

PREDICTING LOSSES IN GRAIN SORGHUM [SORGHUM BICOLOR (L.)
MOENCH] CAUSED BY FREEZES DURING GRAINFILL

by

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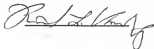
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CHAPTER 1

PREDICTING SEED DRY MATTER ACCUMULATION IN GRAIN SORGHUM FOR ESTIMATING YIELD LOSSES FROM FREEZE

1.1 Abstract

Modelers and crop yield forecasters would like to better predict and comprehend the impacts of natural agronomic disasters such as early fall freezes on grain sorghum [*Sorghum bicolor*(L.) Moench]. Field studies were conducted on a Reading silt loam [fine, mixed, mesic Typic Argiudoll (0 to 1% slope)] in 1986 and 1987 and a Harney silt loam [fine, montmorillonitic, mesic Typic Argiustoll (0 to 1% slope)] in 1987. Percent of maximum seed weight was calculated with treatment variables of bloom date, hybrid, and location-year and regressed on growing degree-days(GDD) from anthesis with base temperatures (Tb) of 1.0 and 5.7 C. Three commercial hybrids ranging in maturity were used: Asgrow 'Dorado E'(early maturity); Golden Acres 'T-E Dinero' (medium maturity); and DeKalb 'DK59E' (late maturity). Cumulative GDD accounted for 97 to 99% of the variability in percent maximum seed weight for each hybrid. Hybrids differed 10% or more between 200 to 500 GDD according to individual regression equations, but the equation combined over hybrids was within 6% of the individual equations.

Combined over all hybrids and location-years: Percent maximum seed wt.= $-43.0 + 0.276\text{GDD} - 0.0001332\text{GDD}^2$ for Tb of 1.0 C. This regression accounted for 95% of the variability in seed weight and predicted maximum seed weight at 1040 GDD. Tb of 5.7 C gave nearly identical results and did not improve precision of prediction. It appears that this equation can be used to determine percent yield loss state-wide.

1.2 Introduction

Annual sorghum [Sorghum bicolor (L.) Moench] acreages in excess of four million (Farm Facts, 1987), exemplifies the success that sorghum has in Kansas. This success has led to an ever increasing number of acres vulnerable to freeze because of late planting and other factors which cause variability in stage of maturity in the fall. Early fall freezes in 1984 and 1985 reduced sorghum yields. Yield reductions were substantial, yet the exact impact was not known.

Many components are involved in determining final yield of a crop including many environmental factors which create difficulty in predicting yields. In grain sorghum, the influence of temperature and water stress on key physiological and developmental processes have been shown to have the greatest relative importance (Eastin, 1976; Lewis et al., 1974; and Nix and Fitzpatrick, 1969). Thus, a thermal component, growing degree-days (GDD), often has been used as a quantitative expressor for a concept introduced more than two centuries ago (Wang, 1960). Using the GDD concept, (Schaffer, 1980) found that regardless of planting date all hybrids basically require the same number of GDD's during the grain filling period.

Yield components (number of heads per acre, seed number

per head, and seed weight) are factors in yield, but tend to compensate for each other, so that any one component is too inconsistent to serve as a reliable yield predictor (Vanderlip, 1979). It has been reported that events in GS2 (panicle initiation to bloom) are important for potential number of seed, while those in GS3 (bloom to physiological maturity) directly affect seed size (Eastin and Sullivan, 1974). Though seed number is more important than seed weight (Saeed et al., 1986), seed weight is the only component left to be determined during grainfill. Seed weight becomes more critical to yield as high temperature stress increases (Saeed et al., 1986). Therefore, final dry weight per kernal is the only component of yield which can change after kernal number has been set (Kiniry, 1988).

Kernels of sorghum do not fill at a constant rate from anthesis to maturity (Kersting et al., 1961). A sorghum kernel exhibits an initial lag period followed by a relatively long period of near linear growth and finally a second lag period just before maturity. Thus, a kernel obtains 90 % of its volume and 10-15 % of its dry weight during the non-linear growth period (Gerik et al., 1987). Kernel dry matter accumulation is similar in wheat (Triticum aestivum L.) (Sofield et al., 1977), oats (Avena sativa L.) (McKee et al., 1979), and corn (Zea mays L.) (Johnson and Tanner, 1972). At the soft dough stage, approximately half the grain dry weight is accumulated. At the hard dough

stage, three-fourths of the grain dry weight has accumulated, and if frozen will produce light, chaffy grain (Vanderlip, 1979). Other studies have been conducted to determine yield loss at various stages of growth from yield limiting conditions. Larson and Maranville (1977) showed reductions of 30% from stalk breakage occurring at the early dough growth stage.

Many kernel dry matter accumulation curves have been based upon days from flowering to physiological maturity, for example in corn (Johnson and Tanner, 1972), oats (McKee et al., 1979), and sorghum (Kersting et al., 1961; Collier, 1963; and Pauli et al., 1964). A cumulative growing degree-day (GDD) method may be a more reliable estimator for grain dry matter accumulation than calendar days.

Thus, the objective of this study was to develop a model using GDD after anthesis to estimate seed dry matter accumulation and predict yield losses one can expect from freeze occurring before maturity. For simplicity, if one component of yield and one environmental factor could predict yield loss with some precision over a variety of blooming dates, hybrids, and locations, this could prove to be helpful.

1.3 Materials and Methods

Field experiments were conducted in 1986 and 1987 at the Kansas State Univ. Research Farm at Manhattan and in 1987 the Fort Hays Branch Exp. Station at Hays. Three commercial hybrids were used: Asgrow 'Dorado E' (early maturity); Golden Acres 'T-E Dinero' (medium maturity); and DeKalb 'DK59E' (late maturity).

Experiments were planted 3 June 1986 and 2 June 1987 at Manhattan and 9 June 1987 at Hays. A randomized complete block design was used with one replication at Manhattan in 1986 and three replications in 1987 at Manhattan and Hays. Individual plots were 45 m in length with 4 rows spaced 76 cm apart at Manhattan in 1986, and 26 m in length with 10 rows in 1987. Plots were 27 m in length with 12 rows spaced 90 cm apart at Hays in 1987. Plant populations were approximately 111,200 plants hectare⁻¹ at Manhattan in 1986 and 1987, and 86,000 plants hectare⁻¹ at Hays. The soil was a Reading silt loam [fine, mixed, mesic Typic Argiudoll (0 to 1% slope)] both years at Manhattan and a Harney silt loam [fine, montmorillonitic, mesic Typic Argiustoll (0 to 1% slope)] at Hays. Plots were fertilized according to the Kansas State University Soil Testing Lab recommendations. At Manhattan, Furadan at the rate of 1.1 a.i. kg ha⁻¹ was furrow applied at planting time. A tank mix of 2.2 a.i. kg

alachlor ha^{-1} and 1.1 a.i. kg atrazine ha^{-1} was applied directly after planting for grass and broadleaf weed control. Seed was treated with Screen^R safener. Propazine at a rate of 2.5 a.i. kg ha^{-1} was applied pre-plant at Hays. Weed control was supplemented by hand hoeing later during the growing season.

To measure seed growth, panicles were tagged in groups of 150 to 200 when they had bloomed half-way down the panicle. A colored tag was then placed around the peduncle just above the flag leaf. After two to three days, another group was tagged with a different color and possibly a third group was tagged with yet another color to signify the various anthesis dates. Beginning approximately two weeks after anthesis in 1986 (one week in 1987), 5 to 15 panicles per anthesis date for each hybrid were taken twice weekly (approximately 3 to 4 day intervals) and placed immediately into a forced air oven at Manhattan and drying room at Hays. Drying temperatures were 55 to 70 C at Manhattan in 1986 and 52 C in 1987. At Hays, samples were dried at 35 to 38 C for approximately two weeks. Panicles were hand cut approximately 15 cm below the base to ensure easy handling during threshing. Several harvests were obtained after black layer (Eastin et al., 1973) occurred at the base of the panicle, until the supply of panicles were exhausted, to ensure that accurate final seed weight was obtained. When a group of samples had dried, panicles were threshed with a

single head thresher with minimum draft to minimize loss of minute seeds from panicles harvested early in the grain fill period. Grain was carefully cleaned by a blower and by hand. Seed counts of 200 were made from a random bulk sample and dried at 70 C for two to three days to determine kernel dry weight.

Growing degree-days (GDD) with base temperatures (T_b) of 1.0 C (Schaffer, 1980) and 5.7 C (Donatelli, 1988 unpublished) were calculated from daily maximum (T_{max}) and daily minimum (T_{min}) temperatures by Eq. [1]

$$GDD = \frac{T_{max} + T_{min}}{2} - T_b \quad [1]$$

with T_{max} not to exceed 38 C. GDD accumulation began the day after anthesis.

Climatic data were obtained from the Physics Dept. of Kansas State Univ. through weather stations located approximately 2 km from the Manhattan plots and 1 km from the Hays plots.

Due to variations in seed weight (Table 1.1) among bloom dates, hybrids, and the three location-year (loc-yr) combinations which occurred, it was decided to convert seed weight to a percent of maximum. Percent maximum seed weight was regressed on linear, quadratic, and cubic functions of GDD. Regressions were run using covariates of bloom date, hybrid, and location-year.

1.4 Results and Discussion

Analysis began by testing for differences in percent maximum seed weight among bloom dates, across hybrids within a particular loc-yr. Bloom dates were highly significant for Manhattan-1987 and Hays-1987, but non-significant for Manhattan-1986. Ideal weather at Manhattan in 1986 created non-stressful, homogenous conditions which may explain the non-significance for bloom dates and hybrids. Ninety-seven percent of the variability in seed weight was accounted for by GDD's for Manhattan-1986 and 99% at Manhattan and Hays in 1987. The linear and quadratic terms accounted for the majority of the sums of squares. Sampling began one week later in 1986 at Manhattan and may explain the non-significance of the cubic term. Standard error (SE) ranged from 5.0 for Manhattan-1986 to 2.6 for Manhattan-1987. Coefficient of variation (CV) ranged from 6.2 for Manhattan-1986 to 3.4 for Manhattan-1987 with Tb of 1.0 C (Table 1.3).

Bloom dates were then combined within hybrids to test for differences in percent maximum seed weight among hybrids for a loc-yr. The results closely paralleled the previous analysis with significant differences among hybrids occurring for Manhattan-1987 and Hays-1987. Little variation in the SE, r-square, or CV occurred.

When hybrids were tested across locations, 98% of the

variability was accounted for with a SE of 3.9 and CV of 5. Nearly all variables and interactions (tests for differences in slope) including hybrids were significant with little variation between Tb's throughout the analysis. Hybrids were then combined and comparisons made among loc-yr combinations. The only noticeable changes occurred with an increase in SE to 5.0 for Tb of 1.0 C and 5.2 for Tb of 5.7 C (Tables 1.3 and 1.4).

An analysis was then run using a cubic function of GDD. This yielded, for Tb of 1.0 C, a SE of 6.4 and a CV of 8.4 with 95% of the variability accounted for. Results from an analysis of a quadratic function were nearly identical to the cubic, contrary to an analysis of only the linear function which yielded a SE of 12.5, CV of 17, and only 81% of the variability accounted for with Tb of 1.0 C (Table 1.3). Tb of 5.7 gave similar results (Table 1.4). It appeared that increase in precision from using the Tb of 5.7 was negligible. Some precision was lost by pooling bloom dates, hybrids, and loc-yr's into combined regressions Eq.[2] and Eq.[3]

$$\begin{aligned} \% \text{ max. seed wt.} &= -43.0 + 0.276\text{GDD} - 0.0001332\text{GDD}^2 \quad [2] \\ &= -46.0 + 0.3585\text{GDD} - 0.000220\text{GDD}^2 \quad [3] \end{aligned}$$

for Tb of 1.0 C and 5.7 C, respectively. The negative intercepts are because little data was collected before 200

GDD. Inaccurate predictions of percent maximum seed weight would occur below 200 GDD. Figures 1.1 and 1.2 show percent maximum seed weight vs. GDD. Apparently, seed weight accumulates more in the first half of development [about 60% (Fig. 1.1)] than second half. Yield loss prediction on a percentage basis would merely be percent maximum seed weight achieved subtracted from 100 percent. The combined regression estimated maximum seed weight to occur at 1040 GDD with Tb of 1.0 C and 810 GDD for Tb of 5.7 C.

Variability in the prediction of percent maximum seed weight among hybrids and the combined equation can be seen in Fig. 1.3 and 1.4. Hybrids differed by 10 % or more between 200 to 500 GDD with Tb of 1.0 C. The combined equation was within 6% of individual hybrids. Differences were much the same among loc-yr's (Fig. 1.5 and 1.6). Number of samples taken after physiological maturity varied and may have influenced regressions since significant differences appeared in the analysis for most variables, though the contribution to the total sums of squares often was small.

Use of a cubic term in the combined equation may have illustrated a more true accumulation curve, yet increased precision would have been small. After reaching a maximum, seed weight has been known to decrease. Thus the downward direction of the latter part of the curve, may be natural

because of weight loss attributed to respiration (Kersting et al., 1961 and Eastin et al., 1973).

Percent maximum seed weight was best described by a quadratic polynomial of GDD after anthesis (Fig. 1.1 and 1.2). Cumulative GDD accounted for 95 to 96% of the variability in percent maximum seed weight across bloom dates, hybrids, and location-years using either a base temperature (Tb) of 1.0 and 5.7 C. As data were grouped into a combined analysis, it was necessary to sacrifice precision to formulate one equation for use across the state (Tables 1.3 and 1.4). Tb of 1.0 and 5.7 C were nearly identical in precision for prediction of percent maximum seed weight throughout this analysis.

As observed in Table 1.1, seed weight differed greatly for various bloom dates, hybrids, and locations thus illustrating the effect various environmental conditions had on seed weight alone, and necessitating the use of percent maximum seed weight. The early hybrid consistently had lower seed weights and the medium hybrid the highest in both years and locations. Poor seed set at Hays with the medium and late hybrids resulted in rather high seed weights.

The number of GDD (Table 1.2) required to reach maximum seed weight (estimated from regression equations) varied somewhat for hybrids and location-year combinations. GDD maxima for hybrids found using Tb of 1.0 C were:

early--1010; medium--1100; and late--1070 GDD. Manhattan-1986 reached maximum at 970; Manhattan-1987 at 1020; and Hays-1987 at 1140. This shows some discrepancy with the postulation that duration is constant across hybrids and locations (Schaffer, 1980). Over-inflated GDD requirements to reach maximum seed weight at Hays in comparison to Manhattan may be attributed in part to the lack of harvests taken after physiological maturity for the medium and late hybrids at Hays.

4.5 Summary and Conclusions

Percent maximum seed dry matter accumulation for grain sorghum was described best by a quadratic polynomial of GDD accumulated after anthesis. A combined analysis accounted for 95% of the variability and yielded the equation: Percent maximum seed wt. = $-43.0 + 0.276\text{GDD} - 0.0001332\text{GDD}^2$ for Tb of 1.0 C. Tb of 5.7 C gave nearly identical results and failed to show any better precision or prediction.

The medium and late hybrids required more GDD to reach maximum seed weight. The cooler temperatures at Hays also trended toward higher GDD requirements. Early senescence of the medium and late hybrids compounded with the fewer harvests taken after physiological maturity may explain higher GDD at Hays.

Many times, covariates of bloom date, hybrid, and location-year were highly significant although their contribution to the total sums of squares was small.

Predictions of percent maximum seed weight differed by as much as 10% among hybrids, however, with the combined analysis only 6% error in the predictions of percent maximum seed weight occurred. Seed weight accumulates more rapidly in the first half of development than the second.

Over a range of environmental conditions and three hybrids, GDD after anthesis accounted for 95% of the

variation in seed dry matter accumulation. Though some precision was sacrificed, the results appear to be acceptable for calculating percent maximum seed weight to estimate yield loss.

Table 1.1. Final seed weights for bloom dates, hybrids, and location-years.

Hybrid	Bloom date	Manhattan-1986	Manhattan-1987	Hays-1987
		-----g/1000-----		
Early	1	20.46	20.06	21.43
Early	2	23.30	23.29	23.86
Early	3	22.75	22.03	26.41
Medium	1	23.50	27.76	35.57
Medium	2	25.79	29.50	34.39
Medium	3	25.59	---	33.81
Late	1	23.71	26.13	32.37
Late	2	24.88	27.52	31.21
Late	3	26.74	---	29.75

Table 1.2. Predicted number of growing degree-days(GDD) required for maximum seed weight for hybrids and loc-yrs for two base temperatures.

Hybrid	GDD required	Loc-yr	GDD required
Base 1.0 C			
Early	1010	Manhattan-1986	970
Medium	1100	Manhattan-1987	1020
Late	1070	Hays-1987	1140
Combined			1040
Base 5.7 C			
Early	800	Manhattan-1986	780
Medium	860	Manhattan-1987	810
Late	820	Hays-1987	880
Combined			810

Table 1.3. R-square, standard error, and coefficient of variation values from analyses for variables including covariates at Tb of 1.0 C.

		Location-year			
Covariate included	statistic	Manhattan 1986	Manhattan 1987	Hays 1987	Combined
Bloom date	R ²	0.97	0.99	0.99	---
	SE	5.0	2.6	2.8	---
	CV	6.2	3.4	3.9	---
Hybrid	R ²	0.95	0.99	0.99	---
	SE	5.3	2.6	3.4	---
	CV	6.5	3.6	4.8	---
Hybrid	R ²	---	---	---	0.98
	SE	---	---	---	3.9
	CV	---	---	---	5.1
Loc-year	R ²	---	---	---	0.97
	SE	---	---	---	5.0
	CV	---	---	---	6.5
None (Cubic GDD)	R ²				0.95
	SE				6.4
	CV				8.4
(Quadratic GDD)	R ²				0.95
	SE				6.4
	CV				8.4
(Linear GDD)	R ²				0.81
	SE				12.5
	CV				16.5

Table 1.4. R-square, standard error, and coefficient of variation values from analyses of given variables including covariates for Tb of 5.7 C.

Covariate included	statistic	Location-year			Combined
		Manhattan 1986	Manhattan 1987	Hays 1987	
Bloom date	R ²	0.97	0.99	0.99	---
	SE	5.2	2.7	2.6	---
	CV	6.4	3.4	3.7	---
Hybrid	R ²	0.94	0.99	0.99	---
	SE	6.0	2.9	3.4	---
	CV	7.4	3.7	4.7	---
Hybrid	R ²	---	---	---	0.98
	SE	---	---	---	4.2
	CV	---	---	---	5.5
Loc-year	R ²	---	---	---	0.97
	SE	---	---	---	5.2
	CV	---	---	---	6.8
None (Cubic GDD)	R ²				0.96
	SE				6.0
	CV				7.9
(Quadratic GDD)	R ²				0.96
	SE				6.1
	CV				8.0
(Linear GDD)	R ²				0.82
	SE				4.0
	CV				150.5

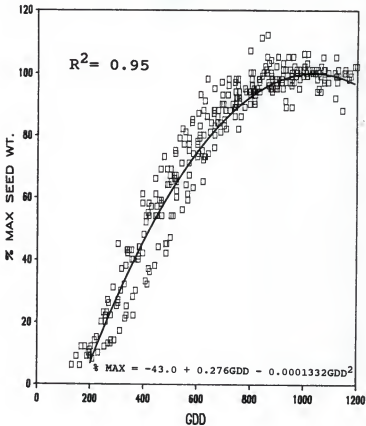


Figure 1.1. Combined regression across bloom dates, hybrids, and location-years of percent maximum seed weight of grain sorghum on GDD after anthesis for base of 1.0 C.

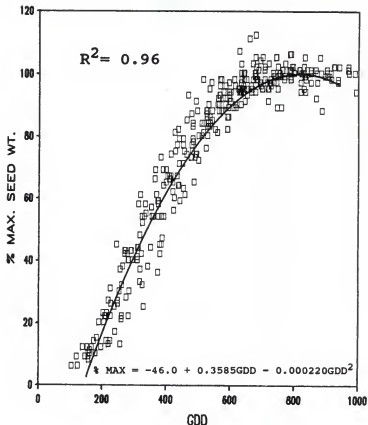


Figure 1.2. Combined regression across bloom dates, hybrids, and location-years of percent maximum seed weight of grain sorghum on GDD after anthesis for base of 5.7 C.

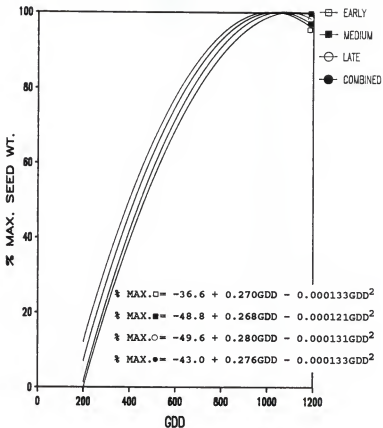


Figure 1.3. Comparison of regressions predicting percent maximum seed weight for individual hybrids and a combined regression for Tb of 1.0 C.

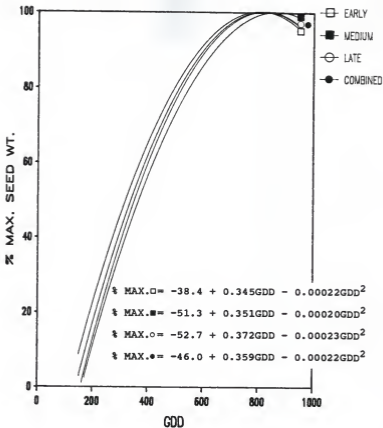


Figure 1.4. Comparison of regressions predicting percent maximum seed weight for individual hybrids and a combined regression for Tb of 5.7 C.

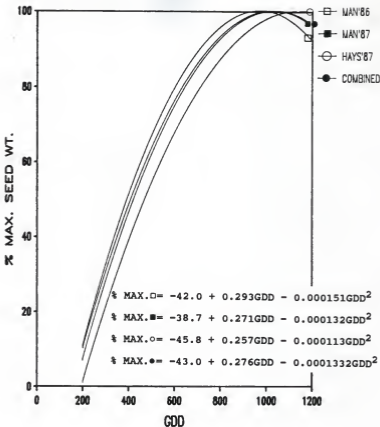


Figure 1.5. Comparison of regressions predicting percent maximum seed weight for individual location-years and a combined regression for T_b of 1.0 C.

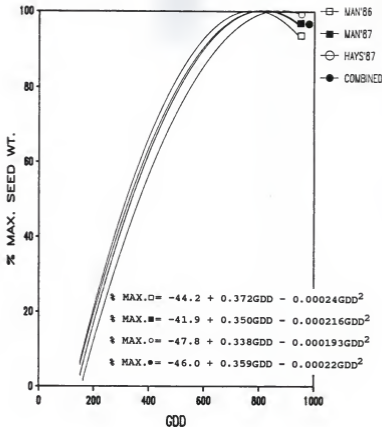


Figure 1.6. Comparison of regressions predicting percent maximum seed weight for individual location-years and a combined regression for Tb of 5.7 C.

CHAPTER 2

ESTIMATION OF GRAIN SORGHUM TEST WEIGHT CHANGES DURING GRAINFILL

2.1. Abstract

The ability to better comprehend the potential impact of early fall freezes on grain sorghum [Sorghum bicolor (L.) Moench], not only on yield, but also reduced test weight would benefit the sorghum producer. Marketing penalties assessed for low test weight grain can be substantial. Field studies were conducted on a Reading silt loam [fine, mixed, mesic Typic Argiudoll (0 to 1% slope)] in 1986 and 1987 and a Harney silt loam [fine, montmorillonitic, mesic Typic Argiustoll (0 to 1% slope)] in 1987. Test weight was measured with variables including bloom date, hybrid, and location-year, and regressed on growing degree-days (GDD) from anthesis with a base temperature of 1.0 C. Three commercial hybrids ranging in maturity were used. Test weight increase was best described by a quadratic polynomial of cumulative GDD, accounting for 86% of the variability in test weight. Coefficients from the equation were used to calculate the maximum test weight of 77.9 kg hL⁻¹ at 912 GDD. Individual regression equations with various bloom date, hybrid

combinations estimated maximum test weight to be reached in the range of 750 to 950 GDD. Harvests taken early in the grainfill period produced test weights higher than the rather low test weights generally reported with frozen sorghum. Some question remains whether test weights following an actual freeze would coincide with the findings in this study. It does appear that maximum test weight was reached before maximum seed weight was obtained.

2.2. Introduction

Literature dealing specifically with test weights of sorghum [Sorghum bicolor (L.) Moench] is rather scarce. The importance to the sorghum producer though can be substantial. For producers who rely on storage and marketing of sorghum through a local elevator, a penalty often is assessed for low test weight sorghum or grain may be refused totally (Table 2.1). On a larger marketing scale, Table 2.2 shows test weights for U. S. grade requirements for sorghum (Schoeff and Page, 1977).

Adverse weather conditions such as wet, cool conditions, early freeze, or droughty conditions have been reported to lower test weights in grain sorghum. Early fall freezes in 1984 and 1985 reduced grain sorghum yields in Kansas, and apparently reduced quality as well. Test weights (weight per unit volume) as low as 41 kg hL^{-1} (32 lb bu^{-1}) were fairly common due to an early freeze and poor maturing conditions in 1975 in Kansas (Feedstuffs, 1975). Larson and Maranville (1977) showed year to year differences in sorghum test weights due to varying environmental conditions.

Subramanyam et al., (1980) showed test weights to be 67.8 kg hL^{-1} at approximately the soft dough stage, 75.0 kg hL^{-1} at hard dough, and 76.8 kg hL^{-1} at physiological

maturity. A study comparing various desiccation and plant severing treatments on sorghum (Bovey and McCarty, 1965), found substantially reduced test weight when treatments were applied at grain moisture levels of 50% (Table 2.3). Larson and Maranville (1977) showed that stalk breakage near the peduncle node at heading resulted in a final test weight of 68.6 kg hL⁻¹, at early dough 69.0 kg hL⁻¹, and at hard dough 70.6 kg hL⁻¹. Highest yielding treatments had highest test weights and lowest yielding treatments lowest test weights.

Studies dealing with freezing of corn (Carter and Hesterman, 1987) showed test weights to be 64 kg hL⁻¹ or less for corn frozen at the dough stage (normal 72 kg hL⁻¹). If frost occurred close to half-milk stage, test weights were close to normal. Scott et al. (1957) found that maximum yield and test weight was reached at about the same time for wheat. It was also shown that continued wetting and drying decreased test weight in wheat.

The objective of this study was to measure sorghum test weight increase in relation to cumulative growing degree-days (GDD) after anthesis and to assess the impact on sorghum grain quality as a result of an early fall freeze.

1.3 Materials and Methods

Field experiments were conducted in 1986 and 1987 at the Kansas State Univ. Research Farm at Manhattan and the Fort Hays Branch Exp. Station at Hays in 1987. Three commercial hybrids were used: Asgrow 'Dorado E' (early maturity); Golden Acres 'T-E Dinero' (medium maturity); and DeKalb 'DK59E' (late maturity).

(For additional information on materials and methods--refer to Chapter 1).

Grain samples were carefully cleaned with a blower and by hand. In 1987, chaff (glumes, rachis, branch fractions, etc.) and seeds with glumes still attached, were removed from samples, manually by sifting lighter materials to the top of a small grain pan with a shaking motion by hand to make samples as homogenous as possible. In 1986, precision in cleaning methods was not as great. Samples varied with the amount of chaff and number of seeds with glumes. Samples were allowed to equilibrate to 10% moisture after cleaning. Samples were then measured for test weight with a Dickey John-GAC II moisture and test weight meter reported in pounds per bushel and converted to kg hL^{-1} . For samples that were too small to be measured by the machine, test weights were obtained by standard elevator procedure using a calibrated volume container. Comparisons were made to

ensure similar test weights were measured by both methods.

Growing degree-days (GDD) base (T_b) of 1.0 C (Schaffer, 1980) were calculated from daily maximum (T_{max}) and daily minimum (T_{min}) temperature by Eq. [1]

$$GDD = \frac{T_{max} + T_{min}}{2} - T_b \quad [1]$$

with T_{max} not to exceed 38 C. GDD accumulation began the day after anthesis.

Climatic data were obtained from the Physics Dept. of Kansas State Univ. through weather stations located approximately 2 km from the Manhattan plots and 1 km from the Hays plots.

Test weight was regressed on linear and quadratic functions of GDD (SAS, 1987). Preliminary regressions were run and it was concluded the cubic term was not needed in this analysis. Regressions were run with covariates of bloom date, hybrid, and location-year.

2.4. Results and Discussion

Test weight increases in relation to cumulative growing degree-days (GDD) was best described by a quadratic polynomial. A combined regression across bloom dates, hybrids, and location-years (loc-yrs) was run in which cumulative GDD accounted for about 86% of the variability in test weight. The regression estimated a maximum test weight of 77.9 kg hL⁻¹ at 912 GDD.

Predicted test weights ranged from 47 kg hL⁻¹ (37 lb bu⁻¹) at 200 GDD to 80 kg hL⁻¹ (62 lb bu⁻¹) at approximately 900 GDD for the three loc-yrs (Fig. 2.1, 2.2, and 2.3). Severe shrinkage occurred with seed from the early harvests thus increasing test weights slightly which otherwise may not have occurred if left to dry naturally under field conditions. Test weights were higher than expected between 200 to 300 GDD in reference to test weights reported for sorghum resulting from a freeze in 1975 in Kansas (Feedstuffs, 1975).

Figure 2.1 illustrates the variability that occurred at Manhattan in 1986. The first harvests (between 200 to 400 GDD) were dried at high temperatures (65 to 70 C) resulting in excessive cracking during threshing thus creating a higher density pack in the test weight containers and possibly increasing test weights. Variability in test

weights after drying temperatures were reduced to 55 C in 1986 was probably because of chaff (glumes, rachis, branch fractions, etc.) and glumes still attached to the seed which varied among hybrids and sampling dates. A slight occurrence of mold appeared during the latter part of grainfill possibly contributing more variability to the data collected at Manhattan in 1986.

Bloom dates were tested by regression analysis for differences in test weights across hybrids in a particular loc-yr. Covariates of bloom date or hybrids were non-significant. For Manhattan-1986, all variables in the regression equation accounted for only 67% of the variability. Linear and quadratic GDD terms were highly significant (Table 2.4 and 2.5). Only 56% of the variability in test weight was accounted for with Manhattan-1986 when bloom dates were grouped and hybrid effects were tested (Table 2.5).

In 1987, 93 to 97% of the variability in test weight at Manhattan and Hays was accounted for with GDD, probably due to the increased precision in cleaning methods as well as more acceptable drying temperatures (Table 2.4). Manhattan-1987 showed no significant main effect differences among bloom dates or hybrids, but did show significant interactions with GDD. Hays-1987 showed significant main effect differences among bloom dates and hybrids as well as significant interactions with GDD.

An analysis was then conducted as though nine different hybrids were being tested by treating the hybrids from each loc-yr as different hybrids. Eighty-seven percent of the total variability was accounted for and showed significant differences for all variables including hybrids (Table 2.6).

Hybrids were then combined across loc-yrs with 81% of the total variability accounted for and no significant differences among hybrids (Table 2.6). When hybrids were grouped to test for differences among loc-yrs, 84% of the variability was accounted for, but significant differences among loc-yrs existed. Slightly wetter conditions and traces of mold occurring on the grain later during grainfill for Manhattan-1987 may also have contributed to this.

Regressions were then run for all bloom date and hybrid combinations (Table 2.7) to ascertain the number of GDD required to reach maximum test weights. Several of the bloom date and hybrid combinations for Manhattan-1986 were deleted because less than 50% of the variability in test weight was accounted for. GDD required to reach maximum test weight varied from approximately 750 to 950. Maximum test weights (calculated from the regressions) for various bloom date-hybrid combinations ranged from 74 to 80 kg hL⁻¹. Maximum test weight appeared to be reached around 830 GDD which yielded a combined maximum test weight of 75.0 kg hL⁻¹ for Manhattan-1986. Manhattan-1987 bloom date-hybrid combinations had much higher r-square values with 907 GDD

required to reach the maximum test weight of 78.2 kg hL⁻¹. Hays-1987 was similar to Manhattan-1987 with a large proportion of the variability accounted for with 913 GDD needed to reach the maximum test weight of 77.9 kg hL⁻¹.

Table 2.8 shows test weight increases for individual hybrids at each loc-yr at 100 GDD increments. With harvests beginning approximately 200 GDD after anthesis, the hybrids varied in test weight from 42 kg hL⁻¹ for the late maturity hybrid at Hays-1987 to 57.4 kg hL⁻¹ for the late maturity hybrid at Manhattan-1986. R-squares (Table 2.8) were low for Manhattan-1986 in comparison to the other two loc-yrs.

Finally, a combined regression was run across bloom dates, hybrids, and loc-yrs which accounted for 86% of the variability in test weight. Maximum test weight of 77.9 kg hL⁻¹ was reached at 912 GDD. GDD required to reach maximum appeared a bit high from observing Figures 2.1, 2.2, and 2.3 and was thought to be due to the variability at Manhattan-1986, therefore another regression was run for Manhattan-1987 and Hays-1987 only. This yielded a slightly higher r-square of 0.90 with maximum test weight of 78.2 kg hL⁻¹ at 918 GDD, thus very similar to using all data.

The freeze of 1975 in Kansas produced test weights that were often 45 kg hL⁻¹ (Feedstuffs, 1975). This would have necessitated a freeze occurring very early during grainfill (200 to 300 GDD) to coincide with results in this study. As mentioned earlier, seeds shrunk substantially, possibly

uncharacteristically of those left under field conditions to dry. Thus more seed could fit into a given volume, increasing test weight measurements. Another possible explanation for lower test weights reported for frozen sorghum could be due to increased chaff with the grain or glumes attached to seeds which would lower test weight.

It does appear from this study that test weight reaches maximum at 800 to 900 GDD as opposed to maximum seed weight which was reached at 1040 GDD (Chapter 1).

2.5. Summary and Conclusions

The pattern of test weight increase in grain sorghum was best described by a quadratic polynomial. A combined regression across bloom dates, hybrids, and location-years accounted for 86 % of the total variability in test weight. Maximum test weight appeared to be reached before physiological maturity when maximum seed weight has been attained (Eastin et al., 1973). Higher than expected test weight measurements were obtained for the early harvests during grainfill.

Individual regressions for various bloom date, hybrid combinations yielded maximum test weights ranging from 74 to 80 kg hL⁻¹ reached between 750 and 950 GDD. Studies conducted on seed dry matter accumulation using these same experimental materials showed maximum seed weight to be reached at just over 1000 GDD. A combined regression showed maximum test weight was reached at approximately 900 GDD. Thus, it appears that maximum test weight was reached before maximum seed weight.

Literature describing the 1975 early freeze in Kansas, gave indications of low test weights that coincide with those from the first harvests taken in this study. Substantial seed shrinkage may have inflated test weights associated with the early portion of grainfill in this

study. In order to have obtained such low test weights later in the grain fill period, it would have required substantial weathering of the grain or excessive chaff and a large number of glumes attached to seeds. Thus a direct effect of freezing, may be lower threshing ability of the grain which has been a common belief among many sorghum producers. Questions still remain as to the exact reason low tests weights seem to be so prevalent in frozen sorghum.

Table 2.1. Penalties in cents per hundred weight for low test weight grain sorghum in pounds per bushel and kilograms per hectoliter at the Farmers Cooperative-Manhattan, KS 1988.

Test Weight		Penalty
lb bu ⁻¹	kg hL ⁻¹	cents cwt ⁻¹
> 56	> 72.1	.00
55.9 - 55.0	72.0 - 70.9	.01
54.9 - 54.0	70.8 - 69.6	.02
53.9 - 53.0	69.5 - 68.3	.03
52.9 - 52.0	68.2 - 67.0	.04
51.9 - 51.0	66.9 - 65.7	.06
50.9 - 50.0	65.6 - 64.4	.09
49.9 - 49.0	64.3 - 63.1	.12
48.9 - 48.0	63.0 - 61.8	.15
47.9 - 47.0	61.7 - 60.6	.19
46.9 - 46.0	60.5 - 59.3	.23
45.9 - 45.0	59.2 - 58.0	.27
< 45	< 58	not accepted

Table 2.2. Test weight requirements for grain sorghum Grades.

Grade U. S.	Minimum test weight	
	lb bu ⁻¹	kg hL ⁻¹
1	57	73.4
2	55	70.9
3	53	68.3
4	51	65.7

* Obtained from Kansas State Coop. Extension Service. L-58. August 1977.

Table 2.3. Test weights for grain sorghum head cut at various moisture percents (Bovey and McCarty, 1965).

Variety	Moisture	Year	
		1961	1962
	%	kg hL ⁻¹	kg hL ⁻¹
Martin	48	64.4	49.0
	38	79.9	72.1
	26	76.0	76.0
Combine Kafir-60	50	67.0	46.4
	38	73.4	68.3
	32	--	73.4

Table 2.4. Significance levels and associated r-square values obtained from Type III sums of squares for analysis of covariance including bloom date.

Variable	Manhattan-1986	Manhattan-1987	Hays-1987
Bloom			**
GDD	**	**	**
GDD ²	**	**	**
GDD*Bloom		**	
GDD ² *Bloom		*	**
R ²	0.67**	0.94**	0.97**

*,**. Significant at the 0.05 and 0.01 probability level, respectively.

Table 2.5. Significance levels and associated r-square values obtained from Type III sums of squares for analysis of covariance including hybrid.

Variable	Manhattan-1986	Manhattan-1987	Hays-1987
Hybrid			**
GDD	**	**	**
GDD ²	**	**	**
GDD*Hybrid		**	
GDD ² *Hybrid			**
R ²	0.56**	0.93**	0.97**

*,**. Significant at the 0.05 and 0.01 probability level, respectively.

Table 2.6. Significance levels and associated r-square values obtained from Type III sums of squares for analysis of covariance including hybrid and loc-year.

Treated as 9 hybrids		Across Hybrids	Across Loc-yrs
Hybrid ¹	**	Loc-yr	*
GDD	**	GDD	**
GDD ²	**	GDD2	**
GDD*Hybrid	**	GDD*Loc-yr	**
GDD ² *Hybrid	*	GDD2*Loc-yr	
R ²	0.87**		0.84**
			0.81**

*,**. Significant at the 0.05 and 0.01 probability level, respectively.

¹Three hybrids X three locations.

Table 2.7. Bloom date and hybrid combinations with required GDD to reach maximum test weight and associated maximum test weights calculated from regressions.

		Manhattan-1986		Manhattan-1987		Hays-1987	
Hybrid Bloom		GDD MAX.TEST		GDD MAX.TEST		GDD MAX.TEST	
		kg hL ⁻¹		kg hL ⁻¹		kg hL ⁻¹	
Early	1	--	--	874	76.2	921	80.2
Early	2	--	--	817	77.0	902	79.7
Early	3	717	75.9	751	76.2	906	79.9
Medium	1	--	--	891	78.9	942	77.2
Medium	2	835	75.6	944	79.1	937	77.3
Medium	3	754	75.9	--	--	878	77.4
Late	1	923	74.6	960	79.5	888	77.6
Late	2	--	--	901	79.2	804	78.0
Late	3	771	76.4	--	--	800	77.4
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Combined		827	75.0	907	78.2	913	77.9

Table 2.8. Test weight increase by hybrid for three location-years measured in 100 GDD increments.

GDD	Manhattan-1986 maturity			Manhattan-1987 maturity			Hays-1987 maturity		
	Early	Medium	Late	Early	Medium	Late	Early	Medium	Late
	-----kg hL ⁻¹ -----								
200	55.0	49.1	57.4	52.4	52.4	53.7	49.4	48.8	42.0
300	60.5	57.2	62.6	59.4	59.3	60.2	57.3	56.1	52.2
400	65.0	63.9	66.9	65.2	65.1	65.7	64.0	62.2	60.8
500	68.6	69.1	70.3	69.8	70.0	70.3	69.6	67.4	67.6
600	71.2	72.8	72.8	73.2	73.9	74.0	73.9	71.4	72.7
700	73.0	75.0	74.4	75.4	76.7	76.8	77.1	74.4	76.1
800	73.8	75.7	75.1	76.4	78.6	78.6	79.1	76.3	77.7
900	73.7	74.9	74.8	76.3	79.5	79.4	79.8	77.2	77.7
1000	72.7	72.6	73.7	74.9	79.3	79.3	79.4	77.0	75.9
R ²	.41	.61	.50	.94	.92	.90	.94	.97	.98

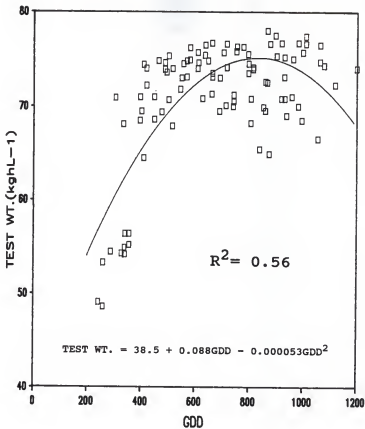


Figure 2.1. Test weight vs. growing degree-days (GDD) for Manhattan, 1986.

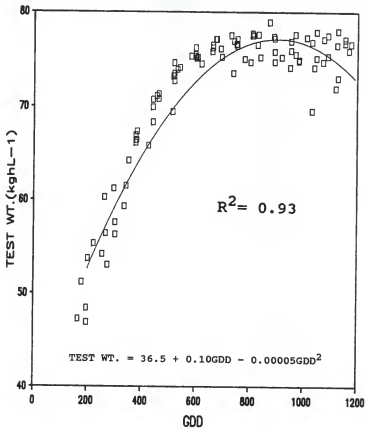


Figure 2.2. Test weight vs. growing degree-days (GDD) for Manhattan, 1987.

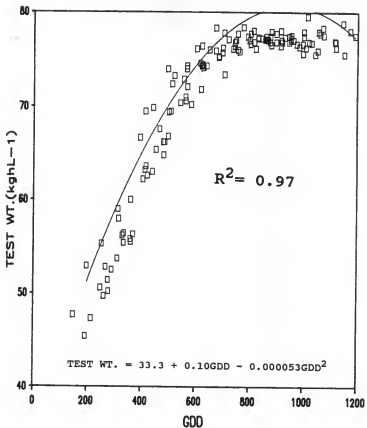


Figure 2.3. Test weight vs. growing degree-days (GDD) for Hays, 1987.

CHAPTER 3

COMPARISON OF DESICCATION vs. HEAD CUT METHODS TO SIMULATE FREEZING IN GRAIN SORGHUM

3.1 Abstract

The methods used to develop growth curves in estimating yield and quality losses of a crop from agronomic disasters can be very important. This study evaluated the effects of foliar application of paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) at weekly intervals following anthesis to simulate effects of freezing on seed weight and test weight of grain sorghum [*Sorghum bicolor* (L.) Moench]. Field studies were conducted on a Reading silt loam [fine, mixed, mesic Typic Argiudoll (0 to 1% slope)] at Manhattan and a Harney silt loam [fine, montmorillonitic, mesic Typic Argiustoll (0 to 1% slope)] at Hays in 1987. Percent maximum seed weight and test weight were regressed with the variables hybrid, and location, and growing degree-days (GDD) from anthesis with a base temperature of 1.0 C. Three commercial hybrids ranging in maturity were used. Cumulative GDD accounted for 93% of the total variability from desiccated rows of sorghum in predicting percent maximum seed weight. A quadratic polynomial best described

this relationship and yielded this equation: Percent max. seed wt.= $5.0 + 0.1741\text{GDD} - 0.0000797\text{GDD}^2$. Cumulative GDD accounted for 83% of the total variability for test weight increase which also was described best with a quadratic equation. The desiccation method gave much higher percent maximum seed weights and test weights especially in the early phase of grainfill (200 to 500 GDD) than the head cut method. Apparently, translocation of materials from the culm contributed to these increased seed weights and test weights. As much as a 20 to 30% difference in maximum seed weight occurred between the two methods for percent maximum seed weight. A 10 to 15 kg hL⁻¹ difference occurred in test weight estimation during the 200 to 300 GDD interval.

3.2 Introduction

Seed dry matter accumulation curves have been developed for many crops through laborious and time consuming effort. These curves are excellent for understanding the pattern of dry matter accumulation in the seed, but their application for predicting the effects from agronomic disasters such as an early freeze is questionable due to the methods used to collect the data. Under circumstances where a freeze has occurred, the physiological functions in the plant can play an important role in terms of translocation of materials to or from the seed. Efforts to simulate freezes through desiccation of the crop canopy have been limited. Much of the work on desiccation of grain sorghum [Sorghum bicolor (L.) Moench] involved finding methods to hasten moisture loss in the grain by killing the canopy to promote earlier harvesting and reduce losses from pests and weathering.

The non-grain parts of cereal crops are known to lose weight during grainfill. This often has been interpreted as a transfer of materials assimilated prior to grainfill to the grain. It has been shown in sorghum that during grain formation culms lose dry weight. This loss indicates a translocation of material out of culms into developing grain (Jacques et al., 1975). At the soft dough stage, the culm is losing weight (Vanderlip, 1979), and at the hard dough

stage, the culm is at its lowest weight. The culm can contribute as much as 10% to the final weight of the grain.

Other work, with corn (*Zea mays* L.), showed that following a frost in late August, grain yield of corn had doubled by early October (Daynard et al., 1969). This suggests that assimilate stored in the stalks prior to grainfill may have contributed to grain yield. Experiments conducted to simulate frost damage in corn using the herbicide paraquat sprayed on leaves [(Brown, unpublished data) as cited by Hume and Campbell, 1972], showed grain yield continued to increase following desiccation, again indicating stored assimilates were translocated to the grain. Redistribution of assimilates from stalks to ears, even with complete leaf death, increased kernel dry weight beyond the weight on the freeze date and reduced yield loss (Afuakwa and Crookston, 1984). Corn frozen at the milk stage will produce very chaffy grain and low test weight, probably less than 64 kg hl^{-1} (normal is 72 kg hl^{-1}). With freezes even at the half-milk stage, test weights would be close to normal (Carter and Hesterman, 1987). Bauer et al., (1986) suggest that in wheat, some grain dry matter accumulation also occurs after windrowing, before complete desiccation of vegetative tissue.

Using various methods to reduce grain moisture in grain sorghum, Bovey and McCarty (1965) reported greatest reductions in grain yields and test weight when grain

moisture was above 40 to 50% at the start of the treatments. A severing treatment was significantly different from other treatments used and produced the lowest seed weight. Test weight, like seed weight, was reduced when a desiccant was applied at the higher grain moisture levels. Severing at the head had the greatest seed weight and test weight reduction followed by severing at the soil, defoliation, and application of DNBP or magnesium chlorate. Clegg et al., (1969) showed a 23% yield loss from desiccating at 42% grain moisture with Diquat (9,10-dehydro-8a, 10a-diazoniaphenanthrene-2A).

The objective of this study was to determine if differences occur in seed weight and test weight accumulation curves using paraquat as a desiccant vs. head cutting.

3.3 Materials and methods

Field experiments were conducted in 1987 at the Kansas State Univ. Research Farm at Manhattan and the Fort Hays Branch Exp. Station at Hays. Three commercial hybrids were used: Asgrow 'Dorado E' (early maturity); Golden Acres 'T-E Dinero' (medium maturity); and DeKalb 'DK59E' (late maturity).

Experiments were planted 2 June 1987 at Manhattan and 9 June 1987 at Hays. A split plot design was used with three replications at Manhattan and Hays. Individual plots were 26 m in length with 10 rows spaced 76 cm apart at Manhattan. Plots were 27 m in length with 12 rows spaced 90 cm apart at Hays. Plant populations were approximately 111,200 plants ha^{-1} at Manhattan and 86,000 plants ha^{-1} at Hays. The soil was a Reading silt loam [fine, mixed, mesic Typic Argiudoll (0 to 1 $\frac{1}{2}$ slope)] at Manhattan and a Harney silt loam [fine, montmorillonitic, mesic Typic Argiustoll (0 to 1 $\frac{1}{2}$ slope)] at Hays. Plots were fertilized according to the Kansas State University Soil Testing Lab recommendations. At Manhattan, Furadan at the rate of 1.1 a.i. kg ha^{-1} was furrow applied at planting time. A tank mix of 2.2 a.i. kg alachlor ha^{-1} and 1.1 a.i. kg atrazine ha^{-1} was applied directly after planting for grass and broadleaf control. Seed was treated with Screen^R safener. Propazine at a rate of 2.2 a.i. kg

ha⁻¹ was applied pre-plant at Hays. Weed control was supplemented by hand hoeing later during the growing season.

Approximately one week after one-half of the panicles were at some stage of bloom in a plot, paraquat (1,1'-dimethyl 1-4,4'-bipyridinium ion) was applied on a single row 4.5 to 6 m in length at Manhattan and 3.5 m at Hays. Paraquat at a rate of 1.12 a.i. kg ha⁻¹ was mixed in water at a spray volume of 188 liters ha⁻¹ at 1.5 kg cm⁻². A surfactant was added at 0.5% of the spray mixture. A hand sprayer was used with a tee-jet nozzle and application was made below the panicle at Manhattan with one application on each side of the row. At Hays, a 3.5 m plexiglass box was used to concentrate the single application made above the panicles. Desiccation treatments were continued at weekly intervals till physiological maturity. Desiccated rows were separated by border rows. Applications were made during the mornings to minimize possible wind drift. Noticable leaf discoloration was visible towards afternoon and leaf senescence was at or near 100 percent after several days. For details concerning the head cut procedure, refer to Chapter 1.

Panicles were allowed to dry under field conditions for at least two weeks after desiccation and as long as five weeks, depending upon the drying conditions. Thirty heads were then harvested and stored indoors till threshing. At Hays the entire 3.5 m length of row was harvested and stored

indoors. Threshing was done with an Almaco plot thresher. The blower on the thresher was almost closed for the early desiccations to ensure little loss of minute seeds. Samples were carefully cleaned with a blower and by hand. Two hundred seeds were counted from a random bulk sample and dried at 70 C for 2 to 3 days to determine seed weight. Test weight measurements for both head cut and desiccation methods and methods for calculating GDD and sources of weather data are described in Chapter 2.

Seed weights were converted to a percent of maximum seed weight as in Chapter 1. Percent maximum seed weight and test weight were regressed on linear and quadratic functions of GDD (SAS, 1987). Regressions were run with covariates of bloom date, hybrid, and location-year.

3.4 Results and discussion

A quadratic polynomial best described the relationship between cumulative GDD and percent maximum seed weight for the desiccation method. Cumulative GDD accounted for 93% of the variability over all desiccations yielding the equation: Percent max. seed wt. = $5.0 + 0.1741\text{GDD} - 0.0000797\text{GDD}^2$. Cumulative GDD accounted for 83% of the variability in test weight over all desiccations.

The desiccation method gave higher percent maximum seed weights and test weights compared to the head cut method (Fig. 3.1 and 3.3), especially during early grainfill between 200 to 500 GDD. This agrees with Bovey and McCarty (1965) that severing treatments gave smaller seed weights and test weights than defoliation or desiccation. At 200 GDD, the head cut method showed 7% of maximum seed weight while the desiccation method resulted in 37%. At 300 GDD, the difference between methods was 22% (Fig. 3.1). At 600 GDD, there was only a 6% difference between the predicted seed weights and at 800 GDD, the methods were nearly identical. Early in grainfill, as much as a 20 to 30% contribution was made through translocation. This compares to other reports on sorghum of 10% (Vanderlip, 1979) and corn of nearly 50% (Daynard et al., 1969).

Table 3.1 shows the GDD required to reach maximum seed

weight predicted from the regression of the desiccation and head cut methods. The desiccation method required 1090 GDD to reach maximum seed weight whereas the head cut method required approximately 1040 GDD. The Manhattan site required 1070 GDD while Hays required 1120 GDD (Figure 3.2). The high GDD requirements may be because no desiccations occurred after physiological maturity. The late hybrid at Hays had a GDD requirement of 933 which may have been because of early leaf senescence. Also, the last desiccation had a lower percent maximum seed weight than the control which may have forced the quadratic to peak prematurely. Since desiccations were only made on weekly intervals rather than sampled twice weekly as with the head cut method, this could explain some of the added variability. Estimated maximum seed weights (Table 3.1) for the desiccation method did not differ much in comparison to maximum seed weights obtained from the head cut method (Chapter 1).

The Manhattan site was expected to have higher percent maximum seed weight at least during early grainfill due to alteration in procedure for application of the desiccant. Panicles were not sprayed at Manhattan, while at Hays, application was made above the panicle. Fischer et al., (1976) reported that after anthesis, photosynthesis by the panicle was 17 percent of the total photosynthesis for the plant. Thus higher percent maximum seed weights were

expected at Manhattan due to photosynthesis by the panicle. This did not appear to be the case.

When hybrids were tested for differences in estimation of percent maximum seed weight at Manhattan, 98% (Table 3.2) of the variability was accounted for through cumulative GDD with no significant differences among hybrids. Hybrids were significantly different at the .05 level at Hays with 96% of the total variability being accounted for. The significant differences may be due, again, to the lack of harvests taken near and after physiological maturity at Hays, as well as early leaf senescence of the medium and late hybrids.

When locations were tested for differences in estimation of percent maximum seed weight, 95% of the variability was accounted for by a quadratic GDD equation with no significant differences (Table 3.4). Locations were then combined and the desiccation and head cut methods were tested for differences. Significant differences occurred at the .05 level (Table 3.4) with 95% of the variability accounted for with cumulative GDD using a quadratic polynomial. Most of this difference occurred within the early phase of grainfill apparently when translocation of materials from the culm occurred (Jacques et al, 1975 and Vanderlip, 1979) and corn (Daynard et al., 1969 and Afuakwa and Crookston, 1984). It is doubtful whether any significant amount of photosynthesis occurred in the leaves the day desiccation applications were made.

Paraquat applications were made in the morning hours and definite leaf discoloration and wrinkling occurred the first day.

Test weight varied between the two methods with maxima reached at 77.7 kg hL⁻¹ for the head cut method and 76.4 kg hL⁻¹ with the desiccation method. The head cut method estimated test weight to be 50.7 kg hL⁻¹ at 200 GDD compared to 64.6 kg hL⁻¹ for the desiccation. GDD required to reach maximum test weight were 910 for head cut and 1050 for the desiccation. Again, the medium and late hybrids had fewer harvests and early leaf senescence that occurred prematurely from low soil moisture conditions caused an apparent over-estimation of the GDD required to reach maximum test weight. A maximum test weight of 76.7 kg hL⁻¹ required 1150 GDD at Hays. Manhattan reached a maximum test weight of 76.2 kg hL⁻¹ at 1000 GDD. At 1000 GDD for Hays, test weight was already 76.4 kg hL⁻¹, thus the additional 150 GDD made little difference.

When hybrids were tested for differences in test weight, significant differences occurred at Manhattan but not at Hays with 96 to 98% of the total variability accounted for (Table 3.3). When hybrids were combined to test for location differences in test weight, 86% of the total variability was accounted for by cumulative GDD using a quadratic polynomial with no apparent location differences. When the two methods (desiccation and head

cut) were tested, differences were found between methods in estimating test weights. Desiccation gave higher test weights which agrees with previous work (Bovey and McCarty, 1965). Differences in GDD when maximum test weight was reached for the two locations may be a result, again, of early leaf senescence at Hays.

It is not known how closely the application of paraquat as a desiccant simulates a total leaf kill which may occur from an actual freeze. But in reference to previous literature concerning translocation from the culm to the grain, it is felt that desiccation more closely simulates freezing as opposed to the head cut method at least in the early phase of grainfill. Test weights were much higher than expected from the desiccation method. As stated in Chapter 2, test weights were higher than expected for the head cut method particularly during early grainfill. This was thought to be due to excessive shrinking of seed since the panicles were not allowed to dry under field conditions. The desiccation method though, gave yet higher test weights. Excess chaff in the grain because of poor threshing as a result of freeze could be a possible explanation for occurrences of low test weights that seem so prevalent with frozen sorghum (Feedstuffs, 1975). These results point more to the threshing problems with frozen sorghum. In this study, samples were meticulously cleaned of all chaff and glume-attached seed.

Results for the desiccation method did not illustrate as well the findings in Chapter 2 (head cut method) that maximum test weight was reached before maximum seed weight. But once again, fewer harvests were taken for the desiccation method near and after physiological maturity which may explain the variability observed.

3.5 Summary and conclusions

Large differences occurred between the desiccation and head cut methods for estimation of percent maximum seed weight and test weight, especially for the early phase of grainfill. A quadratic polynomial of growing degree-days (GDD) accounted for 93% of the variability in percent maximum seed weight and 83% of the variability in test weight for the desiccation method.

There were no significant differences among hybrids or locations in estimation of percent maximum seed weight. When methods (desiccation and head cut) were tested, significant differences did occur. When hybrids and locations were tested for differences in test weight accumulation, only hybrid differences were found at Manhattan. Differences in methods were also found for test weight accumulation with the desiccation method giving higher measurements especially in early grainfill.

Translocation of materials from the culm, as cited in the literature, appears to be the best explanation for the increased seed weight percentages and test weight for the desiccation method over the head cut method early in grainfill. According to the regression analysis, as much as 20 to 30% of the total seed weight was being contributed from the culm when plants were desiccated between 200 to 300

GDD after anthesis. Thus it would appear that the accumulation curves developed with the desiccation method better simulates conditions of an actual freeze. Yield losses would not be as severe as portrayed by the head cut growth curves. No definite explanation has been found for the lower test weights that generally occur in years of a freeze other than excess chaff in the grain.

Table 3.1. Number of growing degree-days (GDD) required to reach maximum seed weights and estimated maximum seed weights for Manhattan and Hays.

Location	Hybrid	Required GDD	Est. Max. Seed Wt.
			g/1000
Manhattan	Early	1043	23.49
Manhattan	Medium	1152	29.58
Manhattan	Late	1051	26.88
Hays	Early	1223	25.20
Hays	Medium	1100	31.29
Hays	Late	933	28.51

Table 3.2. Significance levels for individual regression coefficients for hybrids and associated covariates for percent maximum seed weight at Manhattan and Hays.

Variables	Location	
	Manhattan	Hays
Hybrid		*
GDD	**	**
GDD ²	**	**
GDD*Hybrid		
GDD ² *Hybrid		
R ²	0.98	0.96
CV	4.0	6.8

*,**. Significant at the .05 and .01 probability levels, respectively.

Table 3.3. Significance levels for individual regression coefficients for hybrid and associated covariates for test weight at Manhattan and Hays.

Variables	Location	
	Manhattan	Hays
Hybrid	**	
GDD	**	**
GDD ²	**	**
GDD*Hybrid	*	**
GDD ² *Hybrid		
R ²	0.98	0.96
CV	1.0	1.5

*,**. Significant at the .05 and .01 probability levels, respectively.

Table 3.4. Significance levels for individual regression coefficients for location and associated covariates for percent maximum seed weight and test weight.

Variables	% Max. seed wt.	Test wt.
Location		
GDD	**	**
GDD ²	**	**
GDD*Location		
GDD ² *Location		
R ²	0.95	0.86
CV	6.2	2.3

*,**. Significant at the .05 and .01 probability levels, respectively.

Table 3.5. Significance levels for individual regression coefficients for the desiccation method and associated covariates of percent maximum seed weight and test weight.

Variables	% Max. seed wt.	Test wt.
Method	*	*
GDD	**	**
GDD ²	**	**
GDD*Method	**	**
GDD ² *Method	**	**
R ²	0.96	0.91
CV	7.7	3.4

*,**. Significant at the .05 and .01 probability levels, respectively.

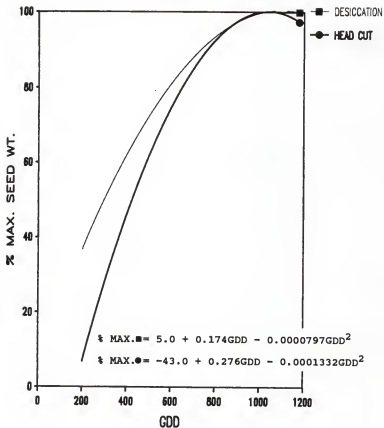


Figure 3.1. Percent maximum seed weight vs. growing degree-days (GDD) of desiccation and head cut methods predicted from regression analysis.

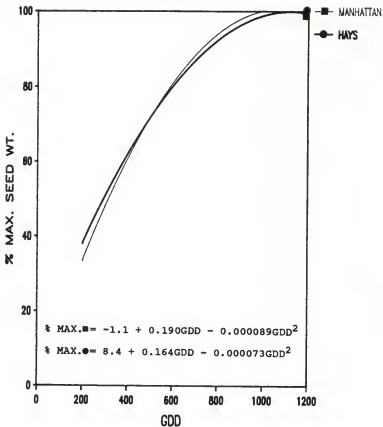


Figure 3.2. Percent maximum seed weight vs. growing degree-days (GDD) for Manhattan and Hays predicted from regression analysis.

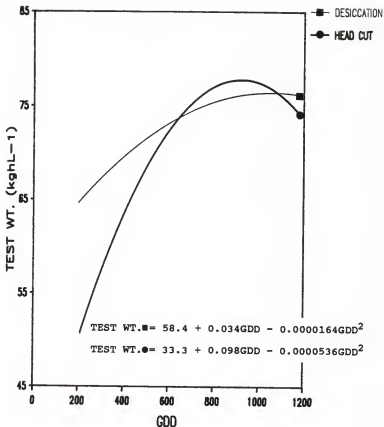


Figure 3.3. Test weight vs. growing degree-days (GDD) for desiccation and head cut methods predicted from regression analysis.

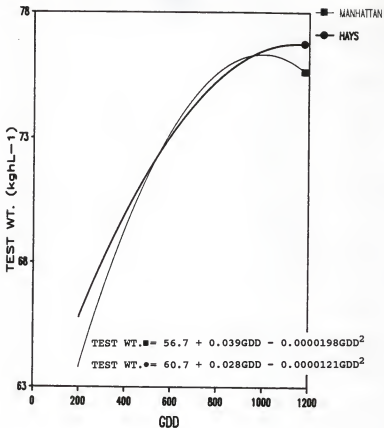


Figure 3.4. Test weight vs. growing degree-days (GDD) for Manhattan and Hays predicted from regression analysis.

REFERENCES

- Afuakwa, J. J., and R. K. Crookston. 1984. Using the kernel milk line to visually monitor grain maturity in maize. *Crop Sci.* 24: 687-691.
- Bauer, A., A.B. Frank, and A.L. Black. 1986. Estimation of spring wheat spike water concentration and grain maturity from air temperature. *Agron. J.* 78: 445-450.
- Bovey, R.W., and M.K. McCarty. 1965. Effect of preharvest desiccation on grain sorghum. *Crop Sci.* 5: 523-526.
- Carter, P.R., and O.B. Hesterman. 1987. Frost damage--how to salvage injured corn. *Crops and Soils.* 39: 19-21.
- Clegg, M.D., R. Mills, D. Lancaster, and G. McVickers. (1969). "Sorghum Management and production efficiency" in "Research in the physiology of yield and management of sorghum in relation to genetic improvement". Cooperative Research by the University of Nebraska Crops Research Division, ARS, USDA and the Rockefeller Foundation, Annual Rep. No. 3, 26-28.
- Collier, J.W. 1963. Caryopsis development in several grain sorghum varieties and hybrids. *Crop Sci.* 3: 419-422.
- Daynard, T.B., J.W. Tanner, and D.J. Hume. 1969. Contribution of stalk carbohydrates to grain yield in corn (*Zea mays* L.). *Crop Sci.* 9: 831-834.
- Eastin, J.D. 1976. Temperature influences on sorghum yields. p. 19-23. *In* Proc. Annu. Corn Sorghum Res. Conf., Chicago, Ill. 7-9 December. American Seed Trade Association. Washington, D. C.
- , J.H. Hultquist, and C.Y. Sullivan. 1973. Physiological maturity in grain sorghum. *Crop Sci.* 13: 175-178.
- , and C.Y. Sullivan. 1974. Yield considerations in selected cereals. p. 871-877. *In* R. Bielecki et al. (ed.) Mechanism of regulation of plant growth. Bull. 12. The Royal Society of New Zealand, Wellington.
- Farm Facts. 1987. Kansas Farm Facts 1986. Kansas Agri. Stats.

- Feedstuffs. 1975. Kansas compares light-weight, normal milo. 47:1:18.
- Fischer, K.S., G.L. Wilson, and I. Duthie. 1976. Studies of grain production in *Sorghum bicolor* (L.) Moench. VII. Contribution of plants parts to canopy photosynthesis and grain yield in field stations. Aus. J. Agri. Res. 27: 235.
- Gerik, T.J., W.D. Rosenthal, and J.R. Kiniry. 1987. Post-anthesis spikelet removal and midge damage effects on kernel weight compensaion of sorghum. (Personal Communication).
- Hume, D.J., and D.K. Campbell. 1972. Accumulation and translocation of soluble solids in corn stalks. Can. J. Pl. Sci. 52: 363-368.
- Jacques, G.L., R.L. Vanderlip, and D.A. Whitney. 1975. Growth and nutrient accumulation and distribution in grain sorghum. I. Dry matter production and Ca and Mg uptake and distribution. Agron. J. 67: 607-611.
- Johnson, D.R., and J.W. Tanner. 1972. Calculation of the rate and duration of grain filling in corn (*Zea mays* L.). Crop Sci. 12: 485-486.
- Kersting, J.F., F.C. Stickler, and A.W. Pauli. 1961. Grain sorghum caryopsis development. I. Changes in dry weight, moisture percentage and viability. Agron J. 53: 36-38.
- Kiniry, J.R. 1988. Kernel weight increase in response to decrease kernel number in sorghum. Agron. J. 80:221-226.
- Larson, J.C., and J.W. Maranville. 1977. Alterations of yield, test weight, and protein in lodged grain sorghum. Agron. J. 69: 629-630.
- Lewis, R.B., E.A. Hiler, and W.R. Jordan. 1974. Susceptibility of grain sorghum to water deficit at three growth stages. Agron. J. 66: 589-591.
- McKee, G.W., H.J. Lee, D.P. Knievel, and L.D. Hoffman. 1979. Rate of fill and length of the grain fill period for nine cultivars of spring oats. Agron. J. 71: 1029-1034.
- Nix, H.A., and L.A. Fitzpatrick. 1969. An index of crop water stress related to wheat and grain sorghum yields. Agri. Meteorol. 6: 321-337.

- Pauli, A.W., F.C. Stickler, and J.R. Lawless. 1964. Developmental phases of grain sorghum (Sorghum vulgare, pers.) as influenced by variety, location, and planting date. *Crop Sci.* 4: 10-13.
- Saeed, M., and C.A. Francis. 1986. Yield-maturity relationship of grain sorghum in diverse environments. *Crop Sci.* 26: 1077-1079.
- ,-----, and M.D. Clegg. 1986. Yield component analysis in grain sorghum. *Crop Sci.* 26: 346-351.
- SAS Institute. 1987. SAS user's guide. SAS Institute, Inc., Cary, NC.
- Schaffer, J.A. 1980. The effect of planting date and environment on the phenology and modeling of grain sorghum, Sorghum bicolor (L.) Moench. Ph. D. Diss. Kansas State Univ., Manhattan (Diss. Abstr. 8114070).
- Schoeff, R.W., and R.E. Page. 1977. Sorghum kernel damage. Kansas State Coop. Ext. Service. L-58.
- Scott, G.E., E.G. Heyne, and K.F. Finney. 1957. Development of the hard winter wheat kernel in relation to yield, test weight, kernel weight, moisture content and milling and baking quality. *Agron. J.* __: 509-513.
- Sofield, I., L.T. Evans, M.G. Cook, and I.F. Wardlaw. 1977. Factors influencing the rate and duration of grain filling in wheat. *Aust. J. Plant Physiol.*, 4: 785-797.
- Subramanyam, M., C.W. Deyoe, and L.H. Harbers. 1980. Corn and sorghum. I. Relationship of grain maturity to nutritional composition. *Nutritional Reports International.* 22: 5.
- Vanderlip, R.L. 1979. How a sorghum plant develops. Special Publication 3. Kansas Coop. Ext. Serv.
- Wang, Y. 1960. A critique of the heat unit approach to plant response studies. *Ecology.* 41: 785-790.

APPENDIX A

SUPPLEMENTARY TABLES AND FIGURES

Table A.1. Significance levels obtained from Type III sum of squares for analysis of covariance including bloom date at T_b of 1.0 C.

LOCATION-YEAR			
Variables	Manhattan-1986	Manhattan-1987	Hays-1987
Bloom date		**	**
GDD	**	**	**
GDD ²	**	**	**
GDD ³		*	**
GDD*Bloom date	*	*	**
GDD ² *Bloom date		*	**
GDD ³ *Bloom date			**
R ²	0.97**	0.99**	0.99**

*,** Significant at the 0.05 and 0.01 probability level, respectively.

Table A.2. Significance levels obtained from Type III sums of squares for analysis of covariance including hybrid at Tb of 1.0 C.

Variables	LOCATION-YEAR		
	Manhattan-1986	Manhattan-1987	Hays-1987
Hybrid		**	**
GDD	**	**	**
GDD ²	**	**	**
GDD ³		*	**
GDD*Hybrid	*	*	**
GDD ² *Hyrid			**
GDD ³ *Hybrid			**
R ²	0.95**	0.99**	0.99**

*,** Significant at the 0.05 and 0.01 probability level, respectively.

Table A.3. Significance levels obtained from Type III sums of squares for analysis of covariance including location-year at Tb of 5.7 C.

Variables	LOCATION-YEAR		
	Manhattan-1986	Manhattan-1987	Hays-1987
Bloom date		**	**
GDD	**	**	**
GDD ²	**	**	**
GDD ³			**
GDD*Bloom date	**		**
GDD ² *Bloom date		*	**
GDD ³ *Bloom date		*	**
R ²	0.97**	0.99**	0.99**

*,** Significant at the 0.05 and 0.01 probability level, respectively.

Table A.4. Significance levels obtained from Type III sums of squares for analysis of covariance including location-year at Tb of 5.7 C.

Variables	LOCATION-YEAR		
	Manhattan-1986	Manhattan-1987	Hays-1987
Hybrid		**	**
GDD	**	**	**
GDD ²	**	**	**
GDD ³		*	**
GDD*Hybrid	**	*	**
GDD ² *Hybrid			**
GDD ³ *Hybrid	*		**
R ²	0.94**	0.99**	0.99**

*,** Significant at the 0.05 and 0.01 probability level, respectively.

Table A.5. Significance levels obtained from Type III sums of squares for analysis of covariance at Tb of 1.0 C when analyzed across loc-yr and when hybrids were combined.

Variables	Across loc-yr	Variables	Hybrids combined
Hybrid	**	Loc-yr	**
GDD	**	GDD	**
GDD ²	**	GDD ²	**
GDD ³	**	GDD ³	**
GDD*Hybrid	**	GDD*Loc-yr	**
GDD ² *Hybrid	**	GDD ² *Loc-yr	**
GDD ³ *Hybrid	**	GDD ³ *Loc-yr	**
R ²	0.98**	R ²	0.97**

*,** Significant at the 0.05 and 0.01 probability level, respectively.

Table A.6. Significance levels obtained from Type III sums of squares for analysis of covariance at 5.7 C when analyzed across loc-yr and when hybrids were combined.

Variables	Across Loc-yr	Variables	Hybrids Combined
Hybrid	**	Loc-yr	**
GDD	**	GDD	**
GDD ²	**	GDD ²	**
GDD ³	**	GDD ³	*
GDD*Hybrid	**	GDD*Loc-yr	**
GDD ² *Hybrid	**	GDD ² *Loc-yr	**
GDD ³ *Hybrid	**	GDD ³ *Loc-yr	**
R ²	0.98**	R ²	0.97**

*,** Significant at the 0.05 and 0.01 probability level, respectively.

Table A.7. Percent of maximum seed weights calculated from regressions with various increments of growing degree-days of hybrids and location-years and Tb of 1.0 and 5.7 C.

GDD	Hybrid			Combined	Loc-yr		
	Early	Medium	Late		MAN'86	MAN'87	HAY'87
Base 1.0							
200	12.0	0	1.1	6.9	10.5	10.2	1.0
300	32.3	20.8	22.6	27.8	32.2	30.6	21.1
400	49.9	39.2	41.4	46.1	51.0	48.4	38.8
500	64.9	55.1	57.6	61.7	66.7	63.6	54.3
600	77.3	68.6	71.2	74.7	79.3	76.2	67.6
700	86.9	79.8	82.2	85.0	89.0	86.1	78.5
800	93.9	88.4	90.5	92.6	95.6	93.3	87.3
900	98.3	94.7	96.3	97.5	99.3	97.9	93.7
1000	99.9	98.6	99.38	99.8	100.0	99.9	97.9
Base 5.7 C							
200	22.0	10.7	12.7	16.9	20.6	19.5	12.0
300	45.8	35.6	38.6	41.7	45.8	43.7	36.2
400	65.2	56.4	59.9	62.2	66.2	63.6	56.4
500	80.3	73.2	76.7	78.2	81.8	79.2	72.9
600	91.2	85.9	89.0	89.9	92.6	90.4	85.4
700	97.8	94.6	96.7	97.1	98.7	97.4	94.1
800	100.0	99.2	99.9	100.0	100.0	100.0	98.9

Table A.8. Dates of anthesis for three location-years and dates for black layer at base of panicle in Julian days.

Location-year	Hybrid	Anthesis date	Black layer
Manhattan-1986	1	203	251
		205	254
		208	254
	2	208	254
		210	254
		211	258
	3	210	258
		212	261
		215	264
Manhattan-1987	1	206	246
		209	251
		212	256
	2	214	266
		217	271
		217	268
	3	220	274
Hays-1987	1	213	258
		215	261
		217	265
	2	225	275
		228	279
		231	282
	3	230	279
		233	286
		236	289

* Daily notes taken in 1987 thus greater precision in dates.

**PERCENT NOT MATURE
BEFORE FIRST FREEZE**

1984	55%	1984	72%	1984	2%
1985	70%	1985	84%	1985	47%
1984	85%	1984	7%	1984	7%
1985	84%	1985	45%	1985	83%
1984	18%	1984	27%	1984	14%
1985	88%	1985	57%	1985	48%

Figure A.1. Percent of acreage not mature before freeze in 1984 and 1985.

AVERAGE DATE OF FIRST 32" FREEZE IN FALL

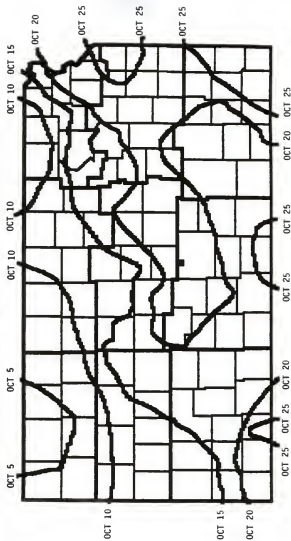


Figure A.2. Average date of first 32" freeze in the fall.

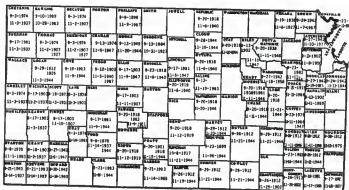


Figure A.3. Range of earliest dates of first 0 C Freezes in fall.

APPENDIX B
WEATHER DATA

Table B.1. Calendar day, daily maximum temperature, and daily minimum temperature at Manhattan, KS, 1986.

Julian date	Maximum (C ^o)	Minimum (C ^o)
120	25.41	10.78
121	22.09	08.42
122	23.06	10.25
123	25.36	09.50
124	26.81	16.50
125	28.55	14.51
126	30.15	14.88
127	27.47	15.35
128	23.26	14.51
129	27.64	15.26
130	22.62	12.40
131	27.14	08.78
132	29.79	16.50
133	25.46	13.05
134	26.26	11.87
135	26.81	14.05
136	27.98	10.05
137	16.93	08.46
138	18.70	08.78
139	22.09	5.181
140	21.75	10.21
141	23.51	09.38
142	23.02	15.09
143	22.72	13.30
144	26.59	10.90
145	22.18	11.54
146	24.48	08.46
147	22.82	11.62
148	22.67	10.53
149	26.86	12.97
150	27.81	12.72
151	30.27	11.83
152	32.22	15.47
153	27.42	17.06
154	28.61	16.50
155	31.20	18.56
156	28.38	15.86
157	30.09	16.76
158	30.76	17.81
159	29.25	14.84

Table B.1., continued.

Julian date	Maximum	Minimum
160	29.67	17.54
161	31.70	15.82
162	26.00	14.71
163	31.33	10.66
164	32.61	13.59
165	30.03	18.74
166	33.47	15.31
167	34.57	20.25
168	34.02	21.04
169	33.07	21.23
170	33.27	20.52
171	33.14	22.52
172	32.67	22.67
173	30.52	19.97
174	31.70	16.46
175	29.55	17.06
176	33.47	17.85
177	34.43	22.43
178	33.07	21.42
179	34.57	17.72
180	36.36	19.06
181	28.50	16.37
182	29.14	18.07
183	32.87	14.42
184	33.27	19.74
185	34.02	23.46
186	34.78	24.48
187	25.89	17.41
188	30.21	18.79
189	34.08	22.38
190	30.89	22.92
191	30.89	18.83
192	31.77	17.11
193	31.70	18.34
194	31.77	18.16
195	34.15	23.97
196	34.43	23.86
197	34.57	23.71
198	34.85	24.42
199	36.43	24.12
200	34.22	23.91
201	30.76	17.85
202	29.43	14.42
203	31.70	19.28
204	34.50	20.06
205	38.17	24.63

Table B.1., continued.

Julian date	Maximum	Minimum
206	32.67	19.65
207	33.95	19.47
208	36.43	20.71
209	35.92	16.93
210	35.85	21.23
211	40.18	21.94
212	29.19	20.52
213	28.38	15.26
214	30.15	12.93
215	30.39	12.72
216	31.96	18.25
217	30.21	16.85
218	31.01	15.31
219	29.91	15.77
220	31.90	13.92
221	22.72	15.94
222	27.42	15.52
223	27.98	14.93
224	29.14	14.76
225	30.95	20.15
226	29.79	19.60
227	31.07	18.92
228	30.95	14.59
229	33.67	18.16
230	28.04	17.90
231	30.03	15.56
232	32.35	15.14
233	29.79	17.59
234	30.76	18.52
235	26.21	16.42
236	31.26	15.47
237	34.02	20.76
238	28.55	19.28
239	23.76	13.71
240	19.47	12.32
241	26.64	09.81
242	26.86	16.33
243	28.44	15.39
244	27.53	14.25
245	25.36	16.50
246	28.61	17.46
247	28.55	17.19
248	29.61	14.84
249	19.51	11.02
250	18.92	08.90
251	18.88	6.661

Table B.1., continued.

Julian date	Maximum	Minimum
252	27.92	17.90
253	29.85	18.34
254	24.32	13.42
255	28.84	11.22
256	29.49	15.26
257	27.42	13.84
258	25.36	17.72
259	23.81	19.24
260	29.67	18.07
261	29.43	19.42
262	31.20	22.92
263	32.09	22.33
264	32.15	21.85
265	31.58	19.28
266	28.32	18.92
267	30.76	19.92
268	31.14	17.19
269	31.45	19.97
270	29.67	18.12
271	31.58	17.81
272	19.15	17.28
273	18.25	12.77
274	20.62	14.51
275	21.56	16.20
276	23.91	14.76
277	16.89	09.38
278	23.97	07.99
279	21.61	5.725
280	24.78	11.06
281	20.57	13.47
282	16.16	10.17
283	17.72	11.10
284	18.43	4.096
285	08.42	3.054
286	10.90	1.670
287	13.59	0.864
288	15.52	2.746
289	24.02	3.247
290	23.97	3.749
291	21.94	07.40
292	24.48	07.60
293	23.31	09.54
294	20.01	07.87
295	15.52	09.22
296	16.93	10.94
297	14.42	11.54

Table B.1., continued.

Julian date	Maximum	Minimum
298	12.85	10.90
299	13.26	5.219
300	23.61	3.710
301	23.11	10.98
302	18.92	5.336
303	20.20	3.710
304	22.52	07.68
305	07.68	0.979

Table B.2. Calendar day, daily maximum temperature, daily minimum temperature, and precipitation at Manhattan, Kansas, 1987.

Julian date	Maximum (C ^o)	Minimum (C ^o)	Precipitation (mm day ⁻¹)
121	31.70	12.56	0.000
122	27.03	16.98	1.000
123	26.43	16.03	1.000
124	18.34	13.59	37.00
125	15.60	12.44	07.00
126	23.16	11.79	5.000
127	24.78	10.82	2.000
128	29.14	09.73	0.000
129	28.61	12.23	0.000
130	30.21	16.67	0.000
131	30.52	18.34	0.000
132	29.14	16.50	0.000
133	31.70	14.97	0.000
134	29.43	16.72	3.000
135	29.31	13.34	0.000
136	30.15	11.99	0.000
137	31.07	18.07	0.000
138	30.83	19.37	4.000
139	33.95	19.06	0.000
140	28.84	18.83	0.000
141	22.04	12.48	25.00
142	22.57	9.57	0.000
143	19.65	08.98	0.000
144	25.20	16.20	14.00
145	27.98	16.42	0.000
146	28.73	17.37	08.00
147	20.29	16.03	48.00
148	26.32	15.09	1.000
149	24.58	16.11	0.000
150	30.09	16.98	0.000
151	31.33	16.33	0.000
152	29.25	18.61	0.000
153	25.73	14.13	1.000
154	25.89	09.97	0.000
155	29.19	09.50	0.000
156	30.33	14.51	0.000
157	30.70	15.47	0.000
158	33.54	18.52	0.000
159	32.74	20.71	0.000
160	31.01	21.46	0.000
161	24.78	20.15	1.000
162	32.41	21.09	0.000

Table B.2., continued.

Julian date	Maximum	Minimum	Precip.
163	34.78	22.38	0.000
164	37.25	22.33	0.000
165	39.04	19.65	0.000
166	38.72	20.99	12.00
167	35.99	21.89	0.000
168	34.92	21.66	0.000
169	33.00	20.06	09.00
170	32.22	18.03	0.000
171	31.01	20.43	0.000
172	34.85	19.42	0.000
173	34.78	19.19	08.00
174	32.02	17.54	0.000
175	32.74	17.81	6.000
176	28.90	17.11	1.000
177	29.79	14.25	0.000
178	30.15	15.39	0.000
179	33.88	17.33	23.00
180	27.08	19.88	0.000
181	22.67	16.98	1.000
182	30.09	13.42	0.000
183	32.41	16.89	0.000
184	30.83	18.25	0.000
185	30.03	19.37	0.000
186	31.26	19.37	2.000
187	35.06	20.15	0.000
188	32.41	19.83	09.00
189	32.94	23.16	3.000
190	32.74	23.11	0.000
191	34.64	23.76	0.000
192	33.88	23.76	0.000
193	26.16	17.28	15.00
194	25.20	12.77	0.000
195	29.14	10.90	0.000
196	34.29	16.07	0.000
197	35.06	19.56	0.000
198	30.27	22.43	1.000
199	34.43	22.18	1.000
200	35.34	24.48	0.000
201	35.77	23.61	0.000
202	35.34	21.46	0.000
203	34.92	21.99	0.000
204	36.50	22.72	0.000
205	38.49	23.61	0.000
206	38.72	24.37	0.000
207	38.25	23.06	0.000
208	37.86	23.21	0.000

Table B.2., continued.

Julian date	Maximum	Minimum	Precip.
209	38.56	23.61	0.000
210	38.64	23.26	0.000
211	39.28	24.17	0.000
212	39.77	23.41	0.000
213	41.35	25.04	0.000
214	41.96	26.05	0.000
215	39.28	22.62	08.00
216	31.70	19.88	1.000
217	33.54	16.59	0.000
218	36.73	19.24	5.000
219	36.88	20.94	0.000
220	30.21	20.57	0.000
221	30.95	18.03	0.000
222	32.41	15.18	0.000
223	37.10	16.37	0.000
224	26.86	21.32	30.00
225	28.96	21.32	0.000
226	34.22	20.94	0.000
227	36.43	24.94	0.000
228	34.71	18.52	0.000
229	33.81	15.47	0.000
230	30.52	18.34	6.000
231	33.00	18.25	0.000
232	36.50	19.60	0.000
233	38.25	25.62	0.000
234	27.47	15.22	0.000
235	25.04	14.63	0.000
236	17.11	15.05	2.000
237	34.15	16.07	29.00
238	21.18	15.22	18.00
239	22.92	13.59	1.000
240	28.50	10.98	0.000
241	28.50	15.94	0.000
242	25.41	14.93	0.000
243	26.86	12.32	0.000
244	30.83	11.62	0.000
245	29.25	14.00	0.000
246	31.20	16.07	0.000
247	33.81	17.54	0.000
248	32.28	19.97	0.000
249	21.75	18.21	5.000
250	28.67	16.85	1.000
251	26.00	13.30	0.000
252	29.02	10.61	11.00
253	25.20	14.63	0.000
254	27.19	13.96	0.000

Table B.2., continued.

Julian date	Maximum	Minimum	Precip.
255	23.51	11.06	0.000
256	30.27	11.91	0.000
257	33.40	19.47	0.000
258	28.73	17.50	12.00
259	24.37	16.42	0.000
260	24.94	15.73	0.000
261	25.57	13.22	1.000
262	24.63	10.17	0.000
263	24.02	07.01	0.000
264	21.94	08.15	0.000
265	23.81	07.20	0.000
266	29.85	07.40	0.000
267	32.74	12.60	0.000
268	29.19	12.81	0.000
269	31.83	15.18	0.000
270	31.01	17.24	0.000
271	25.78	12.93	0.000
272	22.92	08.86	0.000
273	26.05	6.348	0.000
274	31.83	08.31	0.000
275	19.88	2.477	0.000
276	21.09	-01.32	0.000
277	28.44	07.75	0.000
278	21.56	10.74	0.000
279	20.99	4.444	0.000
280	17.72	3.054	0.000
281	23.81	4.522	0.000
282	16.16	5.686	0.000
283	6.465	2.631	0.000
284	14.51	0.442	0.000
285	23.02	1.325	0.000
286	24.53	2.900	0.000
287	25.04	10.94	3.000
288	17.19	11.50	11.00
289	15.35	5.608	19.00
290	21.46	1.325	0.000
291	21.85	5.647	0.000
292	11.99	2.631	0.000
293	10.33	-02.05	0.000
294	12.64	-04.90	0.000
295	19.97	6.504	0.000
296	14.30	4.754	0.000
297	13.76	1.286	0.000
298	10.01	0.481	14.00
299	17.24	3.440	0.000
300	15.26	-0.093	0.000

Table B.2., continued.

Julian date	Maximum	Minimum	Precip.
301	22.23	-02.43	0.000
302	26.81	07.64	0.000
303	28.04	07.20	0.000
304	17.81	14.76	47.00
305	23.41	13.55	0.000

Table B.3. Calendar day, daily maximum temperature, daily minimum temperature, and precipitation at Hays, Kansas, 1987.

Calendar day	Maximum (C ^o)	Minimum (C ^o)	Precipitation (mm day ⁻¹)
121	30.58	10.41	0.000
122	27.36	15.77	0.000
123	24.17	13.71	16.00
124	15.31	12.40	4.000
125	13.09	11.26	13.00
126	21.94	11.54	2.000
127	25.25	10.61	0.000
128	25.62	08.27	0.000
129	28.55	10.09	0.000
130	29.91	12.23	0.000
131	27.87	14.00	0.000
132	27.75	16.03	1.000
133	31.26	15.05	0.000
134	25.84	18.03	3.000
135	28.44	14.25	0.000
136	30.64	10.94	0.000
137	31.20	15.43	0.000
138	26.97	15.69	0.000
139	29.19	17.28	0.000
140	22.72	15.47	4.000
141	21.04	08.90	0.000
142	22.14	09.10	0.000
143	15.69	12.36	6.000
144	18.43	12.56	1.000
145	28.44	11.46	1.000
146	22.57	16.42	10.00
147	23.41	14.97	1.000
148	23.91	13.55	0.000
149	26.97	10.98	0.000
150	28.90	12.81	0.000
151	31.33	12.89	0.000
152	30.83	16.33	0.000
153	23.81	12.36	24.00
154	25.78	09.93	0.000
155	28.84	07.36	0.000
156	30.21	11.46	0.000
157	31.64	12.23	0.000
158	32.61	15.94	0.000

Table B.3., continued.

Julian date	Maximum	Minimum	Precip.
159	33.14	18.34	0.000
160	30.70	18.65	0.000
161	28.90	18.56	6.000
162	34.02	16.42	13.00
163	35.34	17.02	0.000
164	36.21	16.20	0.000
165	38.02	17.63	0.000
166	38.80	19.56	0.000
167	36.65	19.60	0.000
168	34.99	18.30	11.00
169	29.43	16.76	0.000
170	27.75	15.77	2.000
171	31.83	16.59	0.000
172	33.54	17.90	0.000
173	34.50	18.38	0.000
174	33.47	16.54	0.000
175	32.35	17.06	11.00
176	29.67	15.77	0.000
177	31.96	13.63	18.00
178	34.08	15.82	0.000
179	34.57	16.89	2.000
180	24.32	17.37	07.00
181	25.25	14.34	0.000
182	29.61	11.38	0.000
183	31.90	15.82	11.00
184	31.45	19.65	0.000
185	29.08	15.99	26.00
186	34.64	18.38	1.000
187	34.22	17.68	0.000
188	31.64	19.06	0.000
189	32.94	16.80	6.000
190	33.20	19.78	1.000
191	36.36	22.62	0.000
192	35.41	23.26	1.000
193	23.86	12.11	6.000
194	26.70	09.46	0.000
195	26.92	10.82	0.000
196	34.57	15.26	0.000
197	35.70	19.24	0.000
198	26.81	20.52	15.00
199	38.02	19.56	0.000
200	36.36	21.75	0.000
201	35.41	22.23	0.000
202	34.43	20.85	0.000
203	33.88	20.52	0.000
204	36.36	21.46	0.000

Table B.3., continued.

Julian date	Maximum	Minimum	Precip.
205	37.10	20.29	0.000
206	36.73	19.19	0.000
207	36.21	19.74	0.000
208	36.28	18.83	0.000
209	36.95	20.94	0.000
210	37.25	19.60	0.000
211	38.41	20.71	0.000
212	39.77	19.42	0.000
213	42.39	23.51	0.000
214	40.09	22.38	0.000
215	32.48	19.83	13.00
216	31.07	18.38	0.000
217	32.15	15.77	0.000
218	37.71	20.06	0.000
219	36.88	19.92	1.000
220	29.97	19.88	0.000
221	27.70	15.94	0.000
222	32.28	11.79	0.000
223	36.28	18.25	18.00
224	26.97	19.47	49.00
225	26.92	18.65	0.000
226	32.87	18.07	0.000
227	36.80	21.56	0.000
228	33.07	18.56	0.000
229	34.08	16.37	07.00
230	26.75	17.02	6.000
231	34.22	16.76	0.000
232	38.72	18.30	0.000
233	40.43	25.31	0.000
234	25.57	11.99	6.000
235	21.23	11.54	6.000
236	18.65	12.97	3.000
237	31.20	16.46	1.000
238	21.89	14.76	0.000
239	24.73	13.34	0.000
240	28.84	12.03	0.000
241	29.25	13.88	0.000
242	26.10	15.60	0.000
243	26.43	12.72	0.000
244	35.85	12.68	0.000
245	30.21	12.77	0.000
246	35.77	15.64	0.000
247	34.15	18.43	0.000
248	25.52	17.50	1.000
249	28.21	15.14	1.000
250	29.85	12.97	0.000

Table B.3., continued.

Julian date	Maximum	Minimum	Precip.
251	26.26	13.30	0.000
252	32.61	13.09	2.000
253	28.90	09.85	0.000
254	25.68	11.50	0.000
255	25.10	12.03	0.000
256	32.09	13.96	0.000
257	33.20	18.21	0.000
258	29.25	15.22	0.000
259	27.59	13.18	0.000
260	25.25	13.30	0.000
261	25.57	11.42	0.000
262	25.73	09.57	0.000
263	27.75	6.778	0.000
264	22.62	5.608	0.000
265	26.37	3.170	0.000
266	31.96	6.700	0.000
267	33.20	09.50	0.000
268	30.15	08.82	0.000
269	32.22	11.70	0.000
270	30.83	14.63	6.000
271	25.94	09.42	0.000
272	24.12	5.803	0.000
273	27.14	4.754	0.000
274	33.00	07.75	0.000
275	18.92	3.517	0.000
276	23.11	-0.017	0.000
277	34.36	6.544	0.000
278	21.70	4.328	0.000
279	24.53	1.325	0.000
280	20.80	1.517	0.000
281	25.41	4.367	0.000
282	15.64	4.483	0.000
283	5.880	1.171	0.000
284	16.76	2.169	0.000
285	25.10	-01.62	0.000
286	25.46	3.286	0.000
287	24.37	07.32	2.000
288	11.91	6.309	5.000
289	17.68	0.788	2.000
290	23.61	-03.28	0.000
291	17.94	2.131	0.000
292	13.88	2.631	0.000
293	14.51	-01.66	0.000
294	20.62	-03.62	0.000
295	18.38	3.517	0.000
296	12.52	1.478	0.000

Table B.3., continued.

Julian date	Maximum	Minimum	Precip.
297	13.67	2.285	0.000
298	11.87	2.208	08.00
299	20.06	2.631	0.000
300	19.28	1.171	0.000
301	26.75	-0.477	0.000
302	29.31	3.903	0.000
303	23.97	3.517	6.000
304	23.41	11.06	0.000
305	20.15	10.41	0.000

PREDICTING LOSSES IN GRAIN SORGHUM [SORGHUM BICOLOR (L.)
MOENCH] CAUSED BY FREEZES DURING GRAINFILL

by

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B. S. Kansas State University 1985

AN ABSTRACT OF A MASTER'S THESIS

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ABSTRACT

Modelers and crop yield forecasters would like to better predict and comprehend impacts suffered from natural agronomic disasters such as early fall freezes on grain sorghum [Sorghum bicolor (L.) Moench]. Field studies were conducted on a Reading silt loam [fine, mixed, mesic Typic Argiudoll (0 to 1% slope)] in 1986 and 1987 and a Harney silt loam [fine, montmorillonitic, mesic Typic Argiustoll (0 to 1% slope)] in 1987. Percent maximum seed weight and test weight were measured with the variables bloom date, hybrid, and location-year and regressed on growing degree-days (GDD) from anthesis to physiological maturity. Percent maximum seed weight and test weight were best described by quadratic polynomials. Combined over all hybrids and location-years: Percent maximum seed wt. = $-43.0 + 0.276\text{GDD} - 0.0001332\text{GDD}^2$. This regression accounted for 95% of the variability in seed weight and predicted maximum seed weight at 1040 GDD. With a combined regression, cumulative GDD accounted for 86% of the total variability for test weight and predicted maximum test weight to be reached at 912 GDD. It appears that maximum test weight is reached before maximum seed weight. Studies were then conducted to evaluate the effects of

foliar application of paraquat (1,1'-dimethyl-4,4'-bipyridinium ion) to simulate effects of freezing on seed weight and test weight. The desiccation method gave much higher percent maximum seed weights and test weights, especially in the early phase of grainfill (200 to 500 GDD), compared to the head cut method. Apparently, translocation of materials from the culm contributed to these increased seed weights and test weights.