UNITED SORGHUM CHECKOFF PROGRAM

NEBRASKA AND SOUTH DAKOTA PRODUCTION GUIDE

SORGHUM THE SMART CHOICE

Welcome to the United Sorghum Checkoff Program's Nebraska and South Dakota Production Guide. We have integrated research from various sources to produce an easy-to-use guide that can help farmers manage their crop more efficiently. Sorghum has tremendous potential to return a profit to your farm, and Sorghum Checkoff work will only improve that potential over time. As you manage your sorghum, keep these tips in mind:

- Choose a hybrid appropriate for your region and conditions. Check with your extension service for unbiased data as well as your seed company representative.
- Set a realistic yield goal, and apply the appropriate amount of fertilizer to meet that goal.
- Use an integrated weed management strategy that starts with a preemergence herbicide, and then apply an appropriate post treatment as needed.

By following a few guidelines, you'll be amazed at what this crop can do for you. We strive to help you make sorghum more profitable for your operation. Remember, every situation is a bit different, so contact your local county extension office, land-grant university or other area sorghum farmers to help you get the most out of this water-sipping crop.

Funded by:

United Sorghum Checkoff Program

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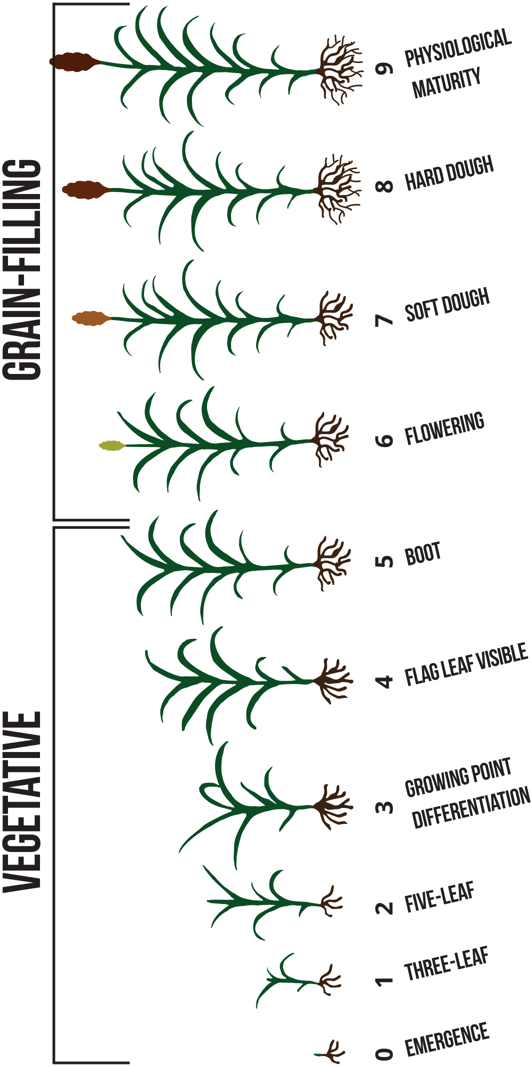
TOPIC PAGE

GROWTH STAGES

It is important to understand the various developmental stages of sorghum to aid in making critical management decisions. The stages are based on key points of sorghum growth used to describe sorghum from planting to maturity. There are 10 recognized stages in sorghum starting with emergence (Stage 0) to physiological maturity (Stage 9).

An excellent publication on sorghum growth and development was published by Kansas State University titled “How a Sorghum Plant Develops." The publication provides excellent pictures of the different growth stages as well as graphs of cumulative nutrient uptake. The 10 crop growth stages are listed on the next few pages along with timely management suggestions for each stage.


GRAIN-FILLING
VEGETATIVE
9 PHYSIOLOGICAL MATURITY
8 HARD DOUGH
7 SOFT DOUGH
6 FLOWERING
5 BOOT
4 FLAG LEAF VISIBLE
3 GROWING POINT DIFFERENTIATION
2 FIVE-LEAF
1 THREE-LEAF
0 EMERGENCE

Emergence (Stage 0)

The plant is visible when the first leaf (coleoptile leaf) breaks through the soil surface. The coleoptile leaf is shorter than the later emerging leaves and has a rounded leaf tip. Emergence time can range from 3-14 days and will depend largely on soil temperature, moisture, seeding depth and seedling vigor.

Three-Leaf (Stage 1)

The collar of the third leaf is visible (once a leaf's collar forms the leaf no longer expands). This stage occurs 10-15 days after emergence, depending on weather conditions. The plant is typically 3-4 inches tall.

Five-Leaf (Stage 2)

The collar of the fifth fully expanded leaf is visible. This stage occurs approximately 20-25 days after emergence and when plants are 7-9 inches tall. The growing point is at or just below the soil surface. Many post herbicides should be applied at or before this time. Side-dress fertilizer applications are best made now or over the next 10-15 days.

Growing Point Differentiation (GPD)(Stage 3)

The growing point can now be found above the ground, and the number of seeds per head will be determined over the next couple of weeks. The plant is now entering a rapid period of growth. This stage typically occurs 30-40 days after emergence and when the plant is 12-15 inches tall.

One or two of the bottom leaves may have been lost, and tillers may now be present originating at the base of the plant. Prior to GPD, the plant can withstand considerable stress with minimum effect on yield. However, stress during GPD can affect the potential number of seeds per head that can be set at flowering. Plants should be adequately fertilized prior to this stage. This is a key stage to apply irrigation if available and if soil moisture conditions are dry.

Flag Leaf Visible (Stage 4)

The last leaf to emerge prior to heading is called the flag leaf. This leaf is shorter than the preceding leaves. The plant is considered to be in the flag leaf stage when the leaf tip is visible in the whorl. The last two or three leaves will fully expand during this period.

Boot (Stage 5)

Leaf collars of all leaves are now visible. The sorghum head, or panicle, can be located just below the flag leaf collar enclosed in the flag leaf sheath. The sorghum head is now being pushed up through the flag leaf collar by the upper stalk known as the "peduncle." The length of the peduncle can be affected by stress at this time and is influenced by hybrid genetics. With most grain sorghum hybrids, the boot stage occurs 50-60 days after emergence. Moisture stress during boot and for the next 14 days will significantly lower yield.

Heading (Not Official Stage)

Sorghum is considered headed when 50 percent of the heads (panicles) in a field are visible.

Flowering (Stage 6)

Flowering is the most critical stage in the life of the sorghum plant. A plant begins flowering (blooming) from the top of the panicle and progresses downward. A field of sorghum is considered to be in the flowering stage when blooming has progressed halfway down the panicle in 50 percent of the plants. The peduncle is still elongating, and it typically takes 4-9 days for a single head to complete the flowering process. Hybrids are rated on their maturity largely based on the length of time it takes to reach the flowering stage.

Milk (Not Official Stage)

Grain begins forming as soon as flowering (pollination) is complete. The grain, or kernel, quickly expands and contains a milky fluid. The sorghum is now in what is often referred to as the grain fill period that will not be completed until physiological maturity is reached.

Soft Dough (Stage 7)

The soft dough stage is reached when the grain can still be crushed between the thumb and index finger but no longer contains a milky liquid. Starch is rapidly accumulating, and 50 percent of the grain's final weight has been achieved. Stress at this time can significantly lower yield. Whole plant moisture is approximately 65-68 percent once the soft dough stage has been reached and is typically when sorghum is harvested for silage. Grain has colored by the end of the soft dough stage.

Hard Dough (Stage 8)

At the hard dough stage, grain has reached 75 percent of its final dry weight, and nutrient uptake is almost complete. The grain can no longer be crushed between the thumb and index finger. Water stress during this time tends to promote lodging.

Physiological Maturity (Stage 9)

Grain has now achieved its maximum dry weight. Physiological maturity is recognized by a dark spot or black layer on the bottom of the kernel. Grain moisture content typically ranges, 25-35 percent. Dessicants can now be safely used to aid in harvest without reducing grain yield.

Determining Leaf Stage

Grain sorghum leaves are numbered by counting the fully expanded leaves with a developed collar. Once sorghum has produced about five fully expanded leaves, counting can become difficult. This is because lower leaves will become crumbled and will start falling off the plant. When counting leaves, keep in mind leaves alternate from one side of the stalk to the other. Also keep in mind the first leaf is a short leaf with a rounded tip that will likely have fallen off the plant within 25 days of emergence.

APPROXIMATE DAYS TO EACH GROWTH STAGE

Boot	→	Heading	→	Flowering	→	Milk	→	S. Dough	→	H. Dough	→	PM
	3-5		5		5		14		10		10-14	

FREEZE DAMAGE & HAIL INJURY

Assessment and formulas used by crop insurance adjusters can get complicated, but yield loss predictions are based on the stage of growth and the amount of plant damage. Plant damage includes both direct damage and leaf defoliation. Direct damage is made up of stand reduction and stalk and head injury.

For the first 30 days after emergence, sorghum can withstand significant damage from a late, light freeze or from hail damage and recover without significant yield loss. This is because the growing point is below or very close to the soil surface. Early hail-damaged sorghum has surprisingly little loss in yield potential provided the plants remain healthy. For example, 50 percent leaf removal five weeks after germination (near growing point differentiation) reduces yield potential by about 5 percent. Losses are substantially higher for older plants, especially if bruising of the stalk occurs leading to broken stalks or disease infection. Yield loss from leaf defoliation reaches its maximum at the bloom stage (Table 1).

It is best to wait 7-10 days after an early to mid-season hail event to assess damage. Under good growing conditions, the sorghum plant will often put on new growth in just a few days. Early in the season, even if a few plants are killed, leaving a skip in the row, yield will be compensated for by an increase in tillering or increased head size of the surrounding plants.

An early freeze during grain fill can have a major effect on yield. Grain at the soft dough stage has only accumulated about 50 percent of its final weight and at the hard dough stage about 75 percent of its final weight.

TABLE 1. YIELD LOSS DUE TO LEAF DEFOLIATION (NEB G86-812)

Growth Stage	Percent Defoliation		
	30	50	70
Boot	18	31	53
Bloom	19	33	57
Milk	13	22	38
Soft Dough	7	12	21

HYBRID SELECTION

Selection of appropriate hybrids is foundational for successful grain sorghum production. It is not unusual for the best hybrid to out-yield the poorest hybrid in a test or farm plot by 40 bushels or more per acre. Even on a multiyear-test-average basis, hybrid yields may differ by more than 20 bushels.

Environment will play an important role in any given hybrid's performance. For this reason, it is critical hybrids be adapted to the local environment. Key resources for hybrid adaptability and performance are local extension and seed company trials available at SorghumCheckoff.com. Since conditions will vary from year to year, it is a good idea to examine a hybrid's performance over multiple years before making the decision to plant significant acres to a new hybrid. Maturity, standability, drought tolerance, insect and disease resistance and head exertion are all important characteristics to consider in selecting a sorghum hybrid.

<u>Maturity</u>

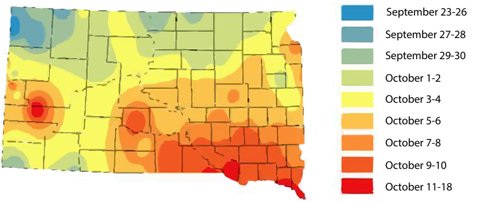
Due to the longer grain-fill period, later maturing hybrids tend to produce higher yields over shorter maturity hybrids. However, in Nebraska and South Dakota, the sorghum growing season is typically much shorter than in southern states, which means later maturing varieties may not reach full yield potential before a killing frost. Different companies often use different standards for maturity ratings in their marketing of sorghum hybrids. Typically, the highest yielding varieties for South Dakota and Nebraska reach 50 percent bloom (flowering) in 55–65 days after planting, which is rated as early to medium maturity. The expected days to reach physiological maturity for the same hybrids can range from 80–110 days after planting. Planting date and in-season weather will affect crop performance. A frost of two hours or more at a temperature of 28°F or lower before black layer is reached will potentially decrease yield and test weight.

The growth rate of sorghum can be quantified using a heat unit approach defined by growing degree-units (GDUs). Cumulative GDUs are calculated by subtracting a base temperature from the average diurnal temperature and adding the daily values over the duration of the growing season. For sorghum growth, the base temperature is set at 50°F and the maximum temperature is 100°F. For short-season hybrids, the range of cumulative GDUs is generally 2600-2900 with 800-1000 GDUs necessary between flowering and black layer. At black layer, the seed has reached its maximum dry mass accumulation, but is generally 25-35 percent moisture and will need to dry down below 20 percent moisture before harvest can begin.

Drydown may last several weeks and depends on weather conditions.

A killing frost will help to hasten the dry down period but will also decrease yield if the plant has not reached maturity. Figure 1 shows the average calendar date where a killing frost might be expected in South Dakota. As a general rule of thumb, hybrids should be selected to reach black layer approximately one to two weeks prior to the first killing frost. For much of the NE/SD region, sorghum hybrids that reach black layer by mid- to late September will finish grain-fill before a killing frost. Choosing a hybrid maturity based on the probability of a first killing frost helps to ensure against heavy yield losses in years of uncommonly early frost.

50 Percentile First Fall 28° F Day Occurance



50% probability that the first fall 28°F temperature will occur on or before this day
(Stations with at least 90 years of data - whole station record)

FIGURE 1. AVERAGE OCCURRENCE OF THE FIRST KILLING FROST ACROSS SOUTH DAKOTA. THIS DATE RANGES FROM LATER SEPTEMBER IN THE NORTHWEST CORNER TO MID-OCTOBER IN THE NORTHEAST CORNER OF THE STATE.

In summary, hybrid maturity plays a major role in choosing the proper hybrid for this region. Both South Dakota State University and the University of Nebraska maintain sorghum yield trials to help growers decide on a hybrid that best fits their needs. Links to the various state hybrid trials can be found on the Sorghum Checkoff website or on states extension websites.

Standability

All sorghum hybrids will lodge under the right conditions. However, genetics do play a significant role in the standability of a hybrid. Standability ratings should be a particularly important consideration when planting in environments where drought stress is common late in the season. Hybrids with more of the staygreen trait as well as those that have charcoal rot tolerance also tend to have better standability.

Drought Tolerance

In the western portion of the region where conditions are drier, a hybrid's drought tolerance becomes important. Selecting a hybrid based on its drought tolerance rating is particularly important on sandy soils with less water holding capacity. Some yield potential may be given up with those hybrids possessing the highest drought tolerance rating, but these may yield more consistently over multiple years.

Disease and Insect Resistance

Diseases and insects are typically not a major problem in sorghum in Nebraska and South Dakota. However, when selecting hybrids, pest resistance should be considered on the basis of probability of a repeat problem, availability of resistance or tolerance in commercially available hybrids.

Head Exertion

Many companies rate hybrids for head exertion – the extent to which the head emerges from the boot, especially under moisture-limiting conditions. In some hybrids, the peduncle may not elongate enough to fully expose the head when soil moisture is limiting during heading. With poor head exertion, the portion of the head still wrapped in the sheath of the flag leaf can have poor seed set or may be more susceptible to grain molds if rains come after pollination and grain-fill. Good head exertion will also improve harvestability and lessen the need for grain cleaning following harvest. However, too much head exertion can lead to the stalk (peduncle) below the head breaking over in adverse weather conditions.

Seed and Plant Color

Producers often prefer hybrids with a certain seed color based on their opinion of how well seedlings emerge in stressful conditions. Although laboratory studies have documented greater stress germination and elongation for seedlings with the purple plant characteristic, no differences in these measures of seed vigor were attributed to seed color. Field studies have shown greater seedling emergence for red seed than for white seed, but the white seeded types had greater yields. Adequate emergence and high yields have been exhibited by hybrids of all seed and plant color combinations. **Specific hybrid and seed lot performance are probably more important than seed or plant color.** Select hybrids with above-average seedling vigor when planting early or in no-till systems.

PLANTING PRACTICES

For optimal germination and emergence, growers should typically wait until average soil temperatures have reached 60°F in the planting layer. Planting as soon as possible after minimum temperatures have been reached will help avoid flowering during the typically hot, dry period in late July and early August. Planting depth should generally be around 1 inch in most soils. In sandy soils, seeds can be placed 2 inches deep with no problems. Planting deeper than 2 inches will lead to slow emergence, and final stand numbers may be reduced.

Typically, the preferred row spacing for grain sorghum in NE/SD has been 30 inches. This spacing is generally more conducive for low-yielding environments. Where moisture is less limiting, 15 and 20-inch row spacing have been increasingly utilized.

Skip-row planting based on 30-inch rows has been evaluated for improving the drought tolerance of sorghum. Skip-row planting involves leaving some rows unplanted. Common configurations are planting alternate rows (plant 1 – skip 1), alternate pairs (plant 2 – skip 2), or planting two rows and skipping one row. Skip-row planting increases competition among plants within a row, thus limiting excessive tillering and utilization of soil water. The large space left between rows conserves soil moisture for the reproductive stage of growth because the roots do not have access to the soil water under the unplanted rows until well into July. Under inadequate rainfall, skip-row planted sorghum will yield higher than fields where all the rows are planted. However, in years with good soil water at planting and average or above average precipitation, planting every row will almost always yield more. Additionally, weed management is more difficult in skip rows.

Similar to other crops, sorghum benefits from soil water conservation practices. These include using no-till, strip-till or reduced-till techniques.

Seeding Rate

Emergence and final plant population are often lower than corn when compared to the initial seeding rate. This is especially true at high seeding rates. Recommended grain sorghum seeding rates for NE/SD vary based on water availability, planting date, elevation and latitude. Therefore, adjustments in seeding rate need to be made across the region for different precipitation zones (Table 2). Alternatively, seeding rates can be based on yield goal (Table 3).

TABLE 2. GUIDELINES FOR GRAIN SOGHUM PLANTING POPULATION

Average Annual Rainfall + Irrigation (inches)			
<15	15-20	20-25	>25
Plants per acre			
30,000	30,000-40,000	50,000-70,000	70,000-90,000

TABLE 3. SEEDING RATE BASED ON YIELD GOAL

Seeding Rate per Acre	Yield Goal
30,000	3,000-5,000 lb or 60-90 bu
50,000	5,000-8,000 lb or 90-145 bu
70,000	8,000-10,000 lb or 145-180 bu
90,000	Greater than 10,000 lb or 180 bu

SORGHUM WATER USE

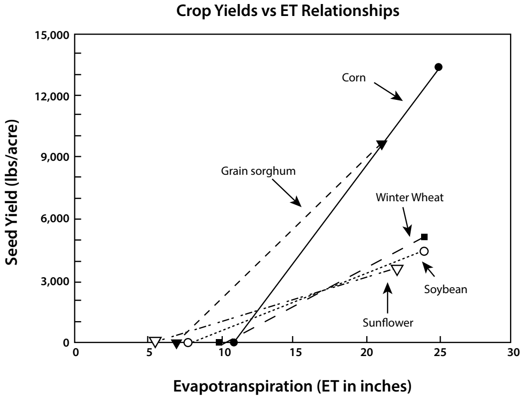
Sorghum is water efficient and has traditionally been considered a dryland crop but also responds well to irrigation. Because acceptable yields can be achieved with grain sorghum at a lower water allocation than corn, sorghum has found favor in areas with mandated water restrictions and producers with limited water supplies. Under certain market conditions, sorghum may also be planted under irrigation replacing corn because of its lower seed costs and competitive price.

Grain sorghum can yield consistently if managed appropriately and grown under conditions providing greater than 15 inches of annual precipitation. Nebraska research has shown grain sorghum to have a yield-to-water use relationship of 6.4 bu/in of water in southeast Nebraska. This relationship decreases from 6.4 bu/in southeast Nebraska to 5 bu/in of water in the Nebraska Panhandle primarily due to a shorter growing season. Depending on environmental conditions, length of the growing season or available soil moisture, grain sorghum is able to compensate by adjusting the number of tillers, head size and final seed weight. The final number of seeds per head is the yield component that most influences yield with grain sorghum.

Grain sorghum has been observed to use a drought avoidance technique that essentially shuts the plant down and limits growth. It will remain in this state until additional moisture is received. While this is helpful when precipitation is limiting, it can delay the maturation of the crop, making it more vulnerable to a season-ending killing frost prior to reaching full maturity.

Irrigation

Grain sorghum responds well to full to moderate irrigation and is a good choice for those growers with low capacity wells. The amount of irrigation water needed will depend on the year, but sorghum can respond well to optimized irrigation scheduling where a limited amount of irrigation water is applied during the season.



Source: "Agricultural Crop Water Use" Pub. No. L-934 Kansas State University Research and Extension, Manhattan, Kansas, KS 66506.

FIGURE 2. SHOWS THE GREATER COMPETITIVENESS OF SORGHUM RELATIVE TO CORN WHEN WATER IS LIMITING. IN THIS KANSAS STATE STUDY, WHEN TOTAL WATER USED BY SORGHUM WAS LESS THAN APPROXIMATELY 21 INCHES, SORGHUM YIELDED MORE THAN CORN. AT THIS WATER USE LEVEL BOTH SORGHUM AND CORN YIELDED APPROXIMATELY 9,750 LB/A (174 BU/A).

CROP ROTATION

Sorghum, a warm-season grass, is commonly grown in drier areas in rotation with cool-season cereals using no-till techniques to save moisture. Because sorghum has fewer weed control options than corn, it is more important to use cultural practices that reduce weed issues in the crop. Warm-season grass species add diversity to crop rotations due to their late spring planting dates, providing an opportunity to control cool-season and winter annual weeds prior to seeding. These weed types (wild oats, downy brome, etc.) become troublesome in rotations predominated by cool-season grasses. In South Dakota, research has shown the value of rotation design and lack of disturbance on controlling the weed seed bank and the weed pressure experienced in semi-arid regions. Best results were attained when soil disturbance was limited (no-till) and there were two consecutive crop sequences that provided the opportunity to attain excellent control of specific weed species. Using both a warm-season grass crop (cool-season grass weeds controlled before seeding) and a cool-season broadleaf crop (cool-season grass weeds controlled in crop) or warm-season broadleaf crop or fallow between wheat crops reduced weed pressure from winter-annual grasses by over 95 percent. Similar rotations should be considered for sorghum. Use of tillage at any time dilutes the rotation impact because some weed seeds are buried, and others are brought to the surface where they germinate. Weed seed eradication is most effective when they are left on the soil surface. Similar effects occur with diseases associated with plant residue or those living in the soil. Management of residue and soil-borne diseases also requires use of a minimum two-year sequential break.

Sorghum also provides a high carbon content and high water-use efficiency component to the system. It produces large amounts of biomass and is among the most efficient at capturing carbon. This helps in cycling nutrients, matching water-use to precipitation available and maintaining soil carbon levels. It also has tolerance to some herbicides that are not utilized with cool-season grasses or broadleaf crops.

Most crop rotations in central South Dakota and Nebraska have either corn or sorghum (or both) as part of rotations that contain winter wheat and one or more broadleaf crops. When prices are high, a producer may choose to use corn on fields with specific weed issues, especially if he or she already owns appropriate seeding and harvest equipment. Many others might choose sorghum depending on economics, especially since grain sorghum costs less to produce. For instance, seed costs can be as low as 1/5 as much as corn. Corn and sorghum are complementary warm-season grasses at many levels. Sorghum and corn share almost no common diseases. Those struggling with issues such as Goss's Wilt (bacterial disease) and extended diapause corn rootworm can break these disease and insect cycles while still maintaining a high proportion of warm-season grasses in the rotation. Sorghum is normally planted later than corn. This spreads the workload and equipment over two windows thus increasing efficiency. Improvement could be achieved by simply planting sorghum in half of the fields designated for corn and not changing the rotation design.

Another approach is to employ a stacked rotation. In stacked rotations, crops of the same type are grown in succession followed by a long interval of crops representing other plant growth habits. "Stacking" the corn and sorghum sequences together provides the ability to adopt practices that can reduce the probability of developing biotype resistance in weeds. This is accomplished because this design allows use of long residual herbicide products during the first year of a stacked sequence and shorter residual herbicides during the second year. There is not an issue with carry-over damage for the long-residual herbicide because another tolerant crop will be grown. The repeated use of the same postemergence herbicide program is dramatically reduced. This principle can be used with other crop types and chemistries, but it is very appropriate with atrazine and the warm-season grasses. In northern areas, it is most common to place the sorghum first in the sequence, followed by corn. There are several reasons for this. Foremost is the fact that there are more short-residual herbicides available for use in corn than in sorghum. Sorghum does a better job of catching snow and provides a seedbed conducive for planting corn. Sorghum can struggle when seeded into heavy corn residue in northern areas due to the shorter growing season and cooler temperatures.

NUTRIENT MANAGEMENT

Nutrient Requirements

Sorghum is considered very efficient in utilizing nutrients from the soil because of a large fibrous root system. However, profitable responses to fertilization can be expected on many soils. **Total nutrient removal by sorghum is similar to that of corn and wheat at comparable yields.**

As a basis for sorghum fertility, pH must first be addressed due to the large effects it has on nutrient cycling and uptake. Liming is advised when the soil pH is 5.8 or less. Surface application of lime without incorporation for no-till fields is effective but will require more time to correct the acidity of the deeper soil.

Assuming adequate pH, Table 4 shows a generalized estimate of total nutrient uptake (grain and stover) for a 100 bushel/acre yield. Precise nutrient requirements can be difficult to estimate and can vary considerably depending on climate, soil type and cultural practices. As a result, a variety of different approaches have been developed to estimate specific crop's needs. Each method includes some generalizations such as fixed factors for nutrient needs and credits for previous manure applications, and crop types (soybean credits). These factors should be considered carefully and in context when applying these equations to an individual farm.

TABLE 4. TOTAL NUTRIENT REMOVAL BY SORGHUM GRAIN AND STOVER BASED ON A 100 BUSHEL YEILD

Element	lbs/A[1]		
	Grain	Stover	Total
Nitrogen (N)	66	78	144
Phosphorus (P2O5)	39	23	62
Phosphorus (P)	17	10	27
Potassium (K2O)	27	118	145
Potassium (K)	22	98	120
Sulfur (S)	6	16	22

[1]Source = IPNI Nutrient Removal Calculator (2014)

Nitrogen (N)

Nitrogen is by far the nutrient in greatest demand. The N requirement for sorghum is commonly assumed as 1.12 lbs N/bu grain yield used in combination with all the credits that include the weighted average of soil test nitrate (0-2 ft), legume credits for soybean (40 lbs N/A), alfalfa and other legumes (Table 5). In the early stages of no-till an additional 20-30 lb N/A is recommended.

TABLE 5. SORGHUM NUTRIENT RATE EQUATIONS FOR N, P AND K IN SOUTH DAKOTA BASED ON YEILD GOAL

Nutrient	Nutrient Rate Reccomendation Equation
Nitrogen	Yield goal x 1.1 - soil test N (0-2ft) - legume credits[A] + 30 lbs N/A for no-till
Phosphorus (Olsen P)	((0.666-(0.033 x soil test P)) x yield goal
Phosphorus (Bray P)	((0.666-(0.041 x soil test P)) x yield goal
Potassium	((0.875- (0.0058 x soil test K)) x yield goal

[A]soybeans = 40 lbs/A, alfalfa based on stand (>5 plants/ft^2=150 lbs N/ft^2, 3-5 plants/ft^2=100 lbs N/ft^2, 1-2 plants/ft^2=50 lbs N/A, <1 plant/ft^2=0 lbs N/A). Decrease alfalfa credits by 50% for no-till.

An alternative approach to calculating the N fertilizer rate is based on the economic optimum N rate (EONR). The EONR incorporates the cost of sorghum grain and the cost of N fertilizer into the traditional yield goal equations. Researchers at the University of Nebraska-Lincoln (UNL) have developed EONR equations for sorghum following either grain, soybeans or alfalfa.

For sorghum following non-legume:
EONR (lb/acre) = [70 + (1.1 x EY) – (20 x OM) – (14 x NO3- N ppm) – other credits] x (PGPN x 0.11) where EY = expected yield (bu/A) estimated as 1.1 x average sorghum grain yield over the past five years or more, OM = percent soil organic matter to a maximum of 3 percent, NO3-N ppm = weighted average nitrate-nitrogen concentration for a 2 foot depth in parts-per-million, and PGPN = the price of grain ($/bu) divided by the price of fertilizer N ($/lb).

Other credits include nitrogen from manure or other applied organic material and from irrigation water.

For sorghum following soybeans or alfalfa:
EONR (lb/acre) = -68 + 0.49 EY + 6.9 PGPN where EY = expected yield (bu/A) estimated as 1.05 x average yield, and PGPN = the price of grain ($/bu) divided by the price of fertilizer N ($/lb).

Additional rules of thumb

- Nitrogen rates should be increased by 20 lb/A where soil organic matter is less than 1.8 percent. When a soil test for organic matter is not available, 1 percent organic matter is assumed for sandy soils and 2 percent is assumed for other soils. The value is capped at 3 percent organic matter due to insufficient data from soils of higher organic matter.
- If N in the top 24 inches of the soil sample is greater than 6 ppm, the N rate should be decreased by 8 lb/A for each additional ppm nitrate-N. For example, an additional 16 lbs N could be subtracted from the above examples based on an average soil test N of 8.75 ppm.
- Manure nitrogen should be credited as necessary. As a general guideline, only 25–50 percent of manure N is available during the first year after application. About 15 percent of the original organic nitrogen in manure or compost is released in year two, 7 percent in year three, and 4 percent in year four. These values may vary widely depending on climate and soil type. Further guidelines on estimating nutrients available from manure are available at http://manure.unl.edu/.

Phosphorus (P)
There are three phosphorus lab tests predominately used in the United States. These are Mehlich-3, Bray-1 and Olsen. Mechlich-3 can be used on all soil types. Bray-1 is used on acid and nuetral soils and Olsen is used on calcareous soils. To convert Mehlich-3 to Bray-1 or Olsen use the follwing formulas: Bray-1 P = Mehlich-3 x 0.85 and Olsen P = Mehlich-3 x 1.5.

Yield increases are expected from phosphorus applications when the soil test phosphorus is below 15 ppm by the Bray-1 P and Mehlich-3 phosphorus soil tests, or 10 ppm by the Olsen phosphorus soil test. Research suggests 0-8 inch soil depth should be sampled. Sampling at shallower depths can result in over-estimation of soil phosphorus levels, while the opposite is true for a deeper sampling depth. This is especially true for no-till and reduced tillage situations where soil phosphorus availability is typically greatest in the surface 2 inches of soil.

Phosphorus is generally less mobile in soils. Therefore, phosphorus applications can be made in the fall or spring prior to planting or banded at seeding. Because phosphorus tends to bind strongly to soil particles, a broadcast application is typically less efficient at delivering phosphorus to the plant root. Phosphorus applications can be made based on a static recommendation (Table 6) or using the yield goal approach (Table 5). A 100 bu/A sorghum yield goal at the “low” P (3 ppm - Bray) soil test requires 54 lbs P2O5/A. A soil test in the “medium” range (10 ppm - Bray) requires 26 lbs P2O5/A, similar to the UNL static recommendation.

TABLE 6. UNL PHOSPHORUS FERTILIZER RECOMMENDATIONS

Phosphorus Soil Test, ppm P		**Amount to Apply Annually (P_2O_5) lb/A**	
Bray-1 P[1]	Olsen P[2]	Broadcast	Band[3]
0-5	0-3	80	40
6-15	4-10	40	20
>15	>10	0	0

[1]Bray-1 for acid and neutral soils
[2]Olsen P for calcareous soils
[3]Band application is typically more efficient, particularly at low soil test levels

Potassium (K)

Potassium is generally not a limiting nutrient in this region and potassium needs are frequently met by the soil supply. However, where a soil test shows insufficient potassium levels, a fertilizer application is recommended (Table 7). As with P, SDSU equations for determining potassium nutrient recommendations for sorghum can be found in Table 5. Keeping with the example of a 100 bu/A sorghum yield goal, a “low” K (60 ppm) soil test requires 53 lbs K2O/A. A soil test in the “medium” range (100 ppm) requires 30 lbs K2O/A. Previous research has shown little yield difference between different potassium formulates, and cost of potassium fertilizer should likely be the primary consideration.

TABLE 7. UNL POTASSIUM FERTILIZER RECOMMENDATIONS

Potassium Soil Test, ppm K		Amount to Apply Annually (K_2O) lb/ac	
		Broadcast	Band
<40	Very Low	120	20
41-75	Low	80	10
76-125	Medium	40	10
>125	High	0	0

[1]Banded beside the seed row but not with the seed, due to potential salt damage

Sulfur (S)

Sulfur levels in the common soils of NE/SD are generally adequate for sorghum production. However, if soil tests sulfate-sulfur in the top 0-2 ft. layer is less than 40 lbs/A, additions of fertilizer sulfur to the soil should be considered (Table 8). Other factors that could affect sorghum's response to sulfur are soil texture and organic matter. Courser textured soils may leach more sulfur if excessive precipitation is received and soils with low organic matter levels have less sulfur available to mineralize.

Banding sulfur fertilizer is generally more effective than a broadcast application. When sulfur is applied in a band at planting, use sulfate-sulfur since the oxidation process is not rapid enough for elemental sulfur to effectively supply early plant growth. Ammonium thiosulfate (12-0-0-26S) is also effective but must not be placed with the seed because of the potential for seed germination damage. Ammonium thiosulfate is an excellent source when injected into irrigation water for sprinkler application and can provide sulfur in-season if a deficiency develops.

TABLE 8. SULFUR RECOMMENDATIONS FOR NE/SD

		Course Soil Texture		**Medium/Fine Soil Texture**	
Sulfur Soil Test	Category	Tilled	No-Till[A]	Tilled	No-Till[A]
lbs/A (0-2 ft.)		lbs/A sulfur recommended			
0-9	Very Low	25	25	25	25
10-19	Low	25	25	15	25
20-29	Medium	15	25	0	15
30-39	High	15	15	0	15
>40	Very High	0	0	0	0

[A]Includes strip till and other very reduced-tillage methods

Zinc (Zn) and other micronutrients

Zinc deficiency is less common in sorghum production. However, zinc deficiencies are more often found in the western parts of South Dakota and Nebraska where calcareous soils with low organic matter are more common. Soil test zinc above 0.8 ppm does not require any fertilizer zinc additions to the soil (Table 9). Zinc can be effectively applied either by broadcasting or in a band beside the row. If banding zinc, it is recommended that approximately 10 lbs. of nitrogen be placed in the same band to promote root growth and nutrient uptake. Inorganic forms of zinc such as zinc oxides, zinc sulfate or ammoniated zinc solutions are more cost-effective than zinc chelates.

TABLE 9. ZINC FERTILIZER RECOMMENDATIONS

Zinc Soil Test Level		**Amount to Apply Annually (Zn) lb/A[1]**			
DTPA Extraction (ppm Zn)	Relative Level	Calcareous Soils[2]		Noncalcareous Soils	
		Broadcast	Band	Broadcast	Band
0-0.4	Low	10	2	5	2
0.41-0.8	Medium	5	1	3	1
>0.8	High	0	0	0	0

[1]Rates are for inorganic forms of Zn such as zinc sulfate
[2]Calcareous soils defined as soils with moderate to excess lime

Iron (Fe) chlorosis may occur in sorghum growing in soils with high pH (>7.8). However, an economic response is unexpected to the current forms of iron fertilizer on the market. Finally, assuming pH is maintained in the typical range for productive agriculture, sorghum has generally not been found to respond to additions of chloride (Cl), magnesium (Mg), calcium (Ca), boron (B), copper (Cu) and manganese (Mn) in NE/SD and should not be a concern for sorghum in most cases.

A note on seed-placed fertilizer

Seed-placed fertilizer should be considered with caution as sorghum is more sensitive than corn to salt content. The variables that control the fertilizer rate applied in the seed furrow are the fertilizer material, row spacing, soil moisture at planting and allowable stand loss. Table 10 compares the effect of row spacing and soil moisture on allowable seed-placed fertilizer. For more detailed information on other fertilizer materials and management scenarios, please visit http://www.ipni.net/article/IPNI-3268.

TABLE 10. SORGHUM SEED-PLACED FERTILIZER RECOMMENDATIONS[A].

	Row Spacing and Soil Moisture Level					
Fertilizer Material	20 inch rows			30 inch rows		
	Dry	Borderline	Moist	Dry	Borderline	Moist
	Maximum amount (lbs/A) of fertilizer material placed with seed					
DAP (18-46-0)	8.7	11.6	17.4	5.8	7.7	11.6
MAP (11-52-0)	16.1	21.5	32.3	10.8	14.3	21.5
10-34-0	43.6	58.1	87.2	29.1	38.8	58.1
Potash (0-0-60)	6.3	8.4	12.6	4.2	5.6	8.4

[A]Based on "Seed-Placed Fertilizer Decision Aid", International Plant Nutrition Institute, http://www.ipni.net/article/IPNI-3268

WEED MANAGEMENT

Grain sorghum is highly sensitive to weed competition, particularly during the first five weeks after planting. For this reason, growers should, “START CLEAN, STAY CLEAN”. Weeds are a persistent problem in row crops, competing directly for water, light and nutrients, causing yield losses in quantity and quality. If all weeds were to emerge at the same time, weed management would be a simple task. Instead, weeds are an annual problem because they germinate at different times, allowing them to escape control, produce seed and create a soil seedbank that may persist for years. Scouting fields for pest problems is essential in any cropping system, and knowledge of the timing and sequence of weed species emergence increases the effectiveness of management practices.

Weed control in grain sorghum is best achieved with an integrated approach using crop rotation, good crop production practices, herbicides and/or tillage. This integrated approach enhances the ability of sorghum to compete with weeds.

Current postemergence (post) herbicides labeled for grain sorghum have limited activity on grasses. Consequently, pre-plant burndown and preemergence (pre) herbicides are the main options for annual grass control in grain sorghum. Grain sorghum, however, is often grown in dry environments under rain-fed conditions and the absence of adequate soil moisture often reduces the activation and efficacy of preemergence herbicides. **Weed management is ranked by growers as one of the biggest challenges for grain sorghum production.**

A herbicide program consisting of pre-plant or pre burndown plus soil residual activity will help growers to “start clean”. Early scouting and programs that contain post plus soil residual activity herbicides should suppress weeds until canopy closure, helping growers to “stay clean”. For burndown pre- and post-herbicide options commonly used in grain sorghum, see Tables 11, 12 and 13.

Overreliance on a single herbicide program within and across growing seasons eventually leads to resistance and weed control failure. Growers should consider using herbicides from multiple effective sites of action at each application to slow the evolution of resistance. Moreover, growers should consider cultural strategies (e.g. crop rotation, plant population, row spacing, planting date and cover crops) as part of their weed management program. **Crop and herbicide rotation are effective ways to manage troublesome weeds in grain sorghum, particularly grasses.** Seeds of grass species typically do not last very long in the soil seedbank, thus proper management of grasses during non-sorghum years becomes a key strategy for grass management in grain sorghum. Pre-plant tillage and inter-row cultivation can effectively reduce weed populations. However, tillage operations are likely to result in water and wind erosion, accelerated decomposition of soil organic matter, and compaction. Delaying grain sorghum planting allows additional flushes of weeds to emerge, providing an additional opportunity to manage broadleaf weeds and grasses using burndown herbicides. **Do not plant grain sorghum when a severe shattercane or johnsongrass infestation is expected.**

Weed management in Inzen and igrowth™ sorghum (As of Oct. 2019, not commercially available)

Grain sorghum tolerant to acetolactate synthase (ALS)-inhibiting herbicides has been developed using traditional breeding. This technology has the potential to improve grain sorghum production by allowing for the post control of traditionally hard-to-control grasses (e.g. foxtails, barnyardgrass, sandburs etc.). Inzen grain sorghum has been developed by Corteva Agriscience™, and is tolerant to sulfonylurea herbicides. Nicosulfuron is the herbicide labeled for use in Inzen sorghum. Igrowth™ sorghum has been developed by Advanta® and is tolerant to the imidazolinone herbicides. It is anticipated that Imazamox is the herbicide that will be labeled for use in igrowth™ sorghum in the U.S. Both of these technologies will make it possible to control annual grasses with post herbicide application.

Grain sorghum, however, does have the potential to outcross with shattercane and johnsongrass. **For this reason, special care should be taken to follow all stewardship guidelines associated with these technologies.** Moreover, ALS-resistant weeds have been widely reported, indicating that over-reliance on ALS-chemistry will select for resistant biotypes. Proper herbicide resistance management becomes extremely important with adoption of Inzen or igrowth™ grain sorghum.

According to Corteva's stewardship guidelines, growers should not plant Inzen grain sorghum in fields known to have ALS-resistant shattercane and/or johnsongrass. Grain sorghum should not be planted the year after growing Inzen grain sorghum. Rotating Inzen sorghum with non-sorghum crops where different effective herbicide options are available is a key strategy to keep shattercane and johnsongrass populations at low levels while delaying the evolution of ALS-resistance. Emerged weeds should be managed by effective burndown herbicides or tillage prior to planting Inzen grain sorghum. Shattercane and johnsongrass growing in road ditches and fence rows near Inzen sorghum fields should be managed to minimize the chance of crop-to-weed gene flow. Nicosulfuron herbicide should be sprayed in Inzen grain sorghum at full recommended rates and when grasses are small. Growers should scout fields after Nicosulfuron application to ensure control has been achieved. Alternative strategies such as inter-row cultivation, rope wick herbicide application (using glyphosate) and/or rogueing surviving resistant or escaped weeds before flowering can also play an important role in managing ALS-resistance. These strategies can reduce the likelihood of pollen-mediated gene flow from Inzen to weedy sorghum species and reduce seedbank replenishment with herbicide-resistant individuals.

Stewardship guidelines for igrowth™ sorghum are being developed but are expected to be similar to those used with Inzen sorghum.

Summary

Since herbicide options in sorghum are more limited than some other commodity crops, following practices to ensure sustainability of the programs and to mitigate resistance is essential. The key for long-term sustainability is diversity. As previously mentioned, systems should incorporate crop rotation and changes in agronomic practices wherever possible. Like many cropping systems, postemergence options are limited, so using residual based products and making timely applications to ensure weed control programs are successful regardless of the chemicals that are being used is essential.

TABLE 11. COMMONLY USED PRE-PLANT BURNDOWN HERBICIDES.[a]

Active Ingredient	Common Trade Names	WSSA Site of Action	Control
atrazine	AAtrex, atrazine	5	Broadleaf weed control and annual grass suppression
glyphosate	Roundup, Touchdown	9	Broadleaf weed and annual grass control
paraquat	Gramoxone SL	22	Broadleaf weed and annual grass control
2, 4-D	2, 4-D, Barrage, Unison, others	4	Broadleaf weed control
dicamba	Banvel, Clarity	4	Broadleaf weed control
saflufenacil	Sharpen	14	Broadleaf weed control
Tank mixes and commercial premix herbicides			
atrazine+glyphosate	atrazine+glyphosate	5+9	Broadleaf weed and annual grass control
atrazine+mesotrione +s-metolachlor	Lexar EZ, Lumax EZ[b]	5+27+15	Broadleaf weed and annual grass control
atrazine+paraquat	Gramoxone SL+ atrazine	5+22	Broadleaf weed and annual grass control
atrazine+gloyphosate +s-metolachlor	Expert[b]	5+9+15	Broadleaf weed and annual grass control

TABLE 11. CONTINUED

2, 4-D+glyphosate	2, 4-D+glyphosate	4+9	Broadleaf weed and annual grass control
2, 4-D+glyphosate	LandMaster II	4+9	Broadleaf weed and annual grass control
saflufenacil+glyphosate	Sharpen+glyphosate	14+9	Broadleaf weed and annual grass control
atrazine+2,4-D	atrazine+2, 4-D	5+4	Broadleaf weed control and annual grass supression
atrazine+dicamba	atrazine+dicamba	5+4	Broadleaf weed control and annual grass supression
2, 4-D+dicamba	dicamba+2, 4-D	4+4	Broadleaf weed control
2, 4-D +carfentrazone-ethyl	Aim+2,4-D	4+14	Broadleaf weed control
saflufenacil+ dimethenamid-p	Verdict[b]	14+15	Broadleaf weed control

[a]Adapted from the Guide for Weed, Disease, and Insect Management in Nebraska (EC130). See herbicide labels for use rates and restrictions.
[B]Seed safener required.

TABLE 12. COMMONLY USED PRE HERBICIDES IN GRAIN SORGHUM.[a]

Active Ingredient	Common Trade Names	WSSA Site of Action	Control
atrazine	AAtrex, atrazine	5	Broadleaf weed control and suppression of annual grasses
acetochlor	Warrant[b]	15	Annual grass control and suppression of small seeded broadleaf weeds
dimethenamid-p	Outlook[b]	15	Annual grass control and suppression of small seeded broadleaf weeds
s-metocachlor	Cinch, Dual II Magnum[b]	15	Annual grass control and suppression of small seeded broadleaf weeds
Saflufenacil	Sharpen	14	Broadleaf weed control
Tank mixes and commercial premix hybrids			
atrazine+acetochlor	Degree Xtra, Fultime NXT[b]	5+15	Broadleaf weed and annual grass control
atrazine+dimethenamid-P	Atrazine+Outlook[b]	5+15	Broadleaf weed and annual grass control
quinclorac	Facet L	4	Mostly for bindweed weed control

[a]Adapted from the Guide for Weed, Disease, and Insect Management in Nebraska (EC130). See herbicide labels for use rates and restrictions. For activation and residual activity, PRE herbicides need adequate soil moisture

[b]Seed safener required.

TABLE 13. COMMONLY USED POST HERBICIDES IN GRAIN SORGHUM.[a]

Active Ingredient	Common Trade Names	WSSA Site of Action	Control
atrazine+mesotrione +s-metolachlor	Lexar EZ, Lumaz EZ[b]	5+27+15	Broadleaf weed and annual grass control
atrazine+s-metolachlor	Bicep II Magnum, Cinch ATZ[b]	5+15	Broadleaf weed and annual grass control
saflufenacil+dimethenamid-p	Verdict	14+15	Broadleaf weed and annual grass control
atrazine	AAtrex, atrazine	5	Broadleaf weed control with soil residual
2, 4-D	2, 4-D, Barrage, Unison, others	4	Broadleaf weed control
bromoxynil	Buctril, Moxy	6	Broadleaf weed control
carfentrazone-ethyl	Aim	14	Broadleaf weed control
dicamba	Banvel, Clarity	4	Broadleaf weed control
fluroxypyr	Starane Ultra, Staredown	4	Broadleaf weed control
halosulfuron	Permit	2	Broadleaf weed control
prosulfuron	Peak	2	Broadleaf weed control

TABLE 13. CONTINUED

Tank mixes and commercial premix herbicides			
atrazine+carfentrazone-ethyl	Atrazine+Aim	5+14	Broadleaf weed control and suppression of annual grasses
atrazine+dicamba	atrazine+dicamba	5+4	Broadleaf weed control and suppression of annual grasses
atrazine+bromoxynil	atrazine+Buctril	5+6	Broadleaf weed control and suppression of annual grasses
atrazine+quinclorac	atrazine+Facet L	5+4	Broadleaf weed control and suppression of annual grasses
dicamba+ carfentrazone-ethyl	dicamba+Aim	4+14	Broadleaf weed control
dicamba+halosulfuron	Yukon	4+2	Broadleaf weed control
dicamba+prosulfuron	dicamba+Peak	4+2	Broadleaf weed control
Pyrasolfotole +bromoxynil	Huskie	27+6	Broadleaf weed control

[a]Adapted from the Guide for Weed, Disease, and Insect Management in Nebraska (EC130). See herbicide labels for use rates and restrictions. For effective control, POST herbicides should be sprayed when weeds are small.

INSECT MANAGEMENT

Sorghum growers in NE/SD seldom have issues with insects, especially in the drier regions out west. Occasionally, problematic insects include aphids (greenbug, sugarcane aphid), headworms (corn earworm and fall armyworm) and stalk borers. Regular monitoring of sorghum fields for insect activity is important for early identification to allow for prompt management response if needed.

Seed insecticide treatments such as clothianidin (Poncho®), thiamethoxam (Cruiser®) and imidacloprid (Gaucho®) have good efficacy on many below-ground soil pests and early seedling pests of sorghum such as flea beetle, chinch bug, stink bug and aphids. Use of these seed treatments normally prevent these pests from being an issue early in the season.

Greenbug (Schizaphis graminun)

Identification

On plant leaves, a colony of greenbugs will consist of both nymphs (immature stages) and adults. The adults are approximately 1/16-1/8 of an inch long. The nymphs are slightly smaller and will range in size depending on growth stage. The adults and nymphs are light green to greenish-yellow in color, **with a narrow dark green stripe down the middle of their backs.** Their legs are green with the exception of the tarsi (feet), which are black. The cornicles (tailpipes) of the greenbugs are green with black tips and are located at the end of their abdomens. The antennae of the greenbugs are darker in color than the rest of the body (Figure 3). Adults may be either winged (alate) or wingless (apterous).

FIGURE 3. GREENBUG NYMPHS AND ADULTS ON A LEAF. NOTICE THE DISCOLORATION ASSOCIATED WITH AREAS WHERE FEEDING HAS OCCURRED. PHOTO COURTESY OF DEPARTMENT OF ENTOMOLOGY, UNIVERSITY OF NEBRASKA-LINCOLN.

Injury

Greenbugs injure sorghum by inserting their needle-like mouthparts into plants and removing plant sap. During this process, greenbugs inject saliva into the plant to feed, and in doing so they further injure the plant due to toxic enzymes present in their saliva. Initial feeding injury may appear as yellow spots, which later turn from red to brown (Figure 3). When greenbugs infest a plant they initially feed on the undersides of lower leaves and when present in large populations, can kill the sorghum leaves.

.Management Recommendations

Most sorghum varieties planted in the U.S. now have excellent resistance to greenbug. As a result, greenbugs seldom reach an economic threshold. However, a biotype change could quickly allow the greenbug to overcome the resistance mechanism of the sorghum. For this reason, growers should not discount the possibility of greenbug becoming an issue. Fortunately, there are a number of beneficial insects that are natural enemies to greenbug and other aphids. Some of the more common natural enemies include lady beetles, syrphid (hover fly) larvae, minute pirate bugs, braconid wasp parasites, as well as fungal pathogens. Photos of beneficial insects can be seen in the appendices (page 83). Greenbugs killed by wasp parasites turn brown and are referred to as "mummies". A variety of foliar insecticides can be applied if thresholds in Table 14 are exceeded at various growth stages.

Sugarcane aphid (Melanaphis sacchari)

At this time, sugarcane aphids are not expected to be a serious problem in NE/SD. However, southern Nebraska may occasionally see infestation levels reach treatment threshold late in the season that could cause issues with harvest.

Table 14. Treatment Guidelines for Greenbugs on Grain Sorghum

Growth Stage	Treatment Guidelines
Seedling (0-5 leaves)	Treat if greenbug colonies are present on 10-20 percent of plants, and visible yellowing or spotting on leaves is present.
Plants 6 inches tall to boot	Treat if greenbug colonies are beginning to cause red or yellow leaf spotting on lower leaves of most plants AND parasite numbers are low (less than 20 percent of greenbugs parasitized).
Boot to soft dough	Treat if greenbug colonies are present on most plants, before one lower leaf has been killed AND parasite numbers are low (less than 20 percent of greenbugs parasitized).

Identification

This aphid is 1/16 inch long at maturity and varies in color from light yellow to grayish white with dark cornicles (tail pipes), dark feet and antennae (Figure 8). Adult aphids can be winged or wingless.

Injury

Sugarcane aphids feed primarily on the undersides of leaves and will generally colonize

FIGURE 4. SUGARCANE APHID NYMPHS AND ADULTS. PHOTO COURTESY OF PATRICK PORTER, TEXAS COOPERATIVE EXTENSION, BUGWOOD.ORG.

the lower leaves of the sorghum plant first. When large populations of sugarcane aphids feed on a leaf, it can result in leaf death. Yield losses of over 50 percent have been reported in southern states where large infestations have occurred. Additionally, it produces an abundance of sticky honeydew, which can lead to other complications and the growth of black sooty mold. Late in the season, sugarcane aphid can infest the panicle leading to harvest interference from the honeydew.

Management Recommendations

In the south, most entomologists recommend treating sugarcane aphid when 20 percent of pre-headed plants are infested with 50 or more aphids per leaf. After flowering, the threshold increases to 30 percent of the plants infested. The later the sugarcane aphid infests sorghum, the less direct yield loss will occur (Table 15).

TABLE 15. YIELD LOSS OF SORGHUM BY SUGARCANE APHID IF LEFT UNCONTROLLED

Crop Stage at 20% Infestation	Percent Yield Loss with no Treatment
Pre-Boot	81-100%
Boot	52-69%
Heading	67%
Soft-Dough	21%

Source: Mississippi State University

Determining if sorghum should be treated to aid in harvest is a difficult decision and is primarily a judgment call. The question that must be asked is if honeydew is present at a high enough amount to interfere with harvest, causing gumming issues with the combine. If treatment is necessary, use the lowest rate available of an effective insecticide. The goal is to control the existing sugarcane aphids. Re-infestation is likely not an issue, so long insecticide residual is not needed. Currently, Sivanto HL (flupyradifurone) or Transform (sulfoxaflor) are the insecticides of choice for controlling sugarcane aphids.

Headworms

Both the corn earworm and fall armyworm can infest the heads of sorghum and directly feed on the immature grain.

Corn earworm (Helicoverpa zea)

Identification

Larvae may reach up to 1.5 inches long at maturity. The color may vary widely from green, yellowish, reddish brown, to black. The head is usually orange. The body is covered with microspines visible with a hand lens (Figure 9).

FIGURE 5. CORN EARWORM CATERPILLAR. PHOTO COURTESY OF DEPARTMENT OF ENTOMOLOGY, UNIVERSITY OF NEBRASKA-LINCOLN.

Injury and Damage

Larvae may be found in the vegetative stage of sorghum where they feed on leaf tissue within the whorl. When these injured leaves emerge they have ragged, elongated holes. However, whorl feeding seldom leads to any yield loss. **The most important damage occurs when the corn earworm feeds on the panicle of the developing grain. Plants are most vulnerable to injury from the bloom to milk stages.**

Management Recommendations

Late-planted fields are at the greatest risk for corn earworm feeding. A variety of effective foliar insecticides are registered for corn earworm management. Researchers at Kansas State University suggest management with an insecticide treatment if 1-2 larvae per head measuring at least 1/2 inch in length are present during grain development.

Fall armyworm (Spodoptera frugiperda)

Identification

The larvae are approximately 1¼ inch long at maturity and vary in color from light tan to green or black. Key characteristics for identification of fall armyworm include a dark brown head with an upside-down Y marking on the front and four black spots on the top of the last abdominal segment arranged in a square pattern (Figure 10).

FIGURE 6. FALL ARMYWORM CATERPILLAR. PHOTO COURTESY OF DEPARTMENT OF ENTOMOLOGY, UNIVERSITY OF NEBRASKA-LINCOLN.

Injury and Damage

Fall armyworm caterpillars may cause defoliation to sorghum leaves during feeding. When young caterpillars feed on the leaves, they may cause windowpane-type injury. This is recognized by the clear or white markings present on leaves. Unless large populations are present, this is not likely to affect yield. Similar to the corn earworm, they may also feed on the grain where yield loss can be significant.

Management Recommendations

Because sorghum is capable of tolerating defoliation injury, fall armyworm is not usually an economically important pest. However, when found in the panicle, treatment thresholds are similar for those used with corn earworm. Treat when 1-2 larvae are present per head measuring at least 1/2 inch long. Fall armyworm is capable of damaging sorghum grain through the soft dough stage.

European corn borer (Ostrinia nubilalis)

Identification

European corn borer at maturity are ¾-1 inch long. The distinguishing characteristics include a dark brown head capsule and a cream-to-white body. The bodies of the larvae have raised darkened spots that are present on each segment of the body (Figure 11).

FIGURE 7. EUROPEAN CORN BORER CATERPILLAR. PHOTO COURTESY OF DEPARTMENT OF ENTOMOLOGY, UNIVERSITY OF NEBRASKA-LINCOLN.

Injury and Damage

Small European corn borer larva feed on leaf tissue in the whorl or on the leaves. This injury is often referred to as window pane injury when the young larva feed on the epidermis but do not feed through the leaf. When the larvae feed in the whorl they often will chew holes in unfurled leaves, which later results in shot-hole type injury.

This is recognized by the lines of holes present on leaves. As the larva develop, they eventually bore into the stem and tunnel within it. European corn borer may also feed on the peduncle, which supports the grain panicle. Infestations on reproductive stage sorghum may result in breakage of the peduncle and harvest losses.

Management Recommendations
Damage to the peduncle is most likely to occur when European corn borer moth flights correspond with the blooming of sorghum. Previous research suggests hybrid selection may play a role in the degree of damage sustained. There are no economic thresholds for European corn borer in sorghum, and previous research has determined that even when applied, insecticides are only 50 percent effective

Soil Insects

Pest Highlights
- Wireworms can reduce sorghum stands. These pests require pre-plant management.
- Cutworms cause minor defoliation on leaves but can reduce plant stands by cutting plants near the soil surface. These pests hide under the soil during the day, and management should occur pre-plant, or insecticide applications should occur later in the day to ensure adequate coverage.

Wireworms (Elateridae; multiple species)

Identification

Wireworm larvae are elongated with cylindrical bodies and three pairs of small legs. They grow up to 1/4 inch long at maturity. Color may vary from coppery brown to grayish white (Figure 12), and some species may have projections at the end of the abdomen.

FIGURE 8. WIREWORMS. PHOTO COURTESY OF DEPARTMENT OF ENTOMOLOGY, UNIVERSITY OF NEBRASKA-LINCOLN.

Injury

Wireworm larvae are attracted to germinating seeds and seedlings. They may kill small plants by injuring the growing point below ground or by boring into the plant at the base. This results in fields with poor, irregular stands.

Management Recommendations

There are no post-plant treatments for wireworm management. Rotations including small grain crops or high populations of grassy weeds may increase populations. Because of their multi-year larval duration, fields damaged the previous year are at risk the following year from wireworm injury. Fields are at greater risk when planted early because cooler temperatures delay germination and seedling growth, prolonging the susceptible stages of crop growth to wireworm larvae. Seed treatments with neonicotinoid insecticides are recommended in fields with history of wireworm problems. These are repellants and will not cause direct mortality.

DISEASES

Although sorghum is susceptible to many diseases, they seldom cause economic losses in Nebraska or South Dakota. Only seedling blights, stalk rots and sooty stripe are likely to occasionally cause economic yield losses. Sorghum is susceptible to many physiological leaf spots. These can be easily confused with a number of commonly occurring foliar diseases, so caution should be taken in making a diagnosis. University plant disease diagnostic laboratories are available to assist in making positive disease identifications.

The most common foliar diseases caused by fungi that may occur in the region include sooty stripe, rust and northern corn leaf blight. Management of these diseases should primarily rely on selecting resistant hybrids and cultural practices such as crop rotation and the removal of residue where soil erosion is not a problem. Bacterial leaf diseases may be present in some fields every year, particularly under wet, humid conditions but are unlikely to cause any yield loss.

Sorghum ergot infection is rare in Nebraska and South Dakota, but when it does occur, it can cause significant harvesting problems because the sticky honeydew can bind up combines, forage cutters and augers.

See Table 16 for a description of diseases that may infect sorghum.

TABLE 16. SORGHUM DISEASES[1]

Disease / Cause	Symptoms	Occurrence	Management
Seed Rots and Seedling Blights			
Pythium Blight Fusarium Blight	• Thin uneven stands • Seeds may rot prior to emergence or plants may die back after emergence • Plants may show stunted growth with red to black roots	• Most noticeable following prolonged periods of cool, wet weather just after planting and in poorly drained soil • Fusarium may be a problem in droughty, sandy soils	• All sorghum comes pretreated with fungicides that aid in management • Efficacy of these chemicals is often decreased by long periods of poor germination and early growth conditions
Stalk Rot			
Fusarium Stalk Rot (See Kansas State University bulletin L-741, "Stalk Rots of Corn and Sorghum")	• Premature death of plants • Roots usually show considerable rot • Infected stalk tissue is discolored with salmon to dark red hues often predominating	• Disease is favored by abundant moisture and moderate temperatures following head initiation	• Select hybrids with good standability ratings • Avoid continous cropping, fertilize adequately and avoid leaf loss to insects or foliar disease • Hail tends to intensify stalk rot

Charcoal Rot (See K-State extension bulletin L-741)	• Disintegration of the lower stalk with numerous small, black bodies (sclerotia) scattered throughout	• Most apt to occur in light or shallow, drought-stressed soils • Disease may be present only in scattered areas of the field	• Some hybrids are more resistant than others • Reduce plant populations to avoid drought stress • Later-maturing hybrids often escape infection
Foliar Diseases Caused by Fungi			
Sooty Stripe	• Elongated spots that may extend several inches with broad, yellow to orange margins • A sooty-like growth (sclerotia) is generally present on the underside of the lesion	• Oldest leaves usually are attacked first and most extensively • Yield losses of 30 percent or more have been recorded	• Crop rotation • Resistant hybrids are available
Gray Leaf Spot	• Dark purple, rectangular lesions one-fourth inch or longer with a grayish cast during spore production	• Same as northern corn leaf blight • Usually occurs late in growing season as the crop matures • Little, if any, losses occur	• Crop rotation • Resistant hybrids are available

Disease / Cause	Symptoms	Occurrence	Management
Northern Corn Leaf Blight	• Large (two inches or more) elliptical spots with gray centers and reddish-tan borders • Very similar to sooty stripe but without sclerotia	• Most prevalent during prolonged periods of warm, humid weather	• Crop rotation • Resistant hybrids are available
Rust	• Small brown pustules or blister-like growths on the upper and lower leaf surfaces starting on the lowest leaf	• Usually appears late in the growing season (late August or early September) • Favored by warm, moist weather • Significant losses are rare	• Resistant hybrids are available
Anthracnose	• Small, circular to elliptical spots one-eighth to one-fourth inch in diameter • Depending on the hybrid, lesions may be tan, orange, red or blackish-purple	• Most prevalent in areas where periods of high humidity alternate with relatively dry periods	• Crop rotation • Resistant hybrids are available

Zonate Leaf Spot	• Circular, reddish-purple bands alternating with tan or straw colored areas which give a concentric zonate or bull's-eye appearance • Lesion diameter may extend several inches	• Most severe during prolonged periods of high humidity	• Crop rotation • Resistant hybrids are available
Foliar Diseases Caused by Bacteria			
Bacteria Stripe	• Long, narrow, reddish or tan stripes depending on hybrids • Lesions usually confined between veins • Shiny, crusty spots from exudates generally found on underside of leaves	• Most common bacterial disease • Prevalent during cool, humid weather	• Crop rotation

Disease / Cause	Symptoms	Occurrence	Management
Bacterial Streak	• Narrow, water-soaked, translucent streaks about 1-8 inches wide by 1-6 inches in length • Lesions turn red	• Very common during warm, humid weather	• Crop rotation
Virus Diseases			
Maize Dwarf Mosaic Virus (MDMV-A) Sugarcane Mosaic Virus (MDMV-B)	• Mosaic patterns (alternating light and dark green areas) on whorl leaves • Cool nights (below 60° F for Strain A, below 70° F for Strain B) may cause red and necrotic areas resembling a blight • Flowering may be delayed and seed may be underdeveloped	• Virus is carried by insects, mostly greenbug and corn leaf aphid • Both overwinter in Johnson grass	• Most current hybrids are resistant to the more severe necrotic symptoms

Other Sorghum Diseases			
Sorghum Downy Mildew	• Vivid green and white stripes on leaves in late spring or early summer • Leaves shredded by wind until only leaf veins are left • Heads partially or completely sterile	• Most common in eastern and southern production areas of the Central Plains • Infections generally take place under saturated soil conditions within the first few weeks of emergence	• Crop rotation • Resistant hybrids are available to pathotype 1
Crazy Top Downy Mildew	• Light colored leaves become stiff, rubbery and twisted • If heads appear, glumes are often proliferated to give "crazy top" symptom	• Most severe when flooding occurs on seedbeds or young seedlings, especially in poorly drained or clay soils	• Avoid areas where the disease is a recurring problem

Disease / Cause	Symptoms	Occurrence	Management
Sorghum Ergot	• Exudation of sweet, sticky "honeydew" from infected flowers occurs • Honeydew drips onto leaves or produces a white, powdery mass during moist conditions • Ovary may be converted to a white fungal mass visible between the glumes	• Occurs only sporadically in the Central Plains • The fungus only infects through unfertilized ovaries • It usually only occurs late in the season when colder temperatures affect pollination of late-planted sorghum or late developing tillers	• Fungicide application at pollination can be made but are usually only economical in hybrid seed production fields • Harvesting right after a rain which temporarily washed off the honeydew may prevent the clogging of harvesting equipment
Heat Smut	• A portion or all of the head is replaced by smut galls	• Plants are infected at seedling stage, but symptoms are not apparent until boot or heading stage • More severe in south-central and southwest areas of the Central Plains	• Chemical controls are not effective • Utilize resistant hybrids

[1] There are many foliar diseases caused by fungi that can occur on sorghum. Management of these diseases should primarily rely on selecting resistant hybrids and cultural practices such as crop rotation and the removal of residue where soil erosion is not a problem. Fungicides should be considered only under high yielding environments. Only seedling blights and stalk rots are likely to cause economic yield losses on a regular basis.

HARVEST

Grain sorghum is considered mature and may be harvested any time after the black layer on the seed has formed. At this point, the grain is hard to penetrate with your fingernail. Sorghum grain matures from the top of the head downward, so it is important to check grain at the bottom of the head to assess maturity. **At maturity, the grain is usually between 25 and 35 percent moisture. Harvesting is not recommended until grain is below 20 percent moisture.**

The choice of when to harvest must be balanced against problems associated with leaving the crop in the field too long. Delaying harvest to let the grain dry down naturally can save money on artificial drying and storage, but yields can be affected by excessive bird damage, severe weather and lodging. Wet snows with high winds can lodge the entire field. Harvest is typically done with a combine equipped with a grain header, but flex headers or row crop headers are used as well. Row crop headers are effective in picking up lodged sorghum after a wet snow. Kits are now also available for converting corn heads into row headers.

Sorghum stalks are generally much wetter than corn stalks at harvest, and they may be sticky from sugars. Stalk material mixed in with grain can cause problems with drying and storing. To avoid problems with green stalks, one should harvest as little of the stems and leaves as possible.

Grain sorghum demands the best combine operators. Most crops have a specific problem (such as header loss in soybeans), but grain sorghum can have difficulties at nearly every point of the combining process. These problems are compounded by the fact grain sorghum often ripens unevenly. In good-standing grain sorghum, losses can usually be kept to 5 percent of the yield, but only careful adjustment and operation of the combine makes that possible. Additional time and effort will be required, but expenses are already in the crop, and every extra bushel saved is clear profit.

Five Types of Harvest Loss

Preharvest loss is typically weather-related and can be minimized by timely harvesting. Crops left in the field too long can be damaged by birds or field shatter. Severe weather before or during harvest can cause lodging, which makes the crop difficult to harvest.

Combine size, crop acreage and available workdays dictate timeliness. Combines should be large enough to harvest the crop in acceptable time. If this is not economically feasible, custom harvesting is an option. Another option is harvesting earlier, but this must be balanced against greater drying costs.

Header loss includes shattered kernels, dropped heads and uncut heads. If a conventional reel is used, the speed of the reel bats should be slightly faster than ground speed. Operating the reel too fast will increase shatter losses, while operating too slow will cause dropped heads. Several attachments are available to improve gathering efficiency. Flexible guard extensions on grain platforms substantially reduce gathering losses in standing-crop conditions. Row attachments on grain platforms or using a row-crop head reduces losses in both standing and lodged conditions.

Cylinder loss or unthreshed grain can be a major problem with grain sorghum. It is often necessary to compromise between adequate threshing and excessive kernel cracking. Cracking can be caused by either too little clearance or an elevated cylinder speed, but speed is usually the cause. Severe threshing action can pulverize the stalks and overload the cleaning shoe and walker. It is often necessary to leave up to 2 percent of the grain in the head to achieve the best overall harvesting results.

In high-moisture grain sorghum, cylinder speed and concave-clearance adjustments are critical. As the head passes through the cylinder area, rolling it (rather than a shearing) provides maximum threshing with minimum kernel and stalk damage. The cylinder concave clearance should be set so the stalks are not crushed, and cylinder speed should be increased until thorough threshing occurs. This often requires wider cylinder-concave clearance than harvesting sorghum at lower moisture contents.

Shoe loss is grain carried or blown across the shoe. Kansas State University research indicates it may be the most serious and most overlooked source of harvesting loss in grain sorghum. In most modern combines, the shoe (and not the cylinder) is the first component of the combine to overload in grain sorghum. If the combine operator pushes the machine as fast as the cylinder can go, the shoe is usually losing large quantities of grain. In one series of tests, a 33 percent increase in ground speed caused shoe loss to increase by more than 4 percent of the total yield. Shoe losses also are increased when operating on hillsides. The amount of air blown on the shoe is important, as is the opening of the louvers. Closing the chaffer louvers will increase the air velocity through the opening. Air opening (or fan speed) should be reduced as the louver opening is closed.

Walker loss can be caused by excessive speed also, but in most combines the walkers overload after the shoe. Therefore, walker overloading is of secondary importance when combining grain sorghum.

How to Measure Combine Loss

Ground counts are tedious work, especially in grain sorghum. Nevertheless, they offer a reasonably accurate idea of how much grain is being lost. **As a rule of thumb, 17-20 kernels per square foot are equivalent to 1 bushel per acre.**

To accelerate ground counts, a 1-square-foot frame may be constructed from heavy wire. It is best to take at least three ground counts at each location. When making ground counts for kernels, look for lost heads. One 10-inch head in a 10-foot-by-10-foot area is approximately 1 bushel per acre.

Total loss can be checked behind the combine. Make ground counts on 1-square-foot areas in three locations uniformly spaced across the header width, with one count being made in the discharge area of the combine. Average the counts and divide by 20 to get bushels per acre. If the result is 5 percent or less of the total yield, losses are within reasonable limits.

If the total loss was more than 5 percent, the next step is to determine the preharvest loss. Check this in front of the combine in the standing sorghum. Take three counts on 1-square-foot areas. Then average them and divide by 20. Subtract the preharvest loss from the total loss to determine the net machine loss. If the net machine loss is more than 5 percent, one should determine where the loss is occurring.

Header loss can be determined by backing the combine a few feet and taking ground counts between the header and the uncut sorghum. The difference between the header count and preharvest count is the net header loss.

Cylinder and separation loss can be determined by subtracting the header loss from the total machine loss. It is sometimes difficult to determine if the loss is being carried over the walkers or blown across the shoe. Provided the combine does not use a straw chopper, the loss can often be pinpointed by observing the shoe while the combine is operating.

Combine loss monitors can indicate changing harvest conditions. They should be set to indicate a representative loss. If time is not spent setting the monitor, the reading is of little value.

Grain Quality

Sorghum grain is placed into U.S. Grade Numbers 1, 2, 3, 4 or is classified as Sample Grade, with U.S. No. 1 being the highest quality (Table 16). The value of grain sorghum follows this grading system. Proper harvesting, drying and storage practices are important to achieve the higher grades.

Drying and Storing Grain Sorghum

Grain quality at harvest is influenced by grain variety, weather and combine adjustment. Minimizing grain damage in order to maintain quality requires good handling, drying and

TABLE 17. SORGHUM GRADES AND GRADE REQUIREMENTS, FROM THE UNITED STATES STANDARDS FOR SORGHUM

Grading Factors	Grades U.S. No.[1]			
	1	2	3	4
Minimum Pound Limits				
Tested Weight per Bushel	57.0	55.0	53.0	51.0
Maximum Percent Limits				
Damaged Kernels: Heat (part of total)	0.2	0.5	1.0	3.0
Total	2.0	5.0	10.0	15.0
Broken Kernels and Foreign Material: Heat (part of total)	1.0	2.0	3.0	4.0
Total	3.0	6.0	8.0	10.0

cooling equipment and conscientious stored-grain management.

Handling

Grain sorghum may need to be cleaned before being stored in a grain bin, depending on the amount of trash that accompanies the grain. The trash can be reduced by harvesting after a killing frost or after using a desiccant. Excessive trash in the bin can accumulate and become hot spots during drying or can even catch on fire.

Drying

Harvest grain sorghum at 18-22 percent moisture if a suitable heated-air system is available for drying the crop. Harvesting above 22 percent moisture will result in more trash material in the grain.

Producers should be extremely cautious in holding high-moisture grain sorghum prior to drying. High-moisture grain sorghum packs much tighter than high-moisture corn. This inhibits air circulation within the grain and can result in heating, molding and sprouting problems. Never hold wet sorghum longer than 2-4 hours unless aeration is provided.

Grain sorghum is much harder to dry than corn because the seed is small and round, and it is harder to force air through it. Actual drying capacity will be about two-thirds to three-fourths as fast as corn for the same grain depth and air temperature.

Continuous flow or batch dryers are the preferred methods for drying grain sorghum. If it must be dried in a bin, the bin should be used as a batch-in bin dryer, limiting the drying depth of each batch to 4 feet. After drying, cool the grain and move it to another storage bin before the next day's harvest. A 3-foot depth of sorghum is equivalent in resistance to a 4-foot depth of corn at an airflow rate of 10 cfm (moving capacity of a fan). An individual seed of grain sorghum will dry faster than an individual seed of corn, but greater flow resistance from a bin of sorghum will reduce the airflow. As a result, drying time for grain sorghum is longer than corn. Cooling time is also longer.

Optimum drying temperature depends on the type of dryer, airflow rate, end use (feed, market, seed) and initial and final moisture contents. Maximum temperature for drying grain sorghum for use as seed should not exceed 110°F. Dry for milling below 140°F in high airflow batch and continuous flow dryers and 120°F in bin dryers. If used for feed, drying temperatures can be up to 180°F. Always cool grain within 5-10 degrees of the average outside air temperature after drying. Natural, unheated air may be used when the relative humidity is 55 percent or less and the grain moisture is 15 percent or less.

Natural, unheated air drying can be used to dry grain sorghum if the moisture content is 16 percent or below and the drying depth is less than 10 feet. Drying fans must be capable of delivering at least 1-2 cfm/bushel. Because the drying process is slow, it is important to start the fans immediately after the floor is covered.

Storage Moisture Content

The final storage moisture for grain sorghum depends on the expected length of the storage period and whether the grain sorghum is to be fed out to the bin continuously or is allowed to remain undisturbed in the bin until it is sold.

To sell at harvest: 14 percent moisture
Short term storage (less than six months): 13 percent moisture
Long term storage (six months or longer): 11-12 percent moisture

Storing Grain Sorghum

Aeration is one of the most important management tools available to producers for maintaining grain quality in sorghum storage. Aeration extends the storage life of grain by removing odors, preventing moisture accumulation and controlling conditions conducive to mold growth and insect activity.

Grain should be aerated after it is dried and in the fall, winter and spring. Begin aeration when the average outdoor temperature is 10-15°F lower than the grain temperature. Average outside temperature can be taken as the average of the high and low temperatures over a 3-5 day period. Check grain temperatures at various locations in the bin with a probe and thermometer.

Inspect all grain in storage at least once a week. Check for indications of moisture such as crusting or condensation on the bin roof. Check and record the temperature at several points in the stored grain. Any increase in temperature indicates a problem unless outside temperatures are warmer than the grain. Probe the grain to check for insects or other problems. If problems are noticed, run the aeration fans.

APPENDICES

i. Beneficial Insects

FIGURE 9. ADULT CONVERGENT LADY BEETLE. PHOTO COURTESY OF ADAM VARENHORST.

FIGURE 10. CONVERGENT LADY BEETLE LARVAE. PHOTO COURTESY OF ADAM VARENHORST.

FIGURE 11. HOVERFLY LARVAE. PHOTO COURTESY OF ADAM VARENHORST.

FIGURE 12. MINUTE PIRATE BUG ADULT. PHOTO COURTESY OF ADAM VARENHORST.

a. Other Insects Found in Sorghum

FIGURE 13. ADULT WINGLESS CORN LEAF APHIDS. PHOTO COURTESY OF DEPARTMENT OF ENTOMOLOGY, UNIVERSITY OF NEBRASKA-LINCOLN.

FIGURE 14. EUROPEAN CORN BORER EGG MASS. PHOTO COURTESY OF DEPARTMENT OF ENTOMOLOGY, UNIVERSITY OF NEBRASKA-LINCOLN.

FIGURE 15. CATTAIL CATERPILLAR. PHOTO COURTESY OF STURGIS MCKEEVER, GEORGIA SOUTHERN UNIVERSITY, BUGWOOD.ORG.

FIGURE 16. BLACK CUTWORM CATERPILLARS. PHOTO COURTESY OF ADAM VAREN-HORST.

FIGURE 17. ARMY CUTWORM CATERPILLARS. PHOTO COURTESY OF DEPARTMENT OF ENTOMOLOGY, UNIVERSITY OF NEBRASKA-LINCOLN.

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