UNITED SORGHUM CHECKOFF PROGRAM

High Plains Production Handbook

SORGHUM CHECKOFF

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

- Make sure you are using the hybrid that works in your area and planting to get the right "plants per acre" in your field.
- Use an integrated weed management strategy.
- Most importantly, provide the crop with adequate fertilizer.

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. But 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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Growth Stages

It is important to understand the various developmental stages of sorghum since this understanding will assist in making irrigation and management decisions. The stages are based on key points of sorghum growth that are used to describe sorghum from planting to maturity.

Another common scale that is used among sorghum researchers is a more simplified growth scale. GS1 would equate to stages 0-5 in this system. GS2 would represent from stages 5-10, and finally, GS3 would be from stage 10 to 11.5.

Comprehensive grain sorghum growth and development guides are available such as Kansas State's "How a Sorghum Plant Develops" (http://www.oznet.ksu.edu, currently being revised with your sorghum Checkoff dollars) and Texas AgriLife's "How a Sorghum Plant Grows," (http://agrilifebookstore.org). Either of these guides provides pictures of different growth stages, graphs of cumulative nutrient uptake relative to growth stages (KSU), or approximate heat unit requirements (base temperature 50°F, maximum 100°F) for attaining a particular growth stage (Texas AgriLife).

Refer to Appendix A, page 65, for more information about the sorghum plant.

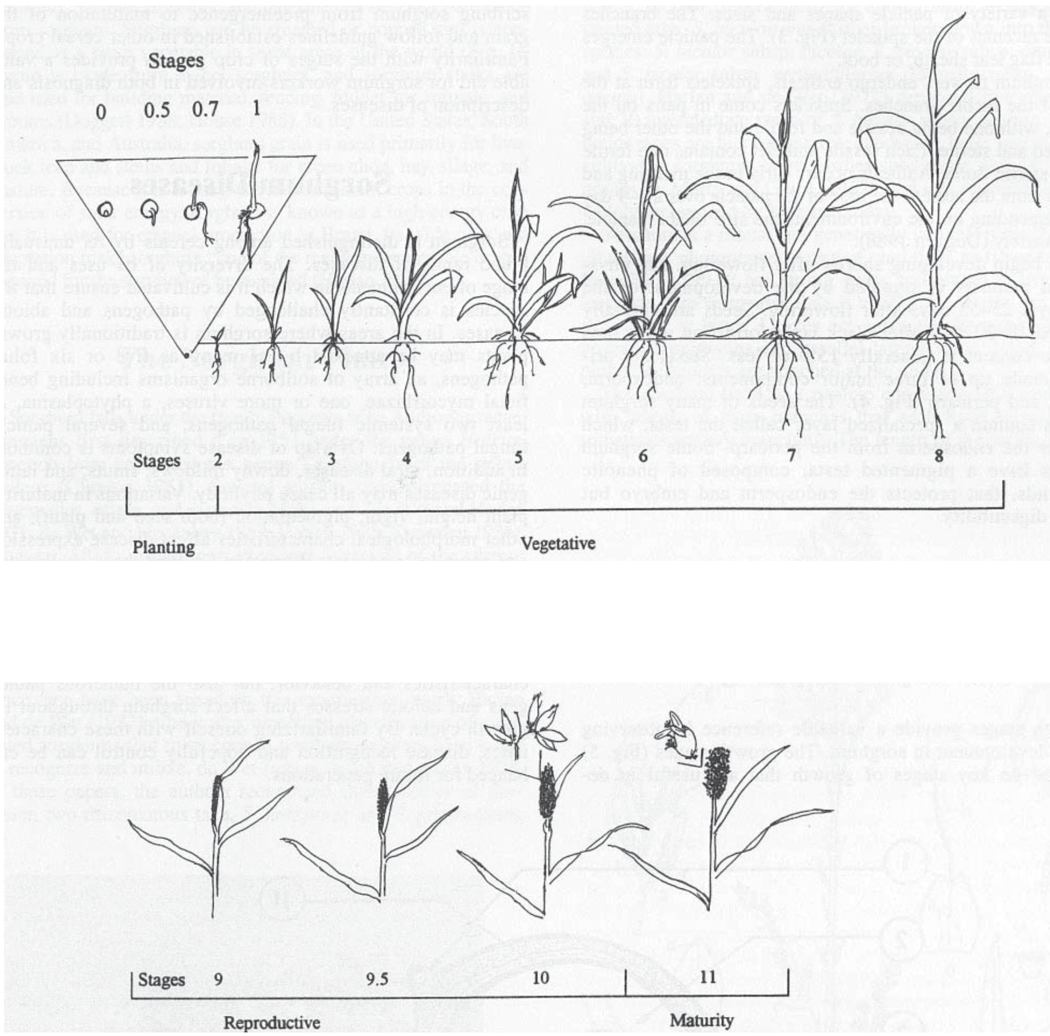

Fig. 1. Stages of sorghum growth: Stage 0: 0.0 planting; 0.1 start of imbibition; 0.5 radicle emergence from seed (caryopsis); 0.7 coleoptile emergence from seed (caryopsis); 0.9 leaf at coleoptile tip; Stage 1: emergence; Stage 2: first leaf visible; Stage 3: third leaf sheath visible; Stage 4: fifth leaf sheath visible; Stage 5: Panicle differentiation and start of tillering; 5.1 main shoot and one tiller; 5.9 main shoot and several tillers; Stage 6: stem elongation (late vegetative stage); Stage 7: flag leaf visible, whorl; Stage 8: booting (end of vegetative stage); Stage 9: panicle just showing, inflorescence emergence; Stage 10: anthesis (50% of panicle flowering); Stage 11: maturity; 11.1 grains at milk stage; 11.2 grains at early dough stage; 11.3 grains at late dough stage; 11.4 grains at physiological maturity (black layer, approximately 30% seed moisture); 11.5 mature grain (seed moisture approximately 15%). (Courtesy K. Cardwell). *For more information see Appendix A, page 65.*

A summary of sorghum growth and development is outlined below including:
•Key growth stages
•In-season management suggestions (fertility, post-emerge herbicide applications, irrigation)
•In-season insect activity, their potential effect on the crop, and scouting timing suggestions

Growth Stages	Description and Management Tips
Emergence	Coleoptile visible at soil surface. Coleoptile is the first leaf and is shorter than the later emerging leaves and has a rounded tip (leaf #1).
3-Leaf	Collar of 3rd leaf is visible (once a leaf's collar forms the leaf no longer expands). This stage occurs ~10 days after emergence, depending on soil temperature, moisture, planting depth, etc. Slow emergence may lead to more injury from pre-emerge herbicides. Insects: Corn leaf aphids may infest the whorl and greenbugs may infest the leaves although not likely.
4-Leaf	Collar of 4th leaf is visible ~15 days after emergence.
5-Leaf	Collar of 5th leaf is visible ~20 days after emergence. May have lost 1st leaf (coleoptile) by this time. Plant ~8-10 inches tall. Cool soil and air temperatures coupled with sunny days to this point may trigger more tillering especially for stands less than 3 plants per row-foot..

Growing point differentiation (GPD)
This key growth stage and its importance largely unrecognized and unappreciated by producers. Occurs 30 to 35 days after emergence perhaps a few days longer for full-season hybrids, and sooner for early maturity hybrids, and generally corresponds with the 7 to 8 leaf stage. Sorghum can tolerate significant stress from drought, hail, and even freezing temperatures prior to this stage; however, stress at this stage can significantly impact yield. Growing point now above the soil surface, and the plant is 12 to 15 inches tall. May have lost 1 to 3 leaves from the bottom of the plant. The sorghum plant is entering a period of rapid growth.

The maximum potential number of spikelets and seeds per spikelet -a major component of maximum yield potential-are determined over a period of 7 to 10 days.

*Managemen*t: When applying midseason nitrogen in one application, ideally the N should be available in the root zone by GPD, and irrigation, if available, is recommended to ensure that the growing point is not subject to moisture stress during GPD. Both good fertility and moisture enhance GPD and the subsequent yield potential. Dryland producers can enhance GPD by applying N early and ensuring that plant population is modest so that each plant has sufficient moisture for good spikelet and seed set.
A note about brace roots, sorghum standability,

and possible cultivation: Brace roots are key to sorghum's standability. If it appears brace roots are having trouble entering the soil (likely more common for sorghum planted on top of beds where the soil is hotter and drier), then cultivation may be needed to move soil around the base of the plant. If this must be done, ensure that any pruning of the expanding root system is minimized after 30 days.

Flag leaf visible

Tip of the flag leaf (last leaf, which will be smaller) is visible in the whorl. The last 3 to 4 leaves may not be fully expanded.
Insect: Greenbug population may begin to rapidly increase.

Boot

Leaf collars of all leaves are now visible. Sorghum head is enclosed in the flag leaf sheath. Potential head size has been determined closer to GPD. Peduncle (stalk supporting the head) is beginning to elongate. Stress at this time will reduce the length of the peduncle.
Management: Maximum water use occurs at this stage. Crop will respond very favorably to irrigation at this stage. Historically, this stage of growth is the optimum time to apply limited irrigation if crop is stressed. If you delay up to 20 percent of N past GPD (i.e., can apply N in small amounts in irrigation water), then final N should be applied within 60 days of planting or mid-boot, whichever comes first.

Insect: Corn leaf aphids begin to decrease. Greenbugs may be approaching an economic threshold.

Heading

50 percent of the plants in the field have visible heads.
Insects: Greenbugs may be at economic threshold levels.

Flowering

Occurs when 50 percent of the plants are in some stage of bloom. {When considering individual plants a plant is considered to be flowering when bloom progresses half way down the head.} Peduncle is rapidly elongating. Flowering occurs over a 4-9 day period. Stress or herbicide drift can lead to blasted heads. Insect: Greenbugs may continue as a problem—mummies may be present. Begin checking for headworms. Sorghum midge potential should be evaluated. For the South Plains and the northern Rolling Plains, sorghum flowering by August 1 will most likely escape significant midge damage potential, but a June 30 flowering is needed in the Concho Valley and lower Rolling Plains to minimize midge potential.

Soft dough

Grain can be easily squeezed between the fingers, and 8 to 12 functional leaves remain. One half of grain dry weight has accumulated. An early freeze will result in shriveled light grain. Suscep-

tible to bird damage.
Insect: Greenbugs may continue as a problem—mummies should be increasing. Continue to check for headworms.

Hard dough

Cannot squeeze grain between the fingers. Three-fourths of grain dry weight has accumulated. Water stress during grain fill may cause lodging.
Insect: Greenbugs and headworms should be on the decline.

Black layer

This stage is identified by the dark spot on the tip of the kernel. Maximum total dry weight has been achieved. Depending on the heat, an individual seed from flower to black layer is typically 30 to 35 days, but could stretch to 40 days or more in prolonged cool fall conditions. Sorghum maturation slows significantly once nighttime temperatures drop below 45°F. Grain is 25 to 35 percent moisture.
Management: If harvest aids are used, label guidelines target application no sooner than black layer and grain moisture less than 30 percent.
{Modified from 'Sorghum development and key growth stages.' Brent Bean, Extension agronomist, and Carl Patrick, Extension entomologist (retired), Texas AgriLife Extension Service, Amarillo.}

What Leaf Stage is My Sorghum At?

Grain sorghum is numbered by the fully sized leaves that have a developed collar. If the seventh leaf (rounded coleoptile leaf is number one) has a collar, even though 2-3 other newer leaves may be visible, the plant is at leaf stage 7. Some herbicide labels cite leaf stage for timing, usually a limitation, of further herbicide applications. The lower leaves may be crumbling and even missing, but by counting back from the last fully formed collar as leaves alternate from one side of the plant to the other one can usually determine leaf stage, at least within one leaf.

Grain Sorghum Yield Components

Sorghum yield is based on three factors: number of heads, head size, which includes the number of seed, and seed size and test weight. Although these factors may compensate for each other, for both irrigated and dryland production the number of seeds per head is the greatest component of yield. This does not mean that having as many seed as possible per acre gives the best yields, rather individual heads that due to fertility and adequate moisture per head (even if there are not a lot of heads), has the best yield potential for the environment.

Tillering is often left out of the discussion on yield potential, and its expression can significantly enhance yield in many instances, but tillering may actually limit yield when drought stress is significant, diminishing the size and yield potential of the primary head. For this reason reduced tillering hybrids have often performed better in West Texas dryland.

Freeze Damage & Hail Injury

Grain sorghum is occasionally hit by a late freeze that may damage leaves, but sorghum likely faces hail damage in the spring and early summer. Early freeze injury often has little effect on sorghum as the growing point remains below the soil surface for several weeks after germination. Early hail-damaged sorghum has surprisingly little loss in yield potential provided the plants remain healthy. For example, a 50 percent leaf removal five weeks after germination (near growing point differentiation) reduces yield potential about 5 percent. Losses are substantially higher for older plants.

For further information on these conditions consult Texas AgriLife Extension's "Assessing Hail and Freeze Damage to Field Corn and Sorghum," B-6014 (http://agrilifebookstore.org, or your county Extension office).

Hybrid Selection

The goal of hybrid selection is to maximize potential yield while optimizing growing season length and available moisture. When selecting grain sorghum hybrids, it is important to choose adapted hybrids that mature before the end of the season. Planting date and water availability will affect hybrid selection. Earlier in the planting period, long season hybrids can be selected, but as the planting season progresses, shorter maturity hybrids should be utilized. If the first season-ending freeze occurs before seed maturation, grain yields and test weights will be lower. Full yield potential is achieved with fully mature seed (Fig. 2).

Grain Sorghum

Seed Mauration and Yield

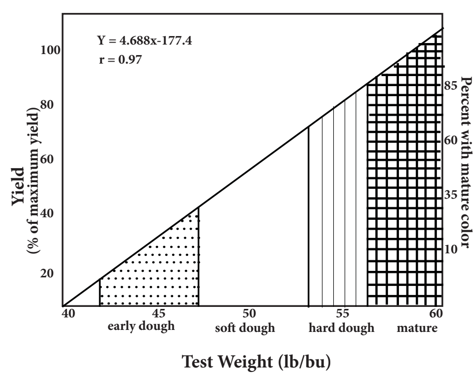

Figure 2: Seed maturation and potential yield of grain sorghum. Data from an early freeze on 20 limited irrigated grain sorghum hybrids at Walsh, Colo. in 1992.

Seeding Density

Typical dryland seeding rates vary greatly from 15,000 to 60,000 seeds per acre. Seeding rates or irrigated land range from 50,000 to 100,000 seeds per acre. Under dryland conditions, the seeding rate should be tied to both planting date and available soil moisture. Use a low seeding rate when soil moisture is limited and a higher seeding rate when soil moisture is plentiful in order to take advantage of higher grain yield potential. In the southern part of the region, lower seeding rates are generally used. A common planting rate is 24,000 seeds per acre (Fig.3). Expect abundant tillering with lower seeding rates. Hybrid selection plays a role in tillering, however, because different hybrids tiller differently. Contact your seed dealer for information on tillering of selected hybrids.

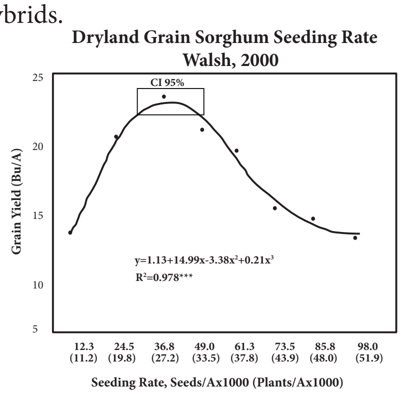

Figure 3: Dryland grain sorghum seeding rate at Walsh. The eight seeding rates tested were 1 to 8 lb per acre at 1lb per acre increments (12,300 seeds per acre to 98,000 seeds per acre at 12,300 seeds pe acre increments).

Seeding Depth

Optimum seeding depth is 1.5 to 1.75 inches deep. Seeding depths greater than two inches may reduce seedling stand and, at the very least, will lengthen the time prior to emergence. Seeding depths less than one inch may result in poor emergence due to drying of the soil surrounding the seed.

Higher seeding rates are recommended for the northern part of the region because of its shorter growing season. In the northwest part of the region, seeding rates of 40,000 seeds per acre and above are frequently used. Also, when seeding rate increases, the percentage of seeds that produce plants decreases. For example, when the seeding rate is 25,400, 66 percent of seeds will produce a plant compared to only 49 percent when 63,500 is planted. Therefore, if seeding rates increase, expect an increase in seedling mortality (Fig. 4).

With higher seeding rates, expect reduced tillering is expected. Single head plants mature earlier and more uniformly than plants with multiple tillers. Tillers will generally mature later and may not mature before the end of the season, which reduces yields and test weights. Time to maturation can be shortened by increasing the seeding rate. For each 10,000 seeds per acre increment, between 20,000 and 70,000 seeds per acre, maturation time is shortened by one day (Fig. 5). A seeding rate of 70,000 seeds per acre matures five days earlier than a seeding rate of 20,000 seeds per acre. This occurs because of reduced tillering. High seeding densities produce more single head plants than lower seeding densities.

Plant Density to Seeding Rate Ratio

Dryland Grain Sorghum, Walsh, 1998

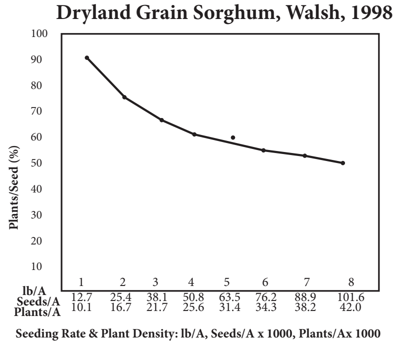

FIgure 4: The eight seeding rates were 1, 2, 3, 4, 5, 6, 7, 8 lb per acre, corresponding to 12,700 to 101,600 seeds per acre at 12,7000 seeds per acre increments.

Dryland Grain Sorghum Seedling Rate and

Days to Seed Maturation, Brandon, CO 2009

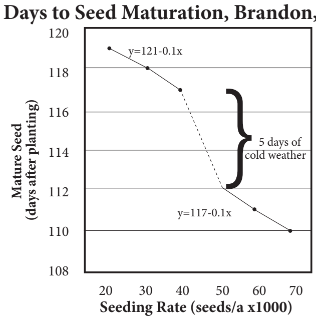

Figure 5: Dryland grain sorghum seeding rate and days to seed maturation at Brandon. The seeding rates were 20, 30, 40, 50, 60, & 70 seeds per acre (x1000), planted June 5, 2009.

Row Spacing

Row spacing also varies throughout the region, but the most common is 30 inches. By managing plant population, producers can utilize the same row spacing for both dry-land and irrigated grain sorghum. In areas with lower precipitation, row spacing has ranged from 40 to 52 inches to accommodate tillage. Utilizing a grain drill for planting grain sorghum is a viable production practice, although seed to soil contact is generally not as good as it is with a planter. In fact, in row spacing studies where seeding rate on a per acre basis is kept constant, narrow row spacing often produced the highest yield, and grain yields decreased linearly with increasing row widths (Fig. 6). Although this yield increase has been observed for narrow row spacing, it is still recommend to use a planter, due to more uniform seed spacing and better seed to soil contact. Also, if any weed problems arise, 30 inch rows allow for sprayers and cultivators to be utilized for post emergent weed control. These weed control options are limited or unavailable for narrow row spacing.

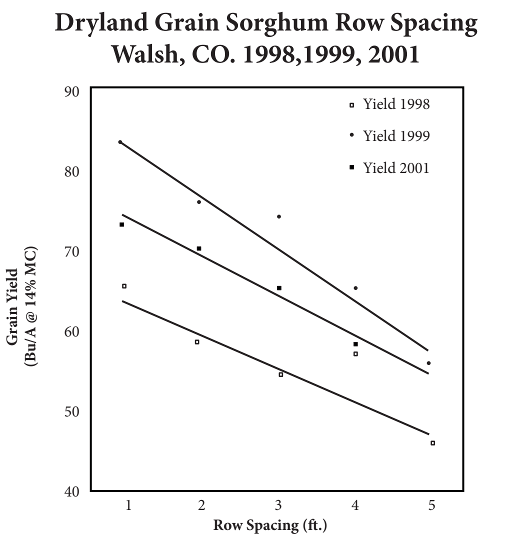

Figure 6: Row spacing on dryland grain sorghum at Walsh, Colo. for 1998, 1999, 2001. The five row spacings tested were: 1, 2, 3, 4 and 5 ft. planted at 40,000 seeds per acre.

Planting

The High Plains region may respond more to no-till production practices than any other region in the country due to climate. The region's annual precipitation is generally 15 to 18 inches per year. However, total annual precipitation does not give the complete picture. The amount of precipitation per event is also generally less than other areas of the U.S. Table 1 shows the relationship between the amount of rainfall and percent of events in Texas County, Okla., from 1948 through 1999. 64 percent of precipitation events were less than 0.25 inches. With the low amount of moisture received per event, it is important to conserve as much water as possible. No-tillage farming helps with this issue by reducing the amount of wind and sun that reaches the soil surface, thus reducing evaporation of soil moisture. Traditionally, the most common tillage practice has been some sort of minimum tillage. Minimum tillage keeps some residue on the soil surface to reduce soil erosion from both water and wind. The more soil is exposed and not covered with residue, the more evaporation will occur. No-till provides the most soil coverage and effectively limits the amount of evaporation. Every time the soil is tilled, some moisture is lost, but some producers utilize tillage for weed control between crops. With newer herbicide chemistry and lower cost of these herbicides, chemical fallow (no-till) has become more common in recent years. Ongoing studies at Tribune, Kan. and Goodwell, Okla., have shown that for grain sorghum production, a no-till system increases grain yield.

In some years, the grain yield for no-till can be double that of minimum tillage. In 2006 and 2007, the Oklahoma Panhandle Research and Extension Center (OPREC) compiled data comparing yields of no-till and minimum till crops. Although higher yields have been obtained with no-till, it is not always the perfect solution. In years when no precipitation is received, no yields

are obtained as shown in 2002.
Increased yields are not immediately seen when first switching to no-till. There is also no reduction in yields for no-till when compared to minimum till (Table 1). It appears that the third time through the rotation, grain sorghum yield for no-till will increase and be significantly higher than that of minimum till. Research from both Kansas State University and Oklahoma State University has shown similar results as shown in Table 1.

In the last decade, strip till has been widely adopted for irrigated corn production throughout the High Plains region. This concept resembles both no-till and minimum till systems and allows anhydrous ammonia (the least expensive nitrogen fertilizer) to be used. In small strip, generally a width of eight inches or less are tilled and fertilizer applied. Strip-till is more like traditional tillage where the residue is removed and the seed is planted into clean soil surface. However, the residue between the strips remains, similar to no-till. For dryland grain sorghum production, strip till could be a good intermediate step for a producer that doesn't want to switch to no-till. Yields for strip till are higher than minimum till, but not as high as no-till. See Table 2.

Table 1. Grain sorghum response to tillage in a WSF rotation, Tribune Kan. 1991-2000

Tillage	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Mean
						bu/ac					
Conventional	23	38	47	20	37	97	71	87	19	13	45
Reduced	39	41	83	38	54	117	94	105	88	37	70
No-till	39	27	68	57	59	119	115	131	99	51	76
$L.S.D._{0.05}$	18	15	11	9	5	12	33	37	10	6	5

Table 2. Yields of grain sorghum (bu/ac) for dry- land tillage and crop rotation study at OPREC.

Tillage	2004	2005	2006	Three-year
No-till	54.8	53.9	73.7	60.8
Strip till	44.2	46.4	51.2	44.6
Minimum till	28.0	38.3	35.6	36.7
Mean	42.3	46.2	53.5	47.4
CV %	6.4	13.6	19.0	20.1
L.S.D.	6.1	NS	24.2	9.9

The timing of strip till is more critical for dryland than for irrigated. Strip till removes the residue in the strip and allows drying of the soil in the seed zone. If adequate precipitation is not received prior to planting, yield will be lower when compared to no-till. In a study at OPREC, timing of strip till was tested against no-till (Table 3). Yields were higher for no-till in two of three years.

As demonstrated in Table 3, it is vital to see minimum till practices through until higher yields are attained. Better yields will result after a four to five year period.

Table 3. Grain sorghum yield (bu/ac) for selected years from a timing of dry-mad strip till experiment at OPRED

Timing	2004	2005	2006	Two-year
No-till	62.5a	81.7a	80.1a	74.8a
September (fall)	47.6b	77.6a	54.1b	59.1b
March (spring)	45.5b	66.9a	56.6b	57.9b
January	42.1b			
November	37.9b			

Nutrient Management

Soil Testing and Recommendations

Grain sorghum is grown over a wide range of growing conditions across the High Plains region. Thus, nutrient management depends on the specific environment in which the crop is grown. This overall production region is characterized by moisture-limited dryland and high-yielding irrigated grain sorghum. The large fibrous root system of grain sorghum is very efficient at utilizing nutrients from the soil, which gives grain sorghum the ability to extract large amounts of residual nutrients and allows it to respond to nutrient application. Because the High Plains commonly incorporates fallow into crop rotation and because grain sorghum is responsive to residual nutrients, accurate soil testing is necessary for economical nutrient and lime application.

Nitrogen

Nitrogen (N) is the most frequently lacking nutrient for optimum sorghum production. Universities and laboratories may differ slightly in how much N is recommended for a particular yield goal. All recommended amounts of N vary with expected yield, crop rotation and residual nitrogen. A soil test for available N deeper in the soil profile is recommended where N or manure applications have been excessive relative to yields. The profile nitrogen soil test is used to potentially reduce the amount of N applied so accumulated available N is utilized. Proper soil sampling is necessary to provide accurate test results. Samples should be taken to a depth of at least two feet from randomly selected locations within a management area. The samples should be air dried and sent to a soil testing laboratory.

Another important consideration is crop rotation. When legumes are grown in rotation with grain sorghum, N credits are substantial and should be factored into N recommendations. However, under no-till conditions, N credits from legumes will be half of what is credited under tillage conditions. During fallow phases, N is mineralized so available N increases and recommendations should decrease. Table 4 shows the adjustments for crops preceding grain sorghum.

Table 4. Previous crop adjustment for nitrogen rate recommendation for grain sorghum.

Preceding Crop	N adjustment (lb N/A)
Corn, Wheat, Sorghum, Sunflower	0
Soybean	-40
Fallow (without soil test)	-20
(with soil test)	0

Nitrogen recommendations can be calculated with the equations in Table 5. Calculated rates at different yield levels are shown in Tables 6-7 for each state in the High Plains region.

Table 5. Grain Sorghum nitrogen recommendations listed by state.

State	N Recommendation
Kansas and Colorado	(Yield Goal in bushels x 1.6) - (%organic matter x 20) - Profile N - Manure N - Other Adjustments + Previous Crop Adjustments
Texas	(Yield Goal in 100lb x 2) - Profile N
Oklahoma	(Yield Goal in bushels x Yield Goal in bushels x 0.0044) + (Yield Goal in bushels x 0.7501) - 2.73

Yield Goal	1.0	1.5	2.0	2.5	3.0
(bu/A)		lb N/A			
40	14	4	0	0	0
80	78	68	58	48	38
120	142	132	122	112	102
160	206	196	186	176	166
200	270	260	250	240	230

Table 6. Fertilizer requirements at various yield and soil organic matter levels assuming 30 lb N per acre residual soil profile (based on Kan. and Colo. recommendations.

Yield Goal (bu/A)	lb N/A
40	45
80	90
120	135
160	180
200	225

Table 7. Fertilizer requiements at various yield and soil organic matter levels assuming 30 lb N per acre residual soil profile (based on Texas recommendations).

Field comparisons of N sources are currently being conducted to evaluate their relative effectiveness as an N fertilizer. For no-till or reduced till systems that leave almost a complete surface residue cover, materials containing urea should be injected below the residue to minimize volatilization and immobilization losses. Source selection should be based on cost (applied), availability, adaptability to farm operation and dealer services. 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 to 70 percent of the total N has been taken into the plant.

Nitrogen applications should be timed so N is available when needed for this rapid growth. Preplant N applications can be made in late fall or spring (except on sandy soils) with little concern for leaching loss. On sandy soils, preplant N applications should be delayed until spring, sidedressed or split with part in the spring and part sidedressed. If N is applied sidedress, the applications should be made shortly after the five-leaf stage (five visible leaf collars).

Phosphorus

Grain sorghum typically responds to phosphorus (P) when soils test low in available P. When P levels are between low and adequate, responses may be erratic or very small. However, P applications under these conditions are recommended to maintain productive soil fertility and keep the yield potential high.

Phosphorus requirements should be based on a soil test. The sample should be taken to a depth of six inches and should represent a given management area of the field. After a representative sample is taken, it should be submitted to a soil testing laboratory. Some laboratories have a variety of soil P extractants including Mehlich 3, Bray Olson. These are all very good extractants that may be used in the High Plains region. However, care should be taken to ensure that the appropriate recommendation equations are used for the correct extractants. The equations used in this chapter are correct for both Mehlich 3 and Bray P1. Phosphorus recommendations can be calculated with the following equation (Equation 1) and calculated rates at different yield levels are shown in Table 8.

Equation 1:

$$\underset{\textbf{(lb } \mathbf{P_2O_5}\textbf{/A)}}{\text{Phosphorous required}} = [50 + (0.16 \times \text{Yield Goal}) + (\text{ppm P} \times -2.5) + (\text{Yield Goal} \times \text{ppm P} \times -0.008)]$$

Table 8: Phosphorous recommendations for grain sorghum in Kansas and Colorado.

Bray P1 or Mehlich 3	40	80	120	160	200
(ppm)			(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

Table 9. Phosphorus recommendations for grain sorghum in the Texas Panhandle

Yield Goal, bu/A(lb/A) Ω

Mehlich 3	40(2,254)	80(4,480)	120(6,720)	160(8,960)	200(11,200)
ppm			Lb P_2O_5/A		
0-5 very low	35-40	65-70	80	80	80
5-10 very low	30-35	60-65	80	80	80
10-15 low	25-30	50-60	80	80	80
15-20 low	20-25	45-50	70-80	80	80
20-25 modearte	15-20	35-45	60-70	80	80
25-30 moderate	15-20	30-35	45-60	60-80	80
30-35 mod. high		20-30	35-45	45-60	60
35-40 mod. high			20-35	30-45	50
40-45 mod. high				15-30	30

Ω P205 rates are capped at 80 lbs. In severly depleted P soils, yield could potentially respond at higher rates of P. VIsit with your Extension agronomist under severely depleted soil P conditions where a high yield goal is deired.

± West Texas soil research suggests that 30-40 ppm soil test P is a "transition level" at which yield responses to additional fertilizer P are inconsistent.

∗ West Texas soil research suggests P fertilizer additions at this level of soil test P does not demonstrate measurable yield difference.

Table 10. Phosphorous recommendations for grain sorghum in Oklahoma.

Mehlich 3 (ppm)	Percent Sufficiency	lb P_2O_5/A
0	40	60
5	60	50
10	80	40
20	95	20
32+	100	0

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 small amounts are applied on acidic soils low in available P. 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 pounds of N plus K per acre. The N and K can cause germination damage with their high salt index. No urea or ammonium thiosulfate should be placed in direct seed contact.

Potassium

Potassium (K) deficiencies are also best determined through soil testing. Typically, the areas of the High Plains (Western Kansas, Eastern Colorado, Oklahoma panhandle and Texas panhandle) are relatively high in K. However, some areas may still be deficient.

Most soil testing labs offer the ammonium acetate extractant for K determination. This extractant is very old, but works very well. Like K, soil samples should be taken to a depth of six inches. K should be applied preplant-broadcast, preplant-knifed or banded at seeding. Broadcast applications should be thoroughly incorporated to get the K in the root zone. The most common K source is muriate of potash (potassium chloride); however, potassium sulfate, potassium nitrate, potassium-magnesium sulfate, and mixed fertilizers are good K sources. K recommendations can be calculated with the following equation (Equation 2), and calculated rates at different yield levels are shown in Table 11:

Equation 2:

$$\text{Potassium required (lb } K_2O\text{/A)} = [80 + (0.17 \times \text{Yield Goal}) + (\text{ppm K} \times -0.616) + (\text{Yield Goal} \times \text{ppm K} \times -0.0013)]$$

Table 11. Potassium recommendations for grain sorghum.

	Yield Goal (bu/A)				
Exch. K	40	80	120	160	200
(ppm)			lb K_2O/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

Liming

As with other crops, pH affects the availability of soil nutrients. Typically, the High Plains region hasmore high pH problems than low pH problems, but there are a few problematic low pH areas in this region. Although grain sorghum is not very responsive to lime, it is very important to maintain adequate pH for other crops in rotations. Lime is recommended when the soil pH is less than 5.5. Soil samples for lime application should be taken to a depth of six inches over a representative area. It is important to note that the soil pH is an indicator that lime is needed, but the buffer pH is used to determine how much is needed. Buffer solutions may change between labs, so check that the correct recommendation data is used for the correct buffer solution.

Secondary and Micronutrients

Grain sorghum will respond to zinc (Zn) fertilization in some situations, what can be reliably predicted with a soil test. The areas most likely affected by Zn deficiency include highly productive fields where the topsoil has been removed or eroded with low organic matter and high pH. Zinc soil samples are taken to a depth of six inches and are commonly analyzed with a DTPA (diethylenetriaminepentacetic acid) extractant. Zinc recommendations can be calculated with the following equation.

Equation 3:

Zinc Required (lb/ac) = 11.5 - (11.25 x ppm DTPA Zn)

If the soil analysis shows that Zn concentration is greater than one part per million no Zn is needed. Zinc is typically applied with P and K at or before planting. The most effective application of Zn is to band it very close to the seed. The sources of Zn are organic chelates and inorganic sources. The chelates are about three to five times more effective per pound than the inorganic sources. Photo 1* illustrates zinc deficiency symptoms. Note the stunted plant with yellowing at the whorl and intervienal striping. Shortened internodes are also characteristic of Zn deficiency.

Similar to Zn, iron (Fe) deficiencies are common on leveled or eroded soils where the topsoil has been removed and organic matter is low. In these situations, highly calcareous soils are exposed, which have a very high pH. Iron soil analysis is identical to Zn, except the calibration data for Fe application based on DTPA extractable Fe is poor. This analysis does not work well on acid soils and has limited use on calcareous soils. Often, the easiest way to diagnose problem areas is to note the yellow to white leaf color that first appears on the younger leaves that will continue to an intervienal chlorosis (Photo 2*). Currently, there are no economical sources of soil applied Fe available. Therefore, the only options for correcting Fe deficiencies are to apply foliar Fe sprays or to apply manure.

** Photos located in Appendices.*

Sulfur (S) deficiencies typically occur with low organic matter (less than 1.5 percent). Since S is mobile in the soil, a deep sample (two feet) should be taken to get a measure of S in the soil. Soil testing labs analyze S with a calcium phosphate extract, but the crop response data is variable. Therefore, S deficient areas should have organic matter analysis to complement the S analysis. A large amount of S comes from organic matter, and credit should be given for organic matter content (organic matter contribution lb S = 2.5 × % OM). Irrigation water is another way S is applied and should be considered when implementing application rates. Sulfur recommendations can be calculated with the following equation (Equation 4):

Equation 4:

$$\text{Sulfur Required (lb/A)} = (0.2 \times \text{Yield Goal}) - (2.5 \times \text{OM}) - \text{Profile Sulfur} - \text{Other Credits}$$

Nutrient Management with Remote Sensing

Remote sensor technology is rapidly improving and has recently been adapted for N management in grain sorghum. The development and improvement of data required for specific nitrogen recommendation is ongoing. Thus, quoting specific equations is not the objective of this chapter. Rather, this chapter is intended to provide the background information for using remote sensors and directions to find the most recent algorithms for this technology.

Remote sensor devices emit light at specific

wavelengths that relate to plant functions. For example, dark green plants absorb more red light than light green or yellow plants. In this way, sensor devices can emit light and detect the amount of light reflected back to the sensor. The difference in light transmitted and reflected relays information regarding the health of the plant. Many of these sensors utilize more than one wavelength of light to collect data on biomass and plant greenness. The data they record is NDVI (normalized difference vegetation index), and is a unitless number between zero and one.

Thus far, the nutrient management work that has been conducted with these sensors has focused on N management. To utilize the technology in the field, a producer must first be willing to only apply a modest rate of pre-plant N to the field. In a marked area, an N strip (higher rate than the rest of the field) should be applied that will not limit growth and productivity of the crop. That strip is termed the N reference strip. During the growing season (about 30 to 40 days after planting), the sensors are used to collect NDVI on the reference strip and the area that only had the pre-plant rate applied. The NDVI on the reference strip gives an estimate of the yield potential of the crop with N fertilization. Using the reference strip and the pre-plant-only area of the field, the sensor will give an indication of the crop's responsiveness of the crop to added N. At the same time, the sensor is using the NDVI in conjunction with the number of days from planting to the sensing date to determine how much growth has occurred since the crop was planted. This data is compared with experimental data that relates the biomass produced since planting to potential grain production at the end of the growing season. The yield potential number generated is back-calculated to the amount of N needed to achieve that yield. Typically, the components needed include: reference strip, modest N rate over all the field, NDVI data on both areas, date of planting and sensing, and an estimate of the yield potential of the field.

Recognize the above description is very vague, as there are different approaches to the use of this data that get more specific than needed for this chapter. Specific data for the High Plains region can be collected through nutrient management extension programs at various universities. Details to this program and online calculators to generate N rate recommendations can be collected at :
http://nue.okstate.edu/ or
http://www.agronomy.ksu.edu/DesktopDefault.aspx?tabid=379.

Most of these sensors have the flexibility to be held by an operator walking through the field or mounted on a sprayer that can sense and apply N on the go through the field. The benefits of the technology ranges from getting the correct rate applied over the whole field with a hand-held sensor to adjusting rates to treat variable spots in the field to get the right rate on the right spot.

Weed Control

Weeds compete with grain sorghum for light, nutrient and water, thus reducing yield and grain quality. In addition, they harbor insects and diseases that further negatively impact yield and increase costs. Effective sorghum weed control begins with identifying problem weeds in a given field and developing a control strategy. If there is any doubt about the potential impact of a particular weed, take it to your county agent or extension specialist for identification. Implement control strategies to first control the weeds that most affect yield.

Weed control in sorghum must begin in the months and days prior to planting. Weeds left uncontrolled during a fallow period will use up valuable soil moisture that could otherwise be used by the sorghum crop. Control these weeds either by tillage or with herbicide application. The use of soil residual herbicides like atrazine can be particularly valuable prior to planting. They reduce tillage and herbicide applications that might otherwise be necessary to control multiple flushes of weeds. However, make certain that any soil residual herbicide used is safe for planting sorghum.

The yield loss associated with sorghum due to weed competition is greater than most other grain crops. Typical losses range from 30 to 50 percent, but complete crop failure can result in extreme cases. In the Southern High Plains, pigweed species and kochia are cited most often as the weeds that infest the largest number of sorghum acres. Studies have shown that even one pigweed within 24 inches of grain sorghum can reduce yield nearly 40 percent. Kochia can be even more competitive than pigweed using one inch of soil moisture by the time it reaches six inches in height. One inch of soil moisture can be worth nine bu per acre shels of grain sorghum yield. Annual grasses generally do not reduce yield as much as broadleaf weeds, but are more difficult to control. Yield loss will be the greatest when weeds emerge with the crop or soon after. The most critical period for weed control is the first four weeks after planting. If weeds are controlled during this time and control is maintained through the remainder of the season, little reduction in grain sorghum yield will occur. Yield reduction from weeds that emerge four weeks after planting is usually minimal.

Broadleaf Weed Control

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 relatively inexpensive and will control most broadleaf weeds. 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. The safest way to use atrazine is to apply the herbicide soon after the crop has emerged but before it reaches 12 inches in height. To control emerged weeds, atrazine should always be applied with crop oil. The smaller the weeds, the better the control will be. If atrazine cannot be used or is ineffective on the weeds present, other herbicides should be considered.

Other commonly used herbicides applied prior to sorghum and weed emergence are propazine, metolachlor, alachlor and dimethenamid (Table 12). These are sold under a host of trade names. Propazine is very effective on many broadleaf weeds and is safer on the sorghum crop than atrazine. The other three herbicides are more specific on which broadleaf weeds they will control and generally do not control the weeds for as long a period of time. Combining atrazine with any of the three improves overall control of broadleaf weeds.

Table 12. Popular pre-emergent herbicides by active ingredient name (common trade names).

Atrazine (AAtrex, atrazine) **Propazine** (Milo-Pro)	Primarily broadleaf weed control. Long residual.
Metolachlor or S-metolachlor (Dual II Magnum, Cinch, Parallel, Me-Too-lachlor) **Dimethenamid** (Outlook) **Alachlor** (Micro-Tech)	Good annual grass control with some broadleaf activity. Must use Concept II treated sorghum seed.
Atrazine + Metolachlor (Bicep II Magnum, Cinch ATZ) **Atrazine + dimethenamid** (Guardsman Max. G-Max Lite) **Atrazine + alachlor** (Bullet, Lariat)	Broadleaf weed and grass control. Must use Concept I treated sorghum seed.
Others	See state and local Extension service recommendations for other pre emergent herbicides.

Herbicides commonly used after crop and weed emergence are listed in Table 13 , along with a brief description of their strengths and weaknesses. Check labels for rates, application timing and other restrictions, as herbicides can often be used in combination with each other. 2,4-D and dicamba have been used for decades for broadleaf weed control. However, these must be applied correctly, or severe crop injury can occur. These should only be applied to sorghum that has not exceeded eight inches in height. Drop nozzles that keep the herbicides out of the whorl of the sorghum can be used on up to 15 inch sorghum. Care should be taken to minimize drift of 2,4-D and dicamba, or damage to other broadleaf crops and ornamentals can occur.

Table 13. Popular broadleaf post emergent herbicides by active ingredient name (common trade names).

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, others)	Will control most broadleaf weeds, crop injury can be significant and drift to cotton fields is a concern.
Dicamba (Banvel, Clarity, Vision)	Will control most broadleaf weeds, crop injury can be significant and drift to cotton 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, morningglory, and devilsclaw.
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.
Others	See state and local Extension service recommendations for other post emergent herbicides.

Grass Control

There are no effective herbicides in grain sorghum that can be used after crop and grass have emerged. Either metolachlor (Dual, Cinch, Parallel, Me-Too-lachlor), alachlor (Micro-Tech) or dimethenamid (Outlook) must be applied prior to crop and weed emergence. The sorghum seed must be treated with a herbicide seed safener (Concept II) or crop injury will occur. The effectiveness of controlling annual grasses will depend greatly on the particular grass species; however, three effective products are currently available for annual grass control. These three products are often sold in combination with atrazine. All herbicides applied pre-emergence require a minimum of 0.5 inches of rain or irrigation to move them into the soil. An alternative to rain or irrigation is to incorporate the herbicides with a rolling cultivator prior to grass emergence. However, care must be taken to avoid damaging the sorghum.

Perennial Weeds

Johnsongrass and bindweed are the two perennial weeds that cause the most problems in sorghum, as with both weeds have the potential to completely eliminate any significant grain sorghum 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 and dicamba, diligently spot treat with glyphosate (Roundup) , 2,4-D, glyphosate, and even some soil sterilants for bindweed. 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 about six inches of growth, treat it 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 four 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 2,4-D or dicamba should be considered for bindweed control. Another herbicide, quinclorac (Paramount), can be used alone or in combination with 2,4-D or dicamba. Quinclorac is safe on sorghum and can be very effective.

New Advances

Some very promising new herbicides for both broadleaf and grass control will soon be on the market. Continue to check with herbicide dealers and the Extension service for information about new products. New grain sorghum hybrids will be available in the next five years that are tolerant of two classes of herbicides, giving

producers many more herbicide options. For the first time, producers will be able to control Johnsongrass as well as annual grasses (including shattercane) with herbicides applied after the sorghum and grass have emerged.

Other Information

Herbicide labels are constantly updated. Before using any herbicide check the label for use under your specific conditions. Most state extension services provide updated herbicide lists and specific weed control recommendations.

Insect Management

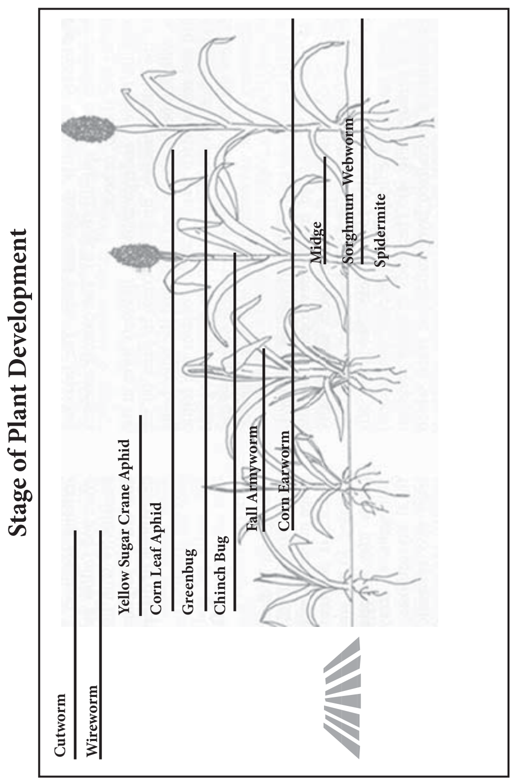

Fig. 7. consists of data compiled by the University of Arkansas Extension service which outlines the time-frame (shown in darkened line) when common insect pests are more likely to occur during the sorghum growing season.

A number of insects can attack sorghum during the growing season in the mid-South. The most common insects found at planting are cutworm, wireworm and grubs. Midseason and late season insects commonly found include greenbugs and other aphids, sorghum midge, flea beetles, grasshoppers, fall armyworm, corn earworm, sorghum webworm and spider mites. The extent of damage by insects to grain sorghum is often related to the planting date. The greenbug is more common in early planted sorghum, while the sorghum midge, corn earworm, fall armyworm and sorghum webworm are more severe in late-planted sorghum.

Seed insecticide treatments such as clothianidin (Poncho®), thiamethoxam (Cruiser®) and imidicloprid (Gaucho®) are fairly new for use in sorghum and have good efficacy on many below ground soil pests and early seedling pests of sorghum such as flea beetle, chinch bug or stink bug. Many granular insecticide products used for control of rootworm in corn can be used in grain sorghum. A number of foliar insecticides provide excellent control of sorghum leaf and grain pests.

Basic identification and threshold information is included below for some of the most trouble-some insect pests in grain sorghum. Refer to the extension publication in your state for specific treatment recommendations for these insects as control options may vary by state. In Kentucky, refer to ENT-24: Insecticide recommendations for grain sorghum (milo) and IPM-5: Kentucky IPM manual for grain sorghum. In Tennessee, use PB1768 2009 Insect Control Recommendations for Field Crops. In Illinois, refer to IAPM-09 2009 Illinois Agricultural Pest Management Handbook.

Greenbug (Photo 3)* The greenbug is a small, light green aphid with a dark stripe down its back, usually found on the underside of leaves. Early planted sorghum is more likely to be infested by this pest. Reproductive potential is very high compared to other aphids. The greenbug injects a toxic substance in its saliva that causes red spots on leaves where it feeds. Treatment for greenbug is suggested to begin once there are one or two greenbugs on the majority of the plants in the seedling stage and when leaves show damage, or when one or more leaves are dying on larger sorghum plants.

Corn leaf aphid (Photo 4)* The corn leaf aphid has a bluish-green body about 1/16th inch long with black cornicles (tailpipes at the end of the abdomen), legs and antennae. Corn leaf aphids are usually found in sorghum whorls. Corn leaf aphids can transmit viral diseases from weeds like Johnsongrass, but sorghum can tolerate large numbers of these aphids. Treatment is not usually necessary for the corn leaf aphid. Corn leaf aphid populations early in the year can help attract

*Photos found in Appendix B, page 87

beneficial insects to combat other pests later in the growing season.

Yellow sugarcane aphid (Photo 5)* Adults and nymphs are bright yellow to light green in color with two double rows of darker spots down the top of the abdomen. Feeding on sorghum causes reddening of leaves and may transmit viral diseases. This aphid feeds on the underside of sorghum leaves in mid to late season, and can reach numbers large enough to require treatment. Treat when one or two aphids are found on most seedling plants and damage is visible or when one or more leaves show severe damage on larger plants.

Corn earworm (Photo 6)* The corn earworm larva has alternating light and dark strips down its body. The color varies from green to pink. The head capsule is a creamy-yellow. Larvae feed on whorl tissue of young sorghum plants and on developing grain in maturing plants. Full-grown larvae are about 1$^1/_2$inches long and feed on grain heads. Treatments should be applied when two or more small larvae or one large (greater than $^1/_2$ inch) larva is found per head.

Fall armyworm (Photo 7)* Fall armyworm larvae have a dark head capsule and a prominent inverted Y on the front of the head. Body color is green to brown with brown to black strips on the sides of the body. Check whorls of young, late-planted sorghum and inside grain heads of more mature plants for tall armyworms. Treat when an average of two or more small larvae or one large (greater than 1/2 inch) larva is found per head.

Sorghum webworm (Photo 8)* These are small, greenish, hairy caterpillars with four reddish brown stripes down the back. Full-grown larvae are about 1/2 inch long and are usually associated with sticky webbing in the area of their feeding. Check inside grain heads for worms and on leaves under grain heads for white fecal droppings. Treat when an average of three to four or more larvae are found on a grain head.

Sorghum midge (Photo 9)*

The sorghum midge is one of the most damaging insects to sorghum. The adult sorghum midge is a small, fragile-looking, orange-red fly with a yellow head, brown antennae and legs, and gray, membranous wings.

During a single day of adult life, each female lays about 50 yellowish-white eggs in flowering spikelets of sorghum. Eggs hatch in two to three days. Larvae are colorless at first but are dark orange when fully grown. Larvae complete development in nine to 11 days and pupate between the spikelet glumes. Shortly before adult emergence, the pupa works their way toward the upper tip of the spikelet. After the adult emerges, the clear or white pupal skin remains at the tip of the spikelet.

*Photos found in Appendix B, page 87

A generation is completed in 14 to 16 days under favorable conditions. Sorghum midge numbers increase rapidly because of multiple generations forming during a season. Midge numbers also increase when sorghum flowering times are extended by a range of planting dates or sorghum maturities. Sorghum midges over winter as larvae in cocoons in spikelets of sorghum or Johnsongrass. Johnsongrass spikelets containing diapausing larvae fall to the ground and become covered with litter. When sorghum is shredded, spikelets containing larvae fall to the ground and are disked into the soil. Sorghum midges emerging in spring do so before flowering sorghum is available, and these adult midges infest johnsongrass. Sorghum midges developing in johnsongrass disperse to fields of sorghum when it flowers. Early-season infestations in sorghum are usually below damaging levels. As the season progresses, sorghum midge abundance increases, especially when flowering sorghum is available in the area. Numbers often drop late in the season.

A sorghum midge damages sorghum when the larva feeds on a newly fertilized ovary, preventing normal kernel development. Grain loss can be extremely high. Glumes of a sorghum midge-infested spikelet fit tightly together because no kernel develops. Typically, a sorghum grain head infested by sorghum midge has various proportions of normal kernels scattered among non-kernel-bearing spikelets, depending on the degree of damage.

Effective control of sorghum midge requires the integration of several practices that reduce sorghum midge abundance and their potential to cause crop damage. The most effective cultural management method for avoiding damage is early, uniform planting of sorghum in an area so flowering occurs before sorghum midges reach damaging levels. Planting hybrids of uniform maturity early enough to avoid late flowering of grain heads is extremely important. This practice allows sorghum to complete flowering before sorghum midges increase to damaging levels. Cultural practices that promote uniform heading and flowering in a field are also important in deciding on treatment and in achieving acceptable levels of insecticidal control. To reduce sorghum midge abundance, use cultivation and/or herbicides to eliminate johnsongrass inside and outside the field. Where practical, disk and deep plow the previous year's sorghum crop to destroy overwintering sorghum midges.

Multiple insecticide applications are used to kill adults before they lay eggs. Sorghum that is planted and flowers late is especially vulnerable to sorghum midge. Evaluate crop development, yield potential and sorghum midge abundance daily during sorghum flowering to determine whether insecticides are needed. Because sorghum midges lay eggs in flowering sorghum grain heads (yellow anthers exposed on individual spikelets), they can cause damage until

the entire grain head or field of sorghum has flowered. The period of susceptibility to sorghum midge may last from seven to nine days (individual grain head) to two to three weeks (individual field), depending on the uniformity of flowering. To determine if adult sorghum midges are in a sorghum field, check at mid-morning when the temperature warms to approximately 85° F. Sorghum midge adults on flowering sorghum grain heads are most abundant at that time. Because adult sorghum midges live less than one day, each day a new brood of adults emerges. Sampling must be done almost daily during the time sorghum grain heads are flowering. Sorghum midge adults can be seen crawling on or flying about flowering sorghum grain heads.

The most simple and most efficient way to detect and count sorghum midges is to inspect carefully and at close range all sides of randomly selected flowering grain heads. Handle grain heads carefully during inspection to avoid disturbing adult sorghum midges. Other sampling methods can be used, such as placing a clear plastic bag or jar over the sorghum grain head to trap adults.

Because they are relatively weak fliers and rely on wind currents to aid their dispersal, adult sorghum midges are usually are most abundant along edges of sorghum fields. For this reason, inspect plants along field borders first, particularly those downwind of earlier flowering sorghum or johnsongrass. If no or few sorghum

midges are found on sorghum grain heads along field edges, there should be little need to sample the entire field.
However, if you find more than one sorghum midge per flowering grain head in border areas of a sorghum field, inspect the rest of the field. Sample at least 20 flowering grain heads for every 20 acres in a field. For fields smaller than 20 acres, sample 40 flowering grain heads. Flowering heads are those with yellow blooms. Avoid plants within 150 feet of field borders. Record the number of sorghum midges for each flowering head sampled and then calculate the average number of midges per flowering head. Almost all of the sorghum midges seen on flowering sorghum heads are female.

Next, calculate the number of flowering heads (yellow blooms present) per acre. Record the number of flowering heads along a length of row equal to 1/1000 of an acre. As an example, for a row spacing of 40 inches, 13.1 row feet is equal to 1/1000 of an acre. Make counts in at least four areas of the field. If flowering (plant maturity) is highly variable across the field, additional sites should be sampled. Average all counts and multiply by 1000 to estimate the number of flowering heads per acre. If there is only one head per plant, then the number of flowering heads per acre is equal to the percent heads in bloom multiplied by the number of plants per acre.

Sorghum midge density per acre is then calculated as the mean number of midges per flowering head times the number of flowering heads per acre. For example, if there are 30,000 flowering heads per acre and scouting records show an average of 0.5 sorghum midge per flowering head, then there are an estimated 15,000 sorghum midges per acre (0.5 sorghum midge per head x 30,000 flowering heads per acre). The percentage of flowering heads changes rapidly during bloom and should be determined each time the field is sampled. Studies have shown that the larvae from a single female sorghum midge will destroy an average of 45 grain sorghum kernels. The seed weight of sorghum hybrids averages 15,000 seeds per pound (range of 12,000 to 18,000, depending on the hybrid). A loss of 45 kernels per midge, therefore, represents 0.0030 pounds (1.364 grams) of grain.

Equation 5:

$$\text{Number of sorghum midges per flowering head} = \frac{(\text{Cost of control as \$ per acre}) \times 33{,}256}{(\text{Value of grain as \$ per cwt}) \times (\text{Number of flowering heads})}$$

In the equation above, the control cost is the total cost of applying an insecticide for sorghum midge control and the grain value is the expected price at harvest as dollars per 100 pounds. The value 33,256 is a constant and results from solving the economic injury equation. The number of flowering heads per acre is determined as described above.

For example, assume field scouting yields an average of 1.1 sorghum midges per flowering head and field sampling shows the number of flowering heads is 18,000 per acre. (This is equal to a plant population of 90,000 with 20 percent of the heads flowering and one head per plant.) If the value of the crop is estimated to be $4.00 per 100 pounds and the cost of control is $5.00 per acre, Equation 6 yields the injury level as:

Equation 6:

$$\frac{\$5 \times 33{,}256}{\$4 \times 18{,}000} = 2.3 \text{ sorghum midges per flowering head}$$

In this example, the field density of 1.1 sorghum midges per flowering head is below the injury level and treatment would not be justified. If the field is scouted two days later and the sorghum midge density is again 1.1 midges per flowering head, but now the number of flowering heads has increased to 45,000 per acre (50 percent of the plants now have a flowering grain head in a plant density of 90,000 per acre and one head per plant), the injury level is will be:

Equation 7:

$$\frac{\$5 \times 33{,}256}{\$4 \times 45{,}000} = 0.9 \text{ sorghum midges per flowering head}$$

In this example, the field density of 1.1 sorghum midges is now above the economic injury level of 0.9 per flowering head and treatment would be justified. This shows the importance of considering the number of flowering heads (grain susceptible to midge damage) in estimating the economic injury level.

Economic injury levels, as determined from the above equation, are shown in Table 14 for a range of typical treatment costs per acre, market values per 100 pounds of grain and numbers of flowering heads per acre. Use the equation for estimating injury levels for your actual control costs, crop value and number of flowering heads per acre.

Table 14. Estimated economic injury levels for sorghum midge for a range of factors. (This table is only a guide. Use the equation in the text to estimate the economic injury level in your field.)

Economic injury level - mean number of midges/flowering head

Control costs, $/acre	**Crop value, $100 lbs**	**Flowering heads = 18,000/acre**	**Flowering heads = 455,000/acre**	**Flowering heads = 67,500/acre**
5	6	1.6	0.6	0.4
5	7	1.3	0.5	0.34
5	8	1.2	0.5	0.3
6	6	1.9	0.8	0.5
6	7	1.6	0.7	0.4
6	8	1.4	0.6	0.35
7	6	2.2	0.85	0.6
7	7	1.9	0.75	0.5
7	8	1.6	0.65	0.45

Insecticide residues should effectively suppress sorghum midge egg laying one to two days after treatment. However, if adults still are present three to five days after the first application of insecticide, immediately apply a second insecticide treatment. Several insecticide applications at three-day intervals may be justified if yield potential is high and sorghum midges exceed the economic injury level (Table 15).

Table 15. Suggested insecticides for controlling sorghum midge

Insecticide	Application Rate	Days from last application to: Harvest	Graze
Chlorpyrifos (Lorsban® 4E)	8 oz	30	30
Cyfluthrin (Baythroid® 2E)	1.0-1.3 oz		14, See remarks
Cyhalothrin			See remarks
(Karate® 1E) (Warrior® 1E)	1.92-2.56 oz		
Esfenvalerate (Asana® XL)	2.95-5.8 fl oz	21	-
Malathion (Fyanon® ULV)	8-12 oz	7	7
Methomyl (Lannate®) (2.4LV), (90WSP)	12-24 oz 4-8 oz	14 14	14 14
Zeta-cypermethrin (Mustang Max®)	1.28-4.0 fl oz	14	45

Table 15 Remarks

Cyfluthrin - If one or two applications are made, green forage may be fed or grazed on the day of treatment. If three applications are made, allow at least 14 days between last application and grazing

Cyhalothrin - Do not graze livestock in treated area or harvest for fodeder, silage or hay.

DISEASES

The following diseases with descriptions are from PPA-10a "Kentucky Plant Disease Management Guide for Corn and Sorghum"

Disease:	**Stalk Rot**
Cause:	Macrophomina phaseolina (Charcoal Rot), Colletotrichum graminicola (Stalk Red Rot/Anthracnose)
Symptoms:	Stalk is spongy, and internal tissue (pith) is shredded and often discolored. Plants sometimes turn grayish-green after jointing.
Key Features of Disease Cycle:	Fungi survive on crop residue. High plant population, high nitrogen and low potash can aggravate the diseases. Charcoal Rot is prevalent in hot, dry weather. Stalk Red Rot is prevalent during warm weather with alternating wet and dry periods.
Management:	Use hybrids resistant to Stalk Red Rot and tolerant to Charcoal Rot. Avoid excessive plant populations. Maintain proper soil fertility. Rotate away from sorghum for two or more years following a severe outbreak of either disease. Avoid soybeans and corn for two or more years following severe outbreaks of Charcoal Rot. Azoxystrobin is labeled for management of C. graminicola and Charcoal Rot.

Disease:	Head Smut
Cause:	Sporisorium reilianum (syns. Sphacelotheca reiliana)
Symptoms:	At heading, large galls occur in place of the head. Head turns into mass of dark brown, powdery spores.
Key Features of Disease Cycle:	Infection occurs in seedlings from spores in the soil.
Management:	Use resistant hybrids.

Disease:	Leaf spots & blights
Cause:	Setosphaeria, Collectotrichum, Cercospora, Gleocercospera, Ascophyta
Symptoms:	Older leaves are infected first with round, oval, or rectangular leaf spots. Spots are tan, yellow, reddish or purple and sometimes have a darker margin.
Key Features of Disease Cycle:	These fungi survive in crop residue and spores are spread by air currents or by splashing rain. Normally, these diseases do not hurt yields. If the upper leaves become infected, then severe yield losses can occur.
Management:	Use resistant hybrids, especially for no-till. Rotate away from sorghum or corn for 1 to 2 years. Control weeds that may be a source of the inoculum. Azoxystrobin is labeled as a foliar spray for Cercospora (Gray leaf spot) control in sorghum.

Disease:	Maize Dwarf Mosaic
Cause:	Maize Dwarf Mosaic Virus
Symptoms:	Irregular, light and dark green mosaic patterns on the leaves, especially the younger leaves. Tan stripes with red borders between the veins ("red-leaf") occurs under cool conditions.
Key Features of Disease Cycle:	The virus lives in johnsongrass rhizomes and other perennial grasses. The virus is transmitted by certain aphids. Late-planted sorghum is at greater risk.
Management:	Use tolerant hybrids and eradicate johnsongrass and other perennial grassy weeds.

Disease:	Root Rot
Cause:	Periconia, Pythium, Rhizoctonia, Fusarium
Symptoms:	Stunting, sometimes leaf yellowing and/or wilting. Rotted roots are pink, reddish brown, or black.
Key Features of Disease Cycle:	Common fungi in soil, but not damaging unless plant is stressed. Common stresses include cool soils, poor drainage or inadequate fertility. Vigorously growing plants are able to replace damaged roots with new roots.
Management:	Use adapted hybrids. Plant in warm (above 65°F) moist soils at the proper depth and seeding rate. Place herbicide, fertilizer, insecticide and seed properly to avoid stress or injury to seedling. Azoxystrobin is labeled for in-furrow use for Rhizoctonia and Pythium diseases.

Disease:	Bacterial Stripe
Cause:	Burkholderia andropogonis (syns. Pseudomonas andropogonis)
Symptoms:	Long, narrow brick-red to purplish-red stripes, becoming tan when dry. Lesions are bound by secondary veins.
Key Features of Disease Cycle:	Bacteria survive in infected seed and in undecomposed sorghum residue. Warm, humid weather contributes to infection. Generally does little damage.
Management:	Use clean seed. Rotate away from grain sorghum for two years. Control weeds, especially shattercane (Sorghum bicolor). Use resistant hybrids, especially for reduced tillage and no-tillage fields.

Disease:	Fusarium head blight
Cause:	Fusarium moniliforme
Symptoms:	The head becomes infected first while stalk tissue at and immediately below the head become infected later. Cream to pink fungal growth can occur on grain.
Key Features of Disease Cycle:	The fungus can occur in seed or crop residue. Spores are spread by air. Warm moist conditions provide a favorable environment for disease development.
Management:	Timely harvest of grain at proper moisture. Hybrids with pigmented seed coats are more tolerant grain mold. Hybrid with dense, compact heads could be more damaged.

Disease:	Sorghum Downy Mildew
Symptoms:	Yellow-green stripes in leaves. "Downy" growth from fungal spores may occur on underside of leaf. Leaves become shredded as season progresses. Heads are partially or completely sterile.
Key Features of Disease Cycle:	The fungus survives in the soil for many years. Spores germinate and infect roots, and colonize plants internally. Infected plants produce spores carried by the air to other plants. Also infects corn and shattercane.
Management:	Use resistant hybrids. Use seed treated with metalaxyl. Control shattercane to reduce inoculum. Long-term rotation to soybeans, wheat or forages reduces inoculum in the soil. Avoid corn-sorghum rotation where the disease occurs.

Irrigation

Sorghum's water use characteristics make it an excellent crop for a wide range of irrigation scenarios in the High Plains. Sorghum has been shown to yield reliably under dryland conditions in many semi-arid environments (greater than 15" annual precipitation) but can also be managed to reach significant yield capacity under full irrigation. Because of sorghum's water use versatility, it can fit very well into many crop and irrigation patterns, a valuable trait considering current trends of declining groundwater and pending regulatory water use limitations.

As with all grain crops, sorghum yield is most directly related to available water during the cropping season. The total available moisture (TAM) that a sorghum crop uses is a combination of applied irrigation water, stored soil water and in-season precipitation. Individual TAM inputs can be managed to optimize the grain yield return per unit of water available.

Evapotranspiration

Indentifying the amount of water to be applied to a crop is one of the most important management contributions that a sorghum producer can make. Evapotranspiration (ET) is the preferred method for measuring and estimating the total crop water use and the irrigation demand of a crop. ET is a comprehensive measurement of crop water use in

a production setting. It measures water evaporated from the soil and plant surface in addition to water transpired through the plant's leaves during photosynthesis. Irrigation demand is the difference between the ET value and the water available from precipitation and/or soil storage. ET values for sorghum can be obtained locally through extension services and, in most agricultural regions, online through weather station networks such as:

- *http://agweather.mesonet.org in Oklahoma*
- *http://txhighplainset.tamu.edu/ and http://texaset.tamu.edu/ in Texas*
- *http://wdl.agron.ksu.edu/ in Kansas*
- *http://weather.nmsu.edu/ in New Mexico*

Over the 10 year period from 2000-2009, the peak daily grain sorghum ET was approximately 0.33 inches at the USDA Conservation and Production Research Laboratory in Bushland, Texas. Sorghum water use commences during planting (May-June), peaks during late July and early August, and continues through harvest. Under fully irrigated conditions, seasonal sorghum ET is approximately 27 inches. (Fig. 8)

Figure 8. 10-year Average sorghum Daily ET at Bushland, Texas

In the High Plains, an irrigated sorghum crop will receive approximately half of its water through irrigation. Irrigation water is the one controllable crop water source and, when managed properly, can optimize the quality and yield returns of all crop inputs, including soil water and in-season precipitation.

Pre-Irrigation

Irrigation immediately following planting is generally recommended for sorghum rather than pre-irrigation. Research has shown that up to 60 percent of water applied as pre-irrigation is not available in the soil at the time of planting, especially close to the soil surface near sown seeds. In dry conditions, sorghum establishment nearly always improves with one inch of irrigation applied at planting.

Growth Stages

Following plant establishment, key water use periods occur 35 days after emergence during the formation of the seed head, during the boot stage, and during early grain fill. Sorghum reaches its maximum daily water use requirement during heading and early grain fill. The most significant sorghum yield response from irrigation occurs during sorghum's rapid growth stage, or the 50-day period encompassing the 4-leaf stage through the boot stage. Sorghum seed set is determined near the end of this rapid growth stage based on nutrient and water availability as the sorghum plant is transitioning from vegetative to reproductive growth. The sorghum plant is also establishing leaf mass and area throughout the rapid growth stage in preparation for nutrient transfer that will occur during grain fill. A producer targeting maximum yield should be prepared to irrigate six to eight inches during this period, depending on seasonal rainfall.

In deficit or low capacity irrigation scenarios, preference should be given to irrigation applications just prior to the boot stage. Stresses caused by lack of water prior to and during the boot stage will cause lower yield capacity that cannot be overcome with adequate or excess water later in the growing season.

The 40 day period following the boot stage, the reproductive stage, is critical in actually harvesting the potential yield established during the rapid growth stage. A producer targeting maximum yield should be prepared to irrigate five to six inches during this period. Adequate water should be completely available through the soft dough stage. Since sorghum water consumption declines as the plant reaches physiological maturity, preference should be given to earlier water application during this growth stage.

Irrigation cut-out should occur once the sorghum grain has reached the hard dough stage, or when the grain color begins to change. A final irrigation should only be applied during this stage if soil moisture storage is completely depleted or drought conditions are severe enough to hinder stalk quality at harvest. For High Plains sorghum, final irrigation will typically occur near the first week of September in all but the driest of conditions.

If a deficit irrigation strategy is desired, either due to limited water or as part of a producer's overall agronomic approach, irrigation water should be applied during the priority periods of rapid growth and reproduction. Smaller, timely applications are recommended for sorghum under deficit irrigation to encourage uniform growth conditions. As little as six inches of timely irrigation water on sorghum in the High Plains has shown to greatly increase yields and profitability. (Fig. 9)

Figure 9: Sorghum ET and recommended irrigation at typical dates and growth stages.

Approx. Date	Crop Stage	Days After Planting	Heat Units After Planting	ET per Stage (in.)	Irrigation per Stage (in.)
1-Jun	Seeded	0	0	1.1	1.0
9-Jun	Emerged	8	200	2.2	0.0
Rapid Growth Stages					
21-Jun	3 leaf	20	500	0.6	1.0
24-Jun	4 leaf	23	575	0.8	0.0
28-Jun	5 leaf	27	660	1.6	2.0
6-Jul	GPD	35	925	3.3	3.0
20-Jul	Flag	49	1290	2.8	2.0
30-Jul	Boot	59	1550	1.8	1.0
Reproductive Stage					
7-Aug	Heading	67	1710	1.4	1.0
10-Aug	Flower	70	1850	3.5	2.0
25-Aug	Soft Dough	85	2210	2.7	2.0
7-Sep	Hard Dough	98	2510	1.8	NONE
17-Sep	Black Layer	108	2700	3.9	NONE
15-Oct	Grain Harvest	136	3100	-	-

Irrigation System Efficiency

Irrigation efficiency is defined as the percentage of water delivered to the field that is beneficially utilized by the crop. Factors such as wind drift, leaching, evaporation, and run-off all lead to decreased irrigation efficiency. To determine the depth of water to be applied during an irrigation event, irrigation system efficiency should be accounted for by using the following Equation 5:

Equation 5

Irr.Depth = (Irr.Demand)/(Irr.System Eff.)

With rising energy and water costs and declining water levels, wasted or underutilized water has the potential to directly impact sorghum profitability. To maximize the return on water and pumping cost inputs, it is recommended that irrigated producers make use of high efficiency irrigation systems such as subsurface drip (SDI) and low elevation center pivot sprinklers (LESA and LEPA) wherever feasible. To reach sorghum yield potential, an SDI, LESA or LEPA irrigation system should be designed or nozzled at four gallons per minute per acre (GPM/acre) or higher. At lower system capacities, irrigation should begin earlier in each crop stage to ensure that soil moisture reserves are present to buffer sorghum water needs during the rapid growth and reproductive stages. (Figure. 10)

Figure 10: Depth of irrigation water applied at various Irrigation System Capacities

GPM/Acre	Daily	Weekly	30 days	45 days	60 days	90 days
2	0.11	0.74	3.2	4.8	6.4	9.5
2.5	0.13	0.93	4.0	6.0	8.0	11.9
3	0.16	1.11	4.8	7.2	9.5	14.3
3.5	0.19	1.30	5.6	8.4	11.1	16.7
4	0.21	1.48	6.4	9.05	12.7	19.1
4.5	0.25	1.67	7.2	10.7	14.3	21.5
5	0.27	1.86	8.0	11.9	15.9	23.9
6	0.32	2.23	9.5	14.3	19.1	28.6
7	0.37	2.60	11.1	16.7	22.3	33.4
8	0.42	2.97	12.7	19.1	25.5	38.2
9	0.478	3.34	14.3	21.5	28.6	43.0
10	0.53	3.71	15.9	23.9	31.8	47.7

Figure 11: Efficiencies for Agricultural Irrigation Systems under optimal field conditions

	Potential Application Eff.
Surface	50-80%
Common Flood	50%
Land Leveled	60%
Row	65%
Alternate Furrow	70%
Surge	80%
Center Pivot	70-92%
LESA	85%
LEPA	90%
Drag Hoses	92%
Drip	90-95%
Above Ground	92%
Subsurface (SDI)	95%

Irrigation Costs

In most sorghum regions, the most significant portion of irrigation cost is related to the energy consumed during pumping. Historically, natural gas and electric pumping plants offer the lowest cost per unit of water pumped, typically by a significant margin. Where natural gas pipelines or electrical services are not available, diesel is the lowest cost pumping option. Although gasoline and propane engines offer the same thermal efficiency as the natural gas engines, they are traditionally more expensive to operate due to the higher cost of fuel on an energy basis (BTU). They should be avoided except for in very specific situations.

Regardless of energy source, the following operational practices universally promote lower irrigation water costs:

- Irrigate to crop needs, not irrigation system capacity
- Regularly maintain and/or replace irrigation motors and pumps
- Properly size irrigation motors and pumps
- Use properly sized pipelines with smooth transi tion fittings
- Operate at lower pressures
- Make use of continuous acting air relief valves to eliminate false head and pressure surges
- Utilize flow meters and pressure gauges to monitor irrigation system conditions

Soil Water

In addition to providing necessary structure and nutrients to crops, soil serves as a holding reserve for water. Each soil has a certain holding capacity for plant available water (PAW), or water that a plant can successfully extract from the soil. Coarse soils with rapid infiltration rates hold a minimal amount of water within the plant root zone, but nearly all of the water is available for plant use. Conversely, fine textured soils hold a significant amount of water within the root zone, but a lesser percentage of the stored water is available for plant use (Figure 12)

Figure 12: Available Soil Moisture by Soil Texture Class

	Inches of Water (3' root zone)
Course Sand	1.50
FIne Sand	2.75
Loamy Sand	3.50
Sandy Loam	4.00
FIne SAndy Loam	5.25
Silt Loam	6.75
Silty Clay Loam	5.75
Silty Clay	5.00
Clay	4.00

Soil moisture is generally considered most valuable to a sorghum crop when it has been captured prior to planting. Field preparation following the crop previous to sorghum is vitally important in capturing off-season precipitation in preparation for the coming sorghum crop. Low impact, minimum tillage operations are recommended where feasible to minimize soil water evaporation and surface run-off as well as maximize soil water infiltration and sub-surface organic matter to assist in water holding capacity.

Capturing off-season precipitation through soil storage is a recommended agronomic strategy that can early season plant growth, can buffer drought stresses throughout the season and can save costs associated with pumping and delivering irrigation water. Ideally, water from soil storage should be exhausted at the end of the season during grain drying.

In-Season Precipitation

Depending on location and weather patterns, in-season precipitation is typically a part of the water budget of irrigated sorghum, despite seasonal variations in quantity and timing. Although difficult to manage, the return on in-season precipitation can be optimized. In areas where in-season precipitation is probable, a portion of soil water capacity should be maintained to provide sufficient room to capture and contain water from small to moderate rainfall events. In addition to increased seasonal water and reduced pumping costs from holding and utilizing in-season precipitation, run-off and erosion are reduced, leaching effectiveness is increased, and, in many cases, nitrogen is supplemented.

In regard to irrigation scheduling, in-season precipitation should be evaluated on an "effective rainfall" basis. Research has shown that only a portion of the water received during a precipitation event will actually become useful to the sorghum crop. To avoid overestimating water received from precipitation, a producer should only credit precipitation events greater than 0.30 inch, or the peak daily sorghum ET. Consideration should be given to forgoing or delaying irrigation only if a precipitation event is larger than the scheduled irrigation depth or exceeds soil holding capacity. The benefit of in-season precipitation can often be redeemed at the end of growing season when irrigation can be terminated earlier with sufficient water stored in the soil profile.

Harvesting

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

Grain sorghum is harvested with a combine containing a grain table with a rigid header, a flex header in the rigid position, and a row crop header.

Guards that help pick up heads are recommended if heads are drooping or stalks are lodged. Sorghum stalks are generally much wetter than corn stalks at harvest, and they may be sticky from sugars. Stalk material pulled into the harvester is more likely to clump in the combine, thus increasing harvest losses, and residue can also collect in the hopper with grain. 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.

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 to 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 two to four hours unless aeration is provided.

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

Continuous flow or batch dryers are the preferred methods for drying grain sorghum. If it must be dried in a bin, the bin should be used as a batch-in bin dryer, limiting the drying depth of each batch to four feet. After drying, cool the grain and move it to another storage bin before the next day's harvest. A three foot depth of

sorghum is equivalent in resistance to a four-foot depth of corn at an airflow rate of 10 cubic feet per minute. 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 five to 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 one to two 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 6 months) 13 percent moisture
- Long term storage (6 months or longer) 11 to 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 three to five 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.

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). Value of grain sorghum follows this grading system. Proper harvesting, drying and storage practices are important to achieving the higher grades.

For more information on harvesting, drying and storage practices in specific states, consult Kentucky's AEN-17: Harvesting, drying and storing grain sorghum, and AE-82-W: Harvesting, drying and storing grain sorghum.

Table 16.
Sorghum Grades and Grade Requirements, from the United States Standards for Sorghum, effective June 2008

Grading Factors	Grades U.S. Nos. [1]			
	1	2	3	4
Minimum pound limits of				
Test weight per bushel	57.0	55.0	53.0	51.0
Maximum percent limits of				
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:				
Foreign material (part of total)	1.0	2.0	3.0	4.0
Total	3.0	6.0	8.0	10.0
Maximum count limits of				
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

U.S. Samples grade is sorghum that:
(a) Does not meet the requirements for U.S. Nos. 1, 2, 3, 4; or
(b) has musty, sour or commercially objectionable foreign odor (except smut odor); or
(c) Is badly weathered, heating or distinctly low in quality

[1]Sorghum which is distinctly discolored shall 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 cockleyburs.

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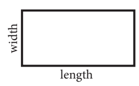
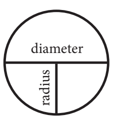
5. U.S. EPA. 2009. Crop Production. Online. *http://www.epa.gov/oecaagct/ag101/printcrop.html*

6. Figure 2. Pocket Guide to Crop Development: Illustrated Growth Timelines for Corn, Sorghum, Soybean, and Wheat. 2003. University of Illinois Extension Publication #C1389.

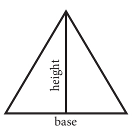
CALCULATIONS & CONVERSIONS



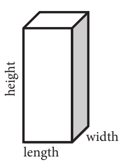
Area of a rectangle or square = length x width



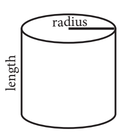
Area of a circle = 3.1416 x radius squared; or 0.7854 x diameter squared
Circumference of a circle = 3.1416 x diameter; or 6.2832 x radius



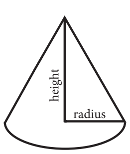
Area of triangle = base x height ÷ 2



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

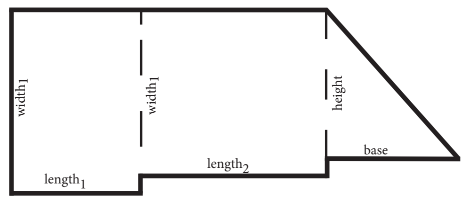


Volume of a cylinder = 3.1416 x radius squared x length



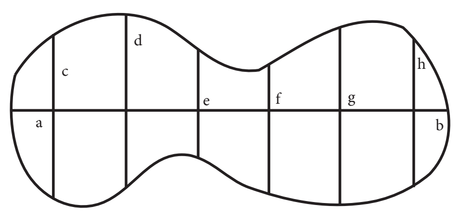
Volume of cone = 1.0472 x radius squared x height

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
Cubit 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
°Celsius (°C)	(+17.98)x1.8	Fahrenheit
°Fahrenheit (°F)	(-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	Centimeters
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 13). The panicle emerges at boot from the flag leaf sheath.

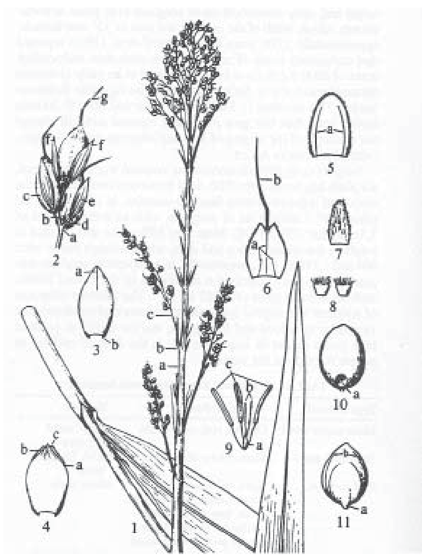


Fig. 13. The panicle of *Sorghum bicolor* subsp. *bicolor* which consists of the inflorescence and spikelets. 1. Part of panicle: a = internode of rachis; b = node with branches; c = branch with several racemes. 2. Raceme: a = node; b = internode; c = sessile spikelet; d = pedicel; e = pedicelled spikelet; 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 flowering. Seeds are normally harvested 10-20 days after black layer when moisture content is generally 15% or less. Black layer can be seen at the base of the grain where it attaches to the rachis branch and indicates that the grain is physiologically mature. Seeds are made up of three major components, the endosperm, embryo, and pericarp (Figure 14). 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 all are said to be free of tannins.

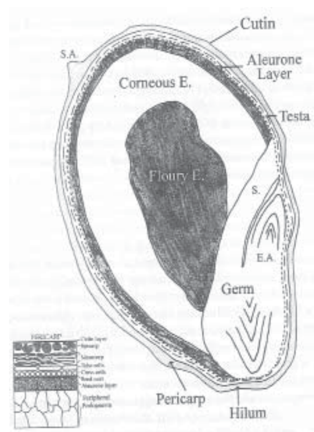


Fig. 14. Sorghum grain, showing the pericarp (cutin, epicarp, mesocarp, cross cells, tube cells, testa, pedicel, and stylar area (SA)), endosperm (aleurone layer, corneous and floury), and the germ (scutellum (S) and embryonic axis (EA). Adapted from L. W. Rooney and Miller, 1982).

b. Photos

Photo 1.

Photo 2.

Photo 3. *Greenbug*

Photo 4. *Corn Leaf Aphid*

Photo 5. *Yellow Sugarcane Aphid**

Photo 6*. Corn Earworm***

Photo 7*. Fall Armyworm**

Photo 8. *Sorghum Webworm**

Photo 9. *Sorghum Midge**

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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.

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