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CONCLUSIONS

1. Crop development models can be used to determine the expected phenological responses of corn hybrids to different planting dates and locations.

2. The number of days from planting to maturity for a particular hybrid varies considerably between different dates of planting at a single location and between locations at the same planting date.

3. The risk of spring freeze damage to corn is very low even at early dates of planting. The probability of a freeze decreases rapidly during germination and seedling emergence. The time required for these processes is longer when the temperature is cooler and the probability of freezing most likely. The freeze risk is negligible by the time the vulnerable growing point within the plant has emerged above the soil surface. The effect of temperature on germination and seedling establishment is a more important consideration than possible risk of freezing.

4. The fall freeze hazard to corn may result from an untimely occurrence of 32'F (0'C) and/or insufficient GDD for crop maturity. The cause of freeze hazard changes with date of planting and the maturity classification of the hybrid. Later planting and later maturing hybrids have a greater proportion of the freeze hazard resulting from insufficient GDD.

5. Computer simulations provide data for determining a corn hybrid's adaptability to time of planting at different locations in Nebraska.

6. Computer simulations provide data showing an index of energy available for natural grain drying for different hybrids, dates of planting, and locations.

7. Corn planted early, when the temperature is cool, accumulates GDD slower and progresses through early stages of development at a slower rate than at later and warmer planting dates.

8. Later planted corn and later maturing hybrids progress through the grain maturation and drying stages at slower rates than earlier dates of hybrids because they require more GDD for these stages and must accumulate them when the temperature is cooler.

9. Regardless of planting date, the critical ear forming, reproduction, and grain filling stages of development coincide with a time of season when temperature and moisture stress are most likely. Changing the planting date affects the fall freeze risk and the rate of crop development before and after this critical period but is not a means of avoiding drought stress.

Simulation Studies of Corn Hybrid-Climate Response

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and
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INTRODUCTION

Hybrid corn (*Zea mays* L.) performance is of interest to both grower and seed producer who compete for a share of Nebraska's six million acre market. Yield differences of only a few bushels per acre are important when large acreages are involved. Field trials, therefore, emphasize measuring potential genetic yield differences among hybrids within a maturity class at single planting dates. Measurement of hybrid response to planting dates at different locations entails greater cost and time and has received less attention.

Drier *et.al.* 1974, found that hybrids requiring a longer time from planting to maturity usually produce higher yields than earlier maturing hybrids in favorable seasons. However, later maturing hybrids face greater freeze risks in the fall and also may need to be artificially dried. This need for and probable cost of artificial vs. field drying is important, particularly in view of increasing costs.

This study involves the use of a computer for statistical simulations of weather-crop response models and historic climatic data to measure the expected response of hybrids of different maturities to planting times at different locations.

PROCEDURE

A more detailed discussion of the GDD concept and the specific crop development models used here can be found in another publication (Neild and Seeley, 1977).

Crop Development Models

Equations of the form $Y=a+bX$

Where:

Y=phenological stage according to Hanway, 1971.

X=accumulated growing degree days (GDD) above 50°F for different hybrids commonly grown in the Corn Belt. These equations were used to construct computer models operated by daily tempera-

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ture and precipitation data. These models used GDD to determine the time of different growth stages and integrated daily weather parameters important to yield on a phenological time scale. They also determine if a late spring freeze occurred after seedling emergence or if an untimely fall freeze occurred before corn was physiologically mature.

Yield Model

The following biological time scale model developed by Seeley, 1978, resulting from multiple regression analysis of 50 years (1925-1974) historic yield and weather data from Butler County, Nebraska was used to study the affects of weather following different dates of planting on yield.

$$Y=58.02-2.086X_1+0.027X_1^2+1.139X_2-1.084X_3+2.580X_4$$

Where:

Y=yield per acre for unirrigated corn

X_1=year number (accounting for technology trend)

X_2=preseason precipitation (September 1 to planting)

X_3=temperature stress days (days over 95°F between ear formation and denting kernels)

X_4=precipitation during reproduction and grain filling

The coefficient of determination, R^2, showed that 74% of the variation in unirrigated corn yield in Butler County can be explained by these four variables.

Climatic Data

A magnetic tape file of continuous daily historical temperature records was used to simulate 70 to 80 seasons of corn growing experience related to crop development at locations representative of different climatic regions in Nebraska. Locations and records involved in this study are presented in Figure 1.

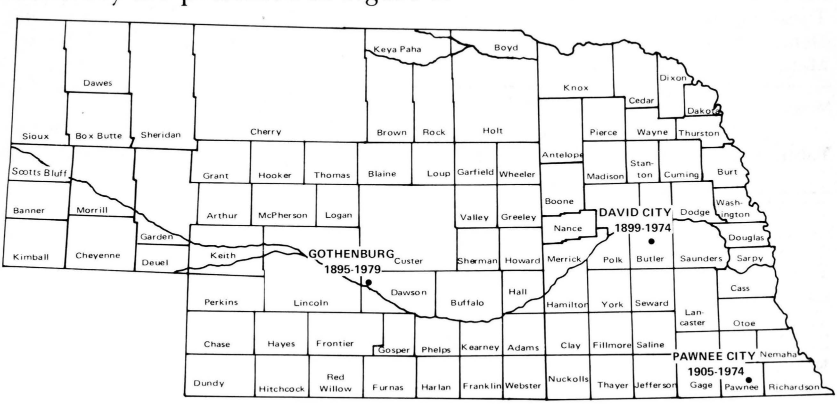

Figure 1. Locations and records of *climatic stations.*

RESULTS AND DISCUSSION

Crop Development

Planting Date Differences

The expected phenological response of a hybrid requiring 2450 GDD to maturity at different dates of planting at Pawnee City is summarized in Table 1. This location in extreme southeast Nebraska has the warmest and longest freeze-free season, over 170 days, in the state. The date and days from planting for critical development stages are shown. The major difference between these plantings is the days for germination and seedling establishment. The April 15 planting required 18 days to develop two leaves; May 15 planting 10 days and June 4 only 6 days. This shorter time for seedling establishment is inversely related to the increasingly warmer temperature as the planting season progresses. The days to maturity for these three planting dates were 113, 101 and 94 days, respectively. This difference is one point of confusion that results from classifying hybrids on the basis of days from planting rather than response to temperature.

Hybrid Differences

The responses of hybrids requiring 2450, 2780 and 3000 GDD to maturity for a May 15 planting date at Gothenburg in west central Nebraska are summarized in Table 2. This is a cooler region, averag-

Table 1. Expected date and days from planting for critical development of a 2450 GDD hybrid for different planting dates at Pawnee City.

		Planting date					
	GDD	April 25		May 15		June 4	
Development stage[a]	requirement	date	days	date	days	date	days
Two leaves (0.5)	193	5/13	18	5/25	10	6/10	6
Ear forming (3.0)	788	6/16	52	6/24	40	7/6	32
Tasseling (5.0)	1264	7/4	70	7/11	57	7/22	48
Denting (8.0)	1979	7/28	94	8/5	82	8/17	74
Mature (10.0)	2450	8/16	113	8/24	101	9/6	94

[a]Stage number according to Hanway, 1971.

Table 2. Expected date and days from planting for critical development stages of different hybrids planted May 15 at Gothenburg.

	GDD requirement								
Development stage[a]	GDD	date	days	GDD	date	days	GDD	date	days
Two leaves (0.5)	193	5/26	11	213	5/26	11	213	5/26	11
Ears forming (3.0)	788	6/29	45	889	7/2	48	979	7/4	50
Tasseling (5.0)	1264	7/17	63	1430	7/22	68	1577	7/26	70
Denting (8.0)	1979	8/13	90	2240	8/23	100	2438	8/29	106
Mature (10.0)	2450	9/5	113	2780	9/22	130	3000	10/3	141

[a]Stage number according to Hanway, 1971.

ing 150 freeze-free days. The major difference in the responses of these hybrids is the progressively longer time interval between their later development stages. The days between denting and maturity were 23, 30 and 35 days, respectively, for each hybrid. The longer interval results from an interaction of a greater GDD requirement between stages for later hybrids and the cooler temperature during which the development takes place.

In addition to slower rates of development for later maturing hybrids, they also must undergo grain dry-down at much cooler temperatures. For example, the 2450 GDD hybrid requires 471 GDD from denting to maturity. The average temperature on September 5 when this hybrid matures is 69°F (20.5°C) or 19 GDD per day. The 3000 GDD hybrid requires 562 GDD from denting to maturity. The average temperature on October 3 when this hybrid matures is 58°F (14.4°C) or 8 GDD per day.

Location to Location Differences

Comparing the 2450 GDD hybrid responses in Tables 1 and 2 show that it takes 113 days to mature at Gothenburg and 101 days at Pawnee City. This location to location difference is another cause of confusion that results from the "days to maturity" classification system.

Freeze Incidence

Planting Date Differences

The freeze incidents in 80 years for simulated plantings between April 25 and June 14 of a 2450 GDD hybrid at Gothenburg are given in Table 3. The computer program counted the number of years when 2450 GDD were available but when an untimely freeze occurred before they were accumulated. This was indicated as a fall freeze (a). The number of years when there were insufficient GDD (b) even though the season had advanced to November 1 were also counted. This date is beyond the record latest fall freeze date at Gothenburg. The number of years that a late spring freeze (c) occurred after the vulnerable growing point was above the soil surface were also counted. The total of these different types of freezes is also shown.

Table 3. The total number and type of freeze to a 2450 GDD hybrid for different planting date simulation at Gothenburg between 1895-1974.

	Planting date					
	4/25	5/5	5/15	5/25	6/4	6/14
Spring freezes (c)	0	0	0	0	0	0
Fall freezes (a)	7	7	8	13	13	22
Insufficient GDD (b)	0	1	3	5	10	23
Total freezes	7	8	11	18	23	45

Table 4. Freeze probabilities in relation to seedling development of a 2450 GDD hybrid planted April 25 and May 5 at Gothenburg.

	Planting date					
	April 25			May 5		
Stage of development	Date	Days from planting	Freeze probability	Date	Days from planting	Freeze probability
Planted	4/25	0	83.0%	5/5	0	46.0%
2 leaves	5/22	27	8.0%	5/25	20	5.0%
3 leaves	5/26	31	4.0%	5/29	26	2.5%
4 leaves	5/30	35	2.0%	6/2	30	1.0%
5 leaves	6/3	39	0.8%	6/5	32	0.5%
6 leaves	6/6	42	0.4%	6/9	36	0.2%

The total number of freezes increased from 7 for the earliest planting date to 45 by June 14. The seven incidents for the April 25 planting date resulted from untimely freezes in the fall. These were sufficient GDD for maturity in all 80 years but in 7 years the season was terminated too soon. The June 14 planting had insufficient GDD for maturity in 23 seasons. Untimely fall freezes terminated the seasons in 22 of the 57 years when sufficient GDD were available. There were no lethal, growing point freezes in the spring even at the early date of planting.

A detailed analysis of spring freeze probabilities in relation to early development stages for hybrids planted on April 25 and May 5 at Gothenburg are given in Table 4. The freeze probability decreases rapidly as the spring season advances and corn seed germinates and becomes established. The probability of 32°F (0°C) on or after an April 25 planting date is 83%. By May 22, 27 days later, when two leaves are expected to have emerged, the freeze probability has decreased to 8%; by the 3-leaf stage on May 26 it was 4%; the 4-leaf stage 2%; the 5-leaf stage 0.8%; and the 6-leaf stage when the vulnerable growing point is above the soil, the freeze probability is reduced to only 0.4%. The freeze probability at the May planting date is 46%. The probabilities of freeze damage to seedlings at this later planting date are lower still.

Hybrid Differences

The freeze incidents in simulations involving a series of hybrids with requirements increasing from 2200 to 3100 GDD to maturity for a May 15 planting date at Gothenburg are presented in Table 5. The total number of freezes increased with the GDD requirement. There were only two freezes in the simulation involving the 2200 GDD hybrid but 64 freezes in 80 years for the 3100 GDD hybrid. The cause of freeze damage varied with the GDD requirement. Hybrids with requirements more than 2800 GDD experienced a greater proportion of years with insufficient GDD than those with requirements under 2800.

Table 5. Number and types of freezes to different hybrids planted May 15 at Gothenburg 1895-1974.

	GDD Requirement									
	2200	2300	2400	2500	2600	2700	2800	2900	3000	3100
Spring freezes (c)	0	0	0	0	0	0	0	0	0	0
Fall freezes (a)	2	7	9	10	12	14	19	19	13	9
Insufficient GDD(b)	0	0	2	4	6	11	18	30	45	55
Total freezes	2	7	11	14	18	25	37	49	58	64

Hybrid Adaptability

Graphs of the percent freeze incidence years from different planting date simulations involving 2450 and 2780 GDD hybrids at Pawnee City and Gothenburg are presented in Figure 2. These graphs enable comparisons of hybrids on the basis of their adaptability to different locations and dates of planting. For example, the horizontal dashed line assumes 15% to be an acceptable freeze risk. On this basis a 2780 GDD hybrid would not be adapted to Gothenburg. A 2450 GDD hybrid would be adapted there for planting before May 15. A 2780 GDD hybrid would be adapted at Pawnee City for planting before May 25; a 2450 GDD hybrid for planting as late as June 14.

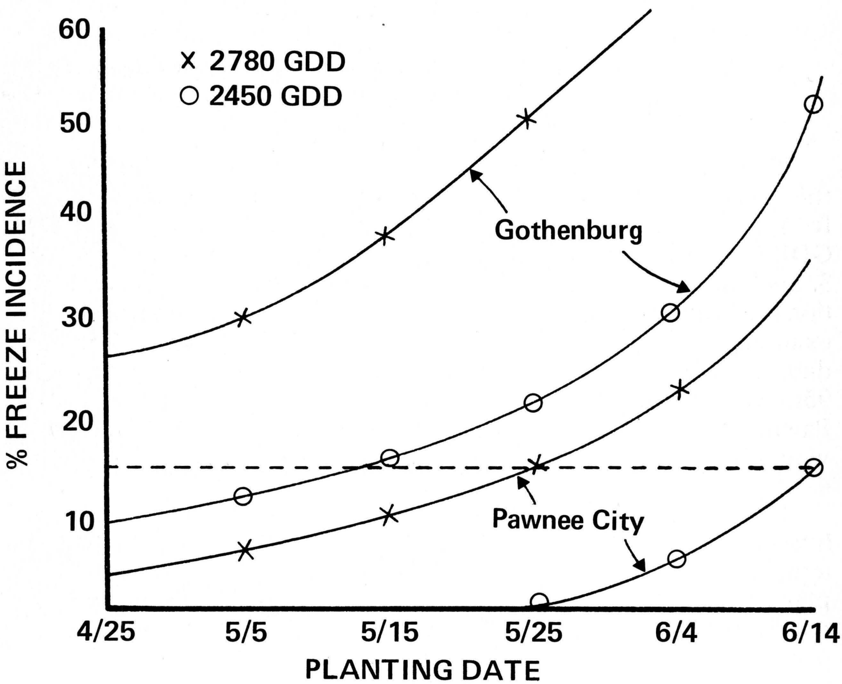

Figure 2. Location, hybrid, planting date and freeze risk.

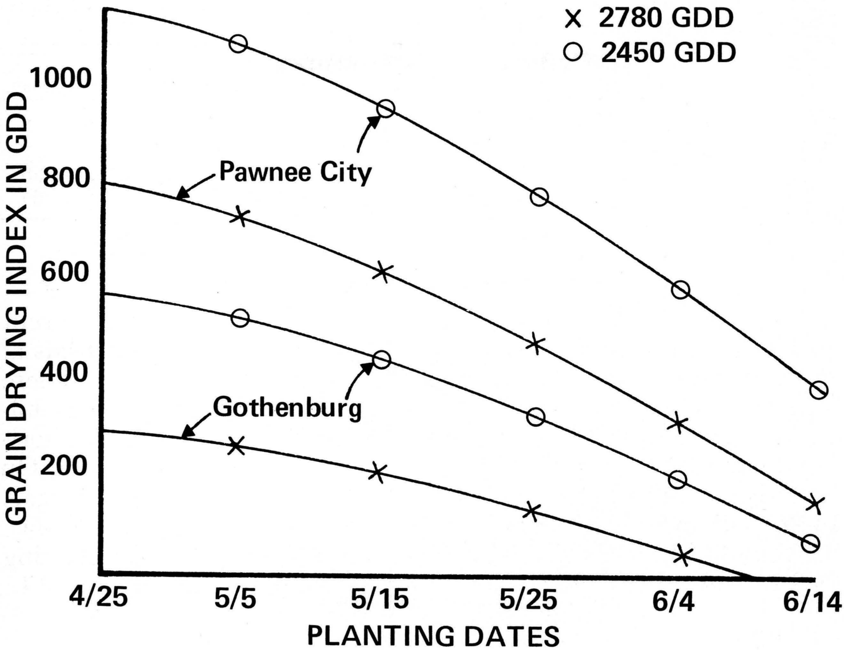

Figure 3. Location, hybrid, planting date and grain drying index.

Energy for Natural Grain Drying

The GDD remaining after physiological maturity is an index of the energy available for natural grain drying. Graphs of these indexes from simulation runs for different planting dates of 2450 and 2780 GDD hybrids at Pawnee City and Gothenburg are presented in Figure 3. Such data permit comparisons of planting dates, hybrids and locations on the basis of this increasingly important consideration. For example, the curves for a 2450 GDD hybrid show the May 15 planting date at Pawnee City and Gothenburg would have indexes averaging 950 and 430, respectively. A 2780 GDD hybrid planted May 15 at Pawnee City has a grain drying index of 600. A 2450 GDD hybrid would have the same index even though planted 20 days later on June 4.

Coincident Temperatures and Crop Development Stages as Related to Date of Planting. The corn plant's response to the seasonal temperature curve is such that development phases from different planting dates encounter different temperature conditions which in turn affect the development of subsequent phases. The average temperature coincident with certain phenological stages and rates of development between subsequent stages for different planting of 2450 GDD hybrid at David City are presented in Table 6.

Table 6. Average temperatures at stages and days between stages for different plantings of a 2450 hybrid at David City.

	Planting date					
	4/25	5/5	5/15	5/25	6/4	6/14
Development Stage			Temperature			
Planting	53	57	61	65	68	71
Tasseling	76	76	76	77	77	77
Maturity	73	73	71	70	67	63
Development Phase			Days			
Planting to ear forming	56	51	45	40	35	32
Ear forming-tasseling to denting	47	46	45	45	45	45
Denting to maturity	20	20	22	22	24	28
Planting to maturity	125	117	112	107	104	105

Corn planted early, when the temperature is cool, germinates and develops slower than at later and warmer dates. For example, the temperature on April 25 at David City averages 53°F (11.6°C). Corn planted at this time would not be expected to begin ear formation until June 20 or 56 days later. Corn planted on June 14 when the temperature averages 71°F (21.6°C) would begin forming ears in only 32 days. Similar comparisons can be made for other planting dates.

Nebraska summers are sufficiently long and hot and corn response such that tasseling coincides with the hottest time of the season regardless of time of planting. The temperature at tasseling for different plantings ranged from 76-77°F (24.4-25°C). The rates of development during the critical ear forming, tasseling and grain filling period were also very similar and ranged from only 47 to 45 days. Grain maturation, denting to maturity, occurs while the seasonal temperature is decreasing so later plantings require a longer time to complete this phase. The April 25 planting requires 20 days for the maturation process compared to 28 days when corn is planted on June 14.

The temperature conditions for grain drying following maturity are also different, particularly for the later dates of planting. Grain from the April and May plantings begins to dry down while temperatures are in the 70s. June planted corn begins drying when temperatures have decreased into the 60s. Later hybrids would have slower maturation rates and begin grain drying at still lower temperatures.

Effect of Time of Planting on Yield. Data showing the average yield for years when no freezes occurred, weather conditions during critical development stages, freeze incidents and the average yield for all 75 years in different simulated plantings using climatic data for 1899-1974 at David City are summarized in Table 7. The yield model was adjusted to a 1977 level of technology without irrigation and responded only to weather conditions following the different planting dates in each of the years.

Table 7. **Average yield and weather conditions of simulated plantings at David City. 1899-1974.**

	4/25	5/5	5/15	5/25	6/4	6/14
Non freeze years-yield						
bu/A	64.3	63.8	63.7	63.9	64.2	64.5
(kg/ha)	4036	4005	3999	4011	4030	4049
Temperature stress days	7	8	8	8	7	8
Critical precipitation, in	1.92	1.76	1.85	1.79	1.77	2.06
cm	4.8	4.4	4.6	4.5	4.4	5.2
% Freeze incidence	5	5	5	8	17	37
Yield bu/A	61.0	60.6	60.3	58.5	52.5	38.9
(kg/ha)	3829	3804	3785	3672	3295	2442

The average yields for different planting dates for the nonfreeze years were quite similar, ranging only from 63.7 bushels per acre (3999 kg/ha) for planting date May 15 to 64.5 bushels (4099 kg/ha) for the June 14 date. The average number of temperature stress days during the critical ear formation to denting period of crop development differed by only one. Precipitation during the critical grain filling stage was also very similar. Averages for the different planting dates ranged from 1.76 inches (4.5 cm) on May 5 to 2.06 (5.2 cm) inches on June 14.

The increasing incidence of freezing for later planting did result in yield reductions, however, as may be seen in comparing the last three rows of data in Table 7. The freeze incidents and yield for plantings through May 15 were similar but for May 25, June 4 and June 14 the freeze incidents and yields were 8, 17 and 37 percent and 58.5, 52.5 and 38.9 bushels per acre (3672, 3296 and 2442 kg/ha), respectively.

Table 8. **Yield and weather conditions of simulated plantings during specific years at David City.**

Year		4/25	5/5	5/15	5/25	6/4	6/14
	Yield bu/A	38.0	39.7	35.9	36.9	39.2	38.0
		2385	2492	2253	2316	2461	2385
1936	Stress days	23	21	24	23	21	22
	Critical precipitation, in	0.42	0.00	0.00	0.00	0.00	0.00
	cm	1.06	—	—	—	—	—
	Yield bu/A	59.9	61.0	58.0	58.1	64.0	64.8
	(kg/ha)	3760	3829	3641	3647	4018	4068
1963	Stress days	8	7	8	8	4	5
	Critical precipitation, in	1.09	1.4	0.39	0.40	1.05	1.79
	cm	2.76	3.5	0.99	1.01	2.66	4.54
	Yield bu/A	88.7	87.1	90.2	91.4	81.8	Freeze
	(kg/ha)	5568	5468	5662	5738	5135	—
1973	Stress days	4	4	3	2	2	—
	Critical precipitation, in	4.30	4.46	4.46	4.47	0.79	—
	cm	10.92	11.32	11.32	11.35	2.00	—

Data for specific years during the simulation runs at 1977 technolgoy are summarized in Table 8. Preseason precipitation for 1936, a drought year, was only 9.10 inches (23.1 cm). All plantings experienced great temperature stress ranging from 21 to 24 days. Critical period precipitation was 0 for all planting dates except April 25 which was only .42 inches (1.1 cm). Yields for the different plantings ranged from 35.9 to 39.7 bushels per acre (2253 to 2492 kg/ha), the lowest in the 75-year series.

Nineteen sixty-three (1963), typical of an average season, received 12.44 inches (31.6 cm) of precipitation before planting. The number of temperature stress days and critical period precipitation ranged from 4 to 8 days and 0.39 to 1.79 inches (.9 to 4.5 cm), respectively. The yield for different planting dates ranged from 58.0 to 64.8 bushels per acre (3641 to 4068 kg/ha). Nineteen seventy-three (1973) was cool and moist and produced the highest yield ever received in Butler County. Preseason precipitation averaged 21.71 inches (55.1 cm). Temperatures stress days were low and critical period precipitation for all planting dates except June 4 was over 4.0 inches (10.1 cm). The June 14 simulated planting froze in the fall.

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