Fall Freeze Damage in Summer Grain Crops

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Late planting or cool growing season temperatures can result in summer crops such as corn, grain sorghum, and soybeans being exposed to freezing temperatures before they reach maturity. When summer crops are exposed to freezing temperatures, producers must determine if the crop should be harvested for grain or for livestock feed.

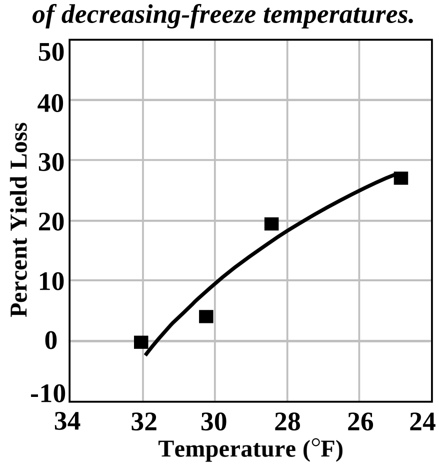
Freeze Temperature and Time of Exposure

The first step in determining yield loss after a freeze is to examine the freeze event. The minimum temperature and length of time at that temperature should be determined, as these two factors will determine if conditions were severe enough to reduce yields. The minimum temperature needed to injure a plant is not the same for all crops.

Sorghum

A recent study at Kansas State University determined the minimum temperature and exposure time required to reduce grain sorghum yields. Sorghum plants were exposed to temperatures of 32°F, 28°F, and 24°F for 2, 4 and 8 hours during grainfill[7]. The results indicate that sorghum grain weight is not reduced by temperatures of 32°F (Figure 1). However, as the air temperatures decrease below freezing, the amount of damage to a sorghum plant increases and seed weight decreases. Maximum damage occurs when plants are exposed for 2 hours or more at a temperature of 28°F or lower. Damage will not be as severe if plants are exposed for less than 2 hours. The research indicates that grain sorghum exposed to air temperatures of 28°F or lower, is unable to continue filling grain from carbohydrates stored in the stem or remaining leaves.

Figure 1. Sorghum yield loss as result of decreasing-freeze temperatures.



Corn

The minimum temperature required to cause freeze injury in corn is similar to that of grain sorghum. Field observations from Canada indicate corn leaves are not seriously damaged at temperatures near 32°F[3]. A conclusion of this study was that damage to corn leaves begins to occur at temperatures below 29°F.

Soybeans

Research conducted in Wisconsin reports that soybean leaves are not damaged until air temperatures reach 26°F[5]. This research also indicates that 80 percent of the leaves on a soybean plant are damaged after being exposed to these temperatures for 5 minutes.

Sunflowers

Observations from North Dakota indicate that sunflowers are most susceptible to frost during the bud and pollination stages (growth stages R4 & R5). At these stages, temperatures of 30°F or less cause poor pollination due to anther and stigma damage. Once the sunflower plant has reached the R7 stage, approximately 10 to 14 days after petal drydown, a sunflower plant can withstand temperatures as low as 25°F with little damage[1].

Determining Yield Losses

After determining whether or not a crop has been exposed to temperatures cold enough to reduce yields, estimating the potential yield loss that may have occurred becomes important. In summer grain crops, this is accomplished by estimating the stage of grain development at the time of the freeze.

Heat Unit Method to Determine Yield Loss for Sorghum and Corn

A precise method for determining stage of grain development in sorghum and corn involves calculating heat units accumulated since grain development began. Grain development is closely related to air temperature. As air temperature increases, the rate of grain development increases and as air temperature decreases grain development is slowed. Because grain development responds in this way, recorded temperatures can be used to estimate the stage of development anytime before maturity.

The heat unit method is not appropriate for determining soybean grain development, since soybeans are day-length sensitive and do not respond to air temperatures as corn and sorghum do.

To determine heat unit accumulation since grain development began, calculate the number of heat units accumulated each day during grain fill using the formula below. Adding the daily heat unit totals for each day since grain development began until the date of the freeze gives the total heat units accumulated.

$$\text{Heat Units} = \frac{T_{max} + T_{min}}{2} - T_b$$

The data required for these calculations are daily maximum (T_{max}) and minimum (T_{min}) air temperatures. These temperatures are recorded at a variety of locations across the state or producers can record their own temperatures with relatively inexpensive equipment that can be purchased from a variety of sources. The base temperature (T_b) in the equation above is the minimum air temperature needed for plant growth to occur. The base temperature will vary by crop.

Sorghum

Stage of grain development in sorghum can be determined using the heat unit method. The base temperature for sorghum is 42°F. Heat unit accumulation begins at anthesis, when the anthers appear on the top half of the sorghum head. If local temperatures are difficult to obtain, Table 1 lists the average heat unit accumulation for several 10-day periods beginning July 22 and continuing until October 19 for seven locations in Kansas. These data may be used to estimate the average number of heat units accumulated.

Once heat unit accumulation from anthesis has been determined, refer to Table 2 to estimate the amount of yield lost as a result of freeze damage. Notice that sorghum accumulates grain weight and final yield rapidly. When the crop has reached hard dough, about the time the grain begins to show color, the plant only has about 27 percent of its final yield left to produce. It is for this reason, that sorghum yield losses due to freezes are typically less than 20 percent.

Table 2. Estimated sorghum yield loss as the result of a freeze occurring at several levels of heat unit accumulation after anthesis and associated grain development stages.

Heat Unit Accumulation after Anthesis	*Approximate Stage of Grain Development*	*Estimated Yield Loss (%)*
500	Soft-Dough	52
700		38
900	Hard-Dough	27
1100		18
1300		11
1500		5
1700		2
1900	Physiological Maturity	0

Table 1. Thirty-year average sorghum (T_b=42°F) heat unit accumulation for 10-day periods from July 22 through October 19 for seven Kansas locations.

	Manhattan	**Parsons**	**Hutchinson**	**St. John**	**Garden City**	**Colby**	**Belleville**
	Heat Units/10 days						
Jul 22 - Jul 31	457	464	468	460	440	431	457
Aug 1-Aug 10	451	460	466	456	432	421	451
Aug 11-Aug 20	437	446	450	442	414	404	435
Aug 21 - Aug 30	414	426	436	419	391	380	410
Aug 31 - Sep 9	385	398	411	383	365	347	373
Sep10 - Sep 19	353	369	356	350	332	312	337
Sep 20 - Sep 29	316	334	315	317	296	274	301
Sep 30 - Oct 9	276	298	287	289	254	235	269
Oct 10 - Oct 19	234	260	247	250	210	191	225

Corn

Grain development in corn can be determined using the heat unit method. The base temperature for corn is 50°F and heat unit accumulation begins at silking. If local temperatures are difficult to obtain, Table 3 lists the average heat unit accumulation for several 10-day periods beginning July 22 and continuing until October 19 for seven locations in Kansas. These data may be used to estimate the average number of heat units accumulated.

Determining heat unit accumulation from silk to the freeze date is not the only step required to estimate corn yield losses. Unlike sorghum, the amount of yield loss from a freeze depends on how much leaf tissue is damaged. When minimum air temperatures are low enough to kill leaf tissue, a corn plant can continue to fill grain by redistributing sugars from the stalk. However, an extremely hard freeze, 28°F or lower, can result in damage to the ear shank. Ear shank damage prevents the plant from moving any stored sugars into the developing grain. A visual inspection of the field may be necessary to determine if ear shank damage has occurred. Table 4 lists estimated yield loss for two scenarios, a freeze with only leaf damage and a freeze with ear shank damage at several levels of heat unit accumulation from silking [2]. As heat unit accumulation from silking increases, corn yield reductions from a freeze decrease. Also as heat unit accumulation increases, the difference in yield loss between a freeze that kills only leaves versus a freeze where shank damage occurs, decreases.

Table 4. Estimated corn yield loss for two damage levels as the result of a freeze occurring at several levels of heat unit accumulation after silk and grain development stages.

Heat Unit Accumulation after Silk	*Approximate Stage of Grain Development*	**Estimated Yield Loss**	
		Leaf Damage Only	*Ear Shank Damage*
600	Dough	35	58
700	Full Dent	26	45
800		18	33
900		11	22
1000	Late Dent	6	12
1100		3	5
1200		0	1
1300	Physiological Maturity	0	0

Visual Inspection Method to Determine Yield Loss

An alternative method to determine stage of grain development at the time of the freeze is by a visual inspection of the kernel. A yield loss estimate can be made based on the grain growth stage at the time of the freeze.

Sorghum

Sorghum grain development stages are defined as follows: milk, the kernel still contains a significant amount of liquid; soft dough, kernel is filled with a soft pasty substance; hard dough, kernel endosperm has a chalky consistency; physiological maturity, kernel weight is at a maximum and kernel growth has ceased and yield can not be reduced by a freeze at this stage[8]. Grain moisture is approximately 30 percent at physiological maturity.

Physiological maturity can be easily determined by looking for the black layer at the base of the kernel. To determine black layer, remove a kernel from the sorghum head and examine the tip of the kernel where it was attached to the head. If a black spot can be seen at or near this point of attachment, the kernel is at black layer.

Once the stage of kernel development has been determined, refer to the appropriate entry in Table 2 to estimate yield loss from a freeze at that particular growth stage.

Table 3. Thirty-year average corn (T_b=50°F) heat unit accumulation for 10-day periods from July 22 through October 19 for seven Kansas locations.

	Manhattan	**Parsons**	**Hutchinson**	**St. John**	**Garden City**	**Colby**	**Belleville**
	Heat Units/10 days						
Jul 22 - Jul 31	270	270	267	265	250	244	267
Aug 1 - Aug 10	265	270	265	256	248	238	264
Aug 11 - Aug 20	258	263	260	246	240	229	256
Aug 21 - Aug 30	246	254	252	232	227	216	243
Aug 31 - Sep 9	233	236	241	215	203	185	210
Sep 10 - Sep 19	191	207	194	188	170	151	175
Sep 20 - Sep 29	154	172	153	156	142	129	139
Sep 30 - Oct 9	122	136	133	140	122	114	118
Oct 10 - Oct 19	100	108	107	119	100	92	96

Corn

As with sorghum, corn yield losses from a freeze can be assessed by a visual inspection to determine stage of kernel development. Corn grain development stages are defined as follows: blister, kernel is white and contains a clear fluid; milk, kernel is yellow and contains a white milky fluid; dough, kernel is filled with a soft pasty substance; dent, kernel is drying and starch accumulation at the top of the seed causes it to dent; physiological maturity, kernel weight has reached a maximum and kernel growth has ceased and yield can not be reduced by a freeze at this growth stage[4].

A plant has reached physiological maturity when a black layer has formed at the base of the kernel, opposite the embryo. Once the stage of kernel development has been determined, refer to the appropriate line in Table 4 to estimate yield loss.

Soybeans

Because soybeans are day-length sensitive, a visual inspection for the stage of grain development is necessary to determine yield loss after a freeze. Soybean grain development is defined by the following stages: R5, beginning seed; R6, full seed; R7, beginning maturity; R8, full maturity. Soybean growth habit can result in one plant having seed at two or more different stages of development. For example, a plant may have pods beginning to mature (R7) at the mid to lower nodes and may also have pods at full seed (R6) at the top nodes. Such a plant may be designated as being at stage R6.5 rather than only R6 or R7.

After a freeze has occurred, visual inspection of the plants will determine to what extent leaf damage has occurred. Check for leaf burn into the middle of the canopy. If little or no leaf damage has occurred or if leaf damage is confined to the upper or outer leaves, then the soybean plants were probably not exposed to cold enough temperatures to damage the plant and reduce yields. If the leaves are damaged close to the stem, then the amount of leaf damage and stage of grain development will determine the amount of yield loss. Estimated soybean yield reduction based on stage of grain development at the time of the freeze is presented in Table 5[5]. Heavy losses will occur if a freeze occurs during early seed development (stages R4 and R5); however, a freeze at this stage would be extremely rare. When the crop approaches full seed size, with mature seed at the lower nodes (R7), yield reductions from a freeze are much lower, approximately 20 percent or less.

Table 5. Estimated soybean yield loss as the result of a freeze occurring at several growth stages.

Soybean Growth Stage	*Numerical Growth Stage*	*Percent Yield Loss if Killing Frost Occurs*
Beginning Seed	5.0	65.4
	5.5	51.0
Full Seed	6.0	37.1
	6.5	23.9
Beginning Maturity	7.0	11.4
	7.5	0.0
Full Maturity	8.0	0.0

Source: Saliba, et al. Crop Sci. 22:73-78

Harvest Options After a Fall Freeze

Yield loss must be considered to make a decision on whether to harvest a freeze-damaged crop for grain or livestock feed. The methods described earlier will enable producers to determine the percent of yield loss to expect, but the decision to harvest for grain versus livestock feed requires an assessment of bushels of grain lost as the result of a freeze. To determine this yield loss, an estimate must be made of what the grain yield would have been had a freeze not affected the plants ability to mature naturally.

The best method for estimating yield potential available to producers is their own judgment. Other methods involving research based simulation models may be appropriate, but are beyond the scope of this publication and are not readily available to county or university personnel. A producer’s estimate of grain yield potential should be based on growing conditions prior to the freeze, past hybrid or variety performance, past performance of a given field, and personal experience. Once a prefrost potential yield level has been established, refer to the appropriate tables discussed earlier in this publication to determine the amount of yield lost, in bushels or pounds, because of a freeze.

Once yield loss from a freeze has been estimated, producers can determine the most profitable harvest option. These options include harvesting for grain, harvesting for forage (silage, hay, grazing), or leaving the crop unharvested. Clearly, leaving the crop unharvested represents a worst-case scenario and will be the option of choice only when the freeze damage is so severe the salvage value of the crop is less than the harvesting cost.

The economic returns of the alternative harvest options are analyzed and compared using partial budgets. Partial budgets only include the income and costs directly associated with the alternatives being compared. Therefore, partial budgets are useful for determining which

Table 6. Partial budget comparing harvesting sorghum as grain versus silage.

	Harvest sorghum as	
	Grain, bu	*Silage, tons*
Yield potential before freeze	90	13.1[1]
Estimated grain yield loss due to freeze	15%	N/A
Estimated yield after freeze	76.5	12.0[1]
Price/value of crop per unit	$1.71[2]	$13.77[3]
Price/value of crop per acre	$130.82	$165.24
Harvest cost per acre	$19.10[4]	$62.04[4]
Returns over harvest costs	$111.72	$103.20[5]
Break-even price compared to grain	xxxxx	$14.48
Break-even yield compared to grain	xxxxx	13.0

[1] Values determined from Table 8. Silage calculated at 65% moisture.
[2] Based on sorghum price of $3.60 / cwt. x 15% quality reduction.
[3] Based on sorghum price of $3.60 / cwt. x 15% quality reduction x factor of 4.5.
[4] Based on Kansas Custom Rates for 1995.
[5] Assumes the residue removed by harvesting as silage has no value.

Table 7. Potential grain and forage yields for corn at several yield loss levels.

	Potential Grain Yield (bu/a)							
Grain loss	***75***	***100***	***125***	***150***	***175***	***200***	***225***	***250***
(%)	**Dry Matter (t/a)†**							
0	4.5	5.5	6.5	7.5	8.5	9.4	10.4	11.4
5	4.4	5.3	6.3	7.2	8.2	9.2	10.1	11.1
10	4.3	5.2	6.1	7.0	8.0	8.9	9.8	10.7
15	4.2	5.0	5.9	6.8	7.7	8.6	9.5	10.4
20	4.1	4.9	5.8	6.6	7.5	8.3	9.2	10.0
25	3.9	4.8	5.6	6.4	7.2	8.0	8.9	9.7

†To convert dry matter values to silage or forage yields, use the following equation: Silage or forage yield = Dry matter yield ÷ (1-Water Content).

Table 8. Potential grain and forage yields for sorghum at several yield loss levels.

	Potential Grain Yield (bu/a)							
Grain loss	***30***	***50***	***70***	***90***	***110***	***130***	***150***	***170***
(%)	**Dry Matter (t/a)†**							
0	2.0	2.8	3.7	4.6	5.4	6.3	7.2	8.1
5	1.9	2.8	3.6	4.4	5.3	6.1	7.0	7.8
10	1.9	2.7	6.5	4.3	5.1	5.9	6.8	7.6
15	1.8	2.6	3.4	4.2	5.0	5.8	6.6	7.3
20	1.8	2.6	3.3	4.1	4.8	5.6	6.3	7.1
25	1.8	2.5	3.2	3.9	4.7	5.4	6.1	6.9

†To convert dry matter values to silage or forage yields, use the following equation: Silage of forage yield = Dry matter yield ÷ (1 - Water Content).

alternative is the most profitable. However, because partial budgets only include the variable costs directly associated with the alternative being analyzed, they are not useful for determining overall profitability of an enterprise or farm.

The income of harvesting the freeze-damaged crop is the estimated yield times the relevant price. The relevant price to use in a partial budget should reflect the value of the crop in its best use[6]. For example, light test weight sorghum may have a higher value if fed to livestock than if sold at a discounted market price. In this case, the sorghum should be priced according to its value as a feed if feeding to livestock is a viable alternative. Likewise, when evaluating the returns for harvesting a freeze-damaged crop as silage or hay, the price should reflect the value of silage or hay when fed or sold. If the freeze-damaged crop is grazed, the value per acre should reflect the cost of feed replaced by the grazing. The costs associated with harvesting a freeze-damaged crop will be the direct harvesting costs as well as potential indirect costs. For example, harvesting as silage reduces the residue available for moisture conservation and erosion control.

The value of residue will be highly variable among operations and is hard to quantify. However, it is important to keep in mind that this could be an indirect cost associated with harvesting as silage to include when budgeting. Table 6 is an example partial budget evaluating the returns for harvesting freeze-damaged sorghum as grain and silage. Tables 7 and 8 illustrate the relationship between expected grain yield of corn and sorghum and dry matter yield (silage or hay). Table 8 is used to calculate the silage yield in the example partial budget. Based on the assumptions used in this example, harvesting as grain is slightly more profitable than harvesting as silage. Estimating the returns per acre from harvesting the crop as grain will often be easier than estimating the returns from silage, hay, or grazing because yields and prices are easier to project for grain. In these instances, it may be beneficial to calculate a break-even yield or price for the forage crop. This allows a producer to see what price and yield are needed for the returns of the alternatives being compared to be equal. Even though the returns to harvesting as grain are greater than harvesting as silage in the example partial budget (Table 6), it can be seen that the returns would be equal with fairly small changes in either the silage yield or price. When a crop has been injured by a freeze, the original intentions for the crop (grain production) may, or may not, be the most profitable use of the crop.

If the freeze damage is severe enough, it may be economically more profitable to harvest the crop as forage rather than grain. Because of this, it is important for producers to evaluate the returns over harvesting costs for the alternatives they have available in their operations. The market for selling forages (silage, hay or grazing) is highly variable and often very thin; therefore, producers having livestock will typically have more alternatives to consider than cash grain producers. Developing partial budgets for each of the alternatives can be helpful as producers consider the most profitable way to harvest their freeze-damaged crop.

Summary

The severity of freeze damage to a crop is determined by the temperature of the freeze event. Critical temperature, the minimum temperature a crop must be exposed to before damage occurs, is different for each of the summer crops discussed in this publication. Yield losses in summer crops as the result of freeze damage can be estimated by determining the stage of grain fill when the freeze occurred. Once yield losses have been estimated, producers should determine the most profitable method of harvest based on crop values and harvesting costs.

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