max Min
6
5
4
3
2
1
0
90
70
50
30
10
0
-10
-30
8/29
10/3
11/7
12/12
1/16
2/20
3/28
5/2
6/6
7/11
8/15
Planted
Headed
Turned

FIG. 7.3

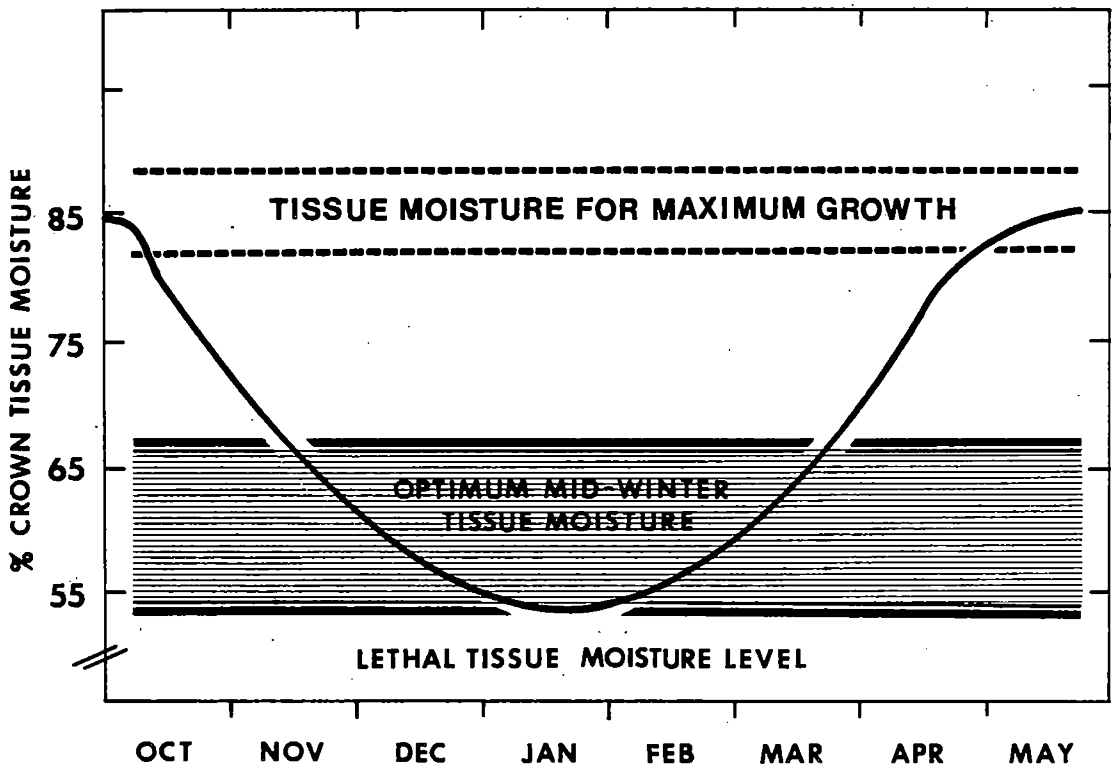


FIG.7.4 A curve depicting the transition of water content in winter wheat tissue for optimal freeze survival.

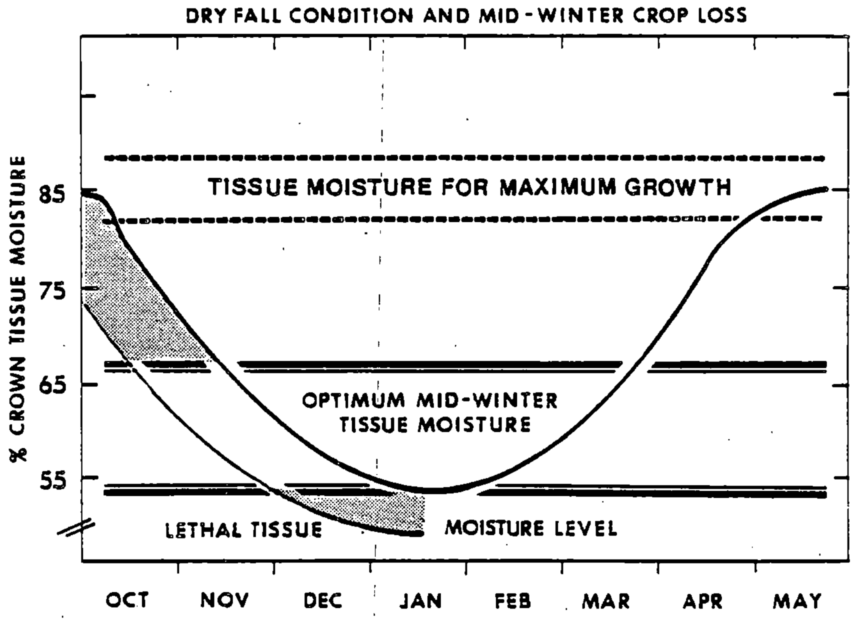


FIG.7.5 FIRST CRITICAL SURVIVAL STAGE. A dry fall condition (shaded area) where the tissue water content drops below the optimum mid-winter level and wheat succumbs to lethal temperatures.

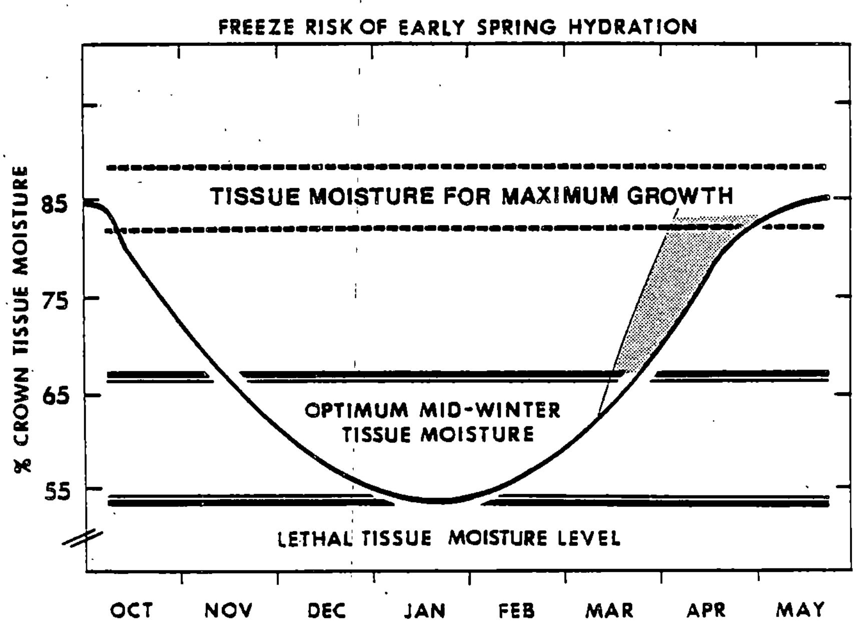
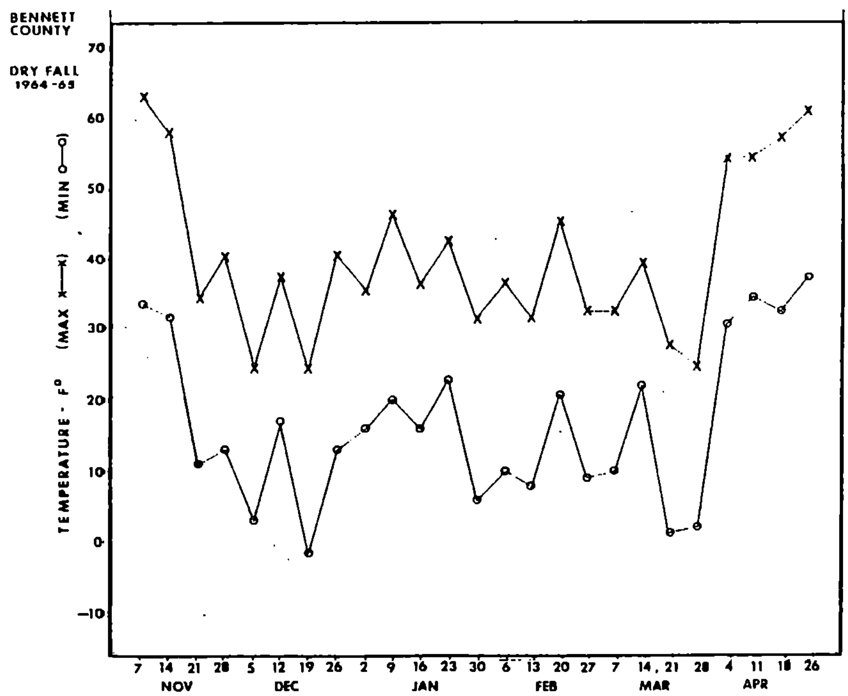


FIG.7.6 SECOND CRITICAL SURVIVAL STAGE. A wet, late-winter condition(shaded area) where the tissue water content exceeds tolerable levels at dates when lethal freezing conditions are eminent.


BENNETT COUNTY
DRY FALL 1964-65
TEMPERATURE - F° (MAX x—x) (MIN o—o)
70
60
50
40
30
20
10
0
-10
7 14 21 28 5 12 19 26 2 9 16 23 30 6 13 20 27 7 14, 21 28 4 11 18 26
NOV
DEC
JAN
FEB
MAR
APR

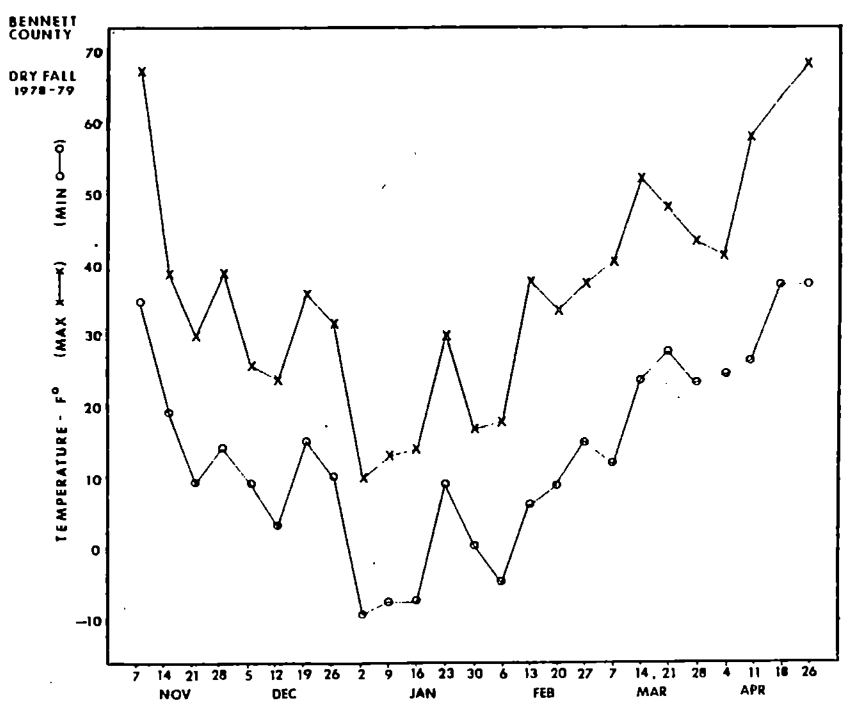
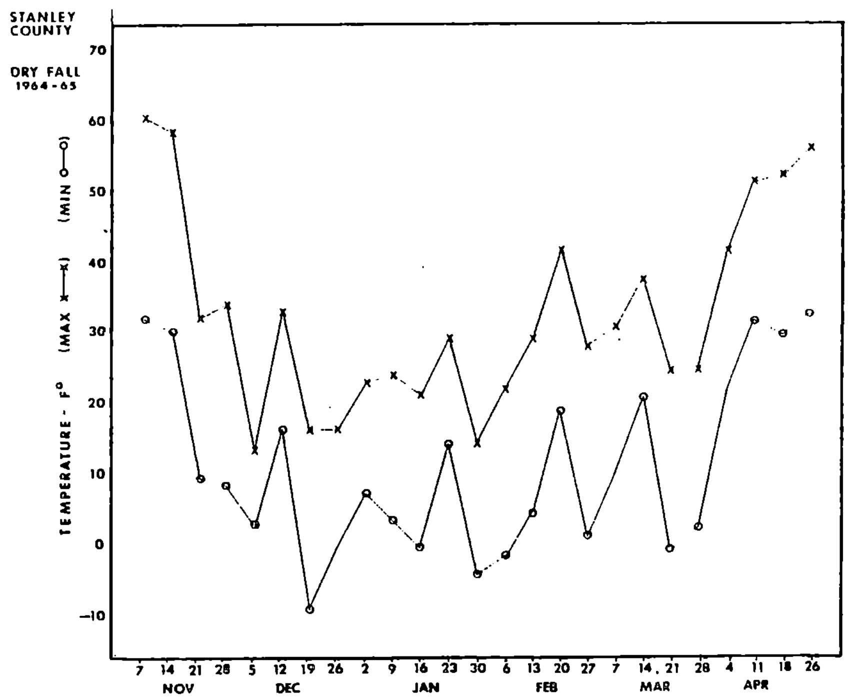

BENNETT COUNTY
DRY FALL 1978-79
TEMPERATURE - F° (MAX x—x) (MIN o—o)
70
60
50
40
30
20
10
0
-10
7 14 21 28 5 12 19 26 2 9 16 23 30 6 13 20 27 7 14, 21 28 4 11 18 26
NOV
DEC
JAN
FEB
MAR
APR

FIG. 7.7


STANLEY COUNTY
DRY FALL 1964-65
TEMPERATURE - F° (MAX x—x) (MIN o—o)
70
60
50
40
30
20
10
0
-10
7 14 21 28 5 12 19 26 2 9 16 23 30 6 13 20 27 7 14, 21 28 4 11 18 26
NOV DEC JAN FEB MAR APR

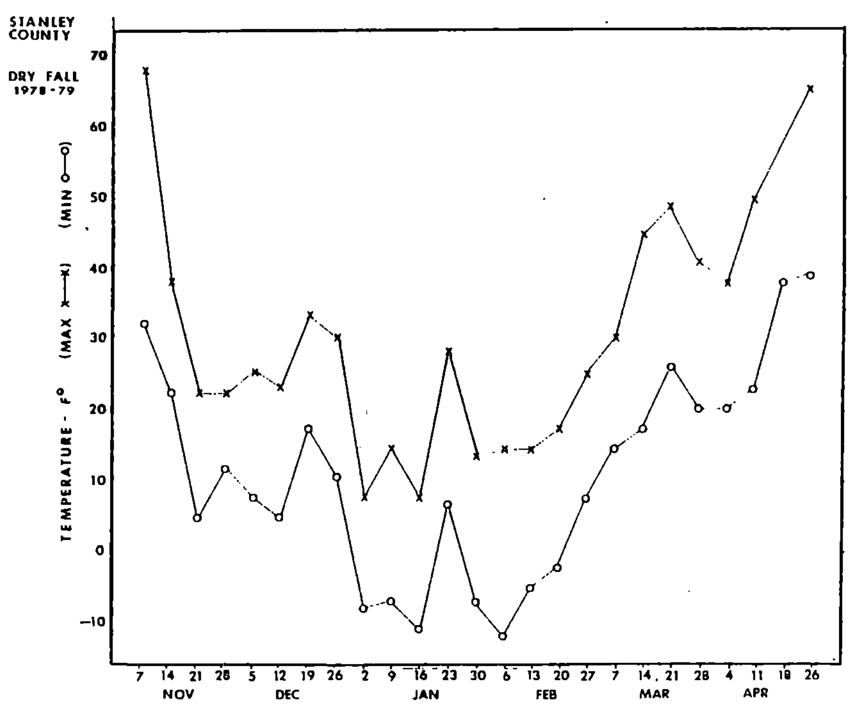
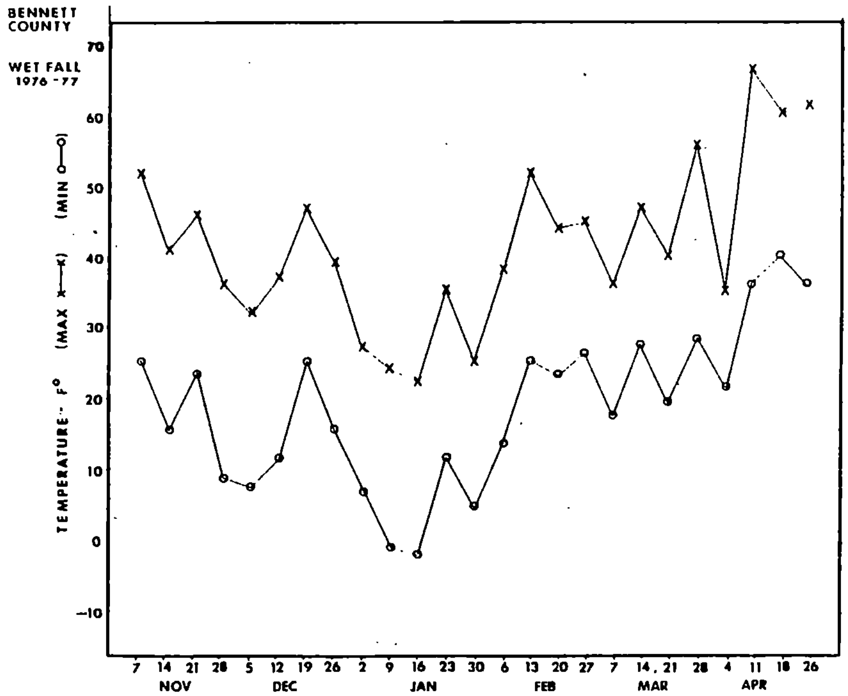

STANLEY COUNTY
DRY FALL 1978-79
TEMPERATURE - F° (MAX x—x) (MIN o—o)
70
60
50
40
30
20
10
0
-10
7 14 21 28 5 12 19 26 2 9 16 23 30 6 13 20 27 7 14, 21 28 4 11 18 26
NOV DEC JAN FEB MAR APR

FIG. 7.8


BENNETT COUNTY
WET FALL
1976 -77
TEMPERATURE - F° (MAX x—x) (MIN o—o)
70
60
50
40
30
20
10
0
-10
7 14 21 28 5 12 19 26 2 9 16 23 30 6 13 20 27 7 14, 21 28 4 11 18 26
NOV
DEC
JAN
FEB
MAR
APR

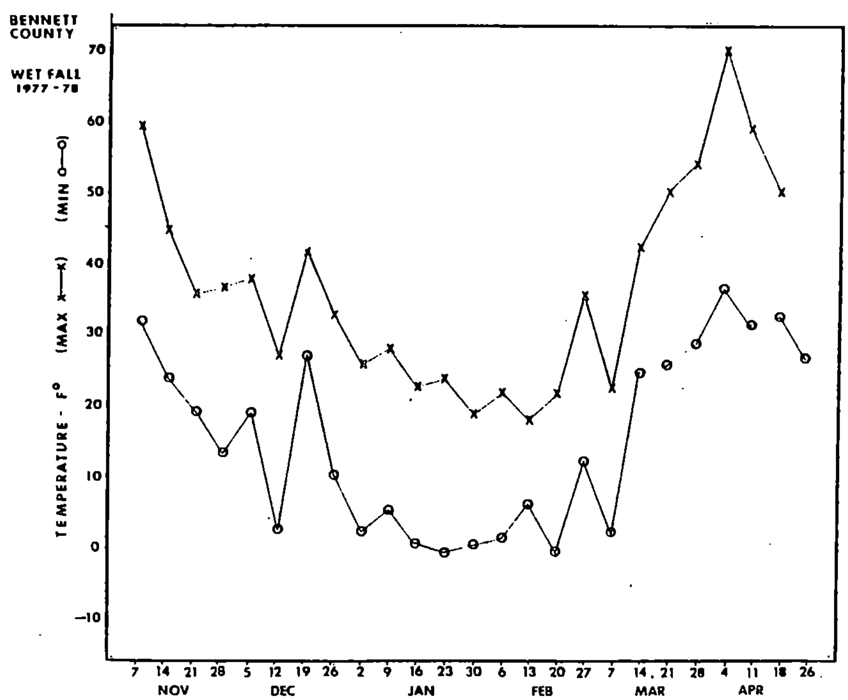
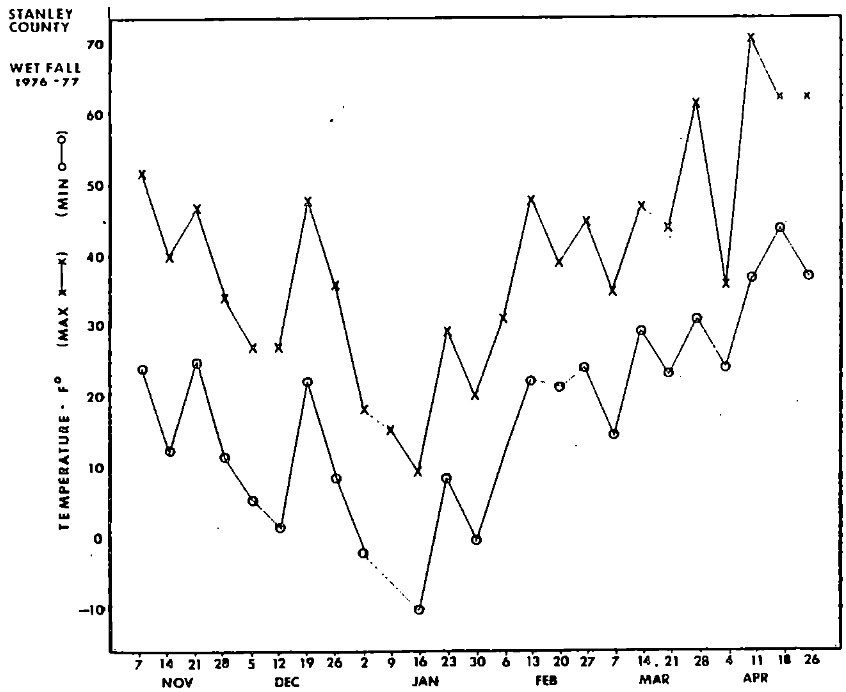

BENNETT COUNTY
WET FALL
1977 -78
TEMPERATURE - F° (MAX x—x) (MIN o—o)
70
60
50
40
30
20
10
0
-10
7 14 21 28 5 12 19 26 2 9 16 23 30 6 13 20 27 7 14, 21 28 4 11 18 26
NOV
DEC
JAN
FEB
MAR
APR

FIG. 7.9


STANLEY COUNTY
WET FALL 1976-77
TEMPERATURE - F° (MAX x—x) (MIN o—o)
70
60
50
40
30
20
10
0
-10
7 14 21 28 5 12 19 26 2 9 16 23 30 6 13 20 27 7 14, 21 28 4 11 18 26
NOV
DEC
JAN
FEB
MAR
APR

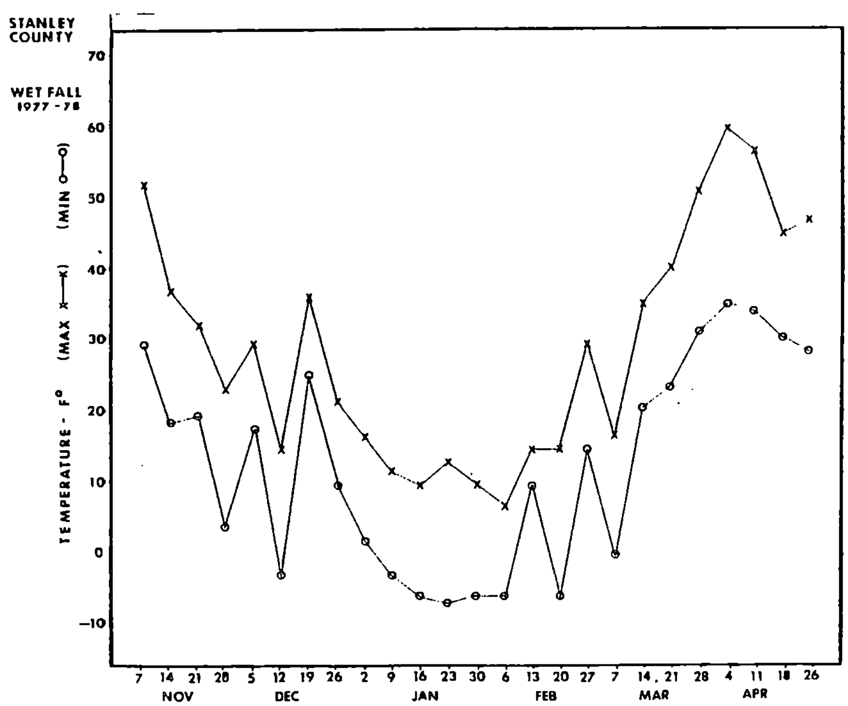
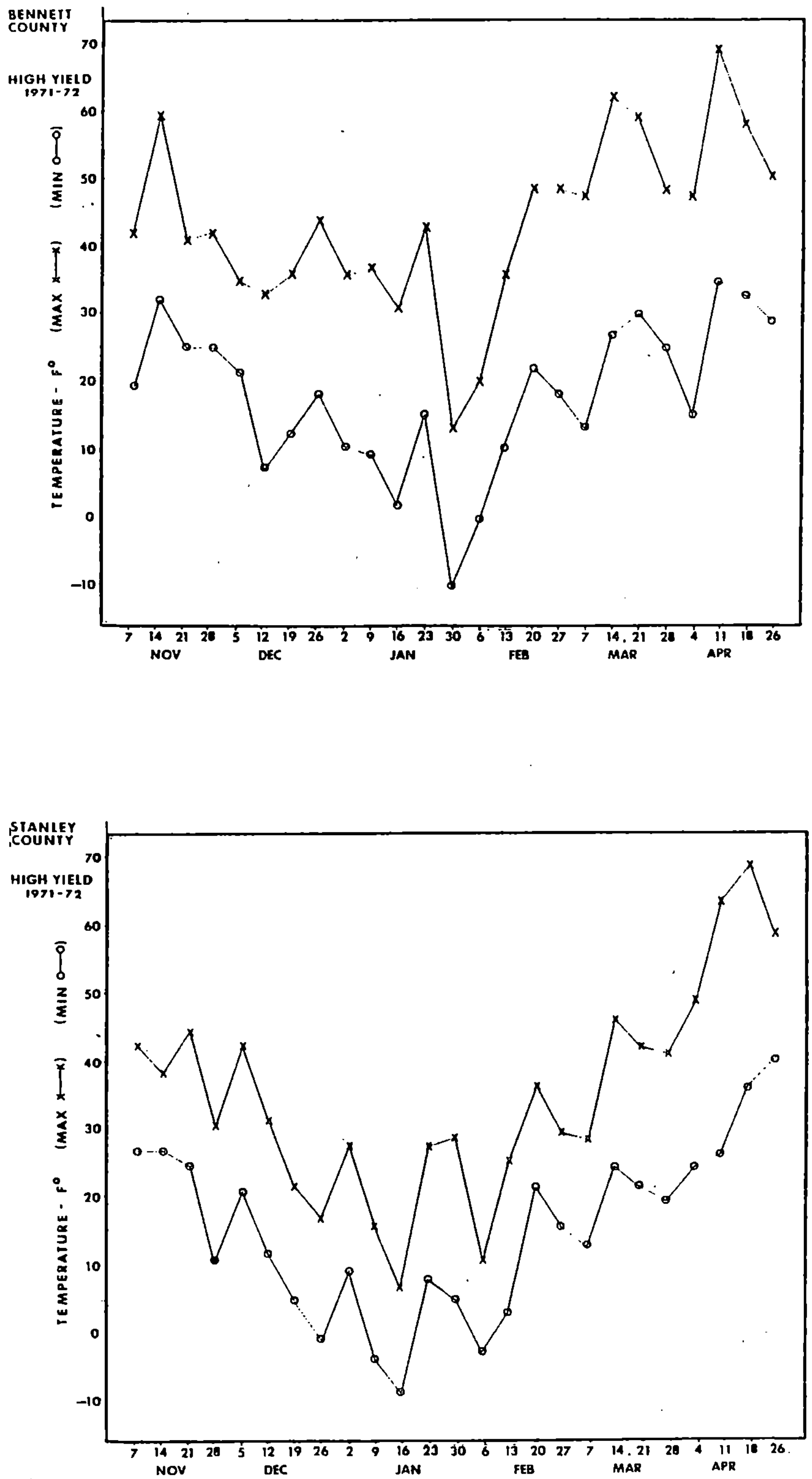

STANLEY COUNTY
WET FALL 1977-78
TEMPERATURE - F° (MAX x—x) (MIN o—o)
70
60
50
40
30
20
10
0
-10
7 14 21 28 5 12 19 26 2 9 16 23 30 6 13 20 27 7 14, 21 28 4 11 18 26
NOV
DEC
JAN
FEB
MAR
APR

FIG. 7. 10



BENNETT COUNTY
HIGH YIELD
1971-72
TEMPERATURE - F° (MAX x—x) (MIN o—o)
70
60
50
40
30
20
10
0
-10
7 14 21 28 5 12 19 26 2 9 16 23 30 6 13 20 27 7 14, 21 28 4 11 18 26
NOV DEC JAN FEB MAR APR
STANLEY COUNTY
HIGH YIELD
1971-72
TEMPERATURE - F° (MAX x—x) (MIN o—o)
70
60
50
40
30
20
10
0
-10
7 14 21 28 5 12 19 26 2 9 16 23 30 6 13 20 27 7 14, 21 28 4 11 18 26
NOV DEC JAN FEB MAR APR

FIG. 7.11

Section VIII. Satellite Imagery Assessment of Crop Stress Situations in South Dakota.

Situation #1: Winter wheat loss in 1979

A lack of complete winter wheat greening was noticed in Bennett, Tripp, and Jones counties during the spring of the 1978-79 growing season. Most of the heavy losses were thought to have occurred prior to March 1, due to a dry fall (Table 7.2) and an exceptionally cold winter. It was expected that patches of green-up would appear in low areas.

Landsat scenes from 10-26-78 and 4-6-79 for Bennett Co. and 11-3-78 and 4-23-79 for Jones Co. were acquired to investigate the problem. The winter wheat fields (red toned fields) on the fall scenes in both county areas indicated healthy green-up. The fields in Jones Co. had a richer hue than the Bennett Co. fields, but the Jones Co. image was also recorded a week later in the growing season. Records indicated that the fall season was moderately dry, but Landsat imagery was not precise enough to detect a potential problem in Jones Co., if in fact it was beginning to cause a problem there by November 3. In Bennett Co. hues were generally a more pale red color and the fields had a slightly more mottled appearance than in Jones Co. This may have been an indication of the problems to come but the dry condition was not severe enough to be conclusively illustrated by imagery (Appendix H).

In both instances the fall season was fairly dry, with less than two inches of precipitation in the critical months of September, October, and November. This in turn may have caused a "dry down" of tissue moisture below the critical level for survival of the plants when soil temperature reached the lowest point in late January and early February. The hard winter apparently compounded the problem as verified by the crop insurance payment records showing much of the damage to the crop was from winterkill (Table 7.2).

In the spring scenes, for the two areas under consideration, very little greening of winter wheat had taken place. Only tinges of red appear in the fields. It was not possible to discern whether the season was just "late" or if a high percentage of the crop was irreversibly damaged. Some fields that were healthy on the fall image show no signs of greening-up, indicating much of it was completely lost. Winter wheat yield figures discussed later give an indication of the severity of the loss.

In the spring of 1979, all vegetation seemed to be lagging behind normal green-up. A number of water bodies were still heavily iced over on the April 6th image and little vegetation was greened up in the April 23rd scene, indicating a cold winter. The assumption of a harsh winter, made from Landsat data, was verified by the weather records for the area.

These two April, 1979 scenes were compared to images from March 25, 1981 and April 12, 1981 which covered Jones Co. The 1981 scenes showed no evidence of winterkill and the general green-up of the vegetation even in the March image was ahead of the April 23, 1979 scene. The 1981 images also showed more vegetation growth than the April 6, 1979 scene from Bennett Co., which ordinarily would green up earlier than the counties to the north. On the March 6, 1981 scene, which was just east of the Jones County area, the landscape was already greening up about as well as the Bennett County area on April 6th of 1979. The April 23rd scene was of poor quality but a check of the 1981 scenes vs the Bennett Co. April 6, 1979 image confirmed that poor image quality on the late April scene could not explain the lack of tonal contrast and green-up alone.

A comparison can be made between acres planted to winter wheat in a given year and how many acres were actually harvested for grain. Although wheat prices, availability of other livestock feed, and so on, can affect how much planted wheat will eventually be harvested for grain, the main criterion in this decision is the condition of the crop. If the winter wheat crop has potential for producing a satisfactory yield, it will be harvested for grain. If not, it will be cut for livestock feed or turned under and the land replanted to some other crop. This decision will depend upon the timing and the severity of the loss. Thus, the percentage harvested for grain is a good indication of the success of that season's winter wheat crop.

Imagery comparisons from the 1978-79 and 1980-81 winter wheat seasons were made earlier and showed that in 1978-79 there was a slow, lagging growth of the crop during that spring leading to a significant amount of winterkill as indemnity records verify. In 1980-81, the winter wheat greened up nicely in early spring, but later had some disease problems that were difficult to detect on Landsat.

The percentage of winter wheat harvested for grain in 1979 and 1981 in some of the counties represented on our imagery is listed below, along with the yields for the harvested grain. The values are those reported by the Crop and Livestock Reporting Service.

County	1979 % W.W. Harvested For Grain	Yield (Bu/A)	1981 % W.W. Harvested For Grain	Yield (Bu)
Dewey	35.4	15.9	91.0	26.5
Ziebach	42.4	15.0	87.1	28.0
Potter	15.3	22.4	98.7	32.9
Sully	11.8	22.0	99.0	30.9
Hughes	15.9	12.8	96.2	30.5
Stanley	40.0	15.5	98.0	29.7
Jones	65.0	19.3	98.3	30.0
Lyman	83.7	17.0	90.7	23.3
Bennett	81.4	17.5	96.5	28.7
Tripp	84.4	27.9	73.6	13.2

In this list of major winter wheat growing counties, covered by our imagery, percentage of winter wheat harvested and the yield confirm, as we deduced from Landsat, that 1980-81 was a better winter wheat growing season than 1978-79. The percent of planted winter wheat eventually harvested for grain was higher in 1981, in many instances more than doubled, and the yields were often 10 bushels/acre higher in 1981 than 1979. There was a noticeable difference between the northern and southern counties in the apparent amount of damage suffered in 1978-79. The northern counties (Potter, Ziebach, Dewey and Sully) frequently have poor survival records, and the wheat exposed to this colder and drier season likely caused greater winterkill as shown by the drop in harvested acreage. The southern counties (Bennett, Jones, and Lyman) had much less total loss, but the yields of harvested wheat were just as low as those of the northern counties. Final yields, however, are often influenced by interseeding with spring wheat.

A May 3, 1977 image was available which covered Jones, Lyman, Stanley, Potter, and Sully counties. No fall scenes were available to locate specific winter wheat fields, but knowledge of the general loss of fields planted to winter wheat makes some interpretation possible. Again, very little of the crop had greened up, especially in Stanley, Jones, and Lyman counties (Section VII). The yields in these counties were fair (av. of 22.8 bu/A), but the percent of harvested crop turned out to be slightly less than 50% of the wheat planted, which was even less than in 1978-79.

Landsat was found to be a useful tool in detecting some weather related cropping problems in winter wheat. In this instance it identified areas of winterkill and could help in estimating winter wheat production in an area. Other information is needed to aid in accurate yield forecasting (such as crop-climate models).

Situation #2: Winter wheat survival in South Dakota for 1978.

In the spring of 1978 there was excellent green-up of winter wheat fields by March 10th (Appendix H). By April 1st reports were coming in from Sully and Potter counties stating that serious losses had occurred in the interim period, indicating that numerous complete fields were lost. The assessment was that winter-kill occurred sometime after March 10th (Appendix H). The most severe losses were found to occur in all areas north of a line along Highway 14. This highway bisects the winter wheat region approximately between Sully and Hughes Counties, and runs through the southern 1/3 of Stanley County and northern 1/4 of Haakon County.

To investigate this problem, Landsat imagery was acquired for coverage of Sully, Potter, and Hughes Counties. A fall scene dated 11-17-77 was used to locate the winter wheat fields and a 3-4-78 image was acquired for pre-winter-kill observation and a 3-22-78 image for identifying the winter-kill.

The fall scene adequately delineated the winter grain fields, although snow cover was a problem in a few small areas of the counties involved. On the 3-4-78 image, practically the entire scene was snow covered. There were areas in Sully, Hughes and Lyman Counties in which field patterns were visible, but no evidence of green-up was noticeable. The patterns were all a very dark tone, indicating the snow cover was off some of the fields, but vegetative growth was not visible in any of the areas.

What was visible on the imagery seemed to be opposite from the early report of excellent green-up by March 10th (Appendix H). Possibly the week between the image date and the reporting time allowed for some green-up from winter dormancy. There is also the good possibility that at this very early spring growth stage, the wheat had not reached spectral emergence whereas from the ground wheat stands were clearly visible and apparently healthy. Much brown dead vegetative material is mixed with only small amounts of new growth and this dead foliage may be the material that was primarily being reflected. It should be noted that spectral emergence of winter wheat is possible at this early date as witnessed by the visible red tones on the March 6, 1981 scene studied earlier.

On the 3-22-78 scene it was also difficult to detect much growing vegetation. Parts of the area were snow covered or under clouds or cloud shadow. Most of the open areas appeared as uniform dark tones, despite efforts to enhance the image to bring out more detail. This was not a problem in all areas. For instance, some faint signs of green-up were evident in Lyman County and a bit in Sully County (Appendix H). What little green-up was visible looked mottled, an indication that only parts of fields were greening up. A March 31, 1978 image was also available for use, but was of questionable quality for interpretive use.

In this data set, it was difficult to draw any definite conclusions as to whether winter-kill occurring after 3-10-82 was detectable on the image. The complete lack of wheat spectral reflectance on the 3-4-78 image left us without a basis to judge whether winter-kill occurred after that date. It does appear on the 3-22-78 scene that winter-kill had probably occurred. On one other study area we did have an image dated this early in the season with which to compare; this was a 3-6-81 scene covering some of the same counties. On the 1981 image, although not showing strong reddish tones, the fields were certainly visible and greening up nicely, as opposed to the dark bleak scene in 1978. Clues to the differing winter conditions were the before-mentioned snow cover in 1978 and, more importantly, the heavily iced Missouri River reservoirs in 1978 versus the completely ice free reservoirs in 1981 indicating a later season in 1978.

As before, a method to check the extent of winter-kill was to evaluate the yield figures and how much of the planted winter wheat was actually harvested. As a means of comparison, we divided the table into counties north of Highway 14 and those south. The counties included were those within approximately 50 miles (N-S) of the highway. Counties which the highway crossed were assigned as to where the majority of the county lay.

County	(North of Highway 14) 1978 % W.W. Harvested for Grain	Yield (bu/acre)	County	(South of Highway 14) 1978 % W.W. Harvested for grain	Yield (bu/acre)
Dewey	52.4	20.2	Haakon	80.1	26.7
Ziebach	52.4	22.1	Hughes	14.1	13.5
Potter	29.2	18.8	Lyman	82.7	28.3
Sully	21.0	12.0	Jones	89.3	28.0
Stanley	47.2	23.5	Jackson	86.5	26.4

As a general pattern, the values confirm what the surface reports indicated (Appendix H), that winter-kill was more severe north of Highway 14. The yields were lower north of the highway and the amount of winter wheat planted that eventually was harvested was also considerably less in the northern counties. A very noticeable exception to this was Hughes County. It was interesting to note that in 1979 (another year of heavy losses of winter wheat from winter-kill) Hughes, Sully, and Potter Counties again suffered the most severe losses due to winter-kill. Interseeding with spring wheat, however, does influence yield results.

The year 1978 was very similar to 1979; in both years severe winter-kill resulted. The spring Landsat scenes from both years also looked similar. Both showed little green-up in the winter wheat areas and as the statistics showed, winter-kill was a major factor in this. On four instances studied, we were able to document winter-kill using satellite imagery, indicating its usefulness in monitoring this type of problem.

Situation #3: Wheat streak mosaic in Potter and Sully counties

In the 1980-1981 growing season, Potter and Sully counties experienced heavy losses in winter wheat fields due to wheat streak mosaic. The disease was most evident in late April and early May. The infestations appeared as yellow borders and large crescent-shaped spots in fields. No winter-kill was reported.

Landsat scenes for the area were acquired to test the validity of using satellite data to identify affected areas. Due to heavy cloud cover, no imagery was available for late April or May. Scenes were acquired from 11-18-80, 3-6-81, 3-25-81, 4-12-81, and 8-15-81.

The scene from 11-18-80 was used to determine the location of winter grain fields. Some of the fields greened up may have been rye but the historical records showed winter rye is only a fraction of that planted to winter wheat in this area. Thus, the great majority of green fields in November were winter wheat and these were used to locate the same fields in the spring.

On the March, 1981 images the winter wheat fields were discernible, mostly as a weak pink, indicating they were in the early stages of spring growth. The fact that the winter wheat fields on the fall scene were visible and greening up by early March confirmed the observation that there was no winter-kill in the area (a contrast to the area in 1979). The March 6, 1981 scene was devoid of any snow cover and the Missouri River reservoirs had very little ice left. Both of these situations were unusual for this time of year and helped to indicate the early and mild conditions for 1980-81.

The main image used was from 4-12-81. The fields had greened up considerably since the March 25th scene. No losses were apparent yet, and other spring grains had not yet reached spectral emergence levels. Generally, it was too early to detect the mosaic problem, but some mottling was evident on certain fields. Initial evidence of this was visible on the late March scene but was very minor. This may have indicated the beginning of the mosaic problem but was probably more related to changes in soil moisture, soil texture, and slope within the fields.

An 8-15-81 scene was available and was used to view the progression of the fields. The majority of them were left in stubble but a few had been fallowed.

As noted in the study for Situation #1, where the imagery from 1978-79 and 1980-81 were compared, we found the 1981 winter wheat crop to be potentially good. Sully and Potter counties, the main objects of this study, had higher yields (30-33 bu/acre) and a higher percentage of the wheat harvested for grain (98-99%) than any of the other counties studied. This seems to contradict the reports of heavy disease losses in the counties, but the heavy losses may have been very localized as to not affect the total county figures appreciably. Yield results in this area can be misleading because of the practice of inter-seeding spring wheat.

The imagery purchased was really dated too early to detect disease problems and our ability to determine it by manual means was questionable; unless the infestation was extensive and severe. Also, by the time the disease was severe, the decision to harvest had probably been made and if it was a localized problem, it would not have affected the county statistical data very much. Thus, although still disturbing, the contradiction in reports need not cause too much alarm. This disease in wheat was attributable in some instances to cross-infection from adjacent corn fields and the particular situation involved a cultivar having low resistance to wheat streak mosaic.

The lack of timely imagery hindered the effort to identify wheat streak mosaic damage in Sully and Potter counties. The beginning of the disease may be visible in the field mottling on the April scene, but the mottling could also be due to other factors. Landsat imagery was useful in detecting non-uniform stands in fields. It also helped identify the winter wheat fields which survived the winter well.

Situation #4: Drought in Beadle County (1981)

Beadle County was cited as a county receiving disaster payments because of low rainfall in the summer of 1981. According to the crop-weather summaries for South Dakota, which are generated every week, the drought in Beadle County essentially began the preceding fall and lasted essentially until September, 1981. For the majority of the spring and summer period the area was critically short of top soil moisture, the eastern 2/3 of the county appearing to have the most severe problem. The drought also appeared to extend more in a north-south direction to include other counties and less in the east-west direction from Beadle County.

Crop-weather records from 1981 for Beadle County were used to compare with the satellite imagery. The actual precipitation at Huron (located near the center of the county) was rather variant over the summer months although the county was rated short or critically short of top soil moisture for nearly all summer. In the 5 weeks preceding the July 12th report, about 1 inch of precipitation fell on Huron and in the 5 weeks between July 12th and August 16th, Huron received approximately 5.5 inches of rain (these 5 weeks were chosen because of the similar interval between the available Landsat imagery). Even though the county received ample rainfall in late July and early August, it still remained critically short of top soil moisture in the weekly summaries. This seeming contradiction may be indicative of the very dry conditions before July 12th, a case of localized rainfall with much runoff (as from small thunderstorms), or an indication of the precipitation coming too late to help some crops.

A check on the moisture conditions can be made by noting the actual yields for various crops. Below is a list of a number of crops and their yields from Beadle County. The 1981 crop year is compared to a 4-year average (1977-1980) taken from available statistics.

Crop Type	1977-1980 (Avg.)	1981
Corn	46.1	57.7
Winter Wheat	22.6	25.0
Spring Wheat	21.7	14.9
Oats	44.1	34.0
Barley	36.0	18.0
Soybeans	21.5	35.0
Sorghum	37.4	37.8

These data indicate that the spring grains appeared to have been hurt the most by the drought of 1981. Winter wheat showed a surprisingly high yield though under these dry conditions. Row crops such as corn and soybeans (although only approximately 1500 acres of soybeans were planted in any given year in Beadle County, the results help confirm the validity of good yields for late summer maturing crops such as corn) had yields well above the average of the four years. Although corn planted to irrigated land may contribute to the fairly high 1981 yields, it is doubtful that the acreage of irrigated corn was significantly greater than the irrigated corn acreages in 1977-1981, and thus could not be used to explain the large yield differences. A drought tolerant row crop, sorghum, varied little from the average yields.

The yield figures closely follow the precipitation totals recorded in the weekly crop-weather summaries. As noted, from June to mid-July, precipitation was very light. This coincided with critical growth stages in the small grains and was reflected in the lower yields. The adequate rainfall from mid-July to mid-August apparently helped increase the yields of the row crops which have their critical growth stages later in the summer than do the small grains. To test their usefulness in identifying the drought area, two Landsat summer scenes dated 7-9-81 and 8-15-81 were acquired. The August scene covered the western 2/3 of the county (path-row 33-29) and the July scene covered the entire county (path-row 32-29).

Contrary to the usual situation, the August image had a richer "red" tone throughout the image than did the July scene (red tones indicate healthy, green vegetation). Part of this seemed to be caused by the photographic processing of the August image but the 5.5 inches of rain received in the region between the images appeared to be the main cause of the green-up, although the drought was reported to continue through August.

The imagery complements the above mentioned statistics fairly well. The July scene is light toned indicating a poorer vegetation cover associated with low rainfall and poor small grain yields confirmed the situation. In August, after 5.5 inches of rainfall, the whole scene had a deeper red hue. Although too late to add green tone to the ripening small grains, it still aided the growth of crops such as alfalfa, soybeans, and corn. Pastures and other grasses also showed a greener color. Weeds would also likely show increased vigor in stubble fields, fallow land, pastures, and elsewhere. Thus, renewed growth of many plant species would account for the richer, red tones on the August image. In this case also, the high yields of corn and soybeans along with the 5.5 inches of rainfall confirm the rich vegetation growth as interpreted from the August image.

Although the change in moisture stress between the July and August images is observable, the specific borders of the drought area are not easily discernible on these two scenes. A general outline of the affected area could be drawn but the change is rather gradual. One problem is the lack of imagery of the adjacent passes for each date (e.g., the four scenes surrounding the July 9th image, the scenes above and below it on the same day and the ones to the east and west imaged on July 8th and 10th, respectively). Some definite breaks are visible in the Beadle County area. On the July scene, a distinct line runs down (N-S) the center of the image near the expected drought border, but it also separates the James Valley from an adjacent glaciated area. This change follows a change in soil type, topography, crop type, and to a small extent, crop growth stage. A number of factors can affect the tonal patterns, complicating the situation. On the August image the tone is fairly uniform throughout but, unfortunately, it does not cover the area with the major physiographic and crop changes as does the July scene. Although the photographic process may be partially to blame for the overall reddish hue of the image, the plentiful rainfall after the July image brought the area up to the spectral reflectance levels of the surrounding regions, indicating some alleviation of the drought conditions.

Another method to aid in assessing this drought is to compare the region in different years and growing seasons. Four July scenes from Beadle County for 1973, 1975, 1977, and 1981 were available for comparison. All the images were recorded within eight days of each other in July of their respective years. From comparison of tonal variations it appeared that the 1981 season was driest of the four years. It had the lightest tones of any of the years, but the area on the eastern part of the image which was not in the severe drought area did appear more similar to the other years studied, consistent with the rainfall pattern. The 1981 scene had a more uniform brown tone in the drought area, compared to more varied tones on the other images.

To test the validity of this tonal comparison, yield and weather data for 1973, 1975, 1977, and 1981 were evaluated. The yield figures (from Beadle County) for four small grain crops are shown below. The scenes compared were all from early July, so yields for corn or other crops which could be affected by late summer rainfall were not included.

Beadle County
Yield (Bushels/acre)

Crop	1973	1975	1977	1981
Winter wheat	27.0	21.0	20.5	25.0
Spring wheat	22.0	14.0	24.9	14.9
Oats	45.0	33.0	43.1	34.0
Barley	33.0	29.0	36.4	18.0

For the crop years 1973 and 1977, the figures bear out the conclusion from Landsat, that 1981 was drier in early July than these two years and that this affected small grain yields. In 1975 the spring wheat and oats had yields comparable to 1981 while the barley yields for 1975 were significantly higher. Thus, although the tonal responses for 1975 and 1981 appear to indicate a more productive year in 1975, the yield figures only partially substantiate this situation.

Winter wheat has been included in the above table, but the yields follow no pattern in relation to the tones on the imagery. This is due primarily to the earlier ripening and harvesting date of winter wheat in comparison to the other three small grains. This makes the tonal variations in early and mid-July of little value in assessing winter wheat condition. It is interesting to note that winter wheat yields showed little relationship to those of the other small grains in any particular year. For example, in 1975 and 1981 the spring wheat and oat yields were poor, but the winter wheat yields were fair, but in 1977 the oat and spring wheat yields were fair while the winter wheat yield was below those for 1975 and 1981.

The other three spring crops show an expected relationship; where one grain had a poor yield in a given year the other two also had subpar yields. An exception to this was the higher than expected yield for barley in 1975 (or the lower than expected yields for spring wheat and oats in that year). The maturing of these small grains are similar, with barley and oats usually ripening and being harvested before the spring wheat.

To bring possible insight into the relationships between the yield results above and the tonal qualities found on the imagery, we gathered information about the moisture conditions in Beadle County during the spring and early summer of these four years. Those figures are listed below.

	Precipitation (inches)				
Year	April	May	June	July	April, May, June Total
1973	1.17	2.04	0.82	2.11	4.03
1975	3.31	1.98	3.44	0.46	8.73
1977	2.13	1.83	1.31	1.50	5.27
1981	0.24	0.68	1.48	2.24	2.40

The precipitation totals generally follow what is discernible on the satellite imagery. It was difficult to rank the imagery in any specific moisture stress order, but qualitatively speaking the 1975 and 1977 scenes appeared to have the best moisture conditions followed by 1973 and then 1981. Having only monthly values restricts what can be interpreted from the data, as heavy rainshowers can alter the conditions on the imagery for a short period of time. For 1981, we had daily precipitation totals, and it was found that the majority of the June precipitation occurred early in the month and most of the July rainfall near the end of the month (although .64 inches was received from July 2 to July 3). This fact along with the low precipitation totals for April and May contributed to the dry appearance of the July 9, 1981 scene.

The yield figures compared earlier show some correlation with the precipitation totals and satellite imagery. To get more accurate comparisons, more precise weather data, temporal imagery, and crop stage information would be needed. Some generalities can be drawn nonetheless.

The 1973 imagery scene appeared to have a fairly good moisture relationship but not as good as 1975 or 1977, and the rainfall totals bear this out. It may be important to note the low precipitation total in June which may be reflected on the imagery (again depending upon when the June and July precipitation occurred). The yields for 1973 were surprisingly as good as 1977 and better than 1975 or 1981.

As stated before, 1975 appeared on the imagery to have good moisture conditions and was found to have the greatest total rainfall over the period. The yields only partially confirmed the imagery and precipitation totals, though. The spring wheat and oats yields were as poor as in 1981. With the ample rainfall in June, we could expect those yields to be better than they were. Possibly the timing of that precipitation, very hot weather at a critical time (Table 2.4), diseases or some other factor may have caused this yield discrepancy.

In 1977, the moisture conditions appeared to be about the best of the four years and the rainfall totals somewhat reflected this fact, although 1975 did receive more moisture (Section II). The yields attest to the adequate moisture received during the 1977 growing season.

In 1981, the year of primary concern, the imagery, yield and precipitation totals complemented each other rather well. It had the least precipitation over the part of the growing season of any of the years, its imagery tones appeared to show the most moisture stress and the yields of the small grains were generally lower than the other years. An exception noted earlier is winter wheat, which seemed to show little correlation with precipitation for any of the four years studied. The 1981 yield was unusually high with so little precipitation received in April, May, and June.

In addition to using the greenishness of vegetation to indicate moisture conditions, moisture stress can be estimated by the changes in the water bodies. The use of the criterion must be tempered by the fact that changes in the size and condition of ponds and lakes can be cumulative over a period of years. For example, lakes may be at a lower level in 1980 than 1976 but 1980 may still be a wetter year than 1976, depending on the moisture conditions in years prior to 1976 and 1980. Some wetland areas also may be drained purposely. Nevertheless, conditions of water bodies can be used to supplement other methods of interpretation.

Comparing the water bodies in the area from 7-9-81 to 8-15-81, it can be observed that a number of small lakes and sloughs that were low or dry as of July 9th had water in them by August 15th. This helped verify the improvement in the moisture situation as noted by the increased greenishness of the landscape on the Landsat imagery. Because the scenes were from the same crop year, the cumulative effect can be discounted as it is doubtful anyone has purposely increased the wetlands during this period.

When comparing the four July images mentioned above, it was found that the lakes and sloughs were fewest in number and at the lowest level on the 1981 scene. It should be noted that there was a general depletion of water resources in the area over the eight years. Numerous small lakes visible in 1973 gradually disappeared on the later images (especially in western Clark County). Despite this trend, the 1981 scene seemed to indicate a drier than average situation.

In this case study, Landsat can be used to give a general view of the moisture situation in the area. The tone of the vegetation and the condition of water bodies are two indications. Within and between year comparisons complemented each other for detecting the moisture stress.

Situation #5: Winter wheat survival in Sully and Potter counties for 1982.

On April 8, 1982, a report (Section VII) was received from Sully County indicating a serious problem with kill in many winter wheat fields. This problem was also very evident in other northern counties such as Dewey and Ziebach. Very little evidence of green-up was found in these areas. The losses were attributed to late winter or early spring damage.

Two Landsat scenes were acquired to test our ability to identify this problem. The images were dated 11-15-81 and 4-17-82. The major winter wheat growing counties covered by the imagery were Ziebach, Dewey, Haakon, and Stanley.

As before, the November scene was used to identify the winter wheat fields. A tonal difference between the southern counties (Haakon and Stanley) and the northern counties (Ziebach and Dewey) was noticeable on the fall scene. The winter wheat fields in the southern counties generally showed a richer red tone while those in the northern counties appeared more as a light pinkish tone. The main cause of this is probably due to the slightly earlier planting dates and warmer temperatures in the southern area. According to the Crop and Livestock Reporting Service, the fall was fairly dry and the winter wheat planting schedule was behind normal. The moisture received at three stations from the beginning of September to the middle of November gave an indication of the fall moisture situation. At Cottonwood (near the SW corner of Haakon Co.) 1.67 inches, and at Dupree (in EC Ziebach Co.) 2.94 inches of moisture was measured. These available stations were not ideally located to indicate specific moisture condition, but the data do tend to show that no serious lack of moisture existed in the northern counties to account for the less vigorous appearance of the winter wheat fields on the November image.

A check of the 11-3-78 Landsat image used earlier which included the same counties as well as Jones, Lyman, Potter, and Sully counties also shows the Dewey and Ziebach area as having a less vigorous stand of winter wheat than the other counties. The yield figures do not indicate this difference between the counties, nor does the percentage of winter wheat fields that were actually harvested differ greatly. For example, Stanley county which shows vigorous winter wheat fields on the November, 1978 image had a 1979 yield of 15.5 bushels/acre and about 40% of the fields planted to winter wheat in the fall were harvested in the summer of 1979. These figures for Ziebach county in 1978-79 were 15.0 bushels/acre and approximately 42% of the fields harvested.

Thus, it appears care must be taken in drawing any conclusions about the winter wheat crop in this northern area by inspecting its tonal patterns on a fall Landsat image. On a general year to year comparison, the yields here will be less than in the southern counties, but this tonal difference cannot safely be used as visual proof, as exceptions to this do occur as noted in the example above.

As stated before, the cooler temperatures in the northern areas may account for the slower growth. More fall scenes would be needed along with more detailed weather information, soils data, farming practices, etc., to do a more detailed study. It should be noted that these northern counties have a smaller percentage of fields planted to winter wheat and generally smaller field sizes than the southern counties. On the imagery this gives the northern areas (on a late fall scene) a general appearance of very little green-up as opposed to southern counties. Thus, this tonal difference can be tempered a bit by the fact that the green-up of fields in Ziebach and Dewey counties in the fall is simply less visible.

From the fall scene, it was observed that the fields greened up in these four counties (although, apparently not at the same rate). The spring image used to interpret how well the winter wheat was progressing was dated April 17, 1982. It was expected that some winter-kill would be visible on the imagery, and this was the case.

On the 4-17-82 image many fields which were greened up on the fall scene showed no signs of vegetative growth. This problem appeared to become more severe as you moved north and east in the four counties considered. The date of the image is such that most of the winter wheat should be at a growth stage where it has reached spectral emergence, although the tones may vary quite a bit depending on when the field came out of its dormant stage and other weather-related factors. Thus, areas not totally lacking in reddish tones may still be capable of producing a good yield.

The imagery appears to confirm the loss of some of the winter wheat due to winter-kill. The same general areas were studied for winter wheat losses for the crop seasons 1977-78, 1978-79, and 1980-81, where in 1977-78 and 1978-79 winter-kill was a problem and 1980-81 disease caused losses. Comparing the four spring images for the respective years '78, '79, '81, and '82, it appears the severity of loss in 1982 was less than in 1978 or 1979 but greater than in 1981. The 1978 image was taken on March 22nd which puts it at least two weeks earlier than the spring scenes of the other years, but the information (or lack of it) on the scene indicated the season may have been as poor as in 1979.

Statistics on the yields and percentage of the wheat harvested indicate that 1979 was the poorest season, followed closely by the 1978 season and 1981 turned out to be a rather successful year for winter wheat. County data for 1982 were not available at the time of this writing.

<u>Situation #6:</u> Excess spring moisture for SE South Dakota in 1982

Late spring and early summer of 1982 were periods of ample moisture over most of South Dakota. In some areas, excess moisture was received. Reports from SE South Dakota indicated that excess moisture was hindering the planting of their primary cash crop, corn.

To investigate whether this moisture problem in relation to corn planting dates was discernible on Landsat, we compared 1982 imagery with imagery from an average corn development season. Because of cloud cover problems in 1982 the counties we were restricted to were Union County, and scattered areas of Lincoln, Yankton, Minnehaha, Turner, and Clay counties. Also visible were parts of NW Iowa which also has the same general cropping patterns, and a portion of NE Nebraska. For the South Dakota counties mentioned, the Reporting Service statistics indicated that about one-third of the land is planted to corn, or that over 50% of the "cropped" land is corn. Assumptions about imagery data were more valid due to this high proportion of corn acreage. Although other crops could interfere with identification of corn on these scenes, so many of the fields were known to be corn that the general state of the corn crop could be assessed.

The dates of imagery chosen were 6-24-82 and 6-25-80. This June date was chosen in an attempt to maximize the imagery difference between 1982 and an average year. The date was chosen to show corn which had reached spectral emergence on an average year (1980) versus 1982 where the late planted corn would not be visibly greening up at this date. Some corn fields could show spectral emergence in 1982 and not in 1980, but it was hoped the overall trend between the two years could be detected. For example, the Crop Reporting Service stated that by 5-30-82, 55% of the corn had been planted but the average percentage planted for that date was 82%. This difference in planting dates was of particular interest in imagery measurements. The late June dates for 1980 and 1982 were also chosen because of the lack of imagery available for 1982, which restricted us to only a couple of possible dates, of which 6-24-82 was the best choice.

The 1980 crop year was gauged to be an average one by checking the corn planting dates of SE South Dakota over the last ten years. The year was found to be "average" with respect to planting dates, but it did not mean the season had an average amount of precipitation or an average yield, conditions beyond the purposes of this probe.

By viewing the imagery, it was concluded that excess moisture in 1982, and its effects on the corn crop, were detectable on the Landsat imagery. It was not possible to see actual excess moisture conditions (such as flooded areas, increase in size of wetlands, and so forth) but some inferences could be made. The number of fields greening up in 1980 vs. 1982 was quite different, with 1980 showing a considerably higher proportion. As noted earlier, most of this can be attributed to differences in corn emergence. By this late June date, small grains should certainly be visible and would appear very similar on the 1980 and 1982 image. Probably soybeans could be confused with corn fields in this district but soybean acreage is less than corn and actually would be affected similarily by the excess moisture, tending to reinforce the differences on the imagery between the two years.

The 1982 moisture problem affected different areas to differing degrees. The largest difference was seen in the Missouri River floodplain and other similar areas. In these flat areas the excess moisture does not easily drain away and this is probably reflected in the considerable absence of green-up in the valleys. This is in contrast to the 1980 image, where the majority of the fields showed vegetation growth.

Areas in NW Iowa also clearly showed vegetation cover in 1980 and lack of it in 1982, but it is not as pronounced as SE area of South Dakota.

The late June differences in green-up became less as comparisons progressed north and west of the SE area. This may be somewhat misleading in terms of spring growth, as the percentage of land in corn and soybeans decrease in the north and west direction. As less of these crops are planted, less variability exists to work with on imagery. Nevertheless, as noted earlier, about 1/3 of the land of these counties is planted to corn (slightly more in SE counties and slightly less in northern counties) and the inability to detect much tonal variation leads to the conclusion that the excess moisture was more of a problem in the extreme SE South Dakota counties than the northerly ones. The precipitation at three pertinent weather stations for 1982 up through 6-13-82 (approximate end of planting season) were: Sioux Falls - 9.1 inches, Yankton - 13.59 inches, and Sioux City - 11.65 inches. The southern edge of the state was wetter through the end of the normal corn planting season.

One other area which was cloud free on the 6-24-82 images was NE Nebraska. The more rugged areas near the Missouri River were mostly in pasture or rangeland (similar to the hillier areas in the South Dakota region of the study) and thus were well covered with a blanket of vegetation. Moving away from the river hills it was found that the 1982 fields were less vegetated than the 1980 fields in the same region. Because it was generally outside of our study area, information about the precipitation totals or major crop types was not gathered.

The satellite imagery did significantly reveal that the corn planting season was behind normal in 1982. It also showed that the river plain or less well-drained areas were most affected by this problem of excess spring moisture. Whether this delay affected yield was not determined. The harvest season itself was slowed considerably by excess fall moisture, and the yield figures available in the spring of 1983 may shed some light on the effects of the 1982 moisture problems.

As an aside to this problem, a very damaging hail storm occurred in northern Minnehaha County in early July. A Landsat scene from about a week after the storm (7-12-82) was acquired to determine how well the imagery could assess the damage.

The aerial extent of the hail damage was very evident. There was a sharp tonal difference from the affected and unaffected areas. In the hail damage area the fields were a greenish tone with a somewhat mottled appearance. If timely imagery is available, Landsat can usually give a quick and inexpensive aerial assessment of storm damage, and with other data can often aid in determining the severity of the damage.

This 7-12-82 image covered the same region as the imagery of the study from late June. This scene was dated about 2.5 weeks after the 6-24-82 scene. A comparison of this image (7-12-82) with the 6-25-80 scene of the same area was made as a check on the comparitive condition of the corn. As a general evaluation, the 1982 corn crop had reached and actually surpassed the maturity of the corn of the 1980 growing season. Granted the corn was 2.5 weeks later and should have been more mature, but this comparison showed that the corn of the SE area did rebound from its slow start in 1982. Again, whether the slow start affected yields depended upon moisture the rest of the summer, the date of the first hard freeze, and the harvesting conditions.

Situation #7: Drought conditions of NE South Dakota in 1982

The 1982 crop season for most of South Dakota was one with sufficient moisture. In many areas, the problem was one of too much moisture, where planting was delayed, diseases and insects were more of a problem, and harvests were slowed.

An area where this was not the case was the northern tier of counties from Roberts to Campbell. As the Crop and Livestock Reporting Service weekly crop - weather summaries showed, the dry region spread from the NE part of the state and moved laterally west to Campbell County and Corson County. After early spring to mid-June, NC South Dakota received very little precipitation.

Landsat scenes covering NC South Dakota were acquired to test how well the drought conditions could be detected using satellite imagery. Cloud cover was a problem along with difficulty in getting timely imagery. The dates of the imagery which were available were 6-27-82 and 7-15-82.

June was the earliest scene available that was reasonably clear, although this image also had significant cloud cover in the study area. An attempt was made to acquire an image which was early enough in the season to predate the drought conditions, but late enough to include the green stage of most crops. Corn establishment was a bit of a problem because of the late planting dates. By the time corn was showing much spectral reflectance, the small grain crops were starting to be damaged by the dry weather. Care in interpretation had to be taken to not confuse land areas having reflectance of the emerging corn crop as evidence against the pending drought problem. A scene earlier in June would have been better as a pre-drought scene but one was not available.

By 7-15-82 the drought had progressed for a few weeks. Residual soil moisture from earlier rainfalls was probably still influencing the crops, but later dated imagery was not available at the time of the 7-15-82 scene purchase. Also, there was the problem of the ripening of the small grains which changes their reflectance patterns. Only 2.5 weeks separated the pre- and post-drought scenes which also made tonal separations difficult.

Problems with the timing of the available imagery hindered the effectiveness of the drought detection. More detailed information about cropping patterns would have aided the stress detection by helping to eliminate natural spectral changes due to changes in the growth stages of the crops. A generalized approach to the situation is cited in Beadle County for 1981.

The areas other than cultivated fields are also useful to detect moisture stress. Pastures and rangeland, weeds, wetlands, water bodies, and so forth show changes in moisture conditions. Often these criteria reflect the general moisture conditions on the imagery better than the field crops do, as their green growth is less affected by human intervention (such as cutting hay and alfalfa, cultivating corn) and early ripening (as for the small grains). Later in the summer and fall most plants will lose their green color, but the increased image reflectance of the 1981 Beadle County area from 7-12-81 to 8-15-81 was evident.

Comparing the two images (6-27-82 and 7-15-82), very little tonal contrast was observed. Some areas in range or pasture appeared to have lost some color but it was not a consistant, noticeable change. It may have been due to the normal loss of grasses from livestock grazing as much as from the drying conditions.

For the cropped fields themselves, the tones on the later image actually appeared to be somewhat richer. This is considering the overall scene, where some fields have lost color and others have gained it. Probably the emergence of the corn and sunflowers to form a more closed canopy had caused the general redder tones. This area is predominately small grain farming but the grain had not ripened enough by 7-15-82 to show a very noticeable loss of green matter on the Landsat imagery. This also may attest to the late planting dates of most crops across the state. There is an appreciable amount of alfalfa grown in the area and according to statistics from the Crop Reporting Service, the first cutting is usually harvested in late June. In a wet spring year such as 1982, the crop was probably harvested at this time, and had good regrowth by July 15, 1982. This may also help explain the richer tones on the later image.

One area which did show definite loss in moisture were a number of shallow lakes and sloughs. The general pattern in the area is for this to normally occur during warmer and drier weather of late summer, so it was difficult to assess the impact of the changes in the water bodies. Conclusive evidence of a drought could not be established from the drying of the wetlands. One could conclude, though, that moisture conditions had not improved appreciably during the 2.5 week period of the two scenes. Ability to make this distinction was shown in the Beadle County study. Thus, the area had become drier, but it would be hard to predict if yields were substantially reduced.

The two scenes were dated too close to the same period to effectively detect a serious drought problem in progress. Residual moisture from the wet spring and early summer was probably still strongly influencing the plant spectral responses. However, the disappearance of wetland areas did show that moisture stress was evolving as a problem. Whether the drought stress occurred early enough to seriously reduce small grain yields needed to be answered by the county yield figures available after May 1983. Because the drought did last through September, an August scene would probably be more appropriate for detecting the drought stress.

Appendix A. Ranking of corn yields in NC South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Brown

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1979	1978	1966	1973	1971	1975	1974	1976
Bu/A	61	60	57	56	33	33	22	17	10
Stage 1*	6/6	5/30	5/30	5/30	5/23	5/23	5/30	5/30	5/16
Stage 4**	9/12	9/19	9/5	9/12	9/12	9/12	9/12	9/19	9/5
G.S. ppt***	17.2	15.3	20.5	16.7	9.2	15.0	15.2	9.8	5.1
Fall ppt	7.3	1.5	8.7	4.3	1.8	4.3	0.8	5.9	3.3

County: Potter

Rank	1	2	3	4	13	14	15	16	17
Year	1980	1979	1966	1972	1981	1975	1973	1974	1976
Bu/A	62	51	49	43	30	25	23	11	9
Stage 1*	5/16	5/30	5/30	6/6	5/23	5/30	5/23	5/30	5/16
Stage 4**	9/5	9/19	9/12	9/12	9/12	9/12	9/12	9/19	9/5
G.S. ppt***	10.2	14.9	16.0	12.0	12.6	16.0	12.5	13.6	4.5
Fall ppt	1.6	1.1	4.1	8.0	3.9	0.9	2.5	4.1	2.0

County: Spink

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1972	1978	1966	1981	1965	1975	1974	1976
Bu/A	65	64	57	52	33	27	23	17	10
Stage 1*	5/30	6/6	5/30	5/30	5/23	5/30	5/30	5/30	5/16
Stage 4**	9/19	9/12	9/5	9/12	9/12	9/12	9/12	9/19	9/5
G.S. ppt***	16.5	19.1	15.6	17.5	9.5	14.6	13.4	12.3	7.2
Fall ppt	1.6	9.1	7.3	4.1	1.9	0.9	0.0	5.5	1.8

County: Walworth

Rank	1	2	3	4	13	14	15	16	17
Year	1978	1979	1980	1966	1971	1981	1974	1975	1976
Bu/A	62	57	56	55	37	36	34	31	10
Stage 1*	5/30	5/30	5/16	5/30	5/23	5/30	5/30	5/30	5/16
Stage 4**	9/5	9/19	9/5	9/12	9/12	9/12	9/12	9/12	9/5
G.S. ppt***	14.9	14.5	8.5	16.9	15.9	17.8	8.4	15.1	8.4
Fall ppt	8.8	1.7	2.5	3.1	5.4	4.5	5.6	1.3	1.4

*50% (+ 20%) of the district acreage planted.
**50% (∓ 20%) of the district acreage with plants having dented ears.
***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix A (Cont). Ranking of corn yields in NE South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Clark

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1969	1966	1972	1965	1967	1975	1974	1976
Bu/A	56	56	54	51	37	36	26	24	14
Stage 1*	5/30	5/30	5/23	6.6	5/23	5/23	5/30	5/30	5/16
Stage 4**	9/19	9/19	9/12	9/19	9/19	9/12	9/12	9/19	8/29
G.S. ppt***	19.4	16.6	18.7	20.6	18.7	9.3	17.9	11.5	6.0
Fall ppt	3.2	5.3	5.8	10.6	1.6	4.1	1.4	3.8	3.6

County: Grant

Rank	1	2	3	4	13	14	15	16	17
Year	1977	1979	1971	1968	1970	1972	1975	1974	1976
Bu/A	64	63	63	61	48	43	39	30	27
Stage 1*	5/16	5/30	5/16	5/23	5/23	6/6	5/30	5/30	5/16
Stage 4**	8/29	9/19	9/5	9/19	9/5	9/19	9/12	9/19	8/29
G.S. ppt***	21.1	14.8	14.9	18.2	14.8	18.7	11.3	13.1	4.5
Fall ppt	1.6	2.8	8.0	2.7	4.4	10.9	3.2	3.9	4.0

County: Hamlin

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1969	1978	1979	1967	1975	1971	1974	1976
Bu/A	65	63	60	59	42	41	37	24	24
Stage 1*	6/6	5/30	5/30	5/30	5/23	5/30	5/16	5/30	5/16
Stage 4**	9/19	9/19	9/5	9/19	9/12	9/12	9/5	9/19	8/29
G.S. ppt***	22.5	14.1	22.1	17.1	12.3	18.3	12.0	13.2	5.8
Fall ppt	10.4	7.2	12.5	3.5	3.3	1.3	7.3	3.7	4.2

County: Roberts

Rank	1	2	3	4	13	14	15	16	17
Year	1973	1978	1979	1972	1965	1975	1980	1976	1974
Bu/A	65	62	62	61	45	44	39	34	32
Stage 1*	5/23	/530	5/30	6/6	5/23	5/30	5/16	5/16	5/30
Stage 4**	9/12	9/5	9/19	9/19	9/19	9/12	8/29	8/29	9/19
G.S. ppt***	12.8	18.2	18.5	17.6	24.2	18.0	12.2	5.4	11.4
Fall ppt	1.3	11.2	2.7	8.6	2.2	1.6	3.3	3.5	4.5

*50% (+ 20%) of the district acreage planted.

**50% (∓ 20%) of the district acreage with plants having dented ears.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix A (Cont). Ranking of corn yields in EC South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Brookings

Rank	1	2	3	4	13	14	15	16	17
Year	1981	1972	1969	1979	1971	1967	1975	1974	1976
Bu/A	62	62	61	60	47	47	39	33	18
Stage 1*	5/16	5/30	/523	5/30	5/16	5/23	5/23	5/16	5/16
Stage 4**	9/12	9/19	9/19	9/12	9/5	9/19	9/19	9/19	8/29
G.S. ppt***	14.1	23.9	17.6	19.3	10.1	17.0	18.0	13.1	10.2
Fall ppt	2.4	8.7	8.7	3.3	5.9	2.3	0.6	6.0	6.5

County: Lake

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1972	1969	1977	1966	1971	1980	1974	1976
Bu/A	68	64	64	59	48	43	42	39	20
Stage 1*	5/30	5/30	5/23	5/16	5/23	5/16	5/16	5/16	5/16
Stage 4**	9/12	9/19	9/19	8/29	9/12	9/5	9/5	9/19	8/29
G.S. ppt***	22.1	22.5	15.4	18.0	13.7	10.7	14.1	16.4	7.8
Fall ppt	3.9	10.5	7.1	3.7	5.8	6.1	5.4	8.2	4.9

County: Minnehaha

Rank	1	2	3	4	13	14	15	16	17
Year	1969	1972	1979	1978	1966	1967	1975	1974	1976
Bu/A	85	85	84	76	60	59	57	35	24
Stage 1*	5/23	5/30	5/30	5/30	5/23	5/23	5/23	5/16	5/16
Stage 4**	9/19	9/19	9/12	9/5	9/12	9/19	9/19	9/19	8/29
G.S. ppt***	17.6	19.8	25.6	18.8	16.2	13.7	21.2	15.9	8.6
Fall ppt	9.0	9.1	3.1	9.8	6.2	8.0	1.1	12.4	3.9

County: Moody

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1969	1979	1978	1970	1977	1966	1974	1976
Bu/A	82	81	81	77	61	61	59	41	30
Stage 1*	5/30	5/23	5/30	5/30	5/23	5/16	5/23	5/16	5/16
Stage 4**	9/19	9/19	9/12	9/5	9/12	8/29	9/12	9/19	8/29
G.S. ppt***	21.7	14.1	24.1	14.1	14.8	18.4	12.2	14.5	7.1
Fall ppt	10.1	10.2	3.1	8.1	4.3	1.9	6.3	8.4	4.1

*50% (+ 20%) of the district acreage planted.

**50% (∓ 20%) of the district acreage with plants having dented ears.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix A (Cont). Ranking of corn yields in SE South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Hutchinson

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1978	1972	1969	1970	1980	1974	1976	1975
Bu/A	73	67	61	52	34	32	29	28	24
Stage 1*	5/30	5/23	5/30	5/23	5/16	5/9	5/16	5/16	5/23
Stage 4**	9/12	9/5	9/12	9/12	9/5	9/5	9/19	8/29	9/12
G.S. ppt***	17.7	17.6	21.8	17.9	12.0	7.8	14.1	12.9	20.7
Fall ppt	3.3	7.3	7.3	10.0	6.9	5.7	11.3	5.3	1.6

County: Lincoln

Rank	1	2	3	4	13	14	15	15	16
Year	1979	1972	1981	1969	1980	1970	1975	1974	1976
Bu/A	86	85	83	81	57	49	43	38	28
Stage 1*	5/30	5/30	5/9	5/23	5/9	5/16	5/23	5/16	5/16
Stage 4**	9/12	9/12	9/5	9/12	9/5	9/5	9/12	9/19	8/29
G.S. ppt***	22.3	17.4	14.5	15.6	10.7	11.1	20.7	13.6	9.0
Fall ppt	1.8	6.3	2.8	9.5	7.2	3.7	1.6	8.2	6.7

County: Turner

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1978	1972	1968	1970	1980	1974	1975	1976
Bu/A	82	77	74	70	45	45	42	40	36
Stage 1*	5/30	5/23	5/30	5/23	5/16	5/9	5/16	5/23	5/16
Stage 4**	9/12	9/5	9/12	9/12	9/5	9/5	9/19	9/12	8/29
G.S. ppt***	18.7	22.4	20.4	20.0	14.0	10.0	12.8	23.3	9.4
Fall ppt	4.7	8.8	9.0	1.9	7.0	6.5	6.9	1.6	7.3

County: Union

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1981	1972	1969	1970	1980	1974	1975	1976
Bu/A	96	95	93	88	59	57	49	38	35
Stage 1*	5/30	5/23	5/30	5/23	5/16	5/9	5/16	5/23	5/16
Stage 4**	9/12	9/5	9/12	9/12	9/5	9/5	9/19	9/12	8/29
G.S. ppt***	23.6	16.4	27.5	20.6	13.4	14.0	15.2	20.5	10.5
Fall ppt	3.2	3.9	6.1	9.4	6.7	9.6	9.4	7.6	4.4

*50% (+ 20%) of the district acreage planted.

**50% (∓ 20%) of the district acreage with plants having dented ears.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix B. Ranking of soybean yields in NE South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Deuel

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1966	1973	1975	1965	1974	1980	1967	1976
Bu/A	22	21	21	21	17	16	16	14	10
Stage 1*	6/13	5/30	5/30	5/30	6/6	5/30	5/30	5/30	5/23
Stage 4**	9/12	9/5	9/12	9/12	9/12	9/12	9/5	9/12	9/5
G.S. ppt***	20.6	14.9	12.1	20.9	22.3	15.4	18.7	13.1	6.5
Fall ppt	3.9	5.2	5.4	1.9	1.6	4.2	4.5	3.5	3.5

County: Grant

Rank	1	2	3	4	13	14	15	16	17
Year	1977	1979	1966	1980	1967	1981	1975	1974	1976
Bu/A	25	24	22	22	17	15	14	13	9
Stage 1*	5/23	6/13	5/30	5/30	5/30	5/30	5/30	5/30	5/23
Stage 4**	8/29	9/12	9/5	9/5	9/12	8/29	9/12	9/12	9/5
G.S. ppt***	21.1	14.8	14.4	15.5	12.3	14.2	11.3	13.1	4.4
Fall ppt	1.6	2.8	7.5	4.1	3.4	2.0	3.2	3.9	4.0

County: Hamlin

Rank	1	2	3	4	13	14	15	16	17
Year	1980	1979	1966	1972	1974	1975	1967	1981	1976
Bu/A	25	24	22	21	16	15	15	13	7
Stage 1*	5/30	6/13	5/30	6/6	5/30	5/30	5/30	5/30	5/23
Stage 4**	9/5	9/12	9/5	9/12	9/5	9/12	9/12	8/29	9/5
G.S. ppt***	14.4	17.1	16.9	22.5	13.2	18.3	12.3	15.3	5.6
Fall ppt	4.0	3.5	7.4	10.4	3.7	1.3	3.3	2.4	4.2

County: Roberts

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1978	1966	1977	1970	1971	1981	1974	1976
Bu/A	30	29	26	25	18	17	12	11	6
Stage 1*	6/13	6/6	5/30	5/23	5/30	5/23	5/30	5/30	5/23
Stage 4**	9/12	9/12	9/5	8/29	9/12	9/5	9/5	9/12	9/5
G.S. ppt***	18.5	18.2	15.4	17.7	11.9	16.8	13.7	11.4	5.1
Fall ppt	2.7	11.2	5.4	1.4	3.2	6.3	1.3	4.5	3.5

*50% (+ 20%) of the district acreage planted.

**<25% (+ 20%) of the district acreage with lower leaves dropping from plants.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix B (Cont). Ranking of soybean yields in EC South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Brookings

Rank	1	2	3	4	13	14	15	16	17
Year	1978	1972	1969	1977	1971	1965	1967	1980	1976
Bu/A	24	24	23	22	16	16	15	12	6
Stage 1*	6/6	6/6	6/6	5/16	5/30	6/6	5/30	5/23	5/23
Stage 4**	9/5	9/12	9/12	9/5	8/29	9/12	9/12	9/5	8/29
G.S. ppt***	17.9	22.6	17.2	21.2	10.1	15.7	16.6	14.4	10.2
Fall ppt	9.3	8.7	8.7	1.9	5.9	1.9	2.3	4.9	6.5

County: Lake

Rank	1	2	3	4	13	14	15	16	17
Year	1969	1972	1975	1981	1968	1967	1978	1974	1976
Bu/A	27	25	24	23	18	18	17	13	4
Stage 1*	6/6	6/6	5/30	5/23	6/6	5/30	6/6	6/6	5/23
Stage 4**	9/12	9/12	8/29	9/5	9/12	9/12	9/5	9/12	8/29
G.S. ppt***	15.1	22.5	21.4	10.7	15.8	14.1	14.3	16.4	7.2
Fall ppt	7.1	10.5	0.8	2.5	2.2	4.5	9.2	8.2	4.9

County: Minnehaha

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1978	1972	1969	1967	1981	1970	1974	1976
Bu/A	31	30	30	28	24	23	23	17	12
Stage 1*	5/30	6/6	6/6	6/6	5/30	5/23	5/30	6/6	5/23
Stage 4**	9/12	9/5	9/12	9/12	9/12	9/5	9/5	9/12	8/29
G.S. ppt***	25.6	18.8	19.2	17.2	13.2	13.1	18.3	15.9	8.6
Fall ppt	3.1	9.8	9.1	9.0	8.0	2.8	5.5	12.4	3.9

County: Moody

Rank	1	2	3	4	13	14	15	16	17
Year	1969	1972	1978	1975	1968	1967	1966	1974	1976
Bu/A	34	31	29	29	24	24	24	19	12
Stage 1*	6/6	6/6	6/6	5/30	6/6	5/30	5/30	6/6	5/23
Stage 4**	9/12	9/12	9/5	8/29	9/12	9/12	9/12	9/12	8/29
G.S. ppt***	13.8	21.0	14.1	15.3	15.6	15.0	12.2	14.5	7.1
Fall ppt	10.2	10.1	8.1	2.0	1.0	7.1	6.3	8.4	4.1

*50% (+ 20%) of the district acreage planted.
**<25% (+ 20%) of the district acreage with lower leaves dropping from plants.
***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix B (Cont). Ranking of soybean yields in SE South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Clay

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1969	1980	1966	1970	1968	1974	1975	1976
Bu/A	31	31	30	30	24	22	22	22	17
Stage 1*	6/6	6/6	5/30	5/30	5/30	5/30	5/30	5/30	5/23
Stage 4**	9/12	9/19	8/29	9/12	9/5	9/12	9/12	9/12	8/29
G.S. ppt***	23.5	20.8	13.2	17.1	13.2	16.1	13.8	15.8	11.4
Fall ppt	1.9	10.7	8.7	7.9	5.6	2.0	10.8	3.7	4.6

County: Lincoln

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1972	1980	1966	1968	1978	1974	1970	1976
Bu/A	33	32	31	31	24	24	20	18	14
Stage 1*	6/6	6/6	5/30	5/30	5/30	5/30	5/30	5/30	5/23
Stage 4**	9/12	9/12	8/28	9/12	9/12	9/5	9/12	9/5	8/29
G.S. ppt***	22.3	17.4	10.1	13.4	18.0	22.3	13.6	12.0	9.0
Fall ppt	1.8	6.3	7.2	8.8	1.8	0.3	8.2	4.7	6.7

County: Turner

Rank	1	2	3	4	13	14	15	16	17
Year	1966	1978	1972	1979	1967	1981	1974	1970	1976
Bu/A	31	31	30	29	21	20	18	17	14
Stage 1*	5/30	5/30	6/6	6/6	5/30	5/30	5/30	5/30	5/23
Stage 4**	9/12	9/5	9/12	9/12	9/12	9/5	9/12	9/5	8/29
G.S. ppt***	19.0	22.4	20.4	18.7	12.6	12.6	12.8	14.3	9.4
Fall ppt	7.0	7.8	9.0	4.7	8.1	3.1	6.9	7.0	7.3

County: Union

Rank	1	2	3	4	13	14	15	16	17
Year	1969	1966	1981	1979	1968	1970	1974	1975	1976
Bu/A	33	32	31	31	25	23	22	21	16
Stage 1*	6/6	5/30	5/30	6/6	5/30	5/30	5/30	5/30	5/23
Stage 4**	9/19	9/12	9/5	9/12	9/12	9/5	9/12	9/12	8/29
G.S. ppt***	20.6	17.1	16.5	23.6	13.6	16.2	15.2	20.5	10.5
Fall ppt	9.4	10.5	3.9	3.2	2.3	6.7	9.4	2.6	4.4

*50% (+ 20%) of the district acreage planted.

**<25% (+ 20%) of the district acreage with lower leaves dropping from plants.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix C. Ranking of sorghum yields in Central South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Aurora

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1969	1971	1966	1965	1980	1974	1967	1976
Bu/A	45	43	43	42	29	26	26	23	11
Stage 1*	6/6	6/6	6/6	5/30	5/30	5/30	6/6	6/6	6/6
Stage 3**	9/12	9/12	8/29	9/5	9/12	9/5	9/12	9/12	9/5
G.S. ppt***	16.7	12.3	12.3	14.9	15.3	10.0	12.2	16.7	8.1
Fall ppt	1.1	5.2	5.4	6.3	1.6	3.1	7.3	3.4	4.3

County: Beadle

Rank	1	2	3	4	13	14	15	16	17
Year	1969	1973	1966	1978	1975	1974	1967	1965	1976
Bu/A	53	45	45	42	22	22	20	19	10
Stage 1*	6/6	5/30	5/30	6/13	6/6	6/6	6/6	5/30	6/6
Stage 3**	9/12	9/5	9/5	9/5	9/5	9/12	9/12	9/12	9/5
G.S. ppt***	14.2	11.1	16.4	13.7	14.8	11.6	13.2	14.1	6.6
Fall ppt	5.0	5.0	4.5	5.7	0.7	5.8	6.2	1.1	1.8

County: Brule

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1978	1977	1979	1965	1975	1974	1980	1976
Bu/A	56	52	46	42	28	22	22	16	5
Stage 1*	6/13	6/13	6/6	6/6	5/30	6/6	6/6	5/30	6/6
Stage 3**	9/12	9/5	8/22	9/12	9/12	9/5	9/12	9/5	9/5
G.S. ppt***	19.8	14.0	15.1	16.7	15.3	13.0	12.2	10.0	8.1
Fall ppt	7.8	5.8	4.4	1.1	1.6	0.8	7.3	3.1	4.3

County: Jerauld

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1973	1979	1977	1974	1980	1967	1965	1976
Bu/A	51	47	47	43	28	23	22	14	8
Stage 1*	6/13	5/30	6/6	6/6	6/6	5/30	6/6	5/30	6/6
Stage 3**	9/12	9/5	9/12	8/29	9/12	9/5	9/12	9/2	9/5
G.S. ppt***	21.2	13.5	16.6	16.1	15.6	12.4	16.4	15.7	7.0
Fall ppt	8.8	5.0	1.4	3.6	6.8	3.0	4.0	0.5	4.4

*50% (+ 20%) of the district acreage planted.

**>50% (+ 20%) of the district acreage heads turning color.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 3. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix C (Cont). Ranking of sorghum yields in EC South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Davidson

Rank	1	2	3	4	13	14	15	16	17
Year	1969	1978	1979	1981	1967	1975	1980	1974	1976
Bu/A	58	54	48	44	27	27	26	17	9
Stage 1*	6/6	6/13	6/6	5/30	6/6	5/30	5/30	6/6	5/30
Stage 3**	9/12	9/5	9/12	9/5	9/19	9/5	9/5	9/5	9/12
G.S. ppt***	12.8	16.0	19.1	15.8	15.0	13.4	11.3	11.3	10.7
Fall ppt	6.9	7.7	2.9	1.8	2.4	0.7	4.4	7.3	4.8

County: Hanson

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1969	1979	1973	1975	1967	1978	1974	1976
Bu/A	56	55	54	50	27	27	26	24	22
Stage 1*	6/20	6/6	6/6	6/6	5/30	6/6	6/13	6/6	5/30
Stage 3**	9/12	9/12	9/12	9/5	9/5	9/19	9/5	9/5	9/12
G.S. ppt***	19.4	14.6	19.0	12.0	15.1	12.7	24.0	10.9	10.5
Fall ppt	8.4	5.5	3.2	5.0	0.7	4.8	10.6	7.6	4.1

County: Miner

Rank	1	2	3	4	13	14	15	16	17
Year	1973	1969	1979	1978	1981	1967	1965	1974	1976
Bu/A	50	47	46	46	28	27	26	24	15
Stage 1*	6/6	6/6	6/6	6/13	5/30	6/6	5/30	6/6	5/30
Stage 3**	9/5	9/12	9/12	9/5	9/5	9/19	9/12	9/5	9/12
G.S. ppt***	14.6	10.8	20.4	16.0	14.1	18.6	16.7	12.0	9.1
Fall ppt	5.0	5.9	2.5	9.0	1.6	3.5	2.2	8.9	4.0

County: Sanborn

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1973	1971	1968	1975	1967	1965	1974	1976
Bu/A	49	44	44	42	28	24	23	21	9
Stage 1*	6/6	6/6	5/30	6/6	5/30	6/6	5/30	6/6	5/30
Stage 3**	9/12	9/5	9/5	9/19	9/5	9/19	9/12	9/5	9/12
G.S. ppt***	17.5	13.6	13.4	18.6	16.2	15.0	15.4	12.5	3.9
Fall ppt	2.4	4.8	5.7	2.3	0.7	3.0	1.5	9.8	9.0

*50% (+ 20%) of the district acreage planted.
**>50% (+ 20%) of the district acreage heads turning color.
***Growth Season (GS) precipitation (inches) between March 1 and Stage 3. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix C (Cont). Ranking of sorghum yields in SC South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Gregory

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1973	1977	1966	1980	1967	1975	1974	1976
Bu/A	54	53	52	47	28	26	24	21	17
Stage 1*	6/6	6/6	6/6	6/6	5/30	6/6	6/13	6/13	6/6
Stage 3**	9/19	9/5	9/5	9/12	9/12	9/19	9/19	9/19	9/5
G.S. ppt***	25.4	19.8	24.5	16.7	14.2	11.5	13.8	13.8	8.3
Fall ppt	7.7	4.6	3.4	6.2	6.8	3.0	1.3	7.9	2.0

County: Lyman

Rank	1	2	3	4	13	14	15	16	17
Year	1978	1977	1966	1972	1970	1980	1974	1967	1976
Bu/A	48	46	42	37	22	20	17	17	5
Stage 1*	6/6	6/6	6/6	6/6	5/30	5/30	6/13	6/6	6/6
Stage 3**	9/12	9/5	9/12	9/19	9/5	9/12	9/19	9/19	9/9
G.S. ppt***	13.6	19.0	12.2	15.6	14.3	10.3	14.8	12.4	7.3
Fall ppt	4.5	1.0	6.1	6.9	2.6	2.4	5.0	3.0	1.6

County: Mellette

Rank	1	2	3	4	13	14	15	16	17
Year	1973	1977	1978	1972	1974	1980	1967	1975	1976
Bu/A	40	35	34	31	18	18	14	14	3
Stage 1*	6/6	6/6	6/6	6/6	6/13	5/30	6/6	6/13	6/6
Stage 3**	9/5	9/5	9/12	9/19	9/19	9/12	9/19	9/12	9/5
G.S. ppt***	15.4	19.6	15.8	16.2	9.0	9.3	12.3	12.9	9.6
Fall ppt	2.5	1.0	4.3	4.7	7.7	3.9	5.7	0.9	3.1

County: Tripp

Rank	1	2	3	4	13	14	15	16	17
Year	1977	1966	1972	1968	1965	1974	1967	1975	1976
Bu/A	50	46	44	38	25	22	19	19	6
Stage 1*	6/6	6/6	6/6	6/6	6/6	6/13	6/6	6/13	6/6
Stage 3**	9/5	9/12	9/19	9/19	9/12	9/19	9/19	9/12	9/5
G.S. ppt***	29.1	17.6	19.0	20.7	21.0	12.2	14.6	14.7	9.0
Fall ppt	2.8	6.0	5.7	3.8	1.6	8.9	4.3	1.6	2.8

*50% (+ 20%) of the district acreage planted.
**>50% (+ 20%) of the district acreage heads turning color.
***Growth Season (GS) precipitation (inches) between March 1 and Stage 3. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix C (Cont). Ranking of sorghum yields in SE South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Bon Homme

Rank	1	2	3	4	13	14	15	16	17
Year	1977	1972	1978	1969	1971	1968	1980	1974	1975
Bu/A	65	64	60	59	42	41	37	35	33
Stage 1*	5/30	6/13	6/6	6/6	5/30	6/6	5/30	5/30	6/6
Stage 3**	8/29	9/26	9/5	9/19	9/5	9/12	9/5	9/19	9/5
G.S. ppt***	22.5	24.7	18.9	17.3	16.8	15.1	10.6	10.7	14.8
Fall ppt	2.1	7.0	10.3	8.2	6.1	2.4	7.6	12.0	1.8

County: Charles Mix

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1978	1973	1969	1967	1980	1976	1974	1975
Bu/A	62	58	54	52	32	30	27	27	25
Stage 1*	6/13	6/6	6/6	6/6	6/6	5/30	5/30	5/30	6/6
Stage 3**	9/26	9/5	9/12	9/19	9/26	9/5	9/5	9/19	9/5
G.S. ppt***	22.1	16.7	18.8	14.6	20.1	13.1	10.0	11.1	15.3
Fall ppt	7.3	7.4	4.8	6.7	3.8	5.7	2.5	9.9	0.7

County: Douglas

Rank	1	2	3	4	13	14	15	16	17
Year	1969	1978	1972	1979	1980	1967	1975	1974	1976
Bu/A	63	63	62	61	31	31	28	24	22
Stage 1*	6/6	6/6	6/13	6/6	5/23	6/6	5/30	5/30	5/30
Stage 3**	9/19	9/5	9/26	9/12	9/5	9/19	2/5	9/19	9/5
G.S. ppt***	14.6	18.3	22.5	16.5	10.6	16.2	14.1	15.0	10.0
Fall ppt	5.9	8.3	7.1	3.2	5.1	3.2	0.9	8.8	2.5

County: Hutchinson

Rank	1	2	3	4	13	14	15	16	17
Year	1978	1969	1977	1966	1968	1975	1974	1980	1967
Bu/A	62	61	60	59	41	39	33	31	30
Stage 1*	6/6	6/6	5/30	5/30	6/6	6/6	5/30	5/30	6/6
Stage 3**	9/5	9/19	8/29	9/12	9/12	9/5	9/19	9/5	9/19
G.S. ppt***	17.6	18.3	18.4	16.8	17.6	19.5	14.4	8.9	13.8
Fall ppt	7.3	10.0	2.3	6.8	2.5	1.6	11.3	5.8	5.1

*50% (+ 20%) of the district acreage planted.

**>50% (+ 20%) of the district acreage heads turning color.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 3. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix D. Ranking of oat yields in NC South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Brown

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1971	1972	1978	1980	1973	1966	1974	1976
Bu/A	61	58	55	55	40	36	33	27	12
Stage 1*	5/16	4/25	5/16	5/16	4/25	4/25	5/2	5/2	4/11
Stage 4**	7/25	7/11	7/25	7/25	7/11	7/18	7/18	7/18	7/11
G.S. ppt***	12.5	11.1	16.4	16.4	6.7	6.1	10.3	8.6	4.0
Fall ppt	1.5	4.3	7.2	8.7	1.2	1.8	4.3	5.9	3.2

County: Edmunds

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1979	1978	1967	1973	1966	1980	1974	1976
Bu/A	58	50	48	47	32	23	23	22	12
Stage 1*	4/25	5/16	5/16	4/25	4/25	5/2	4/25	5/2	4/11
Stage 4**	7/11	7/25	7/25	8/1	7/18	7/18	7/11	7/18	7/11
G.S. ppt***	11.8	10.7	14.9	13.4	7.5	7.7	6.4	12.2	5.4
Fall ppt	4.4	1.2	7.1	3.6	1.6	5.0	1.4	5.7	2.1

County: McPherson

Rank	1	2	3	4	13	14	15	16	17
Year	1978	1971	1979	1969	1973	1974	1966	1980	1976
Bu/A	54	53	47	46	29	23	21	18	16
Stage 1*	5/16	4/25	5/16	5/9	4/25	5/2	5/2	4/25	4/11
Stage 4**	7/25	7/11	7/25	8/1	7/18	7/18	7/18	7/11	7/11
G.S. ppt***	11.9	12.1	11.2	12.0	8.9	9.0	7.2	4.7	6.6
Fall ppt	6.2	4.7	1.5	3.0	2.0	8.1	3.1	2.0	1.5

County: Spink

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1971	1978	1981	1975	1973	1974	1966	1976
Bu/A	52	51	51	50	35	30	30	26	12
Stage 1*	5/16	4/25	5/16	4/18	5/23	4/25	5/2	5/2	4/11
Stage 4**	7/25	7/11	7/25	7/4	8/1	7/18	7/18	7/18	7/11
G.S. ppt***	18.6	11.6	20.5	6.4	11.3	6.8	11.4	9.7	5.3
Fall ppt	1.3	9.1	1.6	2.2	1.8	5.5	0	5.1	2.0

*50% (+ 20%) of the district acreage planted.
**>50% (+ 20%) of the district acreage heads turning color.
***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix D (Cont). Ranking of oat yields in NE South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Clark

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1979	1972	1977	1973	1975	1965	1974	1976
Bu/A	57	51	51	49	44	40	28	25	14
Stage 1*	4/18	5/23	5/23	4/25	4/25	5/23	5/2	5/2	4/11
Stage 4**	7/11	7/25	8/1	7/4	7/18	7/18	7/25	7/18	7/11
G.S. ppt***	10.8	13.1	18.6	13.9	6.8	12.1	15.6	9.4	4.9
Fall ppt	5.9	3.2	10.6	2.2	3.7	1.4	1.6	3.8	3.6

County: Codington

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1965	1980	1977	1970	1973	1966	1974	1976
Bu/A	62	58	57	56	45	41	32	32	12
Stage 1*	4/18	5/2	4/25	4/25	5/9	4/25	5/2	5/2	4/11
Stage 4**	7/11	7/25	7/11	7/4	7/18	7/18	7/18	7/18	7/11
G.S. ppt***	11.4	17.1	10.7	16.2	12.2	8.5	9.9	9.3	5.5
Fall ppt	6.8	1.4	4.3	2.4	5.7	3.1	6.0	6.0	5.5

County: Day

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1978	1979	1972	1970	1966	1975	1974	1976
Bu/A	60	58	54	53	42	38	38	19	17
Stage 1*	4/18	5/16	5/23	5/23	5/9	5/2	5/23	5/2	4/11
Stage 4**	7/11	7/25	7/25	8/1	7/18	7/18	7/18	7/18	7/11
G.S. ppt***	13.3	15.1	12.0	16.8	9.8	9.8	9.0	8.9	3.3
Fall ppt	6.0	8.7	2.4	9.8	2.9	6.3	1.0	5.0	4.0

County: Roberts

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1977	1969	1978	1980	1975	1966	1974	1976
Bu/A	63	59	57	56	45	43	35	26	20
Stage 1*	4/18	4/25	5/9	5/16	4/25	5/23	5/2	5/2	4/11
Stage 4**	7/11	7/4	8/1	7/25	7/11	7/18	7/18	7/18	7/11
G.S. ppt***	12.8	12.6	9.9	15.1	5.4	12.5	8.4	8.3	3.4
Fall ppt	6.4	1.4	8.1	11.2	3.3	1.6	5.4	4.5	3.5

*50% (+ 20%) of the district acreage planted.

**>50% (+ 20%) of the district acreage heads turning color.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix D (Cont). Ranking of oat yields in EC South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Brookings

Rank	1	2	3	4	13	14	15	16	17
Year	1977	1968	1979	1969	1970	1978	1972	1966	1976
Bu/A	60	59	56	56	50	48	45	42	28
Stage 1*	4/18	4/18	5/9	5/9	5/2	5/9	4/25	4/18	4/11
Stage 4**	7/4	7/18	7/25	7/25	7/11	7/18	7/18	7/11	6/27
G.S. ppt***	13.9	12.5	14.0	13.8	14.2	13.6	17.1	9.7	6.7
Fall ppt	1.9	1.7	3.3	8.7	4.4	9.3	8.7	6.0	6.5

County: Kingsbury

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1981	1969	1965	1972	1978	1974	1966	1976
Bu/A	57	56	55	55	45	44	44	36	23
Stage 1*	5/9	4/11	5/9	4/25	4/25	5/9	4/25	4/18	4/11
Stage 4**	7/25	7/4	7/25	7/11	7/18	7/18	7/18	7/11	6/27
G.S. ppt***	12.5	7.2	9.5	19.4	20.8	12.2	10.3	6.6	4.8
Fall ppt	2.8	2.4	6.4	1.6	9.8	9.5	4.6	6.3	4.4

County: McCook

Rank	1	2	3	4	13	14	15	16	17
Year	1977	1971	1965	1973	1966	1981	1978	1968	1976
Bu/A	60	54	52	50	40	37	35	34	33
Stage 1*	4/18	4/18	4/25	4/25	4/18	4/11	5/9	4/18	4/11
Stage 4**	7/4	7/11	7/11	7/18	7/11	7/4	7/18	7/18	6/27
G.S. ppt***	13.2	11.0	16.7	8.4	9.1	8.3	14.2	11.0	7.4
Fall ppt	3.2	6.6	1.8	4.7	5.7	2.8	10.9	2.7	5.7

County: Minnehaha

Rank	1	2	3	4	13	14	15	16	17
Year	1977	1975	1973	1974	1972	1970	1966	1981	1976
Bu/A	66	65	64	63	50	47	45	41	39
Stage 1*	4/18	5/9	4/25	4/25	4/25	5/2	4/18	4/11	4/11
Stage 4**	7/4	7/18	7/18	7/18	7/18	7/11	7/11	7/4	6/27
G.S. ppt***	10.7	10.7	12.4	9.8	16.3	15.8	7.4	8.9	5.8
Fall ppt	1.6	1.1	5.6	12.4	9.0	5.5	6.2	2.8	3.9

*50% (+ 20%) of the district acreage planted.
**>50% (+ 20%) of the district acreage heads turning color.
***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix D (Cont). Ranking of oat yields in SE South Dakota betweem the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Bon Homme

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1977	1979	1967	1974	1966	1976	1981	1968
Bu/A	61	57	53	49	41	39	35	28	23
Stage 1*	4/18	4/18	5/2	4/11	4/25	4/11	4/4	4/11	4/11
Stage 4**	7/4	6/27	7/18	7/18	7/11	7/11	7/4	7/4	7/4
G.S. ppt***	12.7	15.3	12.4	12.4	6.9	7.4	2.6	6.6	9.8
Fall ppt	6.1	2.1	3.2	4.3	11.9	6.3	3.9	3.4	2.4

County: Charles Mix

Rank	1	2	3	4	13	14	15	16	17
Year	1977	1971	1972	1979	1976	1966	1981	1968	1980
Bu/A	52	51	51	50	33	30	30	29	29
Stage 1*	4/18	4/18	4/18	5/2	4/4	4/11	4/11	4/11	4/18
Stage 4**	6/27	7/4	7/18	7/18	7/4	7/11	7/4	7/4	7/4
G.S. ppt***	13.8	11.5	17.1	11.9	7.6	6.6	10.4	8.7	6.3
Fall ppt	2.8	6.2	7.3	2.5	2.5	4.0	3.3	3.5	5.7

County: Hutchinson

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1977	1979	1974	1976	1966	1970	1968	1981
Bu/A	57	54	51	50	39	36	33	28	28
Stage 1*	4/18	4/18	5/2	4/25	4/4	4/11	5/2	4/11	4/11
Stage 4**	7/4	6/27	7/18	7/11	7/4	7/11	7/11	7/4	7/4
G.S. ppt***	12.8	11.5	13.0	9.6	10.2	7.8	10.5	11.2	6.3
Fall ppt	6.7	2.3	3.4	11.3	5.3	6.8	6.9	2.5	2.8

County: Turner

Rank	1	2	3	4	13	14	15	16	17
Year	1977	1971	1974	1965	1969	1978	1968	1981	1970
Bu/A	67	61	55	54	40	40	39	34	32
Stage 1*	4/18	4/18	4/25	4/25	5/9	5/9	4/11	4/11	5/2
Stage 4**	6/27	7/4	7/11	7/11	7/18	7/18	7/4	7/4	7/11
G.S. ppt***	12.3	9.2	9.8	18.1	11.2	13.0	13.4	6.5	12.6
Fall ppt	3.2	7.2	6.9	3.0	9.4	8.8	1.9	3.1	7.0

*50% (+ 20%) of the district acreage planted.

**>50% (+ 20%) of the district acreage heads turning color.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix E. Ranking of spring wheat yields in NW South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Corson

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1972	1978	1973	1977	1970	1966	1974	1980
Bu/A	26	22	21	20	16	16	14	12	12
Stage 1*	4/25	5/2	5/16	4/25	4/25	5/9	4/25	5/2	4/18
Stage 4**	7/25	8/8	8/1	7/25	7/11	7/25	8/1	7/18	7/4
G.S. ppt***	13.5	10.2	13.5	10.7	7.1	11.6	7.4	7.0	2.4
Fall ppt	5.8	6.9	7.3	3.2	0.9	0.6	2.8	7.4	6.7

County: Dewey

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1971	1973	1979	1965	1976	1974	1966	1980
Bu/A	27	25	24	23	13	12	10	9	8
Stage 1*	5/2	4/25	4/25	5/2	5/9	4/18	5/2	4/25	4/18
Stage 4**	8/8	7/25	7/25	7/25	8/1	7/18	7/18	8/1	7/4
G.S. ppt***	11.7	12.3	8.6	7.0	13.1	9.5	7.2	11.6	4.7
Fall ppt	5.9	3.1	2.6	1.8	0.5	1.8	6.6	7.3	2.4

County: Perkins

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1972	1973	1971	1975	1965	1966	1981	1980
Bu/A	30	27	24	23	17	15	14	13	12
Stage 1*	5/2	5/2	4/25	4/25	5/16	5/9	4/25	4/18	4/18
Stage 4**	7/25	8/8	7/25	7/25	8/1	8/8	8/1	7/18	7/4
G.S. ppt***	9.1	14.7	10.8	11.4	14.6	18.5	13.6	9.0	3.9
Fall ppt	2.7	4.9	2.9	4.6	1.4	1.3	2.1	3.3	2.1

County: Ziebach

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1973	1968	1971	1970	1976	1974	1980	1966
Bu/A	28	23	22	21	15	11	10	10	8
Stage 1*	5/2	4/25	4/25	4/25	5/9	4/18	5/2	4/18	4/25
Stage 4**	8/8	7/25	8/8	7/25	8/1	7/18	7/18	7/4	8/1
G.S. ppt***	15.9	11.3	10.6	10.3	10.3	11.1	7.0	5.2	7.7
Fall ppt	5.6	2.3	2.0	4.3	0.6	1.2	6.0	0.8	2.6

*50% (+ 20%) of the district acreage planted.
**>50% (+ 20%) of the district acreage heads turning color.
***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix E (Cont). Ranking of spring wheat yields in NC South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Brown

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1979	1977	1967	1978	1965	1966	1974	1976
Bu/A	30	27	27	26	20	18	17	15	6
Stage 1*	4/18	5/16	4/25	4/18	5/9	5/2	4/25	4/25	4/11
Stage 4**	7/11	7/25	7/4	8/1	7/25	7/25	7/18	7/18	7/4
G.S. ppt***	11.1	12.5	9.4	10.3	16.4	11.0	10.3	8.7	3.9
Fall ppt	4.3	1.5	1.2	3.7	8.7	0.8	4.3	5.9	3.6

County: Edmunds

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1981	1977	1967	1965	1966	1974	1980	1976
Bu/A	25	22	21	21	14	13	13	11	7
Stage 1*	4/18	4/11	4/25	4/18	5/2	4/25	4/25	4/18	4/11
Stage 4**	7/11	7/11	7/4	8/1	7/25	7/18	7/18	7/11	7/4
G.S. ppt***	11.8	8.8	10.3	13.4	11.3	7.7	12.7	5.7	2.1
Fall ppt	4.4	3.5	1.3	3.6	0.8	5.0	5.7	12.2	6.9

County: McPherson

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1981	1967	1978	1965	1974	1966	1980	1976
Bu/A	26	22	21	21	14	12	12	9	8
Stage 1*	4/18	4/11	4/18	5/9	5/2	4/25	4/25	4/18	4/11
Stage 4**	7/11	7/11	8/1	7/25	7/25	7/18	7/18	7/11	7/4
G.S. ppt***	12.1	8.3	11.3	11.9	9.8	9.0	7.2	4.1	6.0
Fall ppt	4.7	4.0	2.0	6.2	0.9	8.1	4.1	2.0	1.5

County: Spink

Rank	1	2	3	4	13	14	15	16	17
Year	1977	1971	1973	1972	1975	1965	1974	1966	1976
Bu/A	28	27	24	24	18	16	15	15	7
Stage 1*	4/25	4/18	4/25	5/9	5/9	5/2	4/25	4/25	4/11
Stage 4**	7/4	7/11	7/11	8/1	7/25	7/25	7/18	7/18	7/4
G.S. ppt***	12.3	11.6	6.6	18.9	11.3	13.2	11.4	9.7	5.3
Fall ppt	2.8	4.5	1.3	9.1	0.1	0.9	5.8	4.1	2.8

*50% (+ 20%) of the district acreage planted.

**>50% (+ 20%) of the district acreage heads turning color.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix E (Cont). Ranking of spring wheat yields in NE South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Clark

Rank	1	2	3	4	13	14	15	16	17
Year	1979	1971	1977	1967	1965	1966	1974	1975	1976
Bu/A	27	26	26	26	18	15	15	15	8
Stage 1*	5/16	4/18	4/18	4/18	5/2	4/25	4/25	5/9	4/11
Stage 4**	7/25	7/11	7/4	8/1	8/1	7/18	7/18	7/25	7/11
G.S. ppt***	13.1	11.0	13.9	8.0	15.7	9.6	9.6	12.5	3.6
Fall ppt	3.2	5.9	2.1	4.1	1.6	5.8	3.8	1.4	4.9

County: Day

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1977	1981	1967	1966	1965	1974	1975	1976
Bu/A	34	29	28	28	19	17	13	13	7
Stage 1*	4/18	4/18	4/11	4/18	4/25	5/2	4/25	5/9	4/11
Stage 4**	7/11	7/4	7/11	8/1	7/18	8/1	7/18	7/25	7/11
G.S. ppt***	13.5	12.0	6.0	10.8	9.8	17.0	8.9	10.2	3.2
Fall ppt	6.0	1.1	1.8	3.9	6.7	2.0	5.0	1.0	4.0

County: Marshall

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1973	1979	1972	1978	1974	1966	1965	1976
Bu/A	36	33	28	28	21	20	20	20	11
Stage 1*	4/18	4/25	5/16	5/16	5/16	4/25	4/25	5/2	4/11
Stage 4**	7/11	7/18	7/25	8/1	7/25	7/18	7/18	8/1	7/11
G.S. ppt***	11.0	9.0	8.8	13.9	14.6	8.2	10.8	17.4	5.6
Fall ppt	5.2	1.6	1.7	7.0	8.2	5.4	4.5	2.2	3.1

County: Roberts

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1973	1967	1977	1974	1965	1966	1978	1976
Bu/A	33	31	28	28	20	20	19	19	14
Stage 1*	4/18	4/25	4/18	4/18	4/25	5/2	4/25	5/16	4/11
Stage 4**	7/11	7/18	8/1	7/4	7/18	8/1	7/18	7/25	7/11
G.S. ppt***	13.3	9.3	15.3	12.6	8.3	19.9	8.3	15.1	3.9
Fall ppt	6.3	1.3	3.2	1.4	4.5	2.2	5.4	11.2	3.5

*50% (+ 20%) of the district acreage planted.
**>50% (+ 20%) of the district acreage heads turning color.
***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix E (Cont). Ranking of spring wheat yields in Central South Dakota between the years 1965 and 1982, associated rainfall, and crop developmental stages.

County: Beadle

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1977	1979	1973	1981	1975	1974	1966	1976
Bu/A	25	25	23	22	15	14	13	12	7
Stage 1*	4/18	4/18	4/25	4/18	4/4	5/2	4/18	4/11	4/4
Stage 4**	7/11	7/4	7/25	7/11	7/4	7/18	7/11	7/11	7/4
G.S. ppt***	7.3	11.2	10.2	7.4	4.9	11.6	10.2	8.0	4.4
Fall ppt	4.6	2.3	1.6	5.5	1.5	0.7	5.7	4.5	1.8

County: Hand

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1973	1977	1979	1965	1978	1966	1974	1976
Bu/A	28	23	23	23	17	13	12	12	5
Stage 1*	4/18	4/18	4/18	4/25	4/25	5/9	4/11	4/18	4/4
Stage 4**	7/11	7/11	7/4	7/25	7/11	7/25	7/11	7/11	7/4
G.S. ppt***	9.8	7.7	11.2	9.7	10.5	11.6	6.9	9.9	3.5
Fall ppt	3.2	3.3	1.9	1.2	0.6	7.5	6.0	3.1	1.8

County: Hughes

Rank	1	2	3	4	13	14	15	16	17
Year	1981	1968	1972	1967	1980	1975	1974	1966	1976
Bu/A	23	22	21	21	15	12	11	10	5
Stage 1*	4/4	4/11	4/25	4/11	4/18	5/2	4/18	4/11	4/4
Stage 4**	7/11	7/18	8/1	7/25	7/4	7/18	7/11	7/11	7/4
G.S. ppt***	12.3	15.6	16.0	11.9	5.6	13.9	9.5	6.3	2.6
Fall ppt	5.2	2.9	5.4	3.6	1.6	1.1	5.2	4.2	6.3

County: Sully

Rank	1	2	3	4	13	14	15	16	17
Year	1981	1971	1972	1968	1975	1980	1974	1966	1976
Bu/A	27	26	24	24	15	14	12	8	8
Stage 1*	4/4	4/18	4/25	4/11	5/2	4/18	4/18	4/11	4/4
Stage 4**	7/11	7/11	8/1	7/18	7/18	7/4	7/11	7/11	7/4
G.S. ppt***	13.2	11.1	14.4	17.2	11.3	4.5	7.6	6.1	5.0
Fall ppt	4.9	4.6	7.9	1.8	1.4	1.7	4.8	3.5	2.5

*50% (+ 20%) of the district acreage planted.

**>50% (+ 20%) of the district acreage heads turning color.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix F. Ranking of winter wheat yields in WC South Dakota between the years 1965 and 1982, associated precipitation, and crop developmental stages.

County: Meade

Rank	1	2	3	4	13	14	15	16	17
Year	1967	1975	1972	1971	1969	1980	1966	1979	1965
Bu/A	41	38	36	36	24	22	22	18	15
Stage 1*	9/19	9/19	9/19	9/19	9/19	9/19	9/12	9/12	9/19
Stage 4**	7/11	7/11	7/4	6/27	7/11	7/4	7/4	7/11	7/11
G.S. ppt***	12.6	13.7	11.2	11.9	8.3	5.4	7.0	7.6	14.6
Fall ppt	2.7	0.7	6.5	1.9	1.7	0.6	2.0	1.8	0.9
Nov. ppt	0.4	0.1	0.8	1.4	0.5	0	0	1.2	0.5

County: Haakon

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1968	1981	1975	1966	1979	1980	1976	1965
Bu/A	41	37	36	35	21	19	19	13	11
Stage 1*	9/19	9/19	9/12	9/19	9/12	9/12	9/19	9/19	9/19
Stage 4**	6/27	7/18	6/27	7/11	7/4	7/11	7/4	6/27	7/11
G.S. ppt***	8.8	9.1	4.5	8.7	5.3	8.3	4.5	5.3	9.8
Fall ppt	3.0	1.2	2.6	1.3	2.6	1.6	1.2	0.7	0.2
Nov. ppt	0.5	0.2	0.5	0.3	0.6	0.8	0	0.3	0

County: Pennington

Rank	1	2	3	4	13	14	15	16	17
Year	1967	1973	1971	1968	1980	1970	1966	1979	1965
Bu/A	40	38	38	37	25	25	23	20	14
Stage 1*	9/19	9/12	9/19	9/19	9/19	9/26	9/12	9/12	9/19
Stage 4**	7/11	7/4	6/27	7/11	7/4	7/11	7/4	7/11	7/4
G.S. ppt***	15.6	9.3	12.2	11.7	5.3	12.9	9.2	8.0	12.7
Fall ppt	5.1	1.9	3.6	2.5	1.2	2.3	2.3	1.5	1.5
Nov. ppt	0.8	0.4	0.8	0.4	0.1	0.5	0.2	0.8	0.2

County: Stanley

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1972	1969	1975	1969	1979	1980	1976	1965
Bu/A	40	38	37	34	21	20	20	14	10
Stage 1*	9/19	9/19	9/19	9/19	9/19	9/12	9/19	9/19	9/19
Stage 4**	6/27	7/4	7/11	7/11	7/4	7/11	7/4	6/27	7/11
G.S. ppt***	8.4	11.1	9.1	10.1	6.3	7.6	7.8	3.9	8.9
Fall ppt	1.8	4.4	1.8	1.0	1.4	1.0	1.2	0.9	0.5
Nov. ppt	0.5	0.5	0	0	0.3	0.4	0	0.1	0.1

*50% (+ 20%) of the district acreage planted.

**50% ($\mp$ 20%) of the district acreage with plants having dented ears.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix F (Cont.). Ranking of winter wheat yields in Central South Dakota between the years 1965 and 1982, associated precipitation, and crop developmental stage.

County: Brule

Rank	1	2	3	4	13	14	15	16	17
Year	1974	1977	1971	1966	1980	1981	1970	1965	1976
Bu/A	35	35	32	32	23	23	22	16	14
Stage 1*	9/19	9/19	9/19	9/19	9/19	9/12	9/26	9/19	9/19
Stage 4**	7/4	6/27	7/4	7/4	7/4	6/27	7/4	7/4	6/20
G.S. ppt***	11.5	12.1	9.2	7.4	6.1	6.8	12.7	10.3	5.1
Fall ppt	7.3	4.4	5.4	6.2	3.1	2.1	4.8	1.5	4.3
Nov. ppt	0	0	1.4	0.5	0.2	0	0.3	0	0.7

County: Hand

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1980	1971	1973	1966	1979	1965	1978	1976
Bu/A	35	31	30	28	20	18	16	16	12
Stage 1*	9/19	9/19	9/19	9/19	9/19	9/19	9/19	9/19	9/19
Stage 4**	7/4	7/4	7/4	7/4	7/4	7/11	7/18	7/4	6/20
G.S. ppt***	8.6	6.5	9.7	7.6	6.3	8.8	10.9	10.6	2.2
Fall ppt	7.2	2.1	3.2	3.3	6.0	1.1	0.6	7.5	1.8
Nov. ppt	1.2	0.8	1.5	1.0	0.1	0.5	0	2.0	0.1

County: Hughes

Rank	1	2	3	4	13	14	15	16	17
Year	1967	1981	1968	1971	1966	1979	1978	1976	1965
Bu/A	34	33	33	32	17	16	15	14	12
Stage 1*	9/19	9/12	9/19	9/19	9/19	9/19	9/19	9/19	9/19
Stage 4**	7/11	6/27	7/11	7/4	7/4	7/11	7/4	6/20	7/4
G.S. ppt***	11.6	10.2	13.8	12.2	5.2	10.2	9.7	2.5	9.8
Fall ppt	3.6	5.2	2.9	4.1	4.2	1.0	6.0	6.3	0.2
Nov. ppt	0.8	0.3	0	0.7	0.3	0.3	1.4	0.1	0.1

County: Sully

Rank	1	2	3	4	13	14	15	16	17
Year	1968	1971	1981	1972	1977	1966	1976	1978	1965
Bu/A	38	36	35	33	20	18	14	14	11
Stage 1*	9/19	9/19	9/12	9/19	9/19	9/19	9/19	9/19	9/19
Stage 4**	7/11	7/11	6/27	7/4	6/27	7/4	6/20	7/4	7/4
G.S. ppt***	13.8	11.1	8.5	9.2	9.1	5.4	4.4	9.8	9.2
Fall ppt	1.8	4.6	4.9	7.9	1.7	3.5	2.5	7.1	0.6
Nov. ppt	0	1.0	0.3	2.0	0.1	0.2	0.2	2.2	0.1

*50% (± 20%) of the district acreage planted.

**50% (∓ 20%) of the district acreage with plants having dented ears.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix F (Cont.). Ranking of winter wheat yields in SW South Dakota between the years 1965 and 1982, associated precipitation, and crop developmental stage.

County: Bennett

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1968	1971	1967	1977	1970	1979	1969	1965
Bu/A	40	38	38	37	28	25	18	17	14
Stage 1*	9/19	9/19	9/19	9/12	9/12	9/26	9/19	9/19	9/19
Stage 4**	7/4	7/4	7/4	7/11	6/27	7/11	7/4	7/4	7/4
G.S. ppt***	9.7	13.4	11.7	9.7	15.2	8.3	10.9	6.3	9.9
Fall ppt	4.4	2.4	3.0	3.1	2.9	3.6	1.5	1.7	1.0
Nov. ppt	0.4	0.2	0.6	0.3	0.2	0.2	0.5	0.4	0

County: Fall River

Rank	1	2	3	4	13	14	15	16	17
Year	1967	1971	1972	1968	1975	1969	1970	1979	1965
Bu/A	39	37	36	36	20	20	19	19	12
Stage 1*	9/12	9/19	9/19	9/19	9/19	9/19	9/26	9/19	9/19
Stage 4**	7/11	7/4	7/4	7/4	7/11	7/11	7/11	7/4	7/4
G.S. ppt***	16.0	12.3	9.7	10.7	9.8	5.5	9.2	7.1	13.6
Fall ppt	5.4	3.2	5.4	2.1	3.0	1.7	1.7	1.4	1.4
Nov. ppt	0.8	0.5	0.8	1.8	0.2	0.4	0.2	0.7	0

County: Washabaugh/Jackson

Rank	1	2	3	4	13	14	15	16	17
Year	1968	1972	1967	1971	1969	1979	1965		
Bu/A	39	36	35	33	22	20	16		
Stage 1*	9/19	9/12	9/12	9/19	9/19	9/12	9/19		
Stage 4**	7/4	7/4	7/4	7/4	7/4	7/11	7/4		
G.S. ppt***	10.6	8.6	16.1	11.0	9.5	9.7	11.2		
Fall ppt	2.3	10.1	4.4	3.6	1.1	1.3	0.3		
Nov. ppt	0.2	1.1	0.3	2.7	0.4	0.6	0.1		

County: Shannon

Rank	1	2	3	4	13	14	15	16	17
Year	1967	1972	1968	1980	1976	1966	1979	1965	1969
Bu/A	42	40	39	33	27	26	19	17	14
Stage 1*	9/12	9/19	9/19	9/19	9/19	9/12	9/19	9/19	9/19
Stage 4**	7/11	7/4	7/4	7/4	6/27	7/11	7/11	7/4	7/4
G.S. ppt***	14.5	12.0	10.0	4.6	6.1	5.0	8.7	14.8	5.1
Fall ppt	3.1	5.8	1.7	2.5	0.8	3.5	1.3	0.4	1.2
Nov. ppt	0.6	0.6	0.2	0.1	0.2	0.5	0.4	0.2	0.1

*50% (+ 20%) of the district acreage planted.

**50% (∓ 20%) of the district acreage with plants having dented ears.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

Appendix F (Cont.). Ranking of winter wheat yields in SC South Dakota between the years 1965 and 1982, associated precipitation, and crop developmental stages.

County: Jones

Rank	1	2	3	4	13	14	15	16	17
Year	1972	1968	1971	1967	1966	1969	1979	1976	1965
Bu/A	39	39	38	37	22	22	21	19	13
Stage 1*	9/12	9/19	9/12	9/19	9/19	9/19	9/12	9/19	9/19
Stage 4**	7/4	7/4	7/4	7/4	7/4	7/4	7/4	6/20	7/4
G.S. ppt***	10.9	14.1	11.4	8.8	8.5	6.5	9.6	3.6	7.5
Fall ppt	6.7	1.9	2.6	3.4	3.7	1.7	0.9	3.0	0.1
Nov. ppt	1.4	0	0.9	0.1	0.1	0.6	0.2	0	0.1

County: Lyman

Rank	1	2	3	4	13	14	15	16	17
Year	1975	1972	1967	1973	1969	1970	1979	1976	1965
Bu/A	35	34	33	33	26	25	20	15	13
Stage 1*	9/19	9/12	9/12	9/12	9/19	9/19	9/12	9/19	9/19
Stage 4**	7/4	7/4	7/4	7/4	7/4	7/11	7/11	6/20	7/4
G.S. ppt***	8.0	11.2	7.2	7.8	4.2	10.5	8.7	3.3	14.2
Fall ppt	1.1	6.9	3.1	2.8	2.0	2.6	1.1	1.6	0.4
Nov. ppt	0	0.6	0.4	1.4	0.5	0	0.2	0.1	0

County: Mellette

Rank	1	2	3	4	13	14	15	16	17
Year	1971	1968	1972	1967	1969	1979	1976	1966	1965
Bu/A	39	39	38	34	22	21	20	17	14
Stage 1*	9/19	9/19	9/12	9/12	9/19	9/12	9/19	9/19	9/19
Stage 4**	7/4	7/4	7/4	7/4	7/4	7/11	6/20	7/4	7/4
G.S. ppt***	8.5	13.1	9.7	10.1	5.3	7.6	4.7	6.5	10.0
Fall ppt	3.8	2.1	4.9	6.1	3.3	2.2	3.5	6.2	1.9
Nov. ppt	1.2	0.1	0.6	0.3	0.2	0.5	0.3	0.3	0.1

County: Tripp

Rank	1	2	3	4	13	14	15	16	17
Year	1973	1972	1977	1968	1969	1970	1965	1976	1981
Bu/A	39	39	36	36	27	26	18	18	16
Stage 1*	9/12	9/12	9/12	9/19	9/19	9/19	9/19	9/19	9/12
Stage 4**	7/4	7/4	6/20	7/4	7/4	7/4	7/4	6/20	6/27
G.S. ppt***	11.1	12.9	21.7	16.1	4.5	10.7	15.4	4.2	9.9
Fall ppt	3.8	5.7	2.8	3.7	4.1	3.5	1.7	2.8	3.6
Nov. ppt	1.8	0.8	0.1	0.1	0.6	0.4	0.1	1.1	0.2

*50% (+ 20%) of the district acreage planted.

**50% (∓ 20%) of the district acreage with plants having dented ears.

***Growth Season (GS) precipitation (inches) between March 1 and Stage 4. Fall ppt is total precipitation for September, October, and November of previous fall.

APPENDIX G

Yield was related to several independent variables according to the following equation:

$$\text{YIELD} = \text{Intercept} + \beta_1 (\text{variable } 1) + \beta_2 (\text{variable } 2) \text{ ------ } + \beta_{14} (\text{variable } 14)$$

A. Independent Variables Evaluated by Stepwise Multiple Regression Analysis as Determinants in Summer Annual Crop Yields

1. May precipitation - inches
2. June precipitation - inches
3. July precipitation - inches
4. August precipitation - inches
5. Previous fall precipitation - inches
6. May highest av. weekly temperature - degrees F
7. July highest av. weekly temperature - degrees F
8. August highest av. weekly temperature - degrees F
9. May - successive weeks < 0.1 inch precipitation
10. June - successive weeks < 0.1 inch precipitation
11. July - successive weeks < 0.1 inch precipitation
12. August - successive weeks < 0.1 inch precipitation
13. September lowest av. weekly temperature - degrees F
14. Location - "dummy variables" Crop Reporting Districts

B. Independent Variables Evaluated by Stepwise Multiple Regression Analysis as Determinants in Winter Wheat Yields. All of above list except #4, #8, #12, and #13, plus the following:

1. January lowest av. weekly temperature - degrees F
2. February lowest av. weekly temperature - degrees F
3. April lowest av. weekly temperature - degrees F
4. November precipitation - inches

Appendix H. Observations* on the 1977-78 and 1978-79 Winter Wheat Seasons in South Dakota

1977-78 Growing Season. Data from the Annual Winter Wheat Survey (AWWS) in mid-October showed very good to excellent levels of soil moisture. About November 9 a heavy snow fell in most areas of the state. This year was unique for South Dakota because in many areas fields were covered with snow from mid-November until mid-March. Normally, such conditions should favor winter wheat survival because of the insulation effect of snow modulating the effects of air temperature change. Another unique characteristic of this season was the unusually warm temperatures from March 28 to April 7, where soil temperatures were 12 to 15°F above average, but soil temperatures also dropped below normal and freezing occurred on April 12 and April 20 in most areas (from Climatological Data of South Dakota, Wm. Lytle). The final distinction was the unusually high levels of soil moisture from mid-March to May 1. Frequently, fields could not be worked until the third week in May because of water saturated soils. Wet conditions prevented walking most fields during an April 19 to 22 trip into the winter wheat area.

Plant Responses in 1977-78. A sequence of environmental occurrences during early spring suggest it as the prime stress period for winter wheat in 1977-78. In most areas, snow cover disappeared in fields around March 12-15. Wheat fields greened uniformly and crop prospects appeared good at this time. Between March 28 and 31 soil temperature approached an unusual high average of 55°F and remained at 50°F for the next week.

During the week of April 10, reports were received of large plant areas turning brown within fields. On April 14, field inspection in Hughes and Stanley counties verified stand losses. Generally, few living plants could be found on north and east slopes in contrast to less severe damage in other areas within a field. Examination of numerous living (green) plants resulted in the observation that secondary roots had not developed.

Poor secondary root development was again found on April 20 in all fields inspected. The number of surviving plants continued to decline, showing as brown patches in fields throughout the winter wheat area. Often grower response was one of surprise because excellent stands (green color) were reported in most areas in mid-March. Typical of such observations was a field of Winalta in the Timber Lake area. This field we judged to have a 100% stand on April 20. However, primary roots were dead and new secondary roots were not apparent. A report was received from Herb Lippert on May 4 indicating that 30 to 40% of the field was replanted.

It was concluded that plants in high loss areas had no functioning roots and had no capacity to develop new secondary ones. Primary roots are often lost through the winter months in South Dakota; however, normally they are replaced

*Summary notes made by D. G. Kenefick following fall/spring surveys of about 120 grower fields made each year. Fields were marked in the fall and a follow-up visit was made about mid-May to determine survival.

by new roots in the early spring, a situation which was not a common occurrence in 1977-78. While surplus soil water helped maintain green plants for at least a month in this unusually wet spring, they eventually succumbed to this "rootless" condition. It is believed that extremely wet soils and freezing conditions before as well as after the March 28-April 7 "hot spell" provided the final blow to the plant's ability to regenerate new roots.

1978-79 Growing Season. Soil moisture conditions were generally good in late summer. However, rainfall was limited in most areas as fall progressed. By mid-October results from the Annual Winter Wheat Survey (AWWS) showed extremely dry soil conditions except for Tripp and Lyman counties. Most fields west and north of these counties contained drought-stressed (wilted) plants, particularly early planted fields. The effect of limited rainfall on plants was further aggravated by an extremely late warm fall period. Soil moisture samples were taken on November 2 at four sites in Stanely County. All showed moisture to be at the incipient wilting point of plants at 12" soil depth and one field showed this deficit at 24". Air temperatures in most areas did not reach the freezing point until around November 10.

The amount of snow cover varied throughout the winter wheat area which influenced the extent to which soil temperature followed changes in air temperature. Early-, mid-, and late-January plus February 16 were periods when lowest air temperatures were observed. The lowest soil temperature recorded at these times was in the range of 2 to -5°F. For the period March 6 to April 15, soil temperature hovered around 32°F which reflects the stabilizing effect of partial snow cover and moderately cool to cold air temperatures during this period.

Plant Responses in 1978-79. An initial report from Harold Wood in mid-March indicated good survival (greening) at the variety plots in Sully County. One week later he reported severe stand reduction which he believed was a consequence of earlier damage rather than freeze stress during the intervening week period.

Field inspections were made on March 29 in the Wall and Sturgis areas revealing serious stand loss at these locations. A more extensive trip covering the area of Winner, Martin, Wall, Eagle Butte, and Pierre was made on April 8-10. This trip confirmed observations made a week earlier. Estimates made at this time projected about a 50% statewide loss, with the area north of Highway 14 experiencing the most severe winterkill. The areas hardest hit corresponded to locations having serious moisture stress during the fall AWWS conducted in mid-October.

The presence of good live secondary roots in the spring of 1979 was in contrast to a lack of such development during the spring of 1978 when inspected as late as April 20-25. In 1977-78, more leaf greening was prevalent. This observation tends to suggest that conditions between the two years had a differential effect on root and leaf development and maintenance. From the standpoint of soil temperature, in 1977-78, soil temperature (under sod) averaged 45 to 50°F for a 10-day period between March 28 and April 7. Through March 31, 1979, only a few soil temperatures (3" below row) were reported above 45°F at one or two recording sites, and typically they ranged between 35 and 40°F. On only two days (March 16 and 17) did temperatures reach or exceed 50°F (Wall) at the 5 PM reading in 1979.

Results from this survey, compared with records of field conditions during the fall Winter Wheat Survey, strongly suggests that those areas where water stressed plants were found last fall were the same areas where total or serious loss was observed this spring. The degree of drought stress may be related to planting date, where early planted fields caused a greater draw-down of soil moisture as a result of a long fall growing period. Plants predisposed to such stress may have been less likely to withstand further freeze stress during the spring and less likely to avoid the invasion of harmful pathogens. Low soil temperatures perhaps stimulate some fungal infection and the lack of bright sunny days has reduced the plant's capacity to combat such infection and to develop new tissues.

SUMMARY

The 1978-79 winter wheat season was the first year where extensive soil temperature measurements were recorded in wheat fields in South Dakota. Therefore, the significance of particular freezing conditions for this year cannot be determined until additional years of data have been accumulated. Furthermore, because of the extensiveness of winter wheat losses this year, the data does not permit a comparison of soil temperatures between areas of high and low survival.

In the Perspectives Section of this report, certain climatic differences between 1977-78 and 1978-79 were highlighted. Besides the temperature differences cited, evidence was proposed as to the role of soil moisture in plant survival. The 1977-78 crop experienced good fall moisture and excessive soil moisture in the spring. In 1978-79, severe moisture stress occurred as observed in mid-October.

Differences were also observed in plant responses between years. The spring pattern of injury in fields for 1977-78 tended to be patches of dead plants, generally most severe on north and east slopes. Early in the spring (mid-March) plants had normal green leaves but frequently had no live roots. This condition was found as late as the end of April. By contrast, in 1978-79 the pattern of stand loss in fields was a uniform thinning of stand without distinction for slope differences. Stands were usually good in low areas or where snow cover remained longer in the spring. Also in contrast to 1977-78 plants, the fields in 1978-79 often contained plants with no green leaves, but extensive and vigorous new secondary roots were present. Plants with green leaves also had good root development, but stand levels (judged by green appearance) seemed to decrease toward late April. This observation suggested that plant disease may have been a secondary factor causing stand loss.

It is intended that this report include general observations about plant response for the purpose of reference in subsequent years. It is not intended to provide definitive conclusions about factors in winter wheat survival at this time.

Finally, as a result of funds provided by the South Dakota Wheat Commission, it is anticipated that at least eight newly developed automatic temperature measuring devices will be available for field installation in the fall of 1979. These instruments should reduce time spent by cooperators in collecting temperature data. Plans also exist for Experiment Station personnel to measure soil moisture in the winter wheat area.

Appendix I. Air Temperatures at Several Locations* in the Winter Wheat Area of South Dakota in February 1982.

Date	Presho		Academy		Winner		Gettysburg		Ft. Meade	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
2/14	51	10	53	22	58	29	18	8	66	30
2/15	44	24	50	22	52	29	44	10	53	33
2/16	46	24	42	25	51	27	27	18	59	29
2/17	52	30	52	31	55	34	37	18	56	39
2/18	53	28	53	30	56	32	47	32	55	34
2/19	54	27	55	30	58	25	44	29	62	40
2/20	59	30	59	35	60	30	50	33	66	41
2/21	71	27	68	31	73	34	52	30	75	40
2/22	59	30	75	33	73	33	65	30	65	27
2/23	.	16	.	18	.	20	.	16	.	19
2/24	.	13	.	15	.	14	.	0	.	12
2/25	.	7	.	10	.	10	.	0	.	5
2/26	.	20	.	15	.	23	.	12	.	13
2/27	.	21	.	27	.	26	.	21	.	18
2/28	.	25	.	25	.	24	.	22	.	22

Date	Martin		Rapid City		Midland		Murdo		Onida	
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
2/14	54	34	65	32	61	15	56	19	43	11
2/15	49	26	61	31	47	27	46	28	38	24
2/16	61	32	61	28	55	22	56	26	39	18
2/17	55	35	59	32	57	29	56	35	50	28
2/18	55	26	55	29	58	27	56	34	48	29
2/19	61	28	64	33	61	28	56	29	54	30
2/20	63	34	62	37	63	35	60	35	59	35
2/21	72	32	74	39	76	29	74	35	68	32
2/22	69	31	71	26	62	33	60	32	57	29
2/23	.	24	.	34	.	22	.	22	.	19
2/24	.	18	.	28	.	15	.	12	.	0
2/25	.	12	.	39	.	5	.	8	.	3
2/26	.	23	.	45	.	20	.	21	.	22
2/27	.	21	.	35	.	21	.	19	.	25
2/28	.	22	.	50	.	23	.	23	.	25

*Data contrasts the air temperature in 10 locations in South Dakota during a critical period in February, when it is believed that serious winter wheat losses occurred in Sully, Potter, Dewey, and Ziebach counties in 1982. All locations showed above 50°F (excepting two days at Gettysburg and one day at Onida) maximum temperatures for a 6-day period starting February 17. However, only Gettysburg and Onida show minimum temperatures below 5°F for two days on 24 and 25 February. The exceptionally cold period on January 10, 1982 was ruled out because field samples of plants on February 14 and 15 showed better than 85% survival at several of these locations. January 10, 1982 was characterized as having -30°F air temperature and a short period of a -100°F chill factor.

Appendix J. Minimum Air* and Soil Temperatures (F) for December/January 1983-84 at Several Locations in the Winter Wheat Area of South Dakota.

Date	Gettysburg			Pierre			Eagle Butte			Brookings			Ideal			Wall		
	Air	2.5"	6.0"	Air	2.5"	6.0"	Air	2.5"	6.0"	Air	2.5"	6.0"	Air	2.5"	6.0"	Air	2.5"	6.0"
12/12/83	13	20	24				13	24	27	-2	26	32	14	29	31			
12/13	8	21	24				5	23	26	8	25	32	10	30	31			
12/14	12	22	24				14	23	25	9	22	32	14	30	31			
12/15	10	21	24				7	22	25	4	25	32	13	30	31			
12/16	-8	15	20				8	20	23	-20	25	32	-2	29	30	6	27	29
12/17	-17	14	19				-16	19	23	-17	29	32	-10	28	30	-8	25	29
12/18	-23	4	12				-20	11	17	-22	25	32	-14	27	29	-21	22	27
12/19	-17	8	13				-12	11	15	-20	19	31	-7	26	28	-7	23	26
12/20	-12	7	12				-12	11	15	-19	16	30	-9	25	28	-8	24	27
12/21	-20	10	13	-20	10	14	-21	14	18	-22	19	30	-24	25	28	-21	24	27
12/22	-23	4	10	-24	6	11	-21	5	12	-22	21	30	-17	23	26	-22	24	27
12/23	-29	-3	4	-30	4	10	-21	3	9	-22	24	30	-30	22	25	-22	24	26
12/24	-21	-1	4	-24	1.8	7.5	-21	0	5	-22	22	29	-20	17	23	-22	20	25
12/25	-4	2	5	-10	2	7.0	-11	1	5	-10	20	28	-12	18	22	-22	17	22
12/26	-4	10	9	-8	8	10	-7	4	8	-2		28	4	21	23	-1	19	22
12/27	6	12	13	4	12	14	4	11	13	7		29	9	23	24	8	22	24
12/28	-3	11	11	-3	10	13	-5	9	12	-5		29	-2	22	25	1	20	24
12/29	-17	4	11	-12	8	11	-10	6	10	-15		28	-10	21	23	-9	19	23
12/30	-3	7	10	-11	8	11	5	9	11	-7		27	11	21	23	11	20	22
12/31	20	15	15	21	11	13	28	20	19	12		28	20	25	25	27	24	25
1/1/84	8	15	17	15	17	19	20	21	21	3		28	21	28	27	19	24	25
1/2	10	16	19	9	18	21	26	22	22	11		29	14	27	28	20	25	26
1/3	37	21	21	36	24	23	32	27	25	30		29	36	28	28	39	27	27
1/4	25	24	18	22	26	26	29	28	27	20		30	28	30	29	32	30	29
1/5	42	28	26	37	29	28	36	31	29	38		30	37	31	31	42	32	31
1/6	24	28	27	27	30	29				31		31	28	31	31	29	31	30
1/7				32	30	29				21		31	33	31	31	35	31	30
1/8				22	30	29				19		31				29	31	31
1/9				20	28	29				12		31				22	31	31
1/10				2	20	24				-13		28				23	29	31
1/11				13	22	23										29	30	31
1/12				-6	17	21				7		28				2	22	28
1/13	-6	14	17	-4	13	17				-11		27				10	20	24
1/14				3	14	17				-2		27				1	19	23
1/15				-6	13	16				-3		27						
1/16				8	15	17				1		27						
1/17				-9	11	14				-13		27						
1/18				-14	4	10				-20		25						

*Some instruments off-scale at -20 to -22F. Ft. Pierre, Sturgis, and Martin data not computed for this interval.

Appendix K. County and Station Code for Computer Tape.

Code	County	STA	Code	County	STA	Code	County	STA
01	Aurora	9232	29	Hand	5561	59	Sully	6292
02	Beadle	4127	30	Hanson	0128	60	Todd	
03	Bennett	5281	31	Harding	1294	61	Tripp	9367
04	Bon Homme	8472	32	Hughes	6597	62	Turner	5228
05	Brookings	1076	33	Hutchinson	5481	63	Union	0943
06	Brown	0020	34	Hyde		64	Walworth	5691
07	Brule	1609	35	Jackson	1972	65	Washabaugh	1972
08	Buffalo		36	Jerauld	9070	66	Yankton	9502
09	Butte	6054	37	Jones	5891	67	Ziebach	2429
10	Campbell		39	Kingsbury	2302			
11	Charles Mix	6574	40	Lawrence				
12	Clark	1739	41	Lincoln	1392			
13	Clay	8622	42	Lyman	4516			
14	Codington	8932	43	McCook	1032			
15	Corson	5406	44	McPherson	2497			
16	Custer		45	Marshall	1049			
17	Davison	5671	46	Meade	2852			
			47	Miner	4037			
18	Day	8980	48	Mellette	9442			
19	Deuel	1777	49	Minnehaha	7667			
20	Dewey	8307	50	Moody	2984			
21	Douglas	0296	51	Pennington	6947			
22	Edmunds	4206	52	Perkins	4864			
23	Fall River	6212	53	Potter	3294			
24	Faulk	2927	54	Roberts	7742			
25	Grant	5536	55	Sanborn	3029			
26	Gregory	3452	56	Shannon	6736			
27	Haakon	6552	57	Spink	1052			
28	Hamlin	1519	58	Stanley	3987			

Appendix L. County Map of South Dakota.