UNITED SORGHUM CHECKOFF PROGRAM

CENTRAL & EASTERN PLAINS PRODUCTION GUIDE

SORGHUM THE SMART CHOICE

Welcome to the United Sorghum Checkoff Program's Central and Eastern Plains Production Guide. We have integrated research from various sources to produce an easy-to-use guide to 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 and seed company representative for unbiased data.
- 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 pre-emergence 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.

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United Sorghum Checkoff Program

SORGHUM CHECKOFF

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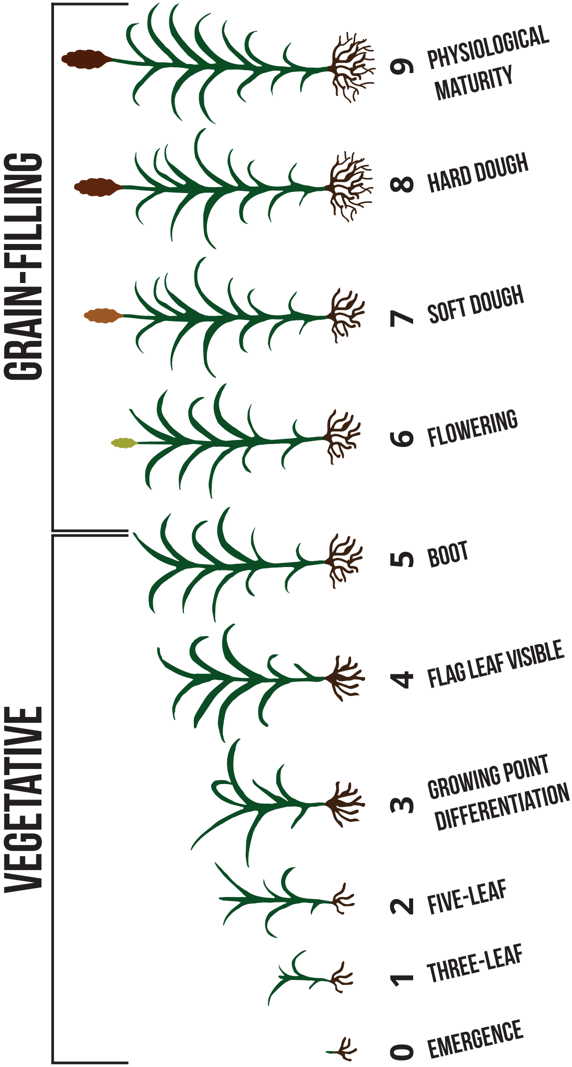
TOPIC PAGE

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 of couple 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 final leaf is visible. 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 $\xrightarrow{\text{3-5}}$ Heading $\xrightarrow{5}$ Flowering $\xrightarrow{5}$ Milk $\xrightarrow{14}$ S. Dough $\xrightarrow{10}$ H. Dough $\xrightarrow{\text{10-14}}$ PM

GRAIN SORGHUM YIELD COMPONENTS

Sorghum yield is based on three factors: number of heads, number of seeds per head, and seed size and test weight. Although these factors may compensate for each other, the number of seeds per head is the greatest component of yield.

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 how any given hybrid will perform. 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.

Maturity

A good full-season hybrid will almost always out-yield a good early-season hybrid, other conditions being equal and favorable for sorghum growth. The stalks of full-season hybrids tend to be larger and stand better than those of earlier hybrids. The rule of thumb is to plant the latest-maturing hybrid available within the limitations of projected moisture availability, average length of growing season and crop sequence. Hybrid selection can then be narrowed to that group of hybrids meeting the maturity criteria.

Maturity is relative in a region that varies 800-1,800 feet in elevation and from nearly 40 to less than 25 inches of annual precipitation. A conservative view is that hybrids should be in the maturity class reaching physiological maturity (black layer or maximum dry-matter content of grain at about 30-40 percent moisture) a week or two before the average date of the first killing frost. To assure adequate time to mature before frost, select and plant sorghum hybrids so they bloom by early to mid-August in south-central and southeast Nebraska and by late August or early September in north-central and northeast Oklahoma.

In the Central and Eastern Plains, the optimum hybrid maturity varies with soil depth and texture, growing season, planting date, and precipitation distribution. In the Eastern Plains with deep soils and low probability of an early fall frost, fuller-season hybrids can be planted through June. If planting is later than early June in the Central Plains, earlier maturing hybrids should be selected. On shallow soils, moisture exhaustion can be more damaging to late hybrids than frost. Earlier hybrids should be planted on those sites. Moisture stress often causes lodging problems because of incomplete development of stalk-strengthening tissue, invasion by organisms that further weaken stalk tissue, or both. By choosing hybrids that mature early enough to avoid severe moisture stress, lodging risk may be reduced. The interaction of hybrid maturity and environmental stress is important in hybrid selection. **Planting two or more hybrids that differ slightly in maturity will help ensure adverse environmental conditions will not affect total grain sorghum production.**

Crop rotations and sequencing can influence hybrid choice as well. Producers wishing to plant wheat in the fall after a sorghum crop should select hybrids that will mature early enough to allow timely sorghum harvest and wheat planting. Early maturing hybrids combined with chemical desiccants (e.g. glyphosate, sodium chlorate) applied after physiological maturity (black layer) can speed dry down and move up harvest, increasing the probability of success for the following wheat crop.

Standability

If a hybrid lodges after having stood well in previous years, producers may wonder what happened. The timing of moisture exhaustion in relation to the plant's growth stage is a prime source of lodging variability. Post-flowering drought stress not only reduces yield, but also increases susceptibility to invasion by organisms, such as charcoal rot, that cause lodging.

In any maturity group—early, medium or late—there are hybrids that consistently lodge worse than others. They should be avoided, especially on fields with a history of frequent lodging. The best sources of information are seed companies, performance test results, personal experiences and extension agents. Be sure to look at lodging notes from several trials before deciding if a hybrid is more or less prone to lodge.

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 with the highest drought tolerance rating, but these may yield more consistently over multiple years.

Disease and Insect Resistance

Diseases and insects often are destructive in specific locations and sometimes cause widespread damage. 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, practicality of chemical control, and use of hybrids best adapted to management practices that have been adjusted to avoid or tolerate pest problems.

Hybrid differences in susceptibility have been documented for sooty stripe, fusarium stalk rot, charcoal rot, viral diseases (maize dwarf mosaic virus and sugarcane mosaic virus), northern corn leaf blight, rust, downy mildew, head smut and others. The importance of resistance to various diseases depends on the cropping system and grower practices. For example, no-till cropping systems increase the probability of some diseases such as sooty stripe, especially if sorghum residue remains from previous crops. Fungicidal seed treatments may adequately control sorghum downy mildew in some cases.

Sugarcane aphid is a new pest that potentially can cause significant yield loss. There are hybrids that have some tolerance to sugarcane aphid. Breeders are now developing hybrids with much better resistance to sugarcane aphid. Growers in areas with a history of sugarcane aphid infestation should consider planting a hybrid with known tolerance or resistance. It is important to note even though a hybrid is considered to have some tolerance to sugarcane aphid, scouting of these hybrids will still be necessary and insecticide applied if threshold levels are reached.

Greenbug populations have shifted over the years making hybrid tolerance traits obsolete over time. Good greenbug-tolerant hybrids were available from 1976-1980, and chemical control generally was needed only for heavy seedling infestations and for large, persistent greenbug populations in later plant-growth stages. Unfortunately, those hybrids had little or no resistance to greenbug Biotype E when it appeared, so insecticides were the primary control method until adapted resistant hybrids became available a few years later. More recent strains, Biotypes I and K, have added additional dimensions to the greenbug-resistance picture.

Historically chinch bugs have been a concern in the northern and eastern parts of the Central and Eastern Plains region. Some hybrids appear to have more tolerance to chinch bugs than others, but insecticides are the major control method. The use of systemic insecticides in the furrow at planting or as seed treatments, planting earlier or later than normal, and avoiding planting sorghum next to small grains can reduce the probability of chinch bug damage to sorghum seedlings. The latest generation of systemic insecticidal seed treatments have proven to be quite effective in preventing early-season damage from chinch bugs.

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. While it is preferable to have fully exposed heads to maximize yield, the negative effects of incomplete head exertion are more pronounced in some hybrids than in others.

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.

Summary

The surest way to select hybrids that will perform well on your farm is to:

- Spend sufficient time searching for improved hybrids.
- Look at hybrids from several companies.
- Look at a broad base of information on hybrids of interest. Avoid reliance on only one source of hybrid-performance information. Use results from company tests, county strip trials and university performance tests to select a small set of hybrids to try on your farm.
- Try this subset of hybrids on a small scale and keep harvest records. This is becoming easier every year with the widespread use of guidance/auto-steer technology and yield monitors. Be sure to replicate comparisons in such a way that you can be confident of your conclusions.
- Plant two or more hybrids of differing maturity to spread out risk from adverse weather conditions.
- Keep alert for hybrids with resistance to pests threatening the next crop. New strains of pests, such as greenbugs and maize dwarf mosaic virus, appear from time to time so it is important to keep up with new developments in both pests and hybrids.

TILLAGE SYSTEMS

Grain sorghum needs a warm, moist soil well supplied with air and fine enough to provide good seed-soil contact for rapid germination. A number of different tillage and planting systems can be used to achieve these conditions. These systems may involve primary or secondary tillage, or no tillage operations at all, prior to planting. Seedbed preparation should provide a means of profitable crop production while minimizing soil erosion due to wind and water. Conservation tillage systems (e.g. reduced-till, mulch-till, ecofallow, strip-till, ridge-till, zero-till and no-till) provide protection from erosion. These systems also provide the additional benefits of moisture, energy, labor and even equipment conservation.

An ideal sorghum production system should provide the following at planting:

- Weed-free conditions
- Moisture conservation
- Improve soil tilth preservation
- Wind and water erosion reduction
- Adequate stand establishment

Tillage and Rotations

The amount of residue necessary for erosion protection depends on several factors, such as climate, soil erodibility, surface roughness, field length, slope length and steepness, cropping practices, and conservation practices. Generally, in the Eastern Plains where water erosion is the primary concern, leaving 30 percent residue cover after planting reduces soil loss to acceptable levels. The actual level of residue required to minimize soil loss will vary with each field. Conservation tillage alone may not adequately protect the soil from erosion. In these situations, conservation tillage can be integrated with other practices—such as terracing, contouring, strip cropping and windbreaks—to provide erosion protection. Long-term research in Kansas has shown grain sorghum can be grown successfully in conservation-tillage systems, but uniform residue distribution, effective weed control, proper seed placement, correct planter adjustment, soil testing, and fertilizer management are important for success.

Crop sequencing and rotation become increasingly important in systems with little or no tillage and greater amounts of surface residue cover. Long-term research at Manhattan, Kansas, documents the importance of rotation in no-till cropping systems, showing a 16 bushel per acre advantage for rotated sorghum compared with continuous sorghum in no-till (Table 2). Results from long-term studies at Belleville, Kansas, and Mead, Nebraska, lead to the conclusion that sorghum rotated with soybeans almost always yields more than continuous sorghum, regardless of how much nitrogen fertilizer was applied. A four-year no-till study at Hesston, Kansas, documented sorghum after wheat produced

12 bushels per acre more than sorghum after sorghum (Table 2). Sorghum after soybean produced 10 bushels per acre more than after sorghum. Sorghum after double-crop sorghum yielded about the same as continuous sorghum.

No-till grain sorghum planting is best suited to moderately and well-drained soils. Soils often remain cooler and wetter through the growing season under no-till conditions. This is particularly true in heavy residue. While wetter soils are an advantage during dry periods, at planting time they can mean slower germination, delayed maturity and a longer period when seeds and seedlings are susceptible to pests. These conditions can result in reduced yields in no-till situations, particularly in cool, wet springs and on poorly drained soils. Other conservation-tillage systems, such as reduced-till or strip-till, may be better choices in those situations.

TABLE 2. GRAIN SORGHUM YIELDS AS AFFECTED BY TILLAGE SYSTEM AND PREVIOUS CROP AT TWO LOCATIONS IN EASTERN AND CENTRAL KANSAS

Previous Crop	Manhattan			Hesston
	Conventional Tillage (bu/A)	Reduced Tillage (bu/A)	No-Till	No-Till
Sorghum	85	85	83	91
Soybean	87	89	99	100
Wheat	---	---	---	103
Double-Crop Soybean	---	---	---	100
Double-Crop Sorghum	---	---	---	89

PLANTING

Row Width

Most grain sorghum is planted in 30-inch rows because other row crops have performed well at that row spacing. Historically, 30-inch rows performed better than wider rows, and narrower rows have not consistently yielded better than 30-inch rows. Results from nearly 20 studies comparing row spacing can be grouped into three categories:

1. Greater yields with narrow rows (10, 15 or 20 inches vs. 30 inches). This response was observed in about half of the studies, all of which were in environments that had yields greater than 110 bushels per acre.
2. Greater yields with wider rows (30 inches). This response was seen in about a quarter of the studies, all of which were in environments with yields of 100 bushels per acre or less.
3. No response to row spacing. This response was observed in about a quarter of the studies, most often in high-yielding environments.

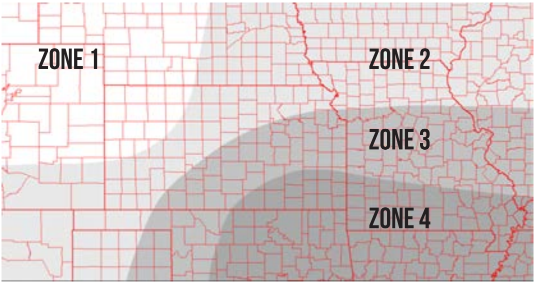
An advantage of narrow rows is that plants shade the soil quicker, improving weed control and reducing soil erosion.

Planting Date

There is a wide range in planting dates for grain sorghum. Planting should be timed so flowering avoids the hottest, driest period of summer.

Suggested planting dates are given in Figure 1. Utilizing several planting dates is suggested to spread the risk of one planting date flowering during a stress period. Quick germination and emergence occur when the soil temperature is 70°F. However, sorghum can be planted once soil temperatures are above 60°F when warm weather is expected for the next few days. Planting too early results in delayed emergence and reduced stands. Plants from early plantings may be taller and more vegetative than later plantings. Late plantings may not allow the crop enough time to mature before a damaging fall freeze. Use earlier-maturing hybrids if planting is delayed into late June or July.

FIGURE 1. SUGGESTED GRAIN SORGHUM PLANTING DATES



Area	Dates
Zone 1	May 15 - June 20
Zone 2	May 10 - June 25
Zone 3	May 1 - June 25
Zone 4	April 20 - May 10, June 5 - June 30

Seeding Rate

Seeding rates or plant populations vary depending on rainfall and growing conditions. In Table 3, recommended plant populations are given for specific rainfall regimes. When seeding in narrow rows in high-yielding environments, populations that are 25-30 percent higher than these recommendations may be able to capture slightly higher yields. Higher seeding rates also should be used with later planting dates because sorghum plants tend to produce fewer productive tillers with warmer temperatures during the vegetative growth stages.

Two formulas can be used in calculating plant populations and seeding rates:

Plant Population or Seeding Rate

$$\frac{\text{12 in.}}{\text{row spacing (in.)}} \times \frac{\text{43,560 ft}^2}{\text{acre}} \times \frac{\text{seeds}}{\text{foot of row}} = \text{seeds/acre}$$

Seeds (Plants) per Foot

$$\frac{\text{target seeding rate}}{\text{43,560 ft}^2} \times \frac{\text{row spacing (in.)}}{\text{12 in.}} = \text{seeds/foot or row}$$

Hybrid seed size varies, so planting in terms of pounds of seed per acre results in large differences in plant population and wastes money. Although there may be emergence differences due to seed size, generally no yield differences are found.

Sorghum plants may tiller and compensate for thin stands. Large heads (more seeds per head) can compensate for thin stands. Heads produced by late tillers may be immature when the head on the main stem is mature, resulting in harvest and storage problems. Seed weight can compensate for reduced seed number to a limited extent. High plant populations result in fewer tillers and are necessary under irrigation and in higher-rainfall areas. Excessive stands produce plants with smaller stems that are more susceptible to moisture stress and lodging.

Table 3. Grain Sorghum Recommended Plant and Seed Spacing

	Average Annual Rainfall (in.)			
	23-26	26-32	>32	Irrigated
	Plants per Acre[1]			
Population	35,000	45,000	70,000	100,000
	Within-Row Spacing at Planting, Assuming 65% Field Emergence			
15-inch Rows	7.8	6.0	3.9	2.7
30-inch Rows	3.7	3.0	1.9	1.4

[1]Populations may be increased or decreased by 25 percent from these values, depending on expected growing conditions without significantly affecting yields.

Seeding Depth

The optimum planting depth differs with soil types and moisture conditions. In heavier soils, a planting depth of 1 inch is satisfactory. In sandy soils, seeds can be placed 2 inches deep without problems. Sorghum seeds can emerge from plantings deeper than 2 inches, but seedlings are slow to emerge, and final stand numbers may be reduced. The seed should be well covered with soil for excellent seed-soil contact to aid germination. Planting into soils that are too wet can result in sidewall compaction, which can inhibit early root growth or poor closure of the seed furrow, which can reduce germination and emergence.

Non-Uniform Stands and Replanting

Results from studies examining the effect of within-row gaps in various patterns and frequencies indicate sorghum yields are not reduced unless gaps are at least 9 feet long or a sufficient number of 3-foot to 6-foot gaps reduce stands by 30 percent or more. Compensation occurs by increases in the number of heads per plant and the number of seeds per head in neighboring plants both within a non-uniform row and in adjacent rows.

NUTRIENT MANAGEMENT

Grain sorghum is grown throughout the Central and Eastern Plains under a wide range of climatic conditions. 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 uptake by sorghum is similar to that of corn and wheat at comparable yields. Table 4 shows harvesting only the grain removes considerably less nutrients than if the entire crop is harvested for silage or forage.

Fertilizer and lime needs can best be determined by soil tests with supporting experience and field history information. However, soil tests are no better than the sample collected in the field. Interpretations of soil tests and resulting fertilization recommendations are made based on many years of research. Fertilizer rates are targeted for optimum yields assuming yield potential is not restricted by other growth-limiting factors.

<u>Nitrogen (N)</u>

Nitrogen is the element most frequently lacking for optimum sorghum production. Nitrogen recommendations will vary with expected yield, soil texture and cropping sequence.

TABLE 4. NUTRIENT CONTENT OF ABOVE GROUND PARTS OF GRAIN SORGHUM

Yield, bu/A	Plant Part	Dry Matter, lb.	Nitrogen, lb.	Phosphorous, lb.P_2O_5	Potassium, lb.K_2O	Calcium, lb.	Sulfur, lb.	Magnesium, lb.
100	Grain	5,080	95	30	25	3	10	7
	Stover	6,750	70	12	100	15	8	13
	Total	11,830	165	42	125	18	18	20
140	Grain	6,780	120	60	30	5	14	10
	Stover	7,980	80	16	120	20	12	15
	Total	14,760	200	76	15	25	26	25
180	Grain	8,510	145	70	35	7	18	13
	Stover	9,520	95	20	135	25	20	18
	Total	18,030	240	90	170	32	38	31

A soil test for available nitrogen in the soil profile is encouraged where nitrogen or manure applications have been excessive relative to yields. The profile nitrogen soil test is used to reduce nitrogen application and thus allow nitrogen that has accumulated in the soil to be utilized. Consult your soil testing laboratory for instructions on proper soil sampling and handling. Samples should be taken to a depth of 2 feet and must be air-dried after collection to minimize mineralization in handling and shipping.

Another important consideration in determining the optimum nitrogen rate is cropping sequence. Research in the Central and Eastern Plains shows nitrogen credits for legumes grown in rotation with sorghum can be substantial. Table 5 summarizes nitrogen credits for legumes in rotation with sorghum and the basic nitrogen recommendation adjustment for these credits. Figure 2 shows the value of including a legume in a rotation. When no nitrogen was applied, grain sorghum grown in annual rotation with soybean yielded 29 bushels per acre greater than continuous sorghum. When averaged over all applied N-rates, rotated sorghum yielded 19 bushels per acre greater than continuous sorghum. Continuous sorghum yield continued to increase with increasing N rate up to 90 lbs. per acre, whereas yield of rotated sorghum was maximized with application of 60 lbs. N per acre.

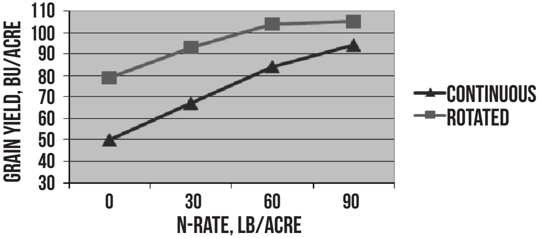
TABLE 5. NITROGEN CREDITS FOR LEGUMES IN ROTATIONS (WITH STAND DESTRUCTION TILLAGE)

Legume	Nitrogen Credits, lb. N/A
Alfalfa	
Excellent Stand (>5 plants/sq. ft.)	-120
Good Stand (2-5 plants/sq. ft.)	-80
Fair Stand (1-2 plants/sq. ft.)	-40
Poor Stand (<1 plant/sq. ft.)	0
Red Clover	
Excellent Stand	-80
Good Stand	-40
Fair Stand	0
Sweet Clover	
Excellent Stand	-110
Good Stand	-60
Poor Stand	0

For no-till production reduce N credit adjustment by 50 percent.

Source: "Using Legumes in Rotation" Pub. No. L-778, Kansas State University Research and Extension, Manhattan, Kansas, KS 66506.

Figure 2. Effects of rotation and nitrogen rate on grain sorghum yields. Belleville, Kansas 1982-2002).



Nitrogen recommendations can be calculated by using these factors:

Recommended Nitrogen =
(Yield Goal x 1.6) - (SOM X 20) - Profile N - Manure N - Other N Adjustments + Previous Crop Adjustments

- Recommended Nitrogen = lbs./A
- Yield Goal = a realistic yield goal in bu/A
- SOM = percent soil organic matter
- Profile N = lb. of nitrogen per acre = 0.3 x sampling depth (inches) x ppm Profile Nitrate - N (2-foot sampling depth). Default a value of 30 lbs. N/A if a sample is not taken.
- Manure N = the previous year's manure (50 lbs. for last year, 20 lbs. for two years ago, and zero for no manure history).
- Previous Crop Adjustment = view Table 4 for previous legumes, 20 lbs. for fallow (if no profile N test) and zero for all other crops.

Field comparisons of nitrogen sources indicate little agronomic difference between sources when properly applied. For no-till or reduced-till systems that leave almost 100 percent residue cover, materials containing urea should be injected below the residue to minimize volatilization and immobilization losses. If urea or UAN (urea + ammonium nitrate solution) fertilizer is surface applied and not incorporated by tillage or does not receive one-half inch of rainfall or irrigation within 24 hours, there is potential for ammonia loss. Enough ammonia loss to reduce crop yields can sometimes occur when urea or UAN is applied to a warm and moist soil or soil heavily covered with crop residue. Source selection should be based on cost, availability, adaptability to farm operation, and dealer services.

Nitrogen applications should be timed so nitrogen is available when needed for this rapid growth. Pre-plant nitrogen applications can be made in late fall or spring (except on sandy soils) with little concern for leaching loss. On sandy soils, pre-plant nitrogen applications should be delayed until spring, sidedressed or split with part in the spring and part sidedressed. If nitrogen is applied sidedress, the applications should be made shortly after the five-leaf stage.Nitrogen application for grain sorghum can be made at various times with equal results on most soils. Nitrogen utilization is quite rapid after the plants reach the five-leaf stage. By boot stage, 65-70 percent of the total nitrogen has been taken into the plant.

Active optical sensing systems are useful in measuring crop biomass early in the growing season and using that measurement to predict final yield. **Coupled with a well fertilized reference strip and an unfertilized check strip, to provide an estimate of the soil's nitrogen supply to the crop sensors, may provide an accurate nitrogen recommendation.** The sensor technology seems to work best 35-45 days after planting; however this provides only a narrow window of opportunity to fertilize the crop. Producers may want to apply a base level of nitrogen on sorghum at planting to ensure optimum yield.

Application of nitrogen through the irrigation system has been quite satisfactory on sandy soils. Application of nitrogen through irrigation systems under other soil conditions is possible, but the fertilizer distribution is no better than the water distribution. No nitrogen material that contains free ammonia should be used when applying through a sprinkler system unless special precautions are taken. A small amount of nitrogen also may be applied in starter fertilizer.

<u>Phosphorous (P)</u>

Phosphorus application should be based on a soil test. Consistent responses to phosphorus fertilization have generally occurred on soils testing very low or low in available phosphorus where yield potential is not restricted by low rainfall. With medium-testing soils, responses have been erratic and normally quite small. Phosphorus applications are recommended on medium-testing soils for their potential yield response and to maintain the soil in a highly productive condition. Phosphorus recommendations are shown in Table 6.

TABLE 6. PHOSPHOROUS SUFFICIENCY RECOMMENDATIONS FOR GRAIN SORGHUM

Soil Test P, ppm	Yield Goal, bu/A				
	40	80	120	160	200
	Phosphorous, lb.P_2O_5/A				
0-5	50	55	60	65	70
5-10	35	40	45	45	50
10-15	20	25	25	30	30
15-20	15	15	15	15	15
20+	0	0	0	0	0
Crop Removal	16	32	48	64	80

P Rec = [50 + (0.16 x Yield Goal) + (Bray P x -2.5) + (Yield Goal x Bray P x -0.008)]
If Bray P is greater than 20 ppm, then only NP or NPKS started fertilizer suggested.
If Bray P is less than 20 ppm, then the minimum P Recommendation = 15 lb. P205/A.

Source: "Soil Test Interpretations and Fertilizer Recommendations" Pub. No. MF-2586, Kansas State and Extension, Manhattan, KS 66506.

Phosphorus can be applied preplant-broadcast, preplant-knifed or banded at seeding. If a difference among methods is found, broadcast is normally inferior. Starter applications are most efficient when applied on soils low in available phosphorus. Starter applications can be placed in direct contact with the seed or placed to the side and below the seed. **If placed in contact, the starter material should contain no more than 10 lbs. of nitrogen plus potassium per acre on rows spaced 30 inches apart**. The nitrogen and potash can cause germination damage with their high salt index. No urea or ammonium thiosulfate should be placed in direct seed contact.

Preplant applications can be made in the fall or spring and should be thoroughly incorporated because phosphorus does not move appreciably in the soil. With no-till or reduced-till seedbed preparation, preplant-knifed or banded at seeding are preferred over broadcast.

Liquids, solids and varying chemical forms of phosphorus (ortho- and polyphosphates) are available. Research indicates that, in general, all are agronomically equal. Selection of a phosphorus source should be made on the basis of cost, availability and adaptability to the operation.

Potassium (K)

As with phosphorus, a soil test is the best guide to potassium needs (Table 7). Potassium removal is much greater with silage than with grain production. Therefore additional potassium should be considered in cropping sequences including forage sorghum. Potassium deficiencies are most likely to be found in clay pan soils with shallow rooting depths and on sandy soils.

Potassium should be applied preplant-broadcast, preplant-knifed or banded at seeding. Broadcast applications should be thoroughly incorporated to get the potassium in the root zone. The most common potassium source is muriate of potash (potassium chloride); however, potassium sulfate, potassium nitrate, potassium-magnesium sulfate and mixed fertilizers are good potassium sources. These sources differ little in potassium availability for crops. Selection should be based on cost, availability and adaptability to the farm operation.

Lodging of grain sorghum at maturity can be a problem in many areas and can result in considerable harvest loss. Research has shown that lodging occurs due to many factors—weather stress, insect and disease damage, hybrid stalk strength, date and rate of planting, and nutrient imbalance. **Adequate potassium is essential for sturdy stalks, and research has shown potassium fertilization can reduce lodging on medium to low-testing soils.** Recent research has shown adequate chloride may be as important as potassium in stalk strength. Potassium chloride at 40-50 lbs. per acre supplies adequate chloride. High application rates of potassium fertilizer for insurance against lodging is not recommended. Fertilization with proper levels of all nutrients plus good crop-management practices in general is the best way to minimize lodging. Weather conditions play a major role in lodging, and they cannot be controlled.

Chloride (Cl)

For many grain crops, chloride has been reported to have an effect on plant diseases by either suppressing the disease organism or

TABLE 7. POTASSIUM SUFFICIENCY RECOMMENDATIONS FOR GRAIN SORGHUM

Soil Test K, ppm	Yield Goal, bu/A				
	40	80	120	160	200
	Potassium, lb.P_2O_5/A				
0-40	75	80	85	90	95
40-80	45	50	55	60	60
80-120	20	20	25	25	25
120-130	15	15	15	15	15
130+	0	0	0	0	0
Crop Removal	10	21	31	42	52

L Rec = [58 + (0.17 x Yield Goal) + (Exch K x -0.616) + (Yield Goal x Exch K x -0.0013)]
If Exch K is greater than 130 ppm, then only NKP or NPKS started fertilizer suggested.
If Exch K is less than 130 ppm, then the minimum K Recommendation = 15 lb. K20/A.

Source: "Soil Test Interpretations and Fertilizer Recommendations" Pub. No. MF-2586, Kansas State and Extension, Manhattan, KS 66506.

improving overall plant health and allowing the plant to withstand infection. Chloride responses have been noted even in absence of disease, suggesting some soils may not be able to supply needed amounts of chloride. **Soil test calibration experiments have shown when soil test chloride levels (0-24 inches) are less than 20-30 lbs. per acre, responses to applied chloride are likely.** Chloride is a very mobile element in soils, similar to nitrogen, and a 24-inch sample is needed to adequately gauge soil chloride content. Table 8 illustrates the value of chloride application on grain sorghum. A Crete silt loam soil in north-central Kansas application of chloride on a deficient soil (12 lbs. Cl/acre) resulted in a yield increase of 11 bushels per acre over the unfertilized check.

Liming

Lime recommendations are intended to maintain productive soils. Sorghum is not the most responsive crop to lime, but liming of acidic soils should not be ignored. Although yield increases may be small, liming is a sound farming practice. In the Eastern Plains, lime is recommended for sorghum on soils with a pH of 6.0 or less. **In the Central Plains, lime is recommended for sorghum on soils of pH 5.5 or less**. If sorghum is grown in a cropping system that includes legumes, the pH should be maintained at the optimum pH for the legume.

TABLE 8. GRAIN SORGHUM RESPONSE TO CHLORIDE (3-YEAR AVERAGE). BELLVELLE, KANSAS.

Chloride, lb./A	Yield, bu/A
0	120
20	131
40	133
LSD (0.05)	5
Soil Test Chloride = 12 lbs./A (0-24 inches)	

<u>Other Elements</u>
Research has demonstrated a need for some secondary and micronutrients in some situations (e.g. zinc and iron), but others are typically not limiting. Calcium and magnesium are relatively abundant in most soils in the Central and Eastern Plains. Liming of acidic soils supplies sufficient calcium, and a deficiency of this element would not be expected. Research with boron, copper and manganese has not revealed any consistent responses, and these elements should not be a problem for optimum sorghum yields.

Sulfur may be lacking on sandy soils low in organic matter (less than 1.5 percent). On irrigated sandy soils sulfur would only be of concern when sulfur levels in the irrigation water are low. Much of the irrigation water in the Central Plains contains an appreciable amount of sulfur. Current sulfur soil tests, when used alone, are poor predictors of sulfur deficiency. Farmers with sandy soils low in organic matter and a low sulfate soil test should try sulfur to ascertain the likelihood of a sulfur response.

The need for zinc and iron can be predicted by soil tests. Zinc is most likely deficient on areas where the topsoil has been removed and under high-yield conditions. Iron deficiency is most likely to occur on soils where erosion or leveling has exposed a highly calcareous subsoil, which also is low in organic matter and has a high pH. Zinc usually is applied in conjunction with phosphorus and potassium, and time and method of application discussed in those sections are applicable to zinc. Inorganic and organic (chelate) sources of zinc are available for application, but the chelates are generally 3-5 times more effective per lb. of metal. Small application rates are more effective if banded close to the seed. No economical source of iron for soil application is currently available for correction of iron deficiency in sorghum. Foliar sprays of iron and manure application are the most effective methods of correcting iron chlorosis.

WEED CONTROL

Weed control in grain sorghum remains a challenge and 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. Before planting grain sorghum, fields should be evaluated for annual and perennial weeds. The current year's weed-management program should be based on field notes from previous years that show weed species present, their relative abundance and locations of perennial-weed infestations.

Common grassy weeds include crabgrass, foxtails, shattercane, longspine sandbur, prairie cupgrass, fall panicum and witchgrass. **In grain sorghum the use of pre-emergence grass herbicides is essential to get adequate control of most of these grass species.** Planting crops in rotations that allow the use of pre or post grass herbicides can prevent weed seed production during that growing season and can reduce the weed seedbank. Because grass seed viability in soil is relatively short for many of these species, maintaining grass weed control for 4-5 years can greatly reduce the grass weed pressure in future growing seasons. Thus, it is also important to prevent these grass weeds from producing seed during a fallow period. Grass weeds that produce seed during a fallow period (i.e. in wheat stubble following wheat harvest) replenish the seed bank, creating problems for the subsequent sorghum crop. **Do not plant grain sorghum when a severe shattercane or Johnsongrass infestation is expected.**

Common annual broadleaf weeds in sorghum include kochia, Russian thistle, Palmer amaranth, waterhemp, redroot and tumble pigweed, venice mallow, velvetleaf, cocklebur, morning glory, devils claw and sunflower. Successful control of annual weeds requires planting the crop into a weed-free environment and other management practices designed to promote crop emergence before weed emergence. Timely post-emergence applications to small broadleaf weeds following a pre-emergence herbicide provide the most effective season long weed control.

Herbicide resistant weeds such as kochia, waterhemp and pigweeds are a growing problem throughout the region. If you suspect a weed has become resistant, treat with a herbicide with a different mode of action and contact your local extension agent to confirm the presence of resistance in order to help manage these weeds.

<u>Cultural Practices</u>
Sorghum should remain nearly weed free the first 4-5 weeks after planting to prevent

yield loss from weed competition. Weed interference greater than two weeks after sorghum emergence generally reduces yields depending on the environmental conditions, weed species and density. Research has shown over a 3 percent reduction in sorghum yield for every week of grass competition, while pigweed densities up to 30/ft^2 in irrigated sorghum reduced grain yield nearly 50 percent. In Nebraska, weed interference with velvetleaf was dependent on the sorghum hybrid that was selected. Narrow-row spacing (less than 30 inches) can reduce the amount of light available to seedling weeds. In Kansas, narrow row sorghum reduced weed growth up to 45 percent and increased yield over 30 bushels per acre when compared to 30-inch rows.

Delayed sorghum planting provides opportunities for effective weed control. In tilled seedbeds, field cultivation prior to planting will control emerged weeds and stimulate the onset of an additional flush of weed germination, reducing weed seed stocks in the soil. The last tillage before planting should be very shallow to avoid bringing new weed seed to the soil surface. In no-till seedbeds, herbicides are used to control emerged weed seedlings. Once several flushes of weed seedlings have been killed without further soil disturbance, weed pressure is often reduced because few weed seeds remain in the germination zone near the soil surface. No-till especially reduces the large seeded broadleaf weed populations. Using "stale seedbed" techniques are especially effective in late seeded crops. Although delayed sorghum planting can help mange weeds in certain situations, it increases the risk of crop failure due to a fall freeze prior to physiological maturity. Late-planted sorghum and shorter season hybrids often have inherently lower yield potential.

Crop rotation is a key component of integrated weed management because it can reduce weed pressure by varying the timing and types of tillage and herbicides used in the system. This is the most effective control for shattercane and Johnsongrass in sorghum. Fallow periods and rotation with glyphosate-tolerant summer crops such as soybeans, corn, and cotton or winter crops such as wheat and canola will greatly reduce weed numbers with timely weed control to prevent weed seed production during the rotational period.

Perennial weeds such as field bindweed, common milkweed, hemp dogbane, bur ragweed (woolly leaf bursage), tumble windmill grass and Johnsongrass also may infest sorghum fields. Perennial weeds can be suppressed, but often are difficult to kill. Cultivation between the rows, directed herbicide applications with drop nozzles, and certain broadcast herbicides are helpful in suppressing perennial weeds in the sorghum crop. Crop rotation with alternate herbicides and additional control measures during fallow periods will help control perennials.

Fall herbicide applications following sorghum harvest and prior to a killing freeze can provide control of some perennial species like bindweed and bur ragweed.

Weed Control Prior to Planting

When sorghum follows wheat from the previous year, weeds must be controlled in the wheat stubble to prevent weed seed production. Using glyphosate and dicamba or 2,4-D can provide excellent broad-spectrum weed control. An atrazine application in late October or into November will help control volunteer wheat and other winter annual weeds, and should keep the field relatively weed-free for a no-till sorghum planting the following spring. The addition of glyphosate is important if winter annual grasses are present. The addition of 2, 4-D or dicambia will help provide adequate winter annual broadleaf weed control. Growers should also consider applying short soil residual herbicides in the spring prior to planting.

Sorghum planted into soybean or row-crop stubble normally requires no seedbed preparation other than a burndown herbicide application. Where weed pressure is light and mainly broadleaf weeds, a March or early-April application of atrazine with crop-oil concentrate and 2,4-D can control winter annual weeds such as mustards and marestail and provide control of most germinating weeds up to planting. Early-spring applied atrazine is a best management practice (BMP) to minimize off-site atrazine movement as there is little potential for loss in surface-water runoff compared to later planting-time applications. Leaving these weeds uncontrolled until the final burndown after or just prior to grain sorghum planting can result in inadequate weed control.

If annual grasses and tough broadleaf weeds like velvetleaf emerge as planting time nears, glyphosate and one pint of 2,4-D LV ester should be applied at least one week before planting. In addition to killing emerged annual weeds, this treatment can be very effective on established perennials such as field bindweed and hemp dogbane. Soil-residual grass herbicides can be added with these foliar-applied treatments for extended weed control. Sharpen is a PPO inhibitor and can provide excellent control of broadleaf weeds, including marestail. Sharpen should be applied with crop oil or methylated seed oil and can be tank-mixed with glyphosate. Use high surfactant oils when mixing with glyphosate.

<u>Herbicides Applied at Planting</u>

It is critical that fields be weed-free at planting and remain nearly weed-free the first several weeks of the sorghum life cycle to optimize yield potential. Most weed control strategies should consider the use of atrazine either applied prior to planting, at planting, prior to crop emergence or soon after crop emergence. **Atrazine is much more effective when applied as a premix with metolachlor, dimethenamid, or actetochlor.** Restrictions and rates of atrazine use vary considerably depending on state and local requirements. Closely examine the label for use in any particular field. Generally, atrazine should only be applied prior to sorghum emergence in medium or fine textured soils at reduced rates or crop injury can occur.

Other soil-applied pre-emergence herbicides for grass and pigweed control in sorghum include the active ingredients metolachlor, acetolchlor and dimethenamid (Table 9). These are primarily used for annual grass control but will also control smaller seeded broadleaf weeds such as pigweed. These are sold under a host of trade names including Dual II Magnum, metolachlor, Cinch, Outlook and Warrant (there are several other generic herbicides). These herbicides may be shallowly incorporated or surface applied, and require the use of sorghum seed treated with a safener (Concep III). These soil-applied herbicides do not control shattercane or large-seeded broadleaf weeds such as cocklebur, velvetleaf, venice mallow, morning glory, devils claw or sunflower. These herbicides are most effective when applied with atrazine and often are marketed in a prepack mixture (Table 9). These prepack mixtures that include atrazine provide broad spectrum grass and broadleaf weed control. For control of large seeded broadleaf and triazine-resistant weeds consider Sharpen (saflufenacil), a PPO inhibiting herbicide that provides burndown broadleaf weed control and very short residual broadleaf weed control. The 1-2 ounce per acre rate of Sharpen will provide perhaps 1-2 weeks residual broadleaf weed control. Sharpen will need to be applied with one of the chloroacetamides or one of the prepackage mixtures of a chloroacetamide and atrazine listed above. Verdict is a premix of Sharpen and dimethenamid. Lumax or Lexar contain the HPPD inhibiting herbicide mesotrione (Callisto) plus Dual II Magnum and atrazine. Lumax is the low atrazine load version of these prepack herbicides. **Lumax or Lexar can provide excellent control of grasses and broadleaf weeds including velvetleaf and triazine-resistant Palmer amaranth and kochia.** Lumax and Lexar should not be used on sandy soils because of excessive risk of crop injury and sorghum stand loss.

The rate of atrazine applied to the soil surface at planting should not exceed 1 lb. per acre, especially where soils are vulnerable to surface-water runoff during May and June. Alternatives for using higher rates of atrazine at planting time include surface application before April 15, preplant incorporation, or application in bands over the sorghum row.

TABLE 9. POPULAR PRE-EMERGENT HERBICIDES BY ACTIVE INGREDIENT NAME (COMMON TRADE NAMES)

Herbicide	Use
Atrazine (AAtrex, atrazine)	Primarily broadleaf weed control. Long residual.
Propazine (Milo-Pro)	
Metolachlor or S-metolachlor (Dual II Magnum, Cinch, Parallel, Brawl Charger, Medal)	Good annual grass control with some broadleaf activity. Must use Concep III treated sorghum seed.
Dimethenamid (Outlook, Commit, Slider, Sortie)	
Acetochlor (Warrant)	
Atrazine + Metolachlor (Bicep II Magnum, Cinch ATZ, Metal II AT, others)	Broadleaf weed and grass control. Must use Concep III treated sorghum seed.
Saflufenacil + Dimethenamid (Vardict)	
Atrazine + Acetochlor (Degree Xtra, Fultime NXT)	
Atrazine + Metolachlor + Mesotrione (Lumax, Lexar)	Broadleaf weeds including triazine resistant pigweed and kochia in addition to grass control. Must use Concep III treated seed.
Others	See state and local Extension service recommendations for other pre emergent herbicides.

Herbicides Applied Post-Emergence

Post-emergence herbicides should be applied to small weeds for optimum weed control (Table 10). Fewer herbicides are available for broadleaf weed control in sorghum than in corn or soybean. Peak and Permit are sulfonylurea herbicides that are often tank-mixed with dicamba, 2,4-D and/or atrazine to control a broader spectrum of weeds and to help control ALS-resistant weed species that may be immune to ALS-inhibiting herbicides. Additional herbicides available for post-emergence broadleaf weed control are Aim (carfentrazone) and Priority (Aim + Permit). Aim is a PPO inhibitor and can help control triazine and ALS-resistant weeds if applied when weeds are small. Aim is especially effective for control of velvetleaf. Dicamba (Banvel or Clarity) and 2,4-D are among the least expensive herbicides for broadleaf weed control in sorghum. These herbicides act as growth regulators, often causing temporary leaning and brittleness in sorghum plants, especially if applied when sorghum is less than 2 inches in height. Such plants are more vulnerable to wind and cultivator damage. Application to sorghum more than 8 inches tall should be made with drop nozzles to reduce potential for sorghum injury. Application of dicamba or 2,4-D after sorghum exceeds 15 inches tall may result in sterility and severe yield reductions. There is limited evidence that suggests sorghum hybrids may vary in their response to these growth regulator herbicides,

TABLE 10. POPULAR BROADLEAF POST EMERGENT HERBICIDES BY ACTIVE INGREDIENT NAME (COMMON TRADE NAMES)

Herbicide	Use
Atrazine (AAtrex, atrazine)	Effective on most broadleaf weeds and will provide soil residual control. Apply with crop oil.
2,4-D (2,4-D, Unison, Barrage, Saber, Weedar 64, others)	Will control most broadleaf weeds, crop injury can be significant and drift to cotton and soybean fields is a concern.
Dicamba (Banvel, Clarity, Rifle, Vision)	Will control most broadleaf weeds, crop injury can be significant and drift to cotton and soybean fields is a concern but safer than 2,4-D.
Prosulfuron (Peak)	Must be applied to small weeds. Best to use with dicamba, 2,4-D or atrazine.
Fluroxypyr (Starane)	Weak on pigweed. Good on kochia, morning glory, and devils claw.
Carfentrazone (Aim)	Fast burn down. Effective only on small weeds (<2 inches).
Halosulfuron (Permit)	Best product to use for nutsedge (nutgrass) control. Ineffective when used alone on most broadleaf weeds.
Pyrasulfotole + Bromoxynil (Huskie)	Excellent on many broadleaf weeds but will cause temporary injury to sorghum leaves. Often used as a rescue treatment. Works best with the addition of 0.5 to 1.0 lb atrazine.
Others	See state and local extension service recommendations for other post emergent herbicides.

but all hybrids are susceptible to damage, especially if the herbicides are misapplied.

Huskie is a premix of a HPPD herbicide and Buctril a contact photosystem II inhibitor. Huskie can be very effective on small broadleaf weeds and gives acceptable control of larger weeds. It will, however, cause some yellowing and burning of the sorghum leaves. Sorghum will grow out of these injury symptoms within a few days. Huskie works best when applied with 0.5-1.0 lb. of atrazine. Huskie can be applied to sorghum up to 30 inches tall or before flag leaf emergence.

Post-Grass Control

Until recently there have been no effective herbicides in grain sorghum that could be used after crop and grass have emerged. Sorghum hybrids tolerant to ALS herbicides have now been developed. The ALS tolerant trait is called "Inzen." The herbicide labeled for use in Inzen sorghum is Zest, which contains the active ingredient nicosulfuron. Zest can be applied over the top of Inzen grain sorghum for the control of annual grasses as well as many broadleaf weeds. **Special care should be taken to follow all stewardship guidelines associated with Inzen technology.** Check with your seed representative regarding the availability of ALS/Inzen hybrids.

Perennial Weeds

Johnsongrass and bindweed are the two perennial weeds that cause the most problems in sorghum and both weeds have the potential to completely eliminate any significant grain yield. Prevention is the best method of control with these weeds. As soon as either weed is detected, producers should do everything possible to prevent their spread. Do not run tillage equipment through isolated spots of weeds, as the spots tend to spread to other parts of the field.

To eradicate Johnsongrass, diligently spot treat with glyphosate (Roundup) or ACCase herbicides such as Select, Fusilade, Assure II or Poast. For Johnsongrass that is already widespread, the best control method is to allow the Johnsongrass to emerge prior to sorghum planting. Once the Johnsongrass has approximately 6 inches of growth, treat with glyphosate. Sorghum should then be immediately planted with as little disturbance of the treated Johnsongrass as possible. Although this will not provide season-long control, it will allow the grain sorghum to grow with very little Johnsongrass competition during the critical 4 weeks after planting. Grain yield will be considerably better than if no control was attempted.

The glyphosate treatment procedure outlined above can also be effective on bindweed. In addition, early in-season treatment of dicamba or 2,4-D should be considered for bindweed control. Another herbicide, quinclorac (Quinstar), can be used alone or in combination with dicamba or

2,4-D. Quinclorac is safe on sorghum and can be very effective.

Cultivation of Sorghum Rows

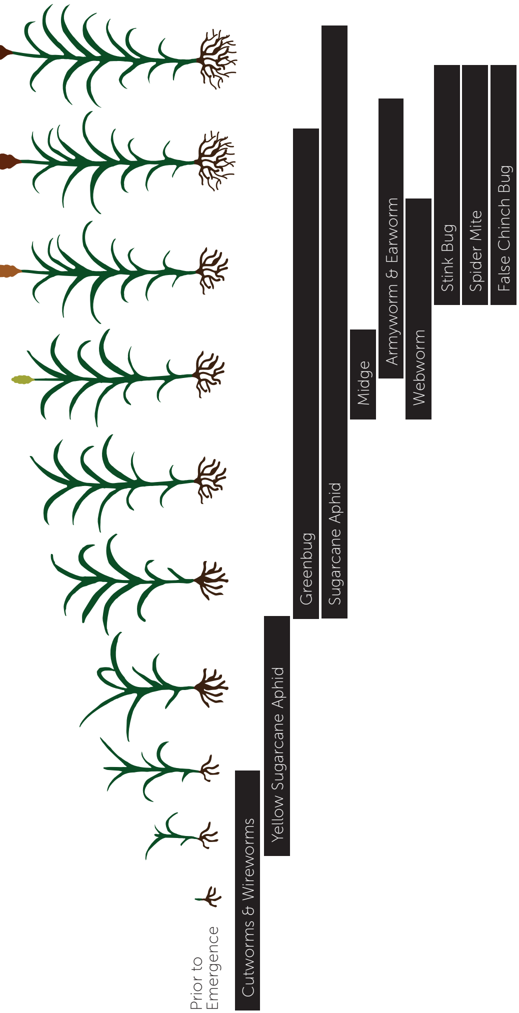
Cultivation remains an integrated option for control of emerged weeds, however it has become very unpopular due to fuel costs, time and labor involved. Cultivation can be an emergency backup where herbicides have performed poorly and where perennial weeds have not been controlled. Electronic guidance systems can increase cultivating speed and efficiency by reducing operator fatigue and cultivator blight. Heavy, high-residue cultivators can be effective even in no-till planted sorghum.

INSECT MANAGEMENT

Sorghum insect pests vary widely from year to year, during different times within a growing season, and across the region. Greenbugs have historically been a problem throughout the region, but with the use of resistant hybrids seldom reach economic thresholds levels. Chinch bugs are a continuous concern with localized infestations sufficient enough to cause seedling stand reductions, replanting or insecticide applications. Sorghum midge populations cause local concern every year in the southeast occasionally in south-central fields. Sugarcane rootstock weevils are another perennial pest in central Kansas and north central Oklahoma. Foliage-feeding insects such as fall armyworms and cattail caterpillars cause concern annually but do little economic damage. Corn earworms (sorghum headworm), and fall armyworms attack sorghum heads some place throughout the region every year, often requiring insecticide applications. These worms can reduce yield very quickly because they are feeding directly on the marketable product.

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

FIGURE 3. OUTLINE OF WHEN THE MOST COMMONLY FOUND INSECTS IN SORGHUM IN THE CENTRAL AND EASTERN PLAINS ARE AN ISSUE BASED ON GROWTH STAGE OF THE CROP



bug, stink bug and aphids. A number of foliar insecticides provide excellent control of sorghum leaf and grain pests.

<u>Sugarcane Aphids</u>

Sugarcane aphid has become the most serious threat to sorghum in the Central and Eastern Plains, particularly in the southern part of the region. Photo 2* shows the four most common aphids found in sorghum including sugarcane aphid.

Sugarcane aphids are gray, tan or pale yellow and sometimes referred to as the white aphid. With the aid of a magnifying glass, a pair of black cornicles or tailpipes can be seen on the aphid's back end. The tips of feet and antennae are black. Colonies or groups of sugarcane aphids are usually clustered around the midrib of the bottom side of the sorghum leaf. The sugarcane aphid has the ability to multiply very quickly in fields depending on weather conditions and the presence of predatory (beneficial) insects that feed on aphids.

Heavy infestations of the sugarcane aphid can cause leaves to be covered with a sticky, shiny substance called honeydew. This honeydew is made up of plant sugars and water, which are harmless to animals. Black sooty mold will often begin growing on the honeydew of sorghum leaves. This mold blocks sunlight and eventually leads to yellowing and death of leaf tissue. Loss of plant sap from the sugarcane aphid feeding directly

*Photos are located in Appendix B on page 111.

impacts yield. In addition, plant stress caused by the sugarcane aphid can lead to uneven and lack of head emergence, poor grain set and may contribute to lodging. Actual yield loss will depend on the sugarcane aphid population level and when the infestation occurs (Table 11).

Fields should be scouted once a week for signs of the aphid. Once they are found, begin scouting at least twice a week. To determine if an insecticide treatment is needed, note the presence and number of aphids on leaves in at least four areas of the field. In each area of the field examined, collect a leaf from the bottom and top of 20 plants and observe the presence and number of aphids.

Entomologists with different state extension services vary slightly on their thresholds for when to apply an insecticide application for sugarcane aphid control. **In general, an insecticide application should be made when 25 percent of**

TABLE 11. YIELD LOSS IF LEFT UNTREATED

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

the plants are infested with 50 aphids per leaf. Sivanto Prime and Transform WG have proven to be effective in controlling the aphid. Refer to SorghumCheckoff.com or local extension entomologists for updates on threshold levels as well as other available insecticides.

<u>Best Management Practices for Sugarcane Aphid Control</u>

1. Sugarcane aphids can only survive on sorghum-related species. To help reduce local populations, control Johnsongrass, volunteer sorghum and other sorghum species in and around your fields during winter and spring prior to planting.

2. Consider planting a hybrid that has tolerance to the aphid. Tolerance does not mean immunity to the aphid. These hybrids still require monitoring and treating with an insecticide if action thresholds are reached. Be careful in giving up hybrid adaptability, yield potential and other favorable agronomic characteristics. In most cases, these characteristics should not be given up in order to plant a sugarcane aphid tolerant hybrid.

3. Plant seeds treated with an insecticide seed treatment. These seed treatments will protect sorghum from potential early season infestations. Acceptable seed treatments include Cruiser (thiamethoxam), Poncho and Nipsit (clothianidin), and Gaucho (imidaclorprid).

4. Plant early. Sugarcane aphids tend to infest fields later in the growing season. Early planting may avoid infestation.

5. Scout fields early and often using proper procedures to determine the level of aphid infestation. Once sugarcane aphid infestation occurs in the field, the number of aphids can increase quickly.

6. Apply insecticide as soon as the action threshold is reached. Threshold levels change and vary with individual states. Check with your local experts for current information.

7. Use only recommended insecticides and follow label rates and application instructions. Coverage is critical. Best results are achieved when high volumes of water are used.

8. If aphids are present in the upper canopy or grain panicle in sufficient numbers to produce honeydew, consider applying an insecticide in order to prevent potential issues with harvest. If a harvest-aid product is used, tank mixing with the insecticide has worked well when the sugarcane aphid is present.

9. Avoid use of insecticides, especially pyrethroids, that are harmful to beneficial insects because they may result in sugarcane aphid numbers increasing rapidly.

Basic identification and threshold information is included for some of the other most troublesome insect pests in grain sorghum. Refer to regional extension publications or visit SorghumCheckoff.com for the most up-to-date recommendations.

<u>Other Insects</u>

Other insects that are a concern in the Central and Eastern Plains are described along with when they occur in Table 12.

TABLE 12. INSECTS OF FREQUENT CONCERN IN SORGHUM

Time of Year / Crop Growth Stage	Description	Distribution	Probably Insect
Planting; Seed-Attacking Insects	• Poor emergence of plants or seeds fail to germinate • Seeds mechanically injured or destroyed	Region-wide	• False Wireworms • Seed Corn Beetles • Kafir Ants • Wireworms
Early Season	• Plants stunted or lodging early in the season • Occasionally, plants die • Underground portion of stems show signs of tunneling and feeding • Hard-shelled yellowish larvae may be present	Region-wide	• Wireworms
Early Season	• Plants stunted or lodged • Roots destroyed or severely pruned • C-shaped whitish grubs present	Region-wide	• White grubs

Time of Year/ Crop Growth Stage	Description	Distribution	Probable insect
Seedlings to 6-inch Pants	• Upper epidermis of leaf tissue chewed away • Pattern shows as a series of streaks or whitish stripes • Definite mechanical destruction of tissue can be observed • Tiny, hard-shelled, shiny beetles, 1/16 inch long, jump rapidly when disturbed	Region-wide	• Flea Beetles
Seedlings to 6-inch Plants	• Small, fine white streaks present on surface of leaf tissue • Small, splinter-like insects present on the plants, usually in the whorls • Less that 1/16 inch long; color varies from transparent to dark; some winged, some not	Region-wide	• Thrips
Seedlings to 6-inch Plants	• Plants partially or totally cut off just above or below the soil surface • Brownish to blackish worms may be present, generally under the soil surface in the vicinity of injured plants	Region-wide	• Cutworms

Time of Year/ Crop Growth Stage	Description	Distribution	Probable Insect
May-June on seedling Plants	• Small seedlings show signs of reddening, sometimes plants dying • Insects present on above-ground portions of the plant • Tiny, light green soft-bodied insects • If insects have disappeared, numerous whitish cast skins present on foliage and soil around affected plants	Region-wide	• Greenbugs
May-June on Seedling Plants	• Plants stunted and/or wilting • Brace roots deformed • Stems, both below and above ground with signs of feeding or tunneling • Roots pruned or destroyed	Region-wide	• Wrieworms • Sugar Cane Rootstock • Weevil • Chinch Bugs • White Grubs

Time of Year/ Crop Growth Stage	Description	Distribution	Probable Insect
May-June on Seedling Plants	• Medium to dark green sucking insects present, especially in whorls of plants • Prominent cornicles or tail-pipes present on upper side near rear of body • Tail-pipes are darkish in color • Area around base of tail-pipes is also darkish in color • Generally no visible injury associated with these insects, even though they may be quite numerous	Region-wide	• Corn Leaf Aphids
May-June on Seedlings to 6-inch Plants	• Damage generally appearing at the margin of the field and progressing inward • Small plants show signs 0-6 inches high of stunting or dying • Occasionally reddish discoloration on lower portions of plants • Partially grown or full-grown bugs feeding either above or below ground on plants • Immature bugs are reddish to blackish with a white stripe across middle of back • Adult black except for whitish wings • Adult insect about 1/8 inch long or less	Generally more common in the Eastern Plains, usually in sorghum fields adjacent to wheat	• Chinch Bugs

Time of Year/ Crop Growth Stage	Description	Distribution	Probable Insect
June, July, August: Whorl Stage	• Leaves shiny and syrupy; excessive honeydew present • Aphids present in upper portions of the plant • Whitish cast skins also frequently present • Some leaves yellow with reddish blotches	Region-wide	• Corn Leaf Aphids
June, July August: Whorl Stage	• Lower leaves shiny and sticky; excessive honeydew present • Light green, soft-bodied insects present on underside of leaves • Reddish areas develop on leaves where colonies are present • Leaves die where heavy infestation develops and is allowed to persist	Region-wide	• Greenbugs
June July, August: Whorl Stage	• Holes in leaves • Occasionally, plants very ragged • Damage often more severe on late-planted fields	Region-wide	• Fall Army Worms • Cattail Caterpillars

Time of Year / Crop Growth Stage	Description	Distribution	Probable Insect
August, September: During Bloom Stage	• Small, light brown, fuzzy striped worms present in heads of sorghum, about 1/2 inch long when full grown	In eastern areas, more common in the southeast	• Sorghum Webworm
August, September: During Bloom Stage	• Seeds fail to develop on part or more of the head • Heads appear to be "blasted" • Tiny orange or red maggots occasionally present, but generally not visible except under microscope	In eastern areas, more common in the southeast	• Sorghum Midge
August, September	• Destroys grain in the developing head • Infestation usually begins during or shortly after bloom • Worms range in size from 1/4 to 1½ inches in length • Larva possess a series of stripes on the body, predominant color may be greenish, pinkish, to almost blackish • Head capsule uniform light brown color	More common in the southern half of the region	• Corn Earworm

Time of Year / Crop Growth Stage	Description	Distribution	Probable Insect
July, August	• Visible feeding on leaves, particularly around field margins • Occasional signs of feeding on developing seeds in the head	Region-wide	• Grasshoppers
July, August	• Discoloration, browning and yellowing of lower leaves • Signs of light webbing on underside of affected leaves • Tiny "crawling specks" may be present • Greenbugs sometimes also present	More common in the High Plains, but can be found in the Central Plains	• Spider Mites
July-September	• Plant showing signs of stress; occasional poor filling of heads is visible • Clusters of reddish to blackish insects present on lower portions of the stalk	Eastern Plains	• Chinch Bugs
July-September	• Small, grayish insects similar in size and shape to ching bugs but color is different, feeding in the heads of developing sorghum	Region-wide	• False Chinch Bugs
Late July-October	• Mostly tan or pale yellow with black cornicles that are located on the bottom side of leaves. Produce honeydew • Can infest sorghum from whorl stage through harvest	Mostly an issue in southern areas of the region	• Sugarcane aphid

DISEASES

Diseases of grain sorghum, like those of other crops, vary in severity from year to year and from one locality or field to another, depending upon environment, causal organism(s), and host (plant) resistance. **Estimates of annual sorghum yield losses to diseases in the Central Plains average less than 10 percent.**

The total eradication of disease in sorghum is not economically feasible, so growers must try to minimize losses using an integrated pest management system. Planting resistant hybrids, providing optimum growing conditions, rotating with other crops, burying infested debris, proper seedbed preparation and seed placement, and accurate application of herbicides and insecticides are all practices used to minimize disease losses.

Although sorghum is susceptible to many diseases there are only a few which cause or have the immediate potential to cause economic losses in the Central Plains on a regular basis. Sorghum is also 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.

TABLE 13. 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 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. In West Texas, only seedling blights and stalk rots are likely to cause economic yield losses on a regular basis.

There are many foliar diseases caused by fungi that can occur on sorghum including sooty stripe, rust and northern corn leaf blight. Sooty stripe and rust can cause economic losses to occur in some years and on some hybrids. 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 under high yielding environments.

Bacterial leaf diseases have not been shown to cause yield losses under Central and Eastern Plains conditions, but they are generally present in some fields every year, particularly under wet, humid conditions.

In the Central and Eastern Plains, only seedling blights, stalk rots and sooty stripe are likely to cause economic yield losses on a regular basis. Crazy top downy mildew and sorghum downy mildew occasionally cause significant yield loss in individual fields or small areas of a field in years with excessive moisture early in the season, but they are not a widespread problem. Sorghum ergot infection is rare in the Central Plains, but when it does occur it can cause significant harvesting problems because the sticky honeydew can bind up combines, forage cutters and augers.

IRRIGATION

Grain sorghum has a drought-tolerant reputation; therefore, it is a viable crop choice for some irrigators with low-capacity wells and limited water because good yield response to limited water applications is possible. However under full irrigation, corn generally becomes the preferred feed-grain crop due to its ability to produce more grain per unit of added water in high-yield situations. The average yield of grain sorghum has increased over time with irrigated yield increasing at about 0.6 bushels per acre per year since 1974.

<u>Water Use Requirements</u>
Grain sorghum will use about 18-22 inches of water to produce a normal yield. The total amount of irrigation water needed depends on the season and the amount of soil water stored in the root zone. Dry-year irrigation estimates (NRCS Irrigation Guide) for grain sorghum range from about 15 inches in western growing regions to less than 7 inches in eastern growing regions. Irrigation estimates for years with average rainfall are from about 13 inches in the west to 4 inches in the east. These range estimates are for well-watered conditions.

Grain sorghum is generally one of the later-planted summer crops. This allows for the soil profile to accumulate water prior to planting and often means the reproductive stage begins after the hottest weather of the summer passes. Water use rates for the various growth stages are shown in Figure 4. Average peak water use rates are about 0.3 inch per day, although occasionally a single-day peak use might approach 0.45 inch per day.

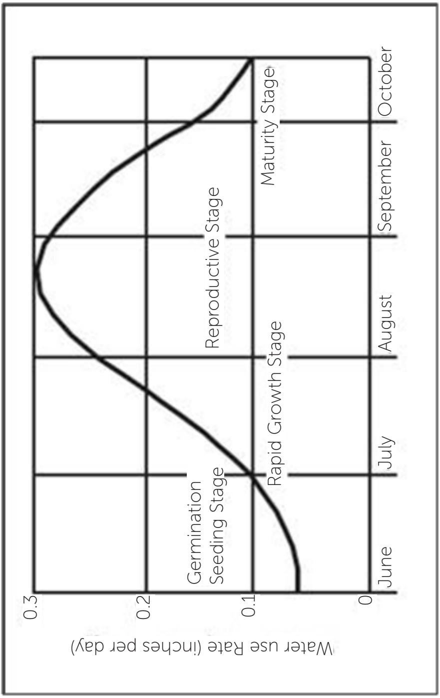


FIGURE 4. CHARACTERISTIC WATER USE PATTERN OF GRAIN SORGHUM

Grain sorghum develops an extensive root system, which can extend to 6 feet in a friable soil. Irrigation scheduling usually accounts for only the upper 3 feet of the root zone since most of the water extraction will occur in this region. About 75 percent of water use will occur in the upper half of the root zone. Under stress conditions, when the upper zone becomes water-limited, the crop will use water from significant soil depth (Table 14).

Irrigation Management

In addition to being able to extract water from a great depth within the root zone (Table 14), grain sorghum is able to extract soil water at a lower percentage of available soil water without yield loss when water is limited in the upper root zone. The general irrigation-management recommendation is to maintain soil water at

TABLE 14. WATER-EXTRACTION PATTERNS UNDER DIFFERENT SOIL-WATER CONDITIONS. GARDEN CITY, KANSAS.

Depth (ft.)	Normal (no stress), %	Moderate Stress, %	Moderate to Severe Stress, %
0-1	31.4	25.3	7.4
1-2	23.2	18.9	7.3
2-3	18.4	19.9	14.8
3-4	13.4	17.9	24.9
4-5	7.6	11.7	24.4
5--6	6.0	6.3	21.0

or greater than 50 percent available water. For grain sorghum, however, the soil water can be depleted to an average of 30-40 percent available water before grain yields are severely reduced. Scheduling based on soil-water depletion or crop-water use (evapotranspiration or ET) rates are recommended when full irrigation of grain sorghum is intended.

Grain sorghum is a crop that lends itself to a limited irrigation-scheduling program. For high water-holding capacity soils, like medium-textured silt loams or heavier clay loams, limited water applications during the growing season of about half the full irrigation requirement for well watered conditions (6-8 inches) will often produce 80-90 percent of the full yield potential under most circumstances.

On deep, silt loam soils, one or two relatively large irrigation applications (4-6 inches), can produce near-maximum yields compared to three or four in-season irrigations. Timing those irrigations during periods of peak demand will maximize yield and water use efficiency (Table 15). Although pre-plant irrigation can be effective on deep soils, it is not recommended if any in-season irrigation is planned. In most years, sufficient rainfall is available to recharge the upper root zone, making pre-plant irrigation an inefficient water use practice.

Full and limited irrigation of grain sorghum on sandy soils require more frequent and smaller irrigation applications in order to avoid plant stress and to not leach nutrients out of the root zone.

If water becomes limited at any stage of growth, grain sorghum has the ability to tolerate water stress for short periods of time. Within certain limits, grain sorghum is a drought-resistant crop. Drought stress can lead to a delay in plant maturity. If plant maturity is delayed, the crop may face frost damage in the event of an early freeze. Late-season water stress during grain filling can result in shriveled seeds, which reduces yield.

TABLE 15. GRAIN SORGHUM YIELD RESPONSE TO LIMITED IRRIGATION AND TIMING. SCANDIA, KANSAS.

Irrigation Frequency and Timing	Yield (bushel/A)
No Irrigation	111
Irrigation at Boot	136
Irrigation at Boot + Grain Fill	145

Irrigation Summary

- Grain sorghum's water use rate peaks at about 0.3 inches per day for a 30-day period starting at the boot stage.
- The typical seasonal water need is 18-22 inches.
- Irrigation requirements vary from less than 6 inches in the east to about 15 inches in the west under well-watered conditions in normal years.
- Grain sorghum has an extensive root system, and its drought tolerance makes it suitable for limited irrigation.

HARVESTING

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, 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 in 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.

<u>Five Types of Harvest Loss</u>
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. Generally, grain sorghum can be combined whenever the moisture content is less than 30 percent.

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 too fast 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 one 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 (Figure 5). When making ground counts for kernels, look for lost heads. **One 10-inch head in a 10-foot-by-10-foot area is approximately one 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, 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.

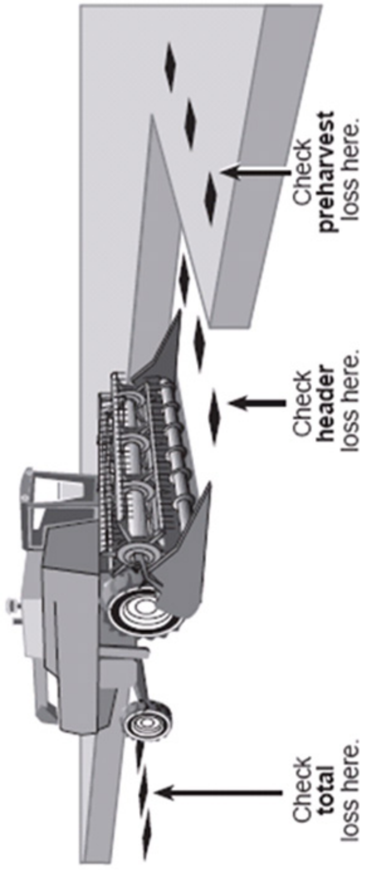
Grain Quality

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

Drying and Storing Grain Sorghum

Grain quality at harvest is influenced by grain

FIGURE 5. DETERMINING HARVEST LOSSES



variety, weather and combine adjustment. Minimizing grain damage in order to maintain quality requires good handling, drying and 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

TABLE 16. 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

TABLE 16 CONTINUED

Maximum Count Limits (Other Material)				
Animal Filth	9	9	9	9
Castor Beans	1	1	1	1
Crotalaria Seeds	2	2	2	2
Glass	1	1	1	1
Stones[2]	7	7	7	7
Unknown Foreign Substance	3	3	3	3
Cockleburs	7	7	7	7
Total[3]	10	10	10	10

[1] Sorghum which is distinctly discolored shall not grade higher than U.S. No. 3.
[2] Aggregate weight of stones must also exceed 0.2 percent of the sample weight.
[3] Includes any combination of animal filth, castor beans, crotalaria seeds, glass, stones, unknown foreign substances or cockleburs.

U.S. Sample Grade sorghum:
(a) Does not meet the requirements for U.S. No. 1, 2, 3 or 4; or
(b) Has a musty, sour or commercially objectionable foreign odor (except smut order); or
(c) Is badly weathered, heating or distinctly low quality.

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 for 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 to 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.

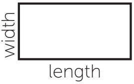
Grain should be aerated after it is dried and in the fall, winter and spring. Begin aeration when the average outdoor temperature is 10 to 15°F lower than the grain temperature. Average outside temperature can be taken as the average of the high and low temperatures over a 3-5 day period. Check grain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

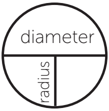
Sorghum Facts

- Sorghum is the fifth most important cereal crop in the world.
- It is used in a wide range of applications such as ethanol production, animal feed, pet food, food products, building material, brooms and other industrial uses.
- Sorghum originated in northeast Africa and spread to Asia, Europe and the Western Hemisphere.
- In the United States, sorghum is the second most important feed grain for biofuel production and is known for its excellent drought tolerance and superior adaptability to different environments.
- The first written record of sorghum in the U.S. traces to a letter that Benjamin Franklin wrote in 1757.

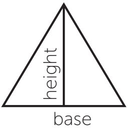
CALCULATIONS & CONVERSIONS



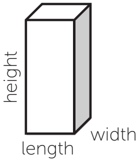
Area of a rectangle or square = length x width



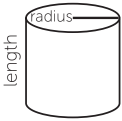
Area of a circle = 3.1416 x radius squared; or 0.7854 x diameter squared
Circumference of a circle = 3.1416 x diameter; or 6.2832 x radius



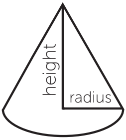
Area of triangle = base x height ÷ 2



Volume of rectangle box or cube = length x width x height

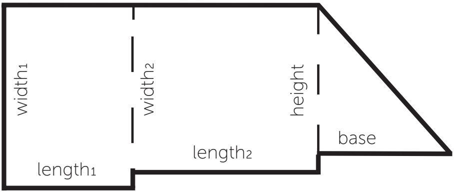


Volume of a cylinder = 3.1416 x radius squared x length



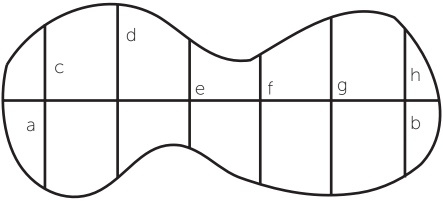
Volume of cone = 1.0472 x radius squared x height

Reduce irregularly shaped areas to a combination of rectangles, circles and triangles. Calculate the area of each and add them together to get the total area.



Example: If b = 25′, h = 25′, L_1 = 30′, W_1 = 42′, L_2 = 33′, W_2 = 31′, then the equation is:
Area = ((b x h) ÷2) + (L_1 x W_1) +(L_2 x W_2)
= ((25 x 25) ÷2) + (30 x 42) + (31 x 33)
= 2595 sq. ft.

Another way is to draw a line down the middle of the property for length. Measure from side to side at several points along this line. Use the average of these values as the width. Calculate the area as a rectangle.



Example: If ab = 45′, c = 19′, d = 22′, e = 15′, f = 17′, g = 21′, h = 22′, then the equation is:
Area = (ab) x (c + d + e + f + g + h) ÷ 6
= (45) x (19 + 22 + 15 + 17 + 21 + 22) ÷ 6
= 870 sq. ft.

Conversion Factors

Acres (A)	x0.405	Hectares
Acres	x43,560	Square feet
Acres	x4047	Square Meters
Acres	x160	Square rods
Acres	x4840	Square yards
Bushels (bu)	x2150.42	Cubic inches
Bushels	x1.24	Cubic feet
Bushels	x35.24	Liters
Bushels	x4	Pecks
Bushels	x64	Pints
Bushels	x32	Quarts
Bushel Sorghum		56 pounds
$CaCO_3$	x0.40	Calcium
$CaCO_3$	x0.84	$MgCO_3$
Calcium (ca)	x2.50	$CaCO_3$
Centimeters (cm)	x0.3937	Inches
Centimeters	x0.01	Meters
Cord (4'x4'x8')	x8	Cord feet
Cord foot (4'x4'1')	x16	Cubic feet
Cubic centimeter (cm^3)	x0.061	Cubic inch
Cubic feet (ft^3)	x1728	Cubic inches
Cubic feet	x0.03704	Cubic yards
Cubic feet	x7.4805	Gallons
Cubic feet	x59.84	Pints (liq.)
Cubic feet	x29.92	Quarts (liq.)
Cubic feet	x25.71	Quarts (dry)
Cubic feet	x0.084	Bushels
Cubic feet	x28.32	Liters
Cubic inches (in^3)	x16.39	Cubic cms
Cubic meters (m^3)	x1,000,000	Cubic cms
Cubic meters	x35.31	Cubic feet
Cubic meters	x61,023	Cubic inches
Cubic meters	x1.308	Cubic yards
Cubic meters	x264.2	Gallons
Cubic meters	x2113	Pints (liq.)
Cubic meters	x1057	Quarts (liq.)
Cubic yards (yd^3)	x27	Cubic feet
Cubic yards	x46,656	Cubic inches
Cubic yards	x0.7646	Cubic meters
Cubic yards	x21.71	Bushels
Cubic yards	x202	Gallons
Cubic yards	x1616	Pints (liq.)
Cubic yards	x807.9	Quarts (liq.)

Cup	x8	Fluid ounces
Cup	x236.5	Milliliters
Cup	x0.5	Pint
Cup	x0.25	Quart
Cup	x16	Tablespoons
Cup	x48	Teaspoons
ºCelsius (ºC)	(+17.98)x1.8	Fahrenheit
ºFahrenheit (ºF)	(-32)x0.5555	Celsius
Fathom	x6	Feet
Feet (ft)	x30.48	Centimeters
Feet	x12	Inches
Feet	x0.3048	Meters
Feet	x0.33333	Yards
Feet/minute	x0.01667	Feet/second
Feet/minute	x0.01136	Miles/hour
Fluid ounce	x1.805	Cubic inches
Fluid ounce	x2	Tablespoons
Fluid ounce	x6	Teaspoons
Fluid ounce	x29.57	Milliliters
Furlong	x40	Rods
Gallons (gal)	x269	Cubic in. (dry)
Gallons	x231	Cubic in. (liq.)
Gallons	x3785	Cubic cms
Gallons	x0.1337	Cubic feet
Gallons	x231	Cubic inches
Gallons	x3.785	Liters
Gallons	x128	Ounces (liq.)
Gallons	x8	Pints (liq.)
Gallons	x4	Quarts (liq.)
Gallons of Water	x8.3453	Pounds of Wa
Grains	x0.0648	Grams
Grams (g)	x15.43	Grains
Grams	x0.001	Kilograms
Grams	x1000	Milligrams
Grams	x0.0353	Ounces
Grams/liter	x1000	Parts/million
Hectares (ha)	x2.471	Acres
Hundred wt (cwt)	x100	Pounds
Inches (in)	x2.54	Centimenters
Inches	x0.08333	Feet
Inches	x0.02778	Yards
K_2O	x0.83	Potassium (K)
Kilogram (kg)	x1000	Grams (g)
Kilogram	x2.205	Pounds

Kilograms/hectare	x0.8929	Pounds/acre
Kilometers (K)	x3281	Feet
Kilometers	x1000	Meters
Kilometers	x0.6214	Miles
Kilometers	x1094	Yards
Knot	x6086	Feet
Liters (l)	x1000	Milliliters
Liters	x1000	Cubic cms
Liters	x0.0353	Cubic Feet
Liters	x61.02	Cubic inches
Liters	x0.001	Cubic meters
Liters	x0.2642	Gallons
Liters	x2.113	Pints (liq.)
Liters	x1.057	Quarts (liq.)
Liters	x0.908	U.S. dry quart
Magnesium (mg)	x3.48	$MgCO^3$
Meters (m)	x100	Centimeters
Meters	x3.281	Feet
Meters	x39.37	Inches
Meters	x0.001	Kilometers
Meters	x1000	Millimeters
Meters	x1.094	Yards
$MgCO^3$	x0.29	Magnesium (Mg)
$MgCO^3$	x1.18	$CaCO^3$
Miles	x5280	Feet
Miles	x1.69093	Kilometers
Miles	x320	Rods
Miles	x1760	Yards
Miles/hour	x88	Feet/minute
Miles/hour	x1.467	Feet/second
Miles/minute	x88	Feet/second
Miles/minute	x60	Miles/hour
Milliliter (ml)	x0.034	Fluid ounces
Ounces (dry)	x437.5	Grains
Ounces (dry)	x28.3495	Grams
Ounces (dry)	x0.0625	Pounds
Ounces (liq.)	x1.805	Cubic inches
Ounces (liq.)	x0.0078125	Gallons
Ounces (liq.)	x29.573	Cubic cms
Ounces (liq.)	x0.0625	Pints (liq.)
Ounces (liq.)	x0.03125	Quarts (liq.)
Ounces (oz.)	x16	Drams
P_2O_5	x0.44	Phosphorus (P)
Parts per million (ppm)	x0.0584	Grains/gallon

Parts per million	x0.001	Grams/liter
Parts per million	x0.0001	Percent
Parts per million	x1	Milligram/kg
Parts per million	x1	Milligram/liter
Pecks	x0.25	Bushels
Pecks	x537.605	Cubic inches
Pecks	x16	Pints (dry)
Pecks	x8	Quarts (dry)
Phosphorus (P)	x2.29	P_2O_5
Pints (p)	x28.875	Cubic inches
Pints	x2	Cups
Pints	x0.125	Gallon
Pints	x473	Milliliters
Pints	x32	Tablespoons
Pints (dry)	x0.015625	Bushels
Pints (dry)	x33.6003	Cubic inches
Pints (dry)	x0.0625	Pecks
Pints (dry)	x0.5	Quarts (dry)
Pints (liq.)	x28.875	Cubic inches
Pints (liq.)	x0.125	Gallons
Pints (liq.)	x0.4732	Liters
Pints (liq.)	x16	Ounces (liq.)
Pints (liq.)	x0.5	Quarts (liq.)
Potash (K_2O)	x0.83	Potassium (K)
Potassium (K)	x1.20	Potash (K_2O)
Pounds (lb)	x7000	Grains
Pounds	x453.5924	Grams
Pounds	x16	Ounces
Pounds	x0.0005	Tons
Pounds	x0.45369	Kilograms (kg)
Pounds of water	x0.01602	Cubic feet
Pounds of water	x27.68	Cubic inches
Pounds of water	x0.1198	Gallons
Pounds/acre	x1.12	Kilograms/ha
Quarts (qt)	x946	Milliliters
Quarts (dry)	x0.03125	Bushels
Quarts (dry)	x67.20	Cubic inches
Quarts (dry)	x0.125	Pecks
Quarts (dry)	x2	Pints (dry)
Quarts (liq.)	x57.75	Cubic inches
Quarts (liq.)	x0.25	Gallons
Quarts (liq.)	x0.9463	Liters
Quarts (liq.)	x32	Ounces (liq.)
Quarts (liq.)	x2	Pints (liq.)

Rods	x16.5	Feet
Square feet (ft^2)	x0.000247	Acres
Square feet	x144	Square inches
Square feet	x0.11111	Square yards
Square inches (in^2)	x0.00694	Square feet
Square meters (m^2)	x0.0001	Hectares (ha)
Square miles (mi^2)	x640	Acres
Square miles	x28,878,400	Square feet
Square miles	x3,097,600	Square yards
Square yards (yd^2)	x0.0002066	Acres
Square yards	x9	Square feet
Square yards	x1296	Square inches
Tablespoons (Tbsp)	x15	Milliliters
Tablespoons	x3	Teaspoons
Tablespoons	x0.5	Fluid ounces
Teaspoons (tsp)	x0.17	Fluid ounces
Teaspoons	x0.333	Tablespoons
Teaspoons	x5	Milliliters
Ton	x907.1849	Kilograms
Ton	x32,000	Ounces
Ton (long)	x2240	Pounds
Ton (short)	x2000	Pounds
U.S. bushel	x0.3524	Hectoliters
U.S. dry quart	x1.101	Liters
U.S. gallon	x3.785	Liters
Yards (yd)	x3	Feet
Yards	x36	Inches
Yards	x0.9144	Meters
Yards	x0.000568	Miles

APPENDICES

a. The Sorghum Plant

Sorghum grain is found on the panicle, commonly referred to as the head. The panicle consists of a central axis with whorls of main branches, each of which contains secondary and at times, tertiary branching. The length of the branches allows for a wide range of shapes and sizes in sorghum and for sorghums with very open panicles or sorghums with very compact panicles. The branches carry the racemes of the spikelets where the grain is found (see Figure 6). The panicle emerges at boot from the flag leaf sheath.

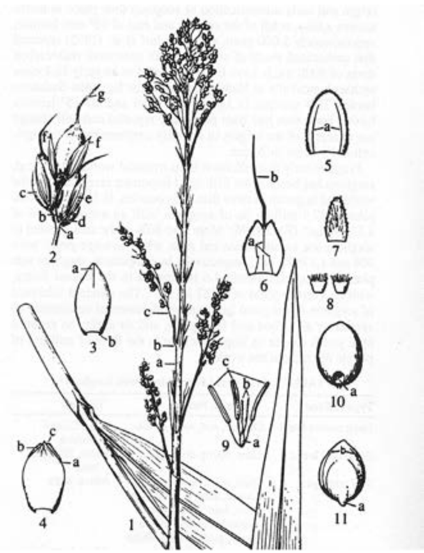


Figure 6. The panicle of Sorghum bicolor subsp. bicolor which consists of the inflorescence and spikelets. 1. Part of panicle: a = internode of rachis; b = node with branches; c = branch with several racemes. 2. Raceme: a = node; b = internode; c = sessile spikelet; d = pedicel; e = pedicelled spikelet; f = terminal pedicelled spikelets; g = awn. 3. Upper glume: a = keel; b = incurved margin. 4. Lower glume: a = keel; b = keel wing; c = minute tooth terminating keel. 5 Lower lemma: a = nerves. 6. Upper lemma: a = nerves; b = awn. 7. Palea. 8. Lodicules. 9. Flower: a = ovary; b = stigma; c = anthers. 10. Grain: a = hilum. 11. Grain: a = embryon-mark; b = lateral lines. (Drawing by G. Atkinson. Reprinted, with permission, from J. D. Snowden, 1936, The Cultivated Races of sorghum, Adlard and Son, London. Copyright Bentham - Moxon Trust - Royal Botanical Gardens, Kew, England).

Seeds begin developing shortly after flowering and reach physiological maturity when the black layer is formed between the germ and the endosperm, some 25-40 days after the black layer is formed when moisture content is generally 15 percent or less. Black layer can be seen at the base of the grain where it attaches to the rachis branch and indicates the grain is physiologically mature.

Seeds are made up of three major components: the endosperm, embryo and pericarp (Figure 7). All sorghums contain a testa, which separates the pericarp from the endosperm. If the testa is pigmented, sorghum will contain tannins. If not, the grain is free of tannins. None of the commercial U.S. grain sorghums have a pigmented testa and are all said to be free of tannins.

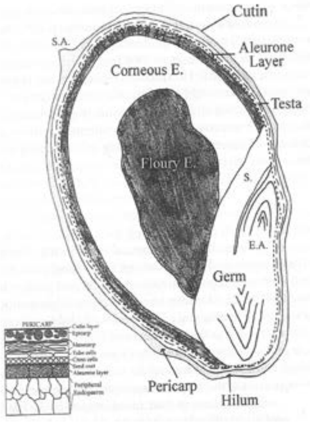


Figure 7. Sorghum grain, showing the pericarp (cutin, epicarp, mesocarp, cross cells, tube cells, testa, pedicel, and stylar area (SA)), endosperm (aleurone layer, corneous and floury), and the germ (scutellum (S) and embryonic axis (EA). Adapted from L. W. Rooney and Miller, 1982.

b. Photos

Photo 1. Iron Deficiency

Courtesy of International Plant Nutrition Institute

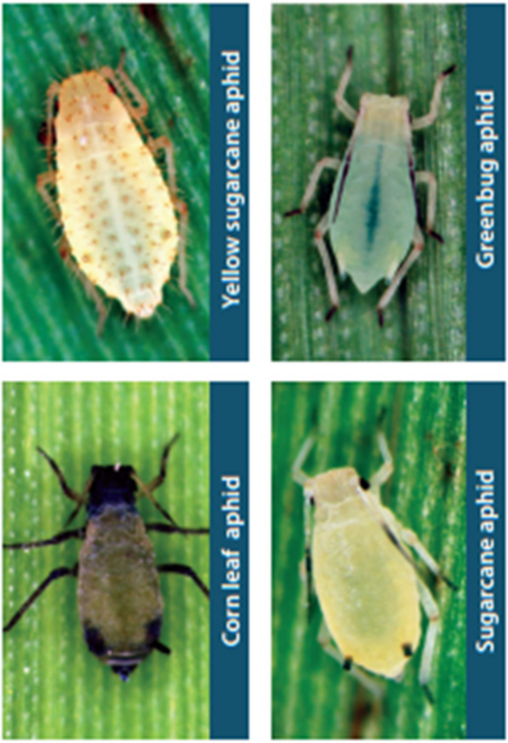


Photo 2. Corn Leaf Aphid, Yellow Sugarcane Aphid, Sugarcane Aphid, Greenbug Aphid

Photo 3. Corn Earworm**

Photo 4. Fall Armyworm*

***Used with permission of USDA-ARS*

Photo 5. Sorghum Webworm*

Photo 6. Sorghum Midge*

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