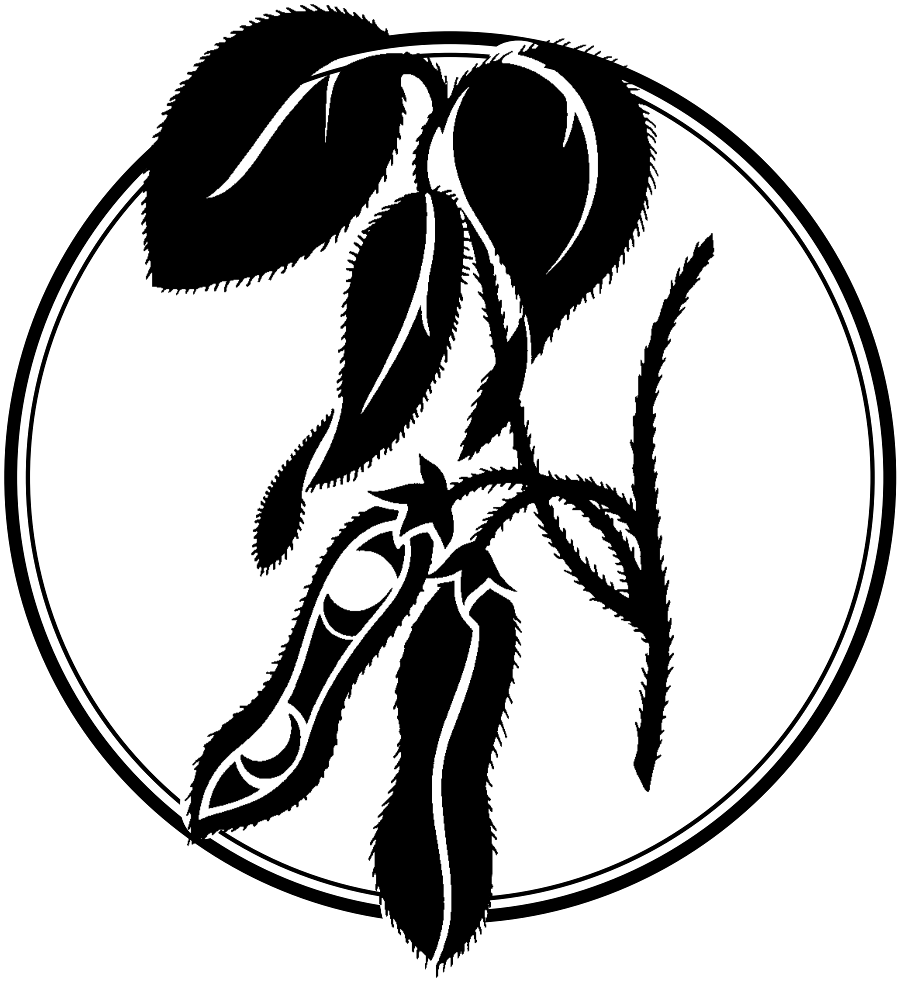
Soybean Production Guide



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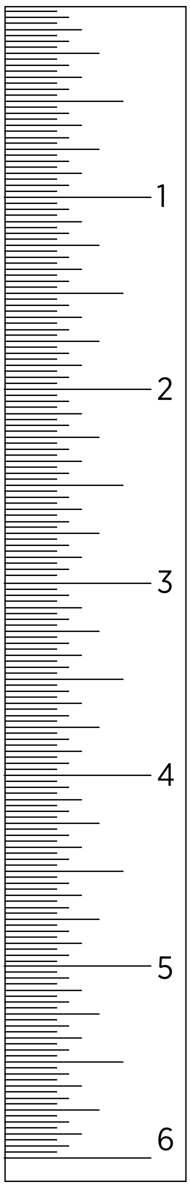

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I. INTRODUCTION

Soybean is one of the most important crops in the world. They provide protein for human consumption directly and indirectly through processed foods or livestock products. Soybean meal contains about 45% protein and provides a high-quality edible oil. When processed, a bushel (60 pounds) of soybeans yields 47.5 pounds of meal and 11 pounds of oil.

Oklahoma is on the western edge of the traditional soybean growing areas of the U.S. Soybeans grow on a variety of soils. Suitable soils are found throughout Oklahoma. Hot and drier climates in the western part of the state limit production, unless irrigation is available.

II. THE SOYBEAN PLANT - STAGES OF DEVELOPMENT

A. VARIATION IN DETERMINATE AND INDETERMINATE SOYBEAN DEVELOPMENT

When identifying growth stages of a soybean plant, the first important factor is to understand the difference between determinate and indeterminate types of soybeans. This will aid in understanding the growth stage of a soybean plant.

1. Determinate Varieties

- Grow very little in height after flowering begins.
- Flowering occurs about the same time at the top and bottom of the plant.
  Flowering and pod initiation begins at the middle of the plant canopy and progresses toward the top and bottom plant evenly.
- Pod and seed development occur at similar times throughout the plant.
- Terminal leaf about the same size.
- Terminal node on main stem usually bears a long flowering stalk.
- Terminal node has several pods.
- Considered southern varieties (for Oklahoma, primarily maturity groups V and VI).

2. Indeterminate Varieties

- At least half their final growth height and node development when flowering begins.
- Grows taller and produce branches while flowering, pod and seed development are taking place.
- Pods and seed development on lower part of plant are more advanced than at the top.
- The top of the plant generally has smaller leaves than those lower on the plant.
- Only few pods at terminal node.
- Little branching when grown in optimum stands.
- Considered northern varieties (for Oklahoma, primarily maturity groups III to IV).

3. Semi-determinate Varieties

- Comprises of characteristics of both determinate and indeterminate varieties.
- Still grows—has vegetative growth for a portion of reproductive growth but not as long as indeterminate varieties.
- Terminal development and branching is very varietal dependent.

B. NODE IDENTIFICATION

Determination of vegetative and reproductive stages require node identification. A node is the part of the stem where the leaf develops. The small scar that remains on the stem identifies the node after a leaf drops from the plant. Nodes, not leaves, are used for stage determination because they are permanent.

Cotyledon nodes, located directly opposite each other on the lower part of the main stem, are part of the seed and emerge from the soil as the seedling develops (see Figure 1).

Two unifoliate nodes are located directly opposite each other, immediately above the cotyledon nodes. The leaf at each unifoliate node is a single leaflet, in contrast to trifoliate leaves, which consist of three leaflets (Figure 2).

All nodes above the unifoliate nodes have trifoliate leaves except for special genetic lines of soybeans. The trifoliate nodes alternate from one side to the other up the main stem.

Nodes on the main stem that have or previously had fully developed leaves are counted in determining stage of development. Young leaves have three leaflets that resemble cylinders. As leaf development progresses, each leaflet unrolls until the edges separate and the leaflet begins to flatten out. To determine when the leaf is fully developed, examine leaf development immediately above the node. A leaf is considered fully developed (node is counted) when the leaf at the node

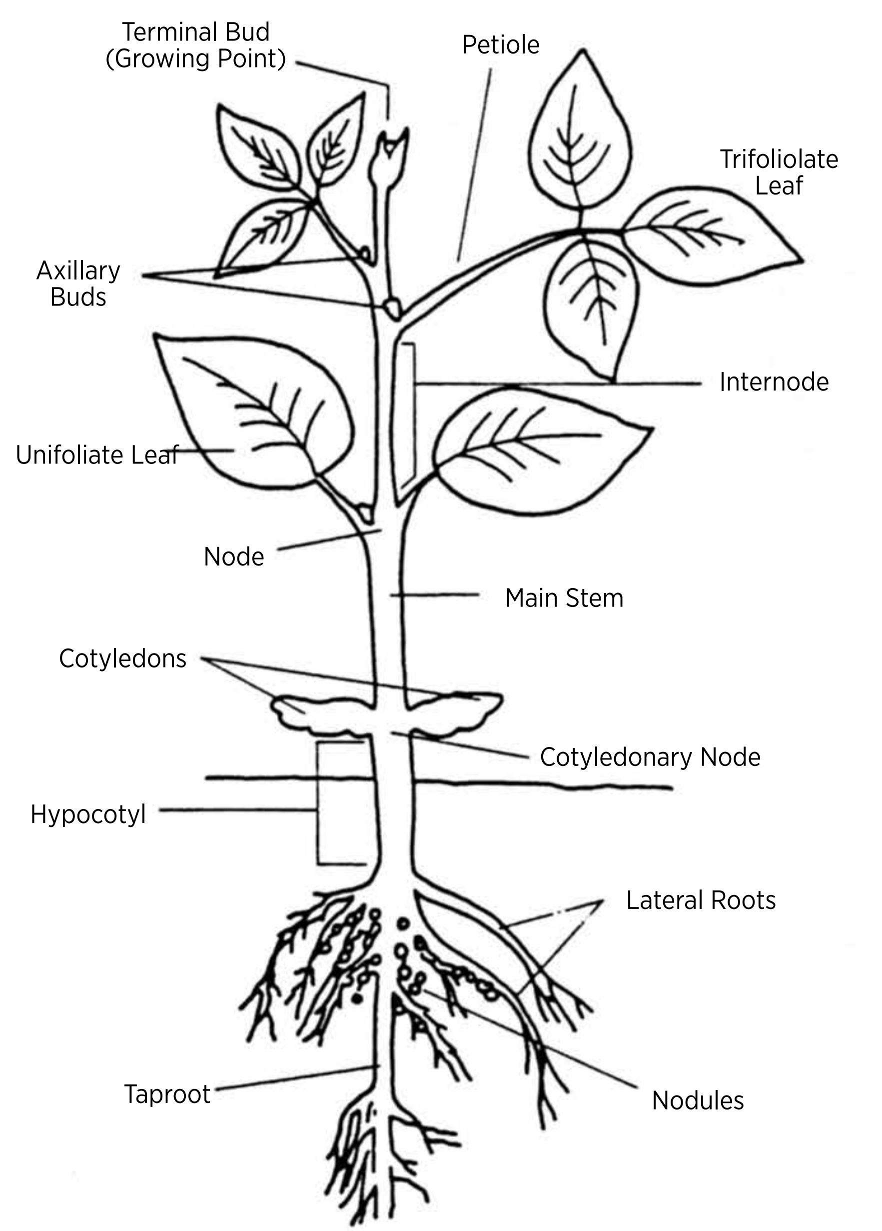

Figure 1. Soybean plant.

Figure 2. Three leaflets.

above has unrolled sufficiently so the two edges of each leaflet are not touching.

The indeterminate soybean plant terminates its growth on the main stem with a terminal node bearing a trifoliate leaf. At the terminal node on the main stem, the leaf is considered fully developed when the leaflets are flat and similar in appearance to older leaves on the plants. For these indeterminate soybeans, the terminal node bears a leaf similar to, but smaller than those lower on the plant. On determinate soybeans, the terminal node bears a leaf about equal in size to those lower on the plant.

C. VEGETATIVE STAGES

Vegetative stages occur from the time the plant emerges from the soil through initiation of first flower. During vegetative stages, maturity is determined by counting the nodes on the main stem. Do not consider those on branches. Choose plants without broken main stems for counting. Development of the new growth will be behind that of main stem that has not been cut off.

Each stage description (Table 1) is given a vegetative stage (V) designation, an abbreviated title to facilitate communication. Vegetative stage numbers are determined by counting the number of trifoliate leaves or nodes on the main stem. Much debate has been had on whether to count the unifoliate node; however, the Iowa State soybean growth stage manual is often thought as standard for the field, which does not count these nodes. Therefore, they will not be counted here but one could make the argument for either method. Best practice is to just note which method is used.

Vegetative stages:

- Begin at emergence
- Include VE (emergence) and VC (cotyledon) stages
- End when the first flower is noted
- Include stages V1 through V(n) where n = last node on the main stem that has been developed (i.e. 4 fully unrolled leaves would be designated as V4)

D. REPRODUCTIVE STAGES

Reproductive stages are based on flowering, pod development, seed development and plant maturation. Stages R1 and R2 (Table 2) may occur nearly simultaneously in determinate varieties because flowering begins at the upper nodes of the main stem. The two stages are approximately three days apart for indeterminate varieties, in which flowering begins in the lower portion of the main stem and progresses upward. Pods reach nearly full size before the seed begins to develop rapidly. As soybean plants mature, leaf and pod yellowing generally occur simultaneously. In some circumstances, however, leaves may remain after the pods have attained their mature pod color. Leaves and stems remaining green after seed and pod maturity can interfere with harvest.

Table 1. Stage descriptions.

Vegetative Stage	*Characteristics*
VE	Emergence of young plants through the soil surface with cotyledons or fleshy seed leaves above the soil surface. This stage corresponds to the “crook” or “cracking” stage and usually occurs about three days after planting, assuming conditions are optimum.
VC	The plant has emerged and cotyledons are fully unfolded. Unifoliate or simple leaves have unrolled so leaf edges are not touching, but are not yet fully developed (three to five days after emergence).
V1	First node appears; trifoliate leaf is fully unrolled so leaf edges are not touching. Figure 2 shows the plant just at or past this stage.
V2	Two sets of unrolled trifoliate leaves present.
V(n)	Vegetative (V) stages continue with more unrolled trifoliate leaves. There is no set number of trifoliate leaves as this will depend on variety and environmental conditions. During late vegetative stages, consider counting nodes on main stem and not visible trifoliate leaves due to potential losses.

Table 2. Reproductive stages

Reproductive Stage	*Characteristics*
R1	First bloom, an open flower at any node on the main stem.
R2	Full bloom, an open flower at one of the two uppermost nodes on the main stem with a fully developed leaf.
R3	Beginning pod growth, pod 3/16 inch long at one of the four uppermost nodes on the main stem with a fully developed leaf.
R4	Full pod elongation, pod 3/4 inch long at one of the four uppermost nodes on the main stem with a fully developed leaf.
R5	Beginning seed growth, seed 1/8 inch long at one of the four uppermost nodes on the main stem with a fully developed leaf (period of rapid seed development).
R6	Full seed, pod containing green seed that fill the pod cavity at one of the four uppermost nodes on the main stem with a fully developed leaf (seed reaches maximum size).
R7	Beginning maturity, seed in one or more pods are physiologically mature. One or more pods have reached mature pod color (e.g. tan).
R8	Full maturity, 95% of the pods have reached mature pod color.

E. DAYS BETWEEN STAGES

Soybean development is influenced by temperature, water availability, day length, variety and other factors. There can be considerable variation in the number of days between stages.

Temperature is the major factor influencing vegetative development. Low temperatures retard and high temperatures enhance seedling emergence and leaf development. Therefore, number of days from planting to the emergence stages (VE) can vary from about five to 15 days, depending on temperature. The effect of temperature becomes less important after the fifth node (V5) stage. A new node is produced on the main stem about every three days after V5. Long days (short nights) delay and short days speed the beginning of reproductive development.

The time intervals listed in Table 3 include the average number of days and the range in number of days between stages that scientists have reported. The average values must be considered as rough estimates of what may occur in any growing season.

Table 3. Number of days required for a soybean plant to develop from one stage to the next.

Stages	*Average Number of Days*	*Range in Number of Days*
Vegetative Stages		
Planting to VE	10	5 to 15
Planting to VE	10	5 to 15
VE to VC	5	3 to 10
VC to V1	5	3 to 10
V1 to V2	5	3 to 10
V2 to V3	5	3 to 10
V3 to V4	5	3 to 8
V4 to V(n)	5	3 to 8
Reproductive Stages		
R1 to R2	0,* 3	0 to 7
R2 to R3	10	5 to 15
R3 to R4	9	5 to 15
R4 to R5	9	4 to 26
R5 to R6	15	11 to 20
R6 to R7	18	9 to 30
R7 to R8	9	7 to 18

* R 1 and R2 generally occur simultaneously in determinate varieties. The time interval between R 1 and R2 for indeterminate varieties is about three days.

Table 4. Yield loss (%) in soybeans.*

Growth stage	Expected % yield loss when % leaf area is destroyed 20%	30%	60%	80%	100%
VE-V4	0	3	5	8	21
V5-V12	1	4	6	9	22
R1-R2	2	5	7	12	23
R3	3	6	11	18	33
R4	5	9	16	30	56
R5	7	13	23	43	75
R6	6	11	18	31	53

* Indeterminated varieties (primarily maturity group III and IV in Oklahoma).

Soybeans are extremely resilient in the vegetative stages of growth. Table 4 shows yield loss due to leaf loss at various stages of growth. Greater yield loss will occur with leaf loss during reproductive stages, mainly due to increased resource utilization.

III. CROP MANAGEMENT

When, where and how to grow soybeans in Oklahoma are critical considerations. Proper cultural practices are the most economical reliable long-term defense against crop stress and is a critical component of integrated pest management systems.

A. CULTURAL PRACTICES

1. Soil Selection

Soybeans will grow and yield well in a variety of soils. Deep, well-drained, level, loamy bottomland soils are ideal for soybean production. These soils are inherently fertile and are not subject to water erosion problems. These soils store water for plant growth, especially during July and August when water stress is likely to occur. Some upland soils are adapted to soybean production as well. Highest yields will be obtained on the deep, nearly level, well-drained, loamy soils. The sandier and shallower soils and those on steeper slopes have lower yield potential. These soils have limited water-holding capacity and runoff decreases the amount of water for uptake by the soil.

2. Planting Date

A wide range of planting dates can be used for soybean production in Oklahoma. Varying the planting date by a week will result in a change in maturity of two or three days. The reason for only changing maturity by a few days is due to soybean being a photoperiod sensitive plant.

a. The Photoperiod Effect

With most row crops, delayed planting requires planting a shorter season variety. With soybeans, this practice can lead to disappointing results or even failure. Soybean varieties respond differently to delayed planting compared to non-photoperiod sensitive crops, such as corn. Flowering of corn depends on temperature accumulated growing degree days. Soybean flowering is related to photoperiod (the length of light and dark periods during a day), with a minor influence of temperature, thus growing degree days mean little for estimating soybean growth stages. The change from vegetative to flowering stage in soybeans is the result of changes in the length of darkness in a 24-hour period. Adapted varieties flower after the dark period lengthens in late June and are said to be short-day plants. During the soybean growing season, there are more daylight hours on a given date in the north than in the south. Flowering of southern-grown varieties is initiated by a shorter day (longer night) than northern-adapted varieties. This results in increased growth, which could result in increased yields or flexibility for later planting.

Day length (photoperiod) causes differences in blooming time between varieties. Warm temperatures after seedling emergence also influence flowering. Temperature differences will cause year-to-year variation in the time of flowering of the same variety planted on the same day. Warm temperatures result in larger plants and earlier flowering. With a very warm vegetative period, flowering can begin before the dark period lengthens (around June 21st).

Soybean plant size attained during the vegetative stage depends on the weather. The amount of growth attained after flowering begins depends on the weather and plant growth habit. Soybean variety habit is classified as indeterminate, determinate and semi-determinate. After flowering begins, indeterminate varieties (northern) continue to grow taller, determinate varieties (southern) stop growing taller and semi-determinates grow taller during the early part of the flowering period, but stop before the indeterminates.

Table 5 shows how maturity group and planting date interact to affect flowering and maturity.

b. Planting Date Factors

Planting date selection depends on the selected variety, temperature, amount and distribution of moisture in the soil profile. Weather patterns and location interact with variety maturity to affect yields from year to year even when the same planting date and variety is used.

Adequate moisture and proper temperature are necessary for soybeans to germinate. Soybeans produce hardy seedlings that are able to survive in cool temperatures, but they are susceptible to cold temperatures under wet soil conditions. There is a risk of crop damage due to cool nights with temperatures below 28 F. The high oil content of soybean seeds make them vulnerable to saturated soil conditions at early planting and high temperatures from late planting. Soybeans will begin to germinate at a temperature of 55 F (at a 3-inch depth). In comparison, corn will begin to germinate at 50 F and cotton requires a temperature of 68 F to germinate. Optimum germination temperatures for soybeans range from 68 F to 86 F. Planting at cool temperatures results in slow germination, delayed emergence and higher incidence of seedling disease. Untilled, heavy textured soils usually remain cold longer than tilled soils that are lighter and drier. After soil temperatures reach 60 F to 65 F, emergence will occur in seven to 10 days. **Soybeans must absorb 50% of their weight in water to germinate. Good seed-to-soil contact is always important but is critical under drier soil conditions.**

c. Effect of Planting Date on Other Soybean Characteristics

In addition to yield, planting date affects other soybean characteristics. Plant height is reduced by later planting, typically after June. Lodging (standabil-

Table 5. Flowering (50%), maturity (95%) and pod-fill data for early season soybeans planted at Bay, Arkansas on April 2 and July 2, 1993.

Variety	*Maturity Group*	*50% Flowering*		*95% Maturity*		*Pod Fill*[1]	
		Apr 2	*Julv 2*	*Apr 2*	*July 2*	*Apr 2*	*Julv 2*
S39-11 (I)	3.9	58[2]	28	143	94	85	66
	5/30[3]	7/30	8/23	10/4			
S48-84 (I)	4.8	59	30	161	100	102	70
	5/31	8/1	9/10	10/10			
RA 452 (I)	4.9	73	39	170	107	97	68
	6/14	8/10	9/19	10/17			
Manokin (D)	4.9	78	39	172	107	94	68
	6/19	8/10	9/21	10/17			
Hill (D) 5.0	89	39	169	107	80	68	
	6/30	8/10	9/18	10/17			

Source: Dr. Howard Gabe, Northrup King Co. as reported in Proceedings of the 1994 Southern Soybean Conference, Memphis, TN.
I = Indeterminate
D = Determinate
[1] Pod Fill = Difference between the numbers of days to 50% flowering and 95% maturity.
[2] Number of days from planting to 50%nt flowering.
[3] Date on which 50% flowering occurred.

ity) is less of a problem with later-planted soybeans, since they are shorter than early-planted soybeans. Pod height from the soil surface is greatest in earlier planted soybeans compared to later planted soybeans. Maturity is also affected by planting date. Usually a three-day delay in planting results in about a one-day delay in maturity. Later in the season, it requires about a five-day delay in planting to equal a one-day delay in maturity. Warm temperatures in the late summer will hasten maturity and cool temperatures or cloudy conditions slow maturity.

Because of Oklahoma's unpredictable weather, it is important to diversify and have a flexible management scheme.

3. Variety Selection

Variety selection plays an important role in soybean management. The variety selected should be not only high yielding, but also nonshattering, nonlodging, disease resistant and cyst nematode resistant (if a problem in production area); in other words, adapted to the production area.

Variety selection and planting date should allow flowering, pod-setting and seed-filling periods to occur either before or after the onset of drought, which normally occurs in July and August in Oklahoma. Lack of soil moisture during the pod-setting and seed-filling periods is the most recurring cause of yield reduction.

Soybean varieties have a wide range of maturities but are adapted to rather narrow belts of latitude. In Oklahoma, early maturing varieties, adapted to the northern part of the U.S., mature during the hot, dry part of the summer. Late-maturing varieties adapted to the southern parts of the U.S., produce substantial vegetative growth but are often killed by frost prior to seed maturity. Producers must be aware that the maturity terms "early," "medium" and "late" used to describe soybean varieties are sometimes altered when planted in different regions or on different planting dates.

There are 13 maturity classes of soybean varieties. Those varieties adapted for use in southern Canada are designated 000 and are the earliest maturing. The higher the number, the later the maturity and the further south the variety is adapted for full-season use. The lines across the map are hypothetical (Figure 3). There are no clearly cut areas where a variety is or is not adapted.

Soybean varieties developed by privately financed research programs are available. These varieties are

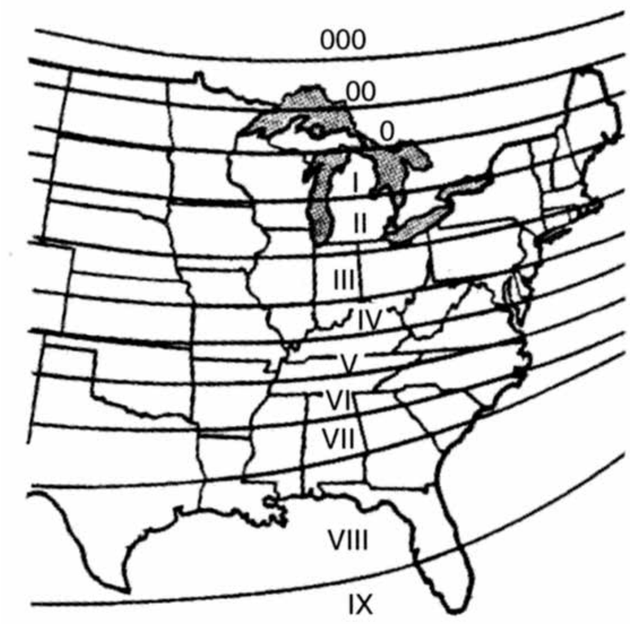

Figure 3. Maturity classes of soybean varieties.

handled as the property of the developer. When considering these varieties, growers should evaluate varietal characteristics: maturity group, pest resistance, resistance to shattering and productive capacity. Growers should refer to annual variety performance reports available in county Extension offices to compare varieties.

Plant more than a single variety each year and a larger producer should plant both early and late-maturing varieties. This practice spreads risk of weather-related yield reductions, allows producers to check out different varieties and permits more timely harvest and efficient machinery use. Try new varieties on a limited basis before attempting full-scale production.

a. Guidelines for planting dates and maturity group selection

- Select three or four varieties of different maturity groups, or maturity within a maturity group, spreads out harvest and periods of stress.
- Use more than one planting date.
- Use more than one production system (i.e. full-season vs. double-crop; crop rotations).

(1) Early season planting (April) of Early Maturing Varieties—Groups III and IV - Plant as early in April as possible to avoid late-July and August drought during critical growth stages. Yields may be very good with a wet spring but poor with a dry spring. Plant Group III varieties for September harvest and Group IV varieties for October harvest.

(2) Full-Season Planting (May 1 to June 30) of Group V Varieties - Use Group V varieties for late October/November harvest. Yields have usually been higher when planting in late May and before June 15. June plantings perform best in northeast Oklahoma. Early May planting can result in diminished yields due to high heat and typically dry conditions. Moderate temperatures (less than 95 F) and rainfall during the reproductive stages are critical for success.

(3) Full-season (May 1 to June 30) of Group VI - Late planting through early July may be successful in seasons with a late frost. Maturity groups VI varieties perform best in southeastern Oklahoma but also perform well in central Oklahoma.

(4) Late-Season Planting (July) of Group V Varieties - It is difficult to get a stand with July plantings. Soybeans planted after July 10 mature late and have an increased risk of seed damage and greatly reduced yield due to fall frost. When planting is delayed beyond the optimum dates, soybeans usually do not produce sufficient vegetative material before entering the reproductive stage, due to planting after the critical photoperiod.

4. Seed Quality

a. General

Soybean seed with good germination, 80% as a minimum, and free of weed seed, trash and damaged beans should be used for planting. Broken soybean seed will be lower in germination and result in an uneven stand. Seed should be well-filled, as the seed is the source of nutrients and energy during germination. In storage, soybean seed rapidly loses its viability and a germination test is essential to determine quality.

Since soybeans are self-pollinated, contamination of the seed source by cross-pollination occurs infrequently. Varietal mixtures may occur due to mishandling of seed and inadequate cleaning of seed-harvesting and cleaning equipment. Seed quality can vary tremendously from year to year and soybean seed has short longevity. Seed for planting must be produced and marketed on an annual basis.

Dozens of varieties, both public and private, are available for growers. Select a soybean variety adapted to the area for good economic returns. Planting locally grown, bin-run seed may be costly. Bin-run seed can easily be low in quality and typically (though not always) produces lower yields than certified seed. If there is any question about seed quality, the seed should be tested for germination and vigor.

Because of its superior quality, Oklahoma-produced soybean seed has been highly valued in the seed trade industry. In some of the major soybean production areas of the U.S., high temperatures and humidity occurring during the pod-filling stage reduces seed quality. Typically, Oklahoma is less affected by these conditions

b. Seed Quality Effects on Yield

Using high-quality (high germination and high vigor) seed to increase the likelihood of obtaining an adequate plant population over a wide range of field conditions. Yields will be reduced if an inadequate stand results from planting low-quality seed.

Most research studies show if an adequate plant population is obtained, larger seed size (normally associated with high quality) has no advantage over planting small seed. Neither germination nor vigor tests have been able to predict field emergence under all field conditions. Because soybeans may yield well over a wide range of plant populations, an exact number of plants per acre is difficult to identify.

c. Seed Storability

Soybean seed may be stored after harvest until planting the next spring, although storage conditions greatly influence the quality of the seed. As seed quality deteriorates during storage, vigor declines before loss in standard germination. Growers having concerns about the quality of planting seed should have the seed vigor tested. This test more accurately predicts field performance compared to the standard germination test. Seed moisture and temperature are the primary factors in quality deterioration during the storage period. During seed storage, quality can remain at the initial level or it may decline to a degree that would cause the seed to be unacceptable for planting.

d. Environmental Factor Effects on Seed Quality

Weather conditions affect seed quality. Environmental conditions during seed development, the drying down period or after physiological maturity (PM), while the seed remains in the pod in the field, may greatly affect seed quality. Seeds produced from later planting dates that reach maturity after hot, dry weather generally have higher germination and field emergence than seed that matures during hot, dry growing conditions. Lower initial germination and seed vigor have been attributed to high temperatures that occurred during the period from PM. Seed quality of earlier-maturing varieties at a particular location is generally lower than that of later-maturing varieties.

Seed quality deteriorates when soybeans remain in the field after PM has been reached. Early-maturing varieties are affected more by delayed harvest than later-maturing varieties. High temperatures, high relative humidity and precipitation will speed field deterioration of soybean seed. The decline in seed quality has been attributed to physical damage to the seed as a result of the wetting and drying cycle that occurs in most years.

Seed vigor declines before decreases in standard germination are observed. Seed vigor is more sensitive to field deterioration than seed viability. Loss in seed vigor while the seed remains in the field is accelerated by warm, moist conditions.

e. Mechanical Influences on Seed Quality

The amount and type of mechanical damage will influence both seed viability and potential seed performance. Standard germination and field emergence decline and the number of abnormal seedlings increase as mechanical injury increases.

Soybean seed is poorly protected from mechanical injury. The embryo is surrounded by a thin seed coat and the radicle-hypocotyl (parts which become the root and plant stem) lie against the base of the cotyledons. This positioning of the radicle-hypocotyl, combined with the thin seed coat, make the seed very susceptible to mechanical injury (Figure 4).

Mechanical injury occurs during harvesting, drying and conditioning of the seed. Damage appears as cracks or breaks in the seed coat, cracks in the cotyledons and injury or breakage of the radicle-hypocotyl.

Mechanical injury relates directly to seed moisture content. Injury occurs at low moisture levels more than at high levels. The optimum moisture level for harvesting or handling soybean seed is 12% to 14%. Physical damage increases significantly as moisture decreases below 12%. Although the physical damage appears less in seed at a high moisture level, the seed may be damaged internally. Large seeds are generally more susceptible to mechanical damage than small seed. Seed exposed to weathering in the field or seed dried at high temperatures is more susceptible to mechanical damage.

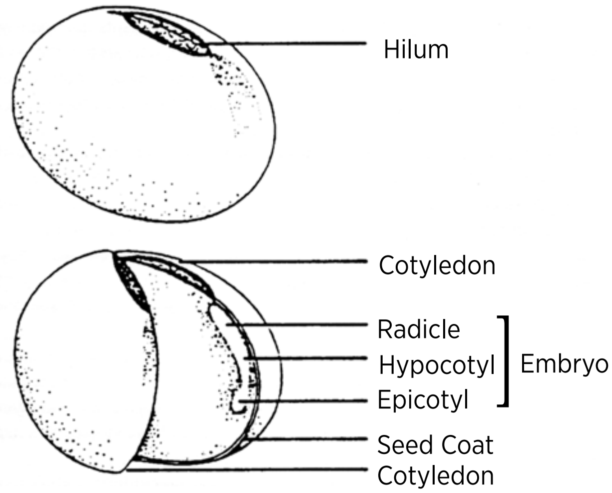

Figure 4. A soybean.

Mechanical damage does not solely occur at harvest. Insect damage can greatly damage soybean seed and effect seed quality. Punctured seed can be an entrance wound for many early and late pod diseases, especially under poor growing conditions. The influence of insect feeding is increased when long periods between maturity and harvest, as this allows for greater chance for disease manifestation.

5. Seed Inoculation

Soybean seed planted on new land or land that has not been in soybean production for several years should be inoculated at planting with a soybean strain of nitrogen-fixing bacteria, *Rhizobium japonicum*. Soybean seed inoculated with the proper strain of bacteria will produce their own nitrogen. The rhizobia species that inoculates soybeans is not native to Oklahoma soils and must be applied to the seed or soil.

Nitrogen fixation is the result of a symbiotic (beneficial to both organisms) relationship of rhizobia bacteria and plants. Rhizobia are unicellular and microscopic bacteria. They invade the soybean plant through root hairs. Once established, they take gaseous nitrogen from the atmosphere and convert it to forms used by the soybean plant. In turn, the soybean plants form special structures called "nodules" and rhizobia colonies are enclosed in the nodules. In the symbiotic relationship, the legume plant provides an adequate environment for the bacteria to fix nitrogen, carbohydrates (sugars) and nutrients to the rhizobia for energy and the rhizobia provides nitrogen to the plant.

It is critical that soybeans planted in new fields be inoculated. Where this is not done, the soybean crop will use available soil nitrogen and often will become nitrogen deficient when the supply of soil nitrogen runs out. Nitrogen-deficient fields are characterized by light green leaves, unthrifty plant growth and lack of nodules on the plant roots. In some cases, crop failures are observed. Many producers inoculate soybean seed for every field planted each year due to the low cost of inoculant. This ensures an abundant supply of nitrogen to the plant.

Inoculant can be either seed- or soil-applied. Seed-applied inoculant should be mixed with water (if required), forming a slurry that coats the seed. Some inoculants are already in the liquid form and simply need to be applied to the seed. This should be done several hours before planting to allow the seed to dry. Inoculant also can be applied directly to the hopper box. Do not mix inoculant, seed and water in the hopper box.

Soil-applied inoculants are applied with a granular or liquid in-furrow applicator at time of planting. Soil-applied inoculants may be particularly valuable on "new" soybean land. Pre-inoculated seed comes from a company and has little benefit because normal degradation of the bacteria from the time of application to the time of planting.

Precautions

- **Inoculant Storage and Handling -** Soybean bacteria are living organisms and must be handled with care. Handle and store inoculants according to manufacturer's instructions. Do not leave in high temperatures (>95 F) or direct sunlight.
- **Compatibility with Fungicides -** Thiram is the only fungicide that has no adverse effect on rhizobia. All other fungicides reduce rhizobia survival and number of nodules. Do not use a seed-applied inoculant with other seed-applied fungicides. Even where Thiram is used, Thiram-treated seed should be planted immediately after treatment. If a seed treatment other than Thiram is used, use a soil-applied inoculant.
- **Bacteria Response to Low pH and Molybdenum -** Soybean bacteria will not survive in acid soils. Low yields usually result on fields with low pH. Fields with a pH below 5.8 should be limed to provide a favorable environment for the bacteria. Molybdenum is important for the nitrogen fixation process and molybdenum deficiencies can occur at a pH below 6.0. At low pH, an inoculant used in conjunction with molybdenum can be used to avoid a molybdenum deficiency. **However, the best solution for low pH and low molybdenum is still to apply lime to the field.**

6. Seedbed Preparation

For conventionally tilled soybeans, tillage operations conducted prior to planting should bury plant residue, loosen the plow layer and destroy weeds. Land should be prepared in the fall or very early spring for full-season soybeans. The choice of implement for this operation primarily depends upon the amount of surface residue present. Light disking or chiseling can be used to destroy weeds and incorporate herbicides.

For decades, soybean growers have thought it was necessary to prepare a level, smooth seedbed believing this would promote rapid, uniform seedling emergence. However, tillage has never really been necessary. Reduced tillage and conservation of moisture are important if soybeans are double-cropped following wheat. The availability of planters that produce adequate stands even in heavy residue and the availability of broad-spectrum herbicides that eliminate the need for cultivation have reduced the need for intensive soil manipulation prior to planting. Good seed-to-soil contact is needed. To avoid poor stands, do not plant soybeans in dry soil. Soybean seed must absorb 50% of their weight in water to germinate compared to 30% for corn. If soybean seed absorbs less than this, partial germination and rot will result. Conserving seedbed moisture or waiting to plant after a rain improves stands and reduces replanting efforts.

Good seed-to-soil contact is of moderate importance in a moist soil. In a drier soil, contact with the soil is critical. In a moderately dry soil, most of the water is held in thin films on soil particles and within the soil aggregates. If the seed is in contact with these films of water, moisture moves to the seed. In a moist soil, the air spaces are high in humidity and provide moisture for germination and early growth. Pressing of the soil around the seed is critical if moisture is deficient and is less important if moisture is high, but good seed-soil contact is recommended across the board.

Soil crusting after planting causes problems with emergence. This is especially true if dry conditions follow slight moisture and soil disturbance at or following planting. In soils prone to crusting, use high-quality seed, rotary hoeing and increase row width from 6 to

7 inches to 12 or 14 inches (increases number of seed per row foot) to potentially help with emergence.

When planting after a small grain crop, straw height should be in the range of 8 to 20 inches. Straw moving through the combine should be chopped and evenly distributed in the field. Straw left in the field aids in moisture conservation, weed control and helps prevent erosion. When planting is done in straw stubble 1) plant when straw is dry and crisp (after dew evaporates) so the straw will not "hairpin" into the furrow opening, 2) plant at an angle to the stubble (i.e. perpendicular) and 3) slow the tractor speed.

7. Planting Rate and Plant Populations

The proper plant population will vary with variety, row width and production system and area. Soybeans possess the ability to compensate for variations in population. The penalty for overplanting or underplanting may be relatively small.

a. Varietal Response

Early maturing varieties tend to produce more at higher plant populations. Early maturing varieties (MG III and IV) tend to have less branching and therefore respond to higher plant populations. Medium- to late-maturing varieties lodge at high plant populations because of reduced light penetration resulting in thin, weak stems.

b. Plant Response

As row width is narrowed, planting rate per foot of row should be reduced. Use of a smaller or larger plant population within a row spacing depends on the fertility level of the field, lodging resistance of the variety and the branching ability of the variety to be used. Varieties having susceptibility to lodging or a strong tendency to branch may do better at lower populations; those most resistant to lodging or those that do not tend to branch will perform better at higher populations. Also, the penalty for overplanting or underplanting nonbranching varieties may be more severe than those that tend to branch profusely at low populations. If planting is delayed until July, an increase in planting rate is desirable because of the short stature of the late-planted soybeans. Increasing population of July planted soybean will increase germination and plant height through natural competition.

Adjust planting rate to the variety used. A variety that branches profusely when spaced at the rate of six to eight plants per foot of row (Figure 5, right) may produce more beans at this spacing than if crowded at a rate of 10 plants (Figure 5, center and left) per foot of row.

Figure 5.

Increasing population affects lodging; however, moderate lodging may be less harmful to yield than underplanting. Varietal selection affects lodging resistance more than small differences in population density.

Increasing the plant population within the row tends to increase plant height, lodging and height of the lowest pod. The number of branches, pods and seeds per plant usually decreases as population increases. With high plant populations, plants will be taller with smaller stalks, higher podset and more barren stalks. Thin stands may cause shorter plants with large stalks, more branching, lower podset and more pods per plant. Other characteristics such as oil content, protein content and seed size of most varieties are relatively unaffected by normal variations in populations. Given soybean seed costs and the soybean's ability to compensate for wide plant spacings, careful attention should be given to seeding rates.

c. Seed Size Effects

A difference of less than 25% in seed size is usually not of critical importance because overplanting or underplanting by as much as 25% normally has little influence on yield. Plant high-quality seed at the rate best for the field, the row width and variety. Do not depend on the ability of the soybean plants to compensate for poor stands.

Experience is the best guide in establishing expected emergence. Expect about 80% of seed planted to produce seedlings when planted in a good seedbed. Reduce that amount to 70% when planting in a no-till seedbed. Growers expect to lose as much as 5% to 10% of the emerged plants if the field is rotary hoed.

d. Seeding Rates

Seeding rate should be based on seeds per foot of row and not on pounds per acre. Other factors such as weed pressure, soil type, seedbed condition and the history of canopy development and stalk size should all be used to help calculate seeding rate. In narrow rows, a slight increase in the number of plants per foot of row can have a major effect on per acre populations.

Adjust planters or drills to put down a specific number of seeds per foot of row. Check planters before planting begins to determine the actual number of seed per foot of row. Make field counts to ensure accuracy and to make appropriate adjustments.

Table 6 lists the number of seeds per foot of row required to achieve a certain final plant population. Three levels of germination are used as examples. Most purchased seed is tagged at 80% germination, which is the lowest germination acceptable by certification standards. This establishes the lower limit for seed soybeans unless lowered by the certifying organization in a particular year. The seed may actually have a higher germination rate resulting in a thicker stand. To be certain of actual germination, conduct a germination test before planting.

Because field conditions are generally less favorable than the laboratory, the seeding rates in Tables 6 and 7 assume 90% emergence of 80% and 90% germination seed. If planting conditions are ideal and high-vigor seed is being used, seeding rates can be reduced by 10%. To calculate the rate of seed per foot of row, use the following formula.

e. Calculating Seed/Row Ft

Determine the desired stand (plants per row foot)
Divide plants/row ft by % seed germination x % expected germination

Example:

Desired stand = six plants per row foot
Seed germination = 90%
Expected emergence = 90%

Calculation:

Seed per row foot = Desired stand/seed germination x expected germination
Seed per row foot = 6/90% x 90% = 6/.81
Seed per row foot = 7.4

Result:

For a desired stand of six plants per row foot and using a seed lot having a germination of 90%and expecting 90% emergence, plant 7.4 seeds per row ft.

f. Calculating Pounds of Seed/Acre Required

Knowing the approximate pounds of seed required per acre is useful to determine the total amount of seed needed for planting. The pounds of seed per acre will depend upon the desired plant populations, seed germination and seed size. Because germination and size can vary considerably, the practice of planting a set number of pounds per acre each year, or from variety to variety, can result in stands too thick or too thin.

Table 6. Suggested plant populations and seeding rates for soybeans planted in Oklahoma.

Row width (inches)	*Feet of row per acre*	*Plants per foot of row*	*Plant populations per acre*	*Seed per foot of row * Germination*		
				90%	*80%*	*70%*
40	13,068	8.00	104,544	10.00	11.10	12.70
36	14,520	7.00	101,540	8.60	9.70	11.10
30	17,424	6.00	104,544	7.40	8.30	9.50
20	26,136	4.00	104,544	4.90	5.60	8.30
15	34,848	3.75	130,680	4.60	5.20	6.00
12	43,560	3.00	130,680	3.70	4.20	4.80
10	52,272	2.75	143,748	3.40	3.80	4.40
7	74,674	2.00	149,348	2.50	2.85	3.20
6	87,120	1.75	152,460	2.20	2.50	2.80

* Assuming 90% field emergence of the live seed

Table 7. Pounds of soybean seed required for various desired stands at two germination levels.*

	Desired final plant population per acre								
	100,000	110,000	120,000	130,000	140,000	150,000	160,000	170,000	180,000
No. seeds per pound	Pounds of seed per acre 90% tag germination								
2,800	44	48	53	57	62	66	70	75	77
3,000	41	45	49	54	58	62	66	70	72
3,200	39	42	46	50	54	58	62	66	68
3,400	36	40	44	47	51	54	58	62	63
3,600	34	38	41	45	48	51	55	58	60
	80% tag germination								
2,800	50	55	60	65	70	75	80	85	87
3,000	46	51	55	60	64	69	74	78	80
3,200	43	48	52	56	60	65	69	73	75
3,400	41	45	49	53	57	62	66	70	72
3,600	39	42	47	51	55	59	62	66	68

* Assumes a final stand of 90% of the seed. For example, the final stand equals 90% germination or 81% of the seed planted. Under ideal conditions and with high vigor seeds, reduce rates by 10%.

Observing the seed counts on bags of commercial varieties and doing actual seed counts is important. Counting the number of seeds in 1 ounce and multiplying by 16 will determine the number of seeds per pound. Check several bags to obtain a reliable average count.

To determine the amount of seed needed, use Table 6 to get the suggested plant population per acre for the desired row width and use actual seed counts. Finally, use Table 7 to find how many bags of seed will be needed to plant a certain number of acres. This exercise should be used only as an estimate of needs, since variation occurs.

Calculating Pounds of Seeds per Acre

To calculate the approximate pounds of seed per acre for situations not covered in Table 3, use this formula:

Pounds of seed per acre = feet of row per acre x seeds per foot of row ÷ Number of seeds per pound

Example:

30-inch rows (17,424 feet of row per acre)

Eight seeds per foot of row (Desired seeding rate)

3,000 seeds per pound (Actual seed count)

Pounds of seed per acre = 17,424 feet of row per acre x eight seeds per foot of row

= 46.5 pounds of seed per acre

An excessive seeding rate may result in a serious lodging problem because of tall, slender and weak-stemmed plants. The plant population also must be adjusted to the area of production. The amount and distribution of moisture is critical for maximum seed yield.

g. Seed Costs

Planting at high rates usually results in a lower percent final stand due to natural mortality and thinning. Seeding at excessive rates is a waste of seed and an added expense. Adjust seeding rates based on growing conditions. Calibrate planter based on seed per foot of row. This can not only lower costs but potentially result in more even stands.

h. Special Situations for Increasing the Seeding Rate

The seeding rates discussed above are based on good growing conditions. Consider increasing the seeding rate when the following conditions exist.

Increase seeding rate by:

- 5% for each rotary hoeing planned
- 10% for rough seedbeds

- 10% for short-season varieties
- 10% for cold soils
- 10% to 20% for no-till
- 20% to 30% for no-till planting after July 10
- 50% for broadcasting

These seeding rate adjustments are not additive but are only suggestions for calculating a suitable seeding rate. The best seeding rates are those based on experience.

i. Steps to Good Soybean Stands

- Start with good quality seed.
- Minimum of 80% germination (germ test if in doubt)
- Pure and free from contamination
- Plant to achieve approximately 100,000 plants per acre at harvest in 30-inch rows. If conditions are favorable for the area where the crop will be grown, (excellent growing season, moisture, deep soil etc.) a higher population will usually produce higher yields. Plant to achieve approximately 100,000 to 115,000 plants per acre in drilled soybeans. If moisture will be limited, reduce plant population by 25%.
- Adjust planter according to seeds per foot of row. Do not plant on pounds per acre.
- Plant into a good seedbed:
    - moist
    - warm (68 F to 86 F)
    - firm (get good seed-to-soil contact)
- Plant 1 to 1 1/2 inches deep but consider the moisture situation. In a heavy textured soil be careful planting 1 1/2 inches deep, it may not be advisable.

8. Row Width

Row width selection varies with production area and system. In most regions, soybean yields increase as row width decreases. A substantial increase in yield is usually obtained when row widths are reduced from 38- to 40-inch rows to 30-inch rows. Yield increases by narrowing rows below 30 inches has been erratic in Oklahoma.

There are advantages to using narrow rows (20 inches). Narrow rows result in earlier closing of the plant canopy, shading the soil surface and suppressing weed growth. The canopy also can contribute to conserving soil moisture. On erodible soils, soil loss can be reduced in narrow row soybean production.

The advantage of narrow rows over wide rows will be greater when early maturing varieties are planted very early, or when the planting date for medium maturing varieties is delayed beyond June 15. Early maturing varieties and/or late plantings such as double-crop plantings generally produce more in narrow rows since sufficient vegetation is usually not produced in wide rows to fully utilize the land area.

Narrowing row widths causes pods to be set higher on soybean stalks and slightly more lodging resistance than beans grown in wide rows. This may contribute to easier combining and increased yields. Additionally, without the cultivator ridges, the combine header can collect almost all the pods.

Fields under stress from weeds, drought, disease, nutrient shortage or insects will be less likely to respond to narrow rows. Narrow row soybeans may require greater post-emergence herbicide usage as cultivation may not be possible. The major advantage of narrow rows can be obtained by using row widths of 15 inches to 20 inches and leaving skips for tractor and/or equipment wheels.

Regardless of production area, the key is to have rows at a sufficient width to allow closing of the soybean canopy by the time the plants begin flowering. At that point, maximum leaf area absorbs needed sunlight, allowing plants to reach its genetic yield potential. Research indicates narrow row soybeans reduce corn earworm problems. By closing the canopy early, fewer insect eggs are laid.

9. Planting Depth

Rapid and uniform seedling emergence is important to soybean production because this speeds canopy closure and gives the soybeans a competitive advantage over weeds. Uniform planting depth contributes to uniform emergence and uniform plant size. For most soils, the best depth to plant soybean seeds is 1 to 1 1/2 inches (Table 8). This varies with the type of soil and existing moisture conditions. Soybeans should be planted shallower in clay loams and other fine-textured soils than in light loams and sandy soils. A 2-inch planting depth is maximum on sandy soils. Soybeans should be planted shallow when planting early in either cool or moist soils.

Deep planting can cause several problems. When seed is planted too deep, soils tend to crust. A packing rain after planting may lead to broken hypocotyls as emergence occurs. Seedlings from deep-planted seeds grow more slowly in their early life than those from seed planted only 1 to 1 1/2 inches. Deep planting can result in poor emergence especially if stress occurs. To increase the probability of obtaining a good stand, soybeans should not be planted below a 2-inch depth, regardless of variety or soil conditions.

10. When To Replant

Soybeans compensate for low populations or gaps in rows with little or no yield loss. Research results from Iowa show a 50% stand reduction may result in little yield loss. Producers frequently underestimate the yield potential of thin stands and replanting may be a poor management choice.

Make a decision on replanting by considering:

- Evaluate the deficient stand to determine the plant population, percent of stand loss to gaps and potential yield.
- The time of season and weather conditions, estimate the yield potential of a replanted stand.
- Determine the economics of leaving the poor stand compared to replanting (include additional costs of seed, fuel and herbicides).
- 70,000 plants per acre have produced yields equal to 110,000 to 125,000 plants per acre.

Hot and dry conditions during planting season may result in thin stands, causing growers to consider the cost/benefits of replanting. Considerations in deciding to replant should include:

- Cost of replanting.
- Lower yields expected with late planted soybeans.
- Weed problems may develop in thin stands.
- Health and condition of remaining plants and chemical needed to terminate current crop.
- Density of the remaining plant population.

B. PLANTING EQUIPMENT

When choosing equipment for soybean seeding, first consider the primary functions of any seeder and determine the needs for your situation. All planters, drills and air seeders should accurately meter seed, form a seed trench, place seed at the desired depth and provide good seed-soil contact. The major difference in metering relates to seed singulation versus volumetric metering. The performance of seeders relative to the last three functions depends on design, adjustment and operating conditions. For best performance, any seeder should be adjusted for the operating conditions. Pay close attention to seeding depth and closing wheel pressure. Getting good seed-soil contact is the key to good stands.

1. Planters

The two distinct features of row crop planters are seed singulation and ability to widen row spacing. Planters typically meter seed by attempting to singulate each individual seed, thus their seeding rate charts are usually in seeds per acre. Planter metering systems are also less likely to damage seed than the fluted cup metering systems on most drills. The typical row spacing on planters is 30 inches due to the wider row units. Traditional row units cannot be placed much closer than 20 inches on the same tool bar. However new planter designs with two tool bars have row units placed at 15-inch spacing. This ability to change between 15- and 30-inch spacing allows for more flexibility within the production and cropping system.

Aside from these two distinct features, planter performance is generally believed to be better than drills. Since planter depth gauge wheels are placed very near the seed drop tube, they have typically provided superior depth control when compared to drills. They also have press wheels that are adjusted independent from depth. These two items together typically translate into better emergence for soybeans planted with a planter. The wider row spacing also allows for many planter attachment options to improve performance in different conditions. These can include coulters or row cleaners for no-till, seed firmers to reduce seed bounce in the trench and improve seed soil contact and different closing wheel options for challenging planting condition.

2. Drills

Drills usually have simpler seed metering systems, furrow openers and furrow closing mechanisms. This reduces their initial cost and maintenance expense. The costs will be greater when features are added to improve seeding precision and soybean stands. Drills weigh less than equipment producing the same number of planter rows, which is an advantage, and they require less hydraulic lift capacity.

Drills are usually used for narrow row seeding (typically 6 to 15 inches). Metering systems in drills are typically volumetric in nature and consist of fluted, wobble slot and double run metering devices.

- Fluted metering cups are probably the most popular style. Seeding rate is adjusted by changing the rotational speed and amount of roller exposed.

- The wobble slot is unique to CrustBuster® drills. Seeding rate is adjusted with the width of slot and rotational speed.
- Double run seed cups are ideal for small seed and low application rates. The feed wheel has two sides and ribs on the inside of the wheel carry seed from the seed box to the seed tube. Seeding rate is adjusted with rotational speed, side of wheel (there are two sides) and feed gate setting.

Volumetric metering is less accurate than seed singulation, but the desired seeding rate can be obtained with repeated adjustments.

Always calibrate the drill on the basis of seeds per row foot. Seeds per pound can vary tremendously between varieties and even within varieties, depending on growing conditions under which the seed was produced. Depth control for drills has gone from nearly non-existent to very similar. Typically, the press wheels control depth on drills, but some drills now use gauge wheels to control depth. Using the press wheel for depth control generally hasn't been too bad. However, when depth is controlled from a location that is more than a foot away from the seed drop tube, rough conditions can cause inconsistent seeding depth. Inconsistent depth control and poor seed/soil contact are the two biggest problems with crop emergence and stand establishment. A drill with 7.5-inch spacing has four times the openers of a 30-inch planter. That means four times as many adjustments to fine tune performance. Naturally, adjustments depend on conditions. More down force is needed if soil conditions are firm. Unfortunately, if the press wheel is the depth control mechanism, more down force also means more force on the press wheel.

3. Air Seeder

Air seeders usually have the same openers as a drill or planter. Thus, there is no real advantage to an air seeder over a drill or planter as far as seed placement is concerned. The big difference is in the central seed hopper and possibly the operating width. With the higher volume of seed being metered with soybeans, the large, central hopper translates into less time spent refilling the seeder and greater productivity.

4. Planter, Drill or Air Seeder - The Bottom Line

Choosing the best seeder for soybeans can be challenging and many items should be considered. The decision on whether to buy a planter, drill or air seeder must consider all crops that will be grown along with the soils, other equipment and management. Choosing a seeder that can plant multiple crops effectively will conserve capital expense, however there may be some trade-off in performance. Overall, drills would give a producer better flexibility when focused around a small grain system, while a planter would provide flexibility for growers within a row-crop focused system. The choice for soybean production should be driven by the desired row spacing and production potential and having the flexibility of both 15- and 30-inch spacing can be greatly beneficial.

C. PRODUCTION CONCEPTS

Four soybean production concepts are used in Oklahoma. Each has a place, but each has limitations. Each concept is discussed below.

1. Early Season Soybean Production

Most soybean production systems in Oklahoma involve planting maturity group V and VI varieties in May and June and harvesting in October or November. Prolonged hot, dry weather in July and August usually coincides with the soybean blooming and seed-filling periods. Yields of full-season soybeans grown under non-irrigated conditions may be very low due to the adverse summer weather conditions.

The Early Production System is an alternative system and involves planting maturity group III or IV varieties in April and harvest in August or September. This system reduces (but does not eliminate) flowering or maturing during hot, dry conditions. In some cases, the results have been better than planting longer-season varieties in May or June. Based on Oklahoma tests, maturity Group III varieties mature in late August and Group IV varieties mature in early to mid-September.

The following general practices are important for early season production.

- **Maturity Group Selection:** Group IV varieties should be selected. Group III varieties mature seven to 10 days earlier than Group IV varieties. Group IV varieties usually yield four to eight bushels per acre more than Group III varieties. Recently, in OSU Performance test Group IV varieties have tended to out yield Group III's.

- **Tillage and Land Preparation:** Sufficient seedbed preparation should be accomplished for the incorporation of herbicides. The planter should follow immediately behind tillage (same day).
- **Seed Treatment and Inoculation:** Select the proper fungicide for seed treatment based on fungus needing to be controlled. For example, water molds such as Pythium and Phytophthora require a different fungicide than the non-water molds such as Rhizoctonia. The seed should be inoculated with the proper strain of *Rhizobium japonicum* for nitrogen fixation. (See precautions under section on seed inoculation.)
- **Planting Date:** Soybeans should be planted as soon as possible after April 5th, but also check the soil temperature. If possible, planting should be before April 30. May plantings are usually not satisfactory for early season production. With April planting, a longer period (10 to 14 days) will be required for emergence than with conventional planting.
- **Row Spacing:** Narrow rows are best unless planting on beds. Twenty-inch rows or less may assist with weed control.
- **Planting Depth:** Planting should be shallow with just enough soil moved to cover the seeds. Seeds should be planted between 1/2 and 1 inch deep.
- **Insect Control:** Insect control will be unlikely. Insects present no greater problem with this system than with full-season soybeans. Fields should be scouted for early season insects. Treatments should be made only if soybean stands are being lost.
- **Weed Control:** Weeds should be monitored and controlled. Rhizome Johnsongrass can be a problem. Pigweed and crabgrass are common problems with this system.
- **Harvesting:** Increased shattering should be expected and timely harvest is essential. Conditions favorable to shattering develop quickly during the hot, dry days of the early harvest season. As much as 10 bushels per acre or 1/3 of the crop can be lost in one day. Weather conditions during the harvest period may not be favorable to producing seed of high quality and the seed may have low germination.
- **Seed Quality:** Poor seed quality is not inherent in these early maturing varieties but is the result of high humidity during seed maturation. Typically, pods will set lower on the plants than with conventional planting and extra care must be given during harvest.

2. Double Cropping Soybeans and Wheat

Double-crop soybean acreage has held fairly steady in Oklahoma. Many growers continue to have success with the practice. Double-cropping can improve cash flow, spread risk, improve utilization of land and equipment and produce greater returns on investment. Soil erosion resulting from wind and water can be reduced because the soil is covered on a year-round basis. Research has shown that double-cropping may produce yields that are equal to or greater than conventionally planted soybeans.

No-till soybean production is an important method for double-cropping soybeans in Oklahoma. Long-term studies indicate that no-till yields increase over time due to increased organic matter, improved soil structure, increased soil pore space, increased infiltration of precipitation and reduced run off, reduced erosion and increased cation exchange capacity.

The following factors are important for this production system.

a. Weather

Double-cropping is not always a success. If adequate moisture for germination and emergence is present at wheat harvest, soybeans should be planted as soon as possible after the wheat has been cut. In an extremely dry year, attempting to establish soybeans following wheat harvest may be difficult.

Research has shown that soybeans can be planted until about July 1 and still obtain acceptable yields. Short growing seasons limit yields on late-planted soybeans. Plantings should be completed by July 10.

b. Tillage Or No-Tillage

The decision to plant soybeans directly into standing stubble (no-till), versus planting into a seedbed prepared by tillage depends on the available equipment, cost of herbicides required for no-till compared to tillage costs and moisture availability. Planting into standing stubble with straw present provides maximum soil and water conservation. However, problems may be encountered with stand establishment, weed control and straw toxicity to young soybean plants.

The ability to plant soybeans immediately after wheat harvest is a major advantage of no-till culture. If rain closely follows harvest, there is less delay in planting when using no-till compared to tillage after harvest. Secondly, this system will conserve more soil moisture than the conventional tillage system. This moisture could be critical in a dry summer. No-till planting would also be advantageous in soils subject to either wind or water erosion.

Conventional tillage requires more fuel, planting delays and reduces top soil moisture, but generally, weed problems will be reduced with tillage. Also, a wider spectrum of herbicides can be used and more uniform stands of soybeans often are obtained.

c. Burning of the Crop Residue

In many double-crop production systems around the U.S., one of the most common residue management methods between wheat and soybeans is residue burning. It has been thought that burning the crop residue provided better yields compared to no-tilling into standing residue as it removed a potential physical barrier of the wheat residue, allowing for increased emergence and early season growth. However, it has been shown that with modern planting equipment, yields are very comparable. In Oklahoma, burning is not recommended as this can be very detrimental to the water dynamics of the double-crop system. Not only can the fire dry the soil surface at and around planting, but with no to little soil cover, the soil will more easily dry during the course of the season.

d. No-till Yields

Yields with no-till systems have been comparable to conventional tillage and greater with no-till in a double-cropping system. Table 9 shows some results of no-till vs. conventional till soybeans in Oklahoma, Tennessee and Kentucky.

The wheat combine should be equipped with a straw chopper and spreader. This will help eliminate straw piles and windrows that interfere with planting. Height of the standing stubble must be considered in no-till culture. Less interference with planting occurs when the stubble is left as high as possible.

Table 9. Yield Comparison of no-till and conventional tillage soybeans.

	Bu/A		
System	*OK* *2 Tests*	*TN* *4 Tests*	*KY* *6 Tests*
Conventional Till, Double Crop	22	26	33
No-Till, Double Crop	25	29	35

e. Row Spacing And Seeding Rates

Narrow rows are recommended for double-cropped soybeans particularly when planting occurs in late season. When planting after wheat harvest, narrower rows are necessary to make optimum use of available land area and the short growing season. One goal in soybean production should be to have a full canopy of plants by the time blooming begins. Narrow rows aid in weed control by shading row middles and increasing soybean yields. The recommended row width for no-till planting is 20 inches or less. The seeding rate for 20-inch rows should be eight to 10 seeds per row foot for a final stand of six to eight plants per row foot and for 10-inch rows, six to eight seeds per row foot for a final stand of four to six plants per row foot. Planting depth should be at least 1 inch, but not more than 2 inches.

f. Variety Selection

Narrow rows are recommended for double-cropped soybeans, particularly when planting occurs in late season. Narrower rows are necessary to make optimum use of available land area and the short growing season when planting after wheat harvest. One goal in soybean production should be to have a full canopy of plants by the time blooming begins. Narrow rows aid in weed control by shading row middles and increasing soybean yields. The recommended row width for no-till planting is 20 inches or less. The seeding rate for 20-inch rows should be eight to ten seeds per row foot for a final stand of six to eight plants per row foot and for 10-inch rows, six to eight seeds per row foot for a final stand of four to six plants per row foot. Planting depth should be at least 1 inch, but not more than 2 inches.

3. Late-Planted Soybeans

A wet spring can cause growers to consider risky late plantings. Two decades ago, the standard recommendation for Oklahoma soybean growers was to begin planting around May 15 and try be to finished by June 15. However, Group V soybeans perform better if the planting is delayed to early or mid-June. Early June-planted soybeans have performed better than mid-May plantings. Delayed planting makes the crop less susceptible to the summer drought stress expected in Oklahoma. Ideally, the crop will still be in the vegetative state during the driest period.

Success or failure depends largely on the weather. Generally, significant yield reductions begin when planting is delayed beyond late June and worsens with continuing delay. Despite that, there are years in which soybeans planted in July have produced good yields. A general rule of thumb has been that there will be a reduction of 1/2 bushel per acre for each day of planting delay after July 1 but the range may actually be from 1/4 bushel to 1 bushel of loss per acre per day. The yield loss is highly dependent on the weather after planting. Extremely hot, dry conditions damage yields of late-planted soybeans.

Minimizing Yield Loss From Late Planting

There are several management practices for late planting that will contribute to increased yield potential.

- **Variety Selection -** Variety selection should be based on maturity group. If specific varietal information is not available, varieties for late planting should still be in maturity Group V or VI. Group V varieties are best suited for Oklahoma conditions even with late planting. Avoid planting Group IV varieties late as the yield potential is less than for Group V varieties.
- **Row Spacing -** Narrowing row spacing (20 inches or less) is essential for late planting dates. Research has shown that late-planted soybeans in narrow rows will yield up to 10 bushels per acre more than soybeans planted in wide rows (38 inches to 40 inches). In very late plantings, drilled soybeans will generally yield higher than 20-inch row spacing.
- **Plant Population -** A plant population of 100,000 to 125,000 plants per acre is a good target for regular planting dates. Plants per acre should be increased when planting is delayed beyond the optimum dates. More plants are needed to compensate for the smaller plant size and branching that results in fewer fertile nodes and fewer pod sets on individual plants. For late June or early July plantings, 156,000 plants per acre (six plants per foot of row) is a good target. To maintain reasonable yield potential with ultra-late plantings (well into July), a plant population of 200,000 plants per acre or eight plants per foot of row is a good target. Late plantings can require twice the seed as needed for optimum planting dates.
- **Irrigation -** Irrigation can help overcome the negative effects of late planting. It is important for late plants to have a rapid growth rate and not suffer from moisture stress. Flowering begins about 35 days after emergence and should not be delayed. Irrigation can help maintain a constant rapid rate of plant growth, pod set and seed fill. Irrigation is especially important with double cropping since moisture is likely to be deficient following a wheat crop.
- **No-till Planting -** No-till planting will save time and help minimize yield losses, especially when double cropping after wheat. No-tillage also conserves soil moisture, which may speed germination and emergence.

4. Stale Seedbed Planting

The concept of stale seedbed soybeans can be used in the dry conditions of Oklahoma.

The key to success is establishing a good seedbed. Without this, the overall production program will almost certainly fail. Planting into a stale seedbed utilizes tillage, either after harvest in the fall or early in the spring, to smooth the seedbed, eliminating ruts and excess residue on the soil surface. Tillage is not used immediately prior to planting. This technique conserves moisture, eliminates costly and time-consuming tillage trips at planting and allows more timely planting. Conservation tillage is not necessarily a principle objective of this concept, rather timely soybean stand establishment following adverse weather conditions. An extra tillage operation will not lose soil moisture. Little or no equipment modification will be needed.

Heavy no-till planters are usually not required for stale seedbed. Most producers add coulters to the planter unit, thus clearing any vegetation and providing a clean furrow for optimum seed-soil contact. Prepare the seedbed with tillage in either the fall or early spring so it will be ready to plant at the appropriate time. The seedbed must be in good condition for planting with the last tillage operation; no ruts, rough seedbed, heavy disk marks, etc.

Production results with soybeans planted into a stale seedbed have varied tremendously. Most variability results from the special needs and different requirements of a stale seedbed program. Although the stale seedbed concept allows earlier entry of planting equipment, stand establishment will not be optimal if the soil is too wet to close the furrow properly. Moisture must be adequate for stand establishment with stale seedbed or any planting practice.

Summer annual weeds, including annual grasses, morningglories, pigweed and prickly sida may emerge by the time planting begins. These weeds must be controlled at planting, since they will be too large for postemergence control by the time the soybean plants emerge enough to permit use of the proper herbicides. Burndown herbicides, when used properly, can control both winter and summer annual weeds. Producers should use soil-applied residual herbicides that have post-emergence activity to control certain weeds present at planting and to control summer annual weeds after planting. Combinations of burndown and soil-residual herbicides are often used.

This system provides tremendous flexibility in years when overly wet or dry conditions occur at planting. If good seedbed preparation and weed control have been achieved, soybean yields following stale seedbed planting will be comparable or better than with tillage at planting.

D. SOYBEAN IRRIGATION

1. Irrigation Water Requirement

While soybeans may be grown in many locations in Oklahoma under dryland conditions, supplemental irrigation can be used to optimize yields. The amount of irrigation required to achieve maximum yield depends on many things such as yield potential of the cultivar, soil fertility and weather conditions. In general, the amount of supplemental irrigation needed may range from as little as 8 inches per year in the northeastern portion of the state to more than 13 inches in the southwest. Figure 6 illustrates normal seasonal irrigation water requirements for soybeans. For five out of every 10 years, enough rain should occur so the irrigation requirement should not exceed these amounts.

2. Effect of Water Stress on Yield

Water stress at some stages of plant development will have a greater effect on soybean yield than at others. If adequate soil moisture is available to germinate and establish a good stand, moderate water stress in the early growing season has a mild effect on yield. If good subsoil moisture is available throughout the root zone, the plant root system will develop normally and irrigation should not be needed for the first six weeks after planting. However, if inadequate off-season rainfall has left the soil profile depleted of moisture below the seedbed or to root restrictive layer, early-season irrigation may be necessary. Roots will not develop in dry soil. An initial profile of deep soil moisture helps ensure an adequate root system to carry the plant through heavy water use periods.

The most critical stage for water stress is the reproductive stage. Inadequate moisture at this stage will result in a reduced number of fruiting sites and poorly

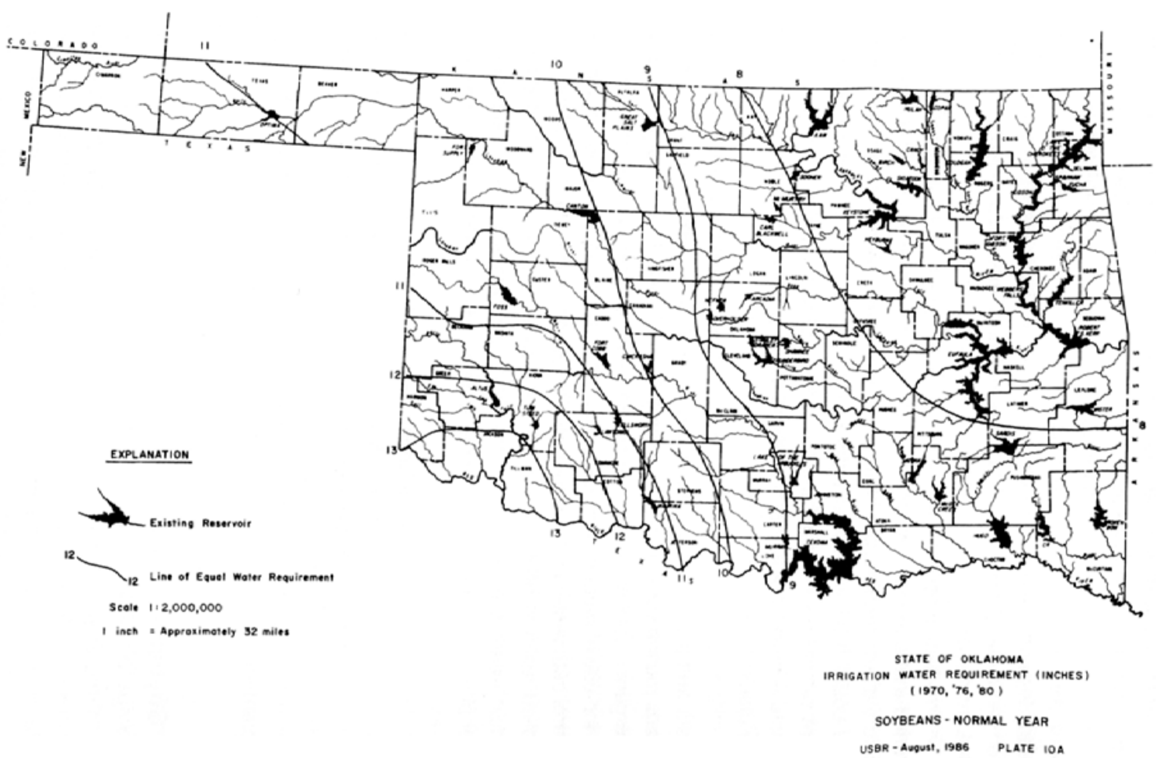

Figure 6. Map of normal seasonal irrigation water requirement for soybeans in Oklahoma.

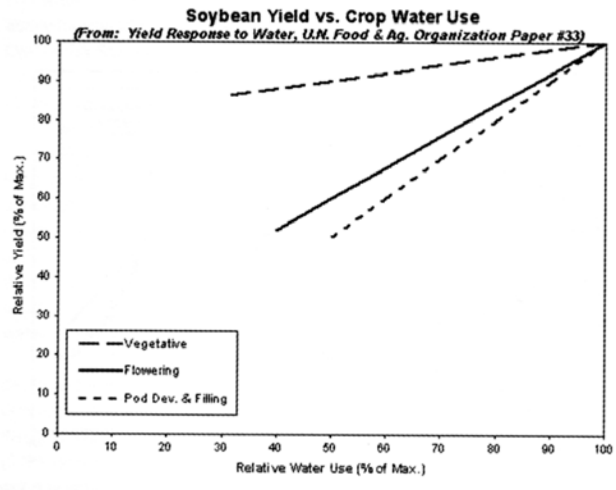

Figure 7. The effect of water stress on soybean yields at various stages of growth.

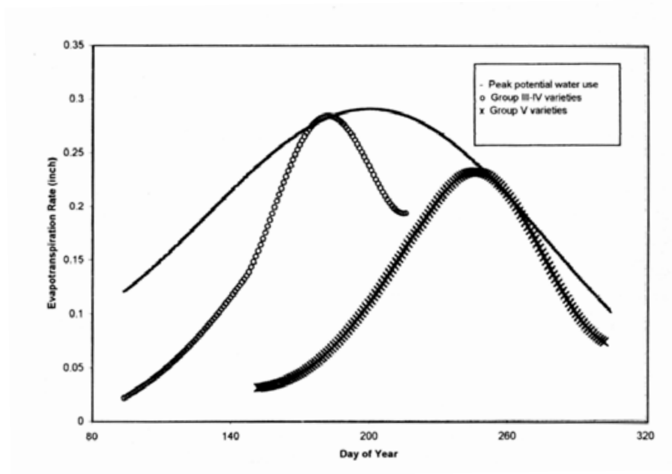

Figure 8. The combined effect of planting date and maturity group on soybean peak water use.

filled pods. As illustrated in Figure 7, research has shown that a 10% reduction in water use by soybeans during flowering results in an 8% reduction in eventual yield, while a 10% reduction in water use during pod filling leads to a 10% yield loss. When limiting irrigation water, it should be saved for flowering and pod set.

Through proper selection of soybean varieties and planting dates, the significance of drought stress can be reduced at the critical stages of growth. Choose the cultivar with the shortest growing season suitable for our climatic region. Plant as soon as soil temperatures promise satisfactory germination and emergence of a good stand. This results in the flowering, pod set and seed-filling stage occurring before the period for peak potential water use from mid July to late August. If a later-maturing cultivar is chosen, planting should be delayed as late as possible while still ensuring full pod set, and filling will take place after late August when lower temperatures will result in lower water use rates. This reduces the possibility of peak moisture stress occurring during the most critical reproductive stage of the crop. This results in improved yield potential, even if limited irrigation water is available.

The first example in Figure 8 illustrates the typical water use pattern of late-Group III/early Group IV cultivars planted on April 1 (day 91) in central Oklahoma. The majority of pod filling should be complete before July 1 (day 182), and peak water use will occur during seed maturation when drought stress has a much lesser effect on yield. The second example in Figure 7 shows a Group V cultivar planted in central Oklahoma on May 30 (day 150). In this case, flowering will not be initiated until about August 20 (day 232), about the time when potential water use begins to decline. In both cases, the stages of most critical crop development have avoided the peak potential moisture use.

3. Water Quality

Soybeans are classified as moderately tolerant to salinity in irrigation water and the crop root zone. No yield loss occurs until the electrical conductivity of the root zone soil reaches 5 millimho/cm. For each additional 1 millimho/cm increase in conductivity above the 5 millimho/cm threshold, the crop will experience a 20% reduction in yield. The salinity level at which no marketable yield will be produced will occur when the conductivity reaches 10 millimho/cm.

If poor quality irrigation water must be used, apply additional water above the crop water requirement to leach any salt build-up below the root zone. Good internal drainage in the soil profile allows leaching to occur. Adequate off-season rainfall leaches accumulated salt from applied irrigation water below the root zone. Water supplies should be tested for suitability for irrigation use. The Soil, Water and Forage Analysis Laboratory at Oklahoma State University can test irrigation water.

4. Irrigation System Design

The required capacity of the irrigation system will depend upon whether the system is meant to supply 100% of the water needs during prolonged drought, or supplement the rainfall of a normal year. Economic considerations will be the major factors affecting growers decisions. The quantity and quality of irrigation water available may limit the system design. Irrigation water may be obtained from lakes, ponds, streams or wells. Where lakes and ponds with limited inflow during the irrigation season are used, 1 1/2 to 2 acre-feet of water should be stored for each acre-foot of water required. This will account for normal seepage and evaporation losses.

The actual capacity of the irrigation system will be determined by the depth and frequency of water application, the hours per day the system operates and the application efficiency of the system. Meeting 100% of the cop water requirement during the period of peak demand in late July (0.30 inches per day), a center pivot irrigation system operating 23 hours per day would need a capacity of 7 1/2 gallons per minute per acre. A power side roll system operating 20 hours per day would require 9 gallons per minute per acre. To supplement normal rainfall during the growing season, a center pivot system should have a capacity of 5 to 5 1/2 gallons per minute per acre, or a side-roll system 6 to 6 1/2 gallons per minute per acre. The higher figure given represents the typical capacity required for the western portion of the state, while the lower figure is for the eastern part of the state.

The irrigation system must be designed so soil infiltration capacity is not exceeded. Applying water at a too high rate will result in standing water on the surface, loss of water and nutrients through runoff and soil erosion. This is not a concern in lighter-textured soils. On heavier soils, the outer end of center pivot irrigation systems may have application rates that temporarily exceed the soil infiltration rate. Applying smaller depths of water by keeping the system travel rate at a higher percentage setting will keep the runoff losses to a minimum. Consult the USDA County Soil Survey for information on soil hydraulic properties. Surveys are available at the district Natural Resource Conservation Service (NRCS) office, or the local county Extension office.

5. Irrigation System Management

Soybeans can extract water from depths of more than 4 feet; irrigations should replenish only the upper 2 1/2 to 3 feet of the root zone, where the majority of the root system is located. This reduces deep drainage loss of irrigation water and maintains some storage capacity for rainfall. Sandy soils do not hold a lot of water. More frequent, lighter irrigations are needed than for crops grown on heavier soils.

Table 10. Soil properties affecting irrigation system design and management.

Soil Texture	*Available water-holding capacity (inches of water/foot of soil)*	*Infiltration capacity (inches of water/hour)*
Fine Sand	0.5 to 0.75	6.0 to 20.0
Loamy Fine Sand	0.75 to 1.0	2.0 to 6.0
Fine Sandy Loam	1.0 to 1.25	0.6 to 2.0
Loam	1.25 to 1.5	0.6 to 2.0
Silt Loam	1.5 to 1.75	0.6 to 2.0

Manage the irrigation system to not exceed the water storage capacity in the crop root zone of the soil. Table 10 shows a loamy fine sand soil will store up to 1 inch of water in each foot of soil depth in the root zone. Assuming the crop roots are 3 feet, then 3 inches of water are stored in the soil of the root zone. A good irrigation manager will not let more than 50% of this water be depleted by the crop before starting the irrigation system. Depleting more water causes yield reductions during most stages of crop growth. No more than half of this water, or 1.5 inches, should be used by the crop before irrigation or rainfall replaces it.

The amount of time it takes to use up the allowable amount of water depends on the weather conditions and the stage of crop growth. As it is shown in Figure 9, water use at emergence will be under 0.1 inches per day. During the peak growing stage, daily water use

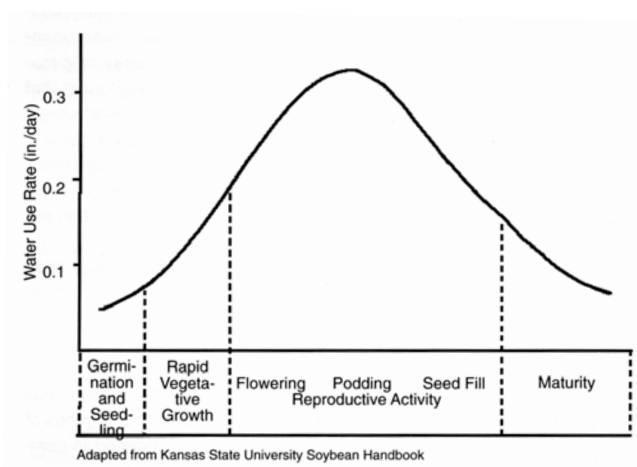

Figure 9. Plot of typical daily water use pattern for soybeans during growing season.

can be 0.3 inches per day or more. As the crop reaches physiological maturity, water use drops below 0.1 inch per day. If the water use rate averages 0.3 inch per day, then it will take five days to deplete the 1.5 inches of readily available water in a loamy fine sand root zone. The irrigation system must replace the amount of depleted water. If it is operated for a short period of time, the depleted water will not be completely replaced. If it is operated too long, some of the water will drain down below the crop root zone and be lost. Over-irrigation wastes water and can carry nutrients and pesticides out of the root zone where they no longer improve crop performance and they contaminate the environment.

Not all of the water applied through the irrigation system enters the crop root zone. In Oklahoma's hot, windy growing season, a large fraction of the water evaporates and drifts. The application efficiency of the irrigation system determines how much water has to be pumped to replenish the water deficit when using a side-roll system, which will have an application efficiency of 70% to 75%, then pump about 2 to 2.15 inches of water to replace an irrigation deficit of 1.5 inches of water. When using a center pivot with low-drift nozzles that is 80% to 85% efficient, then pump 1.75 to 1.9 inches of water. Place a rain gauge in the field located at the same height of the soybean canopy to measure how much water is delivered to the field. A subsurface drip system with an efficiency of 95% would require only 1.6 inches of water to replace a 1.5-inch water deficit.

6. Irrigation System Types

Soybeans are irrigated with either center pivot or side-roll sprinkler systems. Pivots are used in large square fields, covering a 125-acre circle out of a quarter section of land. They can be equipped with end guns or corner units that allow them to cover up to 145 acres of the same area. Usual sprinkler packages on pivots include low-pressure impact sprinklers mounted directly on the pivot line. Application losses from these sprinklers may exceed 25% of the applied water in hot, dry, windy conditions encountered in western Oklahoma. Pivots equipped with drop tubes and low-pressure spray nozzles or low-drift nozzles are more efficient than impact sprinklers. Placing sprinklers close to the crop canopy reduces spray evaporation and wind drift. Low-drift nozzles have larger water droplet sizes that are less susceptible to drift and evaporation. Low-drift nozzles are more prone to losses by runoff on low-intake soils. However, using booms with multiple spray nozzles on each drop-tube can spread the water over a wider area and reduce the instantaneous application rate on heavy soils. Pivot systems are seldom adjusted to apply more than 1 1/2 inches of water per application, which is enough to last five to seven days.

Side-roll systems are best suited to smaller rectangular fields. Individual wheel lines are usually 1/4-mile long and can normally irrigate up to 25 acres per line. A larger field requires multiple lines to cover it in time to meet crop water demands. Side roll systems are normally operated for two irrigation sets per day, each 10 hours to 11 hours in length. Impact sprinklers are usually spaced 30 feet to 40 feet apart on the wheel line, with adjacent sets spaced 40 feet to 60 feet apart. These systems usually apply 2 inches to 3 inches of water at each setting, sufficient to last the seven to 14 days needed to completely cover the field and return to the irrigation starting point.

Subsurface drip irrigation is another irrigation method that has been gaining popularity in areas with limited water. The method has been used only on a limited basis in the commercial production of soybeans. Polyethylene drip tubing is plowed into the field, between alternate soybean rows prior to planting, generally at a depth of 12 inches to 15 inches. If 5/8-inch diameter tubing is used, row lengths are limited to about 600 feet long. If 7/8-inch tubing is used, rows can be up to 1/4-mile long. The tubing must be buried deep enough to ensure sufficient capillary rise of the irrigation water to allow proper wetting throughout the root zone. Row positions must be maintained from year to year to keep crop rows aligned with the buried irrigation tubing. Traffic running across the drip tubing can affect its working life by compacting the soil and squeezing the tubing flat, reducing water flow. Application efficiency of subsurface drop irrigation is 95% in most cases. The system is very well adapted to automated operation. Many of the disease problems associated with high humidity in the crop canopy from irrigation are reduced or eliminated. Initial system costs are high and the system must be properly maintained by filtering and treating the water to allow reuse of the tubing for several years.

7. Chemigation

Chemigation is the application of agricultural chemicals through irrigation systems. Fertilizers and pesticides are available that are approved for chemigation. There are several important factors to consider when applying chemicals in irrigation water. The system must have a series of check valves and vacuum relief valves to prevent contamination of the water supply due to back-flow of chemicals in case of an unscheduled pump shut down. Any pesticide applied through an irrigation system must be allowed on the pesticide label. Any chemicals applied simultaneously must be compatible. Chemical tank agitation and irrigation system flow rate must be adequate to maintain the suspension of wettable powder chemicals. The uniformity of chemical application will be limited to the uniformity of application of the irrigation water. The economics of chemigation compare quite favorably with ground and aerial application methods if several chemical applications per season are required. Safety should be a major concern.

E. FERTILIZATION

A healthy, well-nourished plant yields better and resists pest damage better than one that lacks some essential nutrients. Soybeans are efficient at utilizing the nutrients available in the soil. A 40-bushel-per-acre yield requires 240 pounds of nitrogen, 50 pounds of P_2O_5 and 70 pounds of K_2O. To reach maximum yields all nutrients have to be at an adequate level. Any deficiency that requires fertilizer addition will result in lost yield if no action is taken. The primary methods for achieving optimum yields is to take a soil test. Various materials are available on how to take a good soil sample and interpret soils test reports (PSS-2207, How to Get a Good Soil Sample and PSS-2225, OSU Soil Test Interpretations).

1. Liming

The first decision to make in growing soybeans involves that of limestone application. Soil pH, along with all other nutrient levels, is determined by a representative soil sample. Soybeans prefer a pH of 5.8 to 6.2; this is the most ideal pH range. Soybeans will produce excellent yields at pH values above this range, but high yields are seldom seen when the pH is below the ideal range. Nutrient availability, rhizobia activity and some herbicide efficiencies are significantly reduced as the pH deviates from 6.0.

Table 11 shows the effect of soil pH on soybean yields. Relative yield is the percent of maximum yield achievable.

Table 11. The relative yield of soybeans in acid soils and the expected yield when maximum yield is 40 bushel per acre.

Soil pH	*% Relative Yield*	*Yield Bu/ac*
4.2	53	21.2
4.5	85	34.0
5.0	92	36.8
5.5	96	38.4
6.0	98	39.2
6.5	100	40

Adapted from G9102 Liming Missouri Soils, MU Extension.

2 Nitrogen

Soybeans are a relatively high users of nitrogen (N). However, fortunately soybeans are a legume and can obtain most (around 65% to 95%) of its nitrogen needs from nitrogen fixation by legume bacteria if the field is well inoculated with proper strains of bacteria.

Soybeans are not likely to respond to nitrogen fertilizer at yield levels up to 60 bushels. Research preformed in Oklahoma has shown some increase in plant growth due to nitrogen, but this increase in size did not translate to an increase in yield. It has been shown that in very high-yielding areas, the crop can respond to fertilizer nitrogen when the soil residual levels are low and the yields are greater than 60 bushels; however, this response depends on other limiting factors (such as environmental stress or pest pressure) associated with the production system. At this yield level, the bacteria are not able to produce enough nitrogen for maximum yields. Often, when a response is seen from an addition of a starter fertilizer, it is the phosphorous that the soybeans are responding to, not the nitrogen. It should be noted that soybeans are extremely sensitive to salt injury and any addition of seed starter should be done with caution.

Most nitrogen deficiencies seen in Oklahoma are not from exceptional yields, but improper inoculation procedures or conditions that limit proper inoculation. Nitrogen-deficient soybeans are light green or yellow in appearance, stunted and yields are poor. Firing (chlorosis) of the lower leaves is the first symptom, with the deficiency gradually working to the top leaves. Seed inoculation with efficient strains of bacteria is essential. In the instance of poor nodulation, soybeans are more likely to respond to the addition of fertilizer nitrogen.

3. Phosphorous

It is sometimes said that soybeans do not respond to phosphorous (P) fertilization. However, this is not true. A high level of available phosphorous in the soils is one of the factors always associated with high soybean yields. Some soils naturally contain adequate amounts of phosphorous for high yields, but others do not.

It is important that the phosphorous level of the soil be determined through soil testing. If the soil cannot supply adequate amounts of phosphorous, it must be added in the form of phosphate fertilizer.

Additionally, soil pH can drastically influence soil phosphorous availability and potential response to added phosphorous fertilizers. At both low and high soil pHs, soil phosphorous can be tied up and not readily available to the plant. This can be partially alleviated with the application of additional phosphorous but the most cost-effective and agronomically effective method would be to correct the soil pH.

The phosphorous requirement of soybeans is not as high as some of the other legumes and rates of application of 20 pounds to 50 pounds of P_2O_5 per ace on low phosphorous soil usually give the most profitable yield results. It is best to follow the recommendations from the soil test results. It is possible to slightly reduce the rates of P fertilizer if it is applied as a band below the soil surface and not surface broadcast and incorporated.

Phosphorous banded with the seed can give a faster start and promotes growth, especially in cool wet soils. This early flush of growth may not always equate to greater yield but it could reduce weed competition. Phosphorus deficiency symptoms are not as definite in soybeans as with other crops, but the plant as a whole is usually stunted. The best way to identify phosphorous deficiency will be through soil testing.

4. Potassium

Soybeans have a high potassium (K) requirement and create a heavy drain on the potassium supply of the soil. The soybean plant has a higher capacity to extract potassium from the soil than other legumes, but potassium must be applied on soils testing low in potassium especially if high yields are to be obtained. Proper potassium nutrient management is important for both ful-season and double-crop soybean systems.

Potash deficiency is usually expressed by yellowing on the edges of the leaves and the leaves eventually become cupped (see photos below). If potassium deficiency is identified at an early growth stage recovery is still possible with an over-the-top application of potash 60-0-0.

5. Micronutrients

Currently, very few micronutrients are recommended for soybeans in Oklahoma. For most or all of the micronutrients, a soil test is the only definite determination of deficiency.

6. Molybdenum

Molybdenum (Mo) is sometimes deficient in highly acidic soils. A seed treatment of 0.2-ounce to .04-ounce of molybdenum per acre may be applied. However, if the soil is properly limed, the molybdenum

is this correct??

Potassium deficiency in soybean. Courtesty International Plant Nutrition Institute www.ipni.net.

deficiency is corrected. In Oklahoma tests, liming has proven to be the best solution for molybdenum deficiency problems.

7. Iron and Zinc

Iron (Fe) and Zinc (Zn) deficiencies may occur on soybeans grown in calcareous (calcium and magnesium rich) and/or high pH (>7.5) soils. The most effective way to treat iron deficiency is by foliar spraying, but this method can be expensive and often fields that are only slightly deficient will grow out of the deficiency without a loss of yield. There are some varieties that are more sensitive to iron chlorosis in high pH soils, the local seed dealer should be able to help in the selection of the correct variety for the situation. Zinc deficiencies can be corrected by the application of 2 pounds to 4 pounds per acre of zinc in the form of a zinc sulfate or zinc chelate. Normally, zinc is applied with a starter fertilizer and may not need to be applied every year.

8. Other Fertility Considerations

Of the crops traditionally grown in Oklahoma, soybeans are one of the most sensitive crops to high amounts of fertilizer close to or with the seed. Fertilizers containing high amounts of nitrogen and potassium can be hazardous to obtaining good stands. Urea (46-0-0) and DAP (18-46-0) should be avoided, as they can release large amounts of free ammonia (NH_3) that will damage seed and seedlings.

Generally, germination and seedling emergence damage can be avoided by either applying the fertilizer as a broadcast application preplant or a 2x2 band (2 inches below and 2 inches to the side). Band application is recommended for soybeans, but broadcast application ahead of planting works well.

A historically successful approach for fertilization has been to build the fertility levels on the crop previous to soybeans in the rotation, especially in double crop soybeans. Soybeans do have the ability to utilize residual fertility, but caution must be exercised in depending entirely upon this source. Sufficient fertility must be carried over for the soybeans or additional fertilizer will have to be added for the soybean crop. For nutrients such as phosphorus and potassium, the total amount applied is less if the fertilizer is applied prior to the soybean crop as opposed to applying enough for the previous and soybean crop.

V. PEST MANAGEMENT

Producers face many crop and pest management decisions in soybean production. Decisions must be timely and accurate for profitable production. Integrated pest management (IPM) is a long-term management strategy for sustainability and to economically maximize soybean yields and profits.

A. Field Scouting

Field monitoring provides information on day-to-day and season-to-season field conditions, which can be used to evaluate crop and pest problems. Scouting assists in selecting the best measures from available alternatives in efficient crop management. Observations by a producer or scout determine if control measures or changes in crop management are necessary. Unnecessary operations add to production cost, reduce or eliminate profits, kill beneficial insects and contribute to pesticide resistance. When needed practices are not followed, a substantial loss in crop yields and profits may result. Records of monitoring results, weather and management activities should be maintained. Information on pest numbers, distribution and damage must be considered, along with the economics of the crop, crop growth stage and management alternatives.

Field sampling of soybeans need not be complicated to provide a good picture of field conditions. Fields should be checked weekly to obtain an idea of potential problems. Late in the season, during August and September, checking at five-day intervals is suggested for insect pests. General guidelines to ensure that sampling is accurate and unbiased include:

- Make sure samples represent the whole field by randomly selecting at least five sites per 40-acre field.
- More sites should be checked in larger fields.
- Observe each plant, the general appearance of the field and plant growth stage.
- If unrecognizable problems are encountered, specimens should be collected, labeled and sent to the local county Extension office.

B. Treatment Decisions

Soybeans tolerate large numbers of insects and their damage with little or no reduction in yield. How many pests and how much damage can be tolerated is referred to as the “economic threshold.” The decision to apply insecticides should be based on the common-sense rule "don't spray unless a positive return on investment is expected." Guidelines for weeds, diseases and nematodes are less quantitative and based on the history of a field, stage of crop development, weather and other field observations. Control action guidelines are useful only when practical, with accurate pest identification and careful field monitoring.

C. Weed Management

1. Scouting for Weeds

Weed maps are an effective weed management tool and are dependent on correct identification of weeds. A weed map is a diagram of the field with notations as to the location and estimated size of weed infestations. A weed scouting and mapping program produces a multi-year history of the field. If good weed management programs are followed and weed populations in the field are small, scouting field borders gives a good indication of potential weed problems for the next year.

A critical time to scout soybean fields is during the first eight weeks following planting. If soybeans are kept weed free for approximately six weeks after planting, a vigorous crop can successfully compete with most late-germinating weeds. The first post-emergence herbicide application is typically applied within two weeks after soybean emergence. It is essential that scouting of fields begin within seven to 10 days after planting in order to economically control these early, competitive weeds.

A second critical time for weed mapping is late in the season when perennial and annual weeds are large and easily seen. This helps to determine future weed control programs.

2. Weed Control

The best program for weed control in soybeans involves the proper selection of herbicides in combination with the use of various cultural and mechanical methods. Detailed discussion of agronomic management that could be used to aid in weed management strategies can be found in PSS-2794, Meshing Soybean Weed Management with Agronomic Practices in Oklahoma.

Crop Rotation - Crop rotation can be very important in a total weed control program. By rotating crops and using herbicides which cannot be used in soybeans, a specific weed problem can be reduced. For example, a grower could rotate grain sorghum into soybean fields with heavy pigweed, cocklebur and morningglory infestations. Growing grain sorghum in the rotation would permit the use of 2,4-D, which provides effective and economical control of broadleaf weeds. Conversely, soybeans also can be a useful rotational crop if trying to reduce populations of grassy weeds in wheat.

Row Spacing – Soybeans planted in narrow rows provide earlier and greater canopy cover than soybeans planted in wide rows. The earlier canopy cover will help shade out late-germinating weeds and suppress their growth.

Seedbed Preparation - Good seedbed preparation provides the foundation for any successful weed control program. A firm, weed-free seedbed should be prepared. Rapid germination will be enhanced by planting soybeans in a warm, moist soil. This practice will give the soybean plants a head start on weed seedlings.

In no-till production systems, it is especially important to start the growing season with a weed-free seedbed. Perennial and winter annual weeds, such as curly dock, common chickweed and marestail, can interfere with planting and reduce yields due to early-season competition for light, nutrients, moisture and space. Additionally, several winter annual weeds can serve as alternate hosts for diseases, insects and nematodes and should be controlled either in the fall or early spring to reduce pest populations. Burndown applications that include glyphosate and 2,4-D are usually the most effective at controlling weeds prior to planting. When using 2,4-D before planting, remember that rates up to 0.5 lb ai/acre (1 pt of LV4) must be applied at least seven days before planting. Rates greater than 0.5 lb ai/acre of 2,4-D (greater than 1 pt of LV4) require at least 30 days between application and planting. Other herbicides, such as Gramoxone Inteon® (paraquat) or Ignite® (glufosinate) may also be used for burndown applications. Before using any herbicide, be sure to check the label for planting restrictions following application.

Cultivation - Cultivation of soybeans helps reduce weed competition and herbicide costs. A rotary hoe can be used when most of the weeds have germinated but have not emerged from the soil. The rotary hoe can be used from one to three times, but use should be delayed until the heat of the day when uprooted weeds will die quickly. If herbicides are not used for weed control, shallow cultivation with sweeps may be needed. If herbicides are banded in the soybean rows, cultivation with sweeps can be used to control weeds

Table 12. Burndown, preplant or preemergence herbicide options. (See Table 14 for descriptions of Mode of Action).

Trade name	*Active ingredient(s)*	*Mode(s) of action*	*Weeds controlled*
2,4-D ester	2,4-D	4	broadleaf weeds
Aim	carfentrazone	14	pigweed, velvetleaf, morningglory
Authority Assist	sulfentrazone	14	
	imazethapyr	2	broadleaf weeds
Authority First, Sonic	sulfentrazone	14	
	cloransulam	2	broadleaf weeds
Authority MTZ	sulfentrazone	14	
	metribuzin	5	broadleaf weeds
Boundary	s-metolachlor	15	
	metribuzin	5	grass and broadleaf weeds
Canopy	chlorimuron	2	
	metribuzin	5	broadleaf weeds EXCEPT nightshade
Canopy EX	chlorimuron	2	
	tribenuron	2	broadleaf weeds EXCEPT nightshade
Clarity	dicamba	4	broadleaf weeds
Command 3ME	clomazone	13	annual grasses, lambsquarters, velvetleaf
Domain DF	flufenacet	15	
	metribuzin	5	grass and broadleaf weeds
Dual II Magnum, Cinch	s-metolachlor	15	annual grasses, yellow nutsedge
Envive	chlorimuron	2	
	flumioxazin	14	
	thifensulfuron	2	broadleaf weeds
FirstRate	cloransulam	2	marestail, broadleaf weeds
Gangster FR	flumioxazin	14	
	cloransulam	2	broadleaf weeds
glyphosate (many trade names)	glyphosate	9	grass and broadleaf weeds
Gramoxone Inteon[r]	paraquat	22	most annual and broadleaf weeds
Ignite 280 SL	glufosinate	10	annual grass and broadleaf weeds
Intro[r]	alachlor	15	annual grasses, yellow nutsedge
Linex	linuron	7	broadleaf weeds
Outlook	dimethenamid-P	15	annual grasses, yellow nutsedge
Prefix	s-metolachlor	15	
	fomesafen	14	grass and broadleaf weeds EXCEPT velvetleaf
Prowl H2O	pendimethalin	3	annual grasses,
Pursuit Plus	imazethapyr	2	
	pendimethalin	3	grass and broadleaf weeds EXCEPT cocklebur
Python	flumetsulam	2	broadleaf weeds
Scepter	imazaquin	2	broadleaf weeds
Sencor	metribuzin	5	broadleaf weeds EXCEPT nightshade
Sequence	s-metolachlor	15	
	glyphosate	9	grass and broadleaf weeds
Sonalan HFP	ethafluralin	3	annual grasses
Synchrony XP	chlorimuron	2	
	thifensulfuron	2	broadleaf weeds EXCEPT nightshade
Treflan HFP	trifluralin	3	annual grasses
Valor SX	flumioxazin	14	nightshade, pigweed, lambsquarters, morningglory
Valor XLT	flumioxazin	14	
	chlorimuron	2	broadleaf weeds

Table 13. Postemergence herbicide options.

Trade name	*Active ingredient(s)*	*Mode(s) of action*	*Weeds controlled*
2,4-DB (many trade names)	2,4-DB	4	broadleaf weeds
Assure II	quizalofop	1	annual and perennial grasses
Basagran	bentazon	6	yellow nutsedge, broadleaf weeds EXCEPT pigweed, nightshade and morningglory
Cadet	fluthiacet	14	velvetleaf and pigweed
Classic	chlorimuron	2	broadleaf weeds EXCEPT lambsquarters, nightshade
Cobra	lactofen	14	broadleaf weeds EXCEPT lambsquarters, smartweed and velvetleaf
Extreme	imazethapyr	2	
	glyphosate	9	grass and broadleaf weeds
FirstRate	cloransulam	2	marestail, broadleaf weeds EXCEPT pigweed, lambsquarters and nightshade
Frontrow	cloransulam	2	
	flumetsulam	2	broadleaf weeds
Fusilade DX	fluaziflop	1	annual and perennial grasses
Fusion	fluaziflop	1	
	fenoxaprop	1	annual and perennial grasses
glyphosate (many trade names)	glyphosate	9	most grass and broadleaf weeds
Harmony GT XP	thifensulfuron	2	lambsquarters, pigweed, smartweed and velvetleaf
Ignite 280 SL	glufosinate	10	most grass and broadleaf weeds
Poast, Poast Plus	sethoxydim	1	annual and perennial grasses
Pursuit	imazethapyr	2	cocklebur, pigweed and broadleaf weeds
Raptor	imazamox	2	grass and broadleaf weeds
Reflex, Flexstar	fomesafen	14	broadleaf weeds
Resource	flumiclorac	14	velvetleaf
Scepter	imazaquin	2	cocklebur and pigweed
Select, Select Max	clethodim	1	annual and perennial grasses
Sequence	s-metolachlor	15	
	glyphosate	9	grass and broadleaf weeds
Ultra Blazer	acifluorfen	14	broadleaf weeds EXCEPT lambsquarters and velvetleaf

Table 14. Herbicide Modes of Action (categorized by group number)

Group Number	*Mode of Action*
1	ACCase inhibitors
2	Branched-chain amino acid inhibitors (ALS inhibitors)
3	Microtubule assembly inhibitors (Root growth inhibitors)
4	Growth regulators (Auxin-type herbicides)
5	Photosynthesis inhibitors (PSII inhibitors)
6	Photosynthesis inhibitors (PSII inhibitors)
7	Photosynthesis inhibitors (PSII inhibitors)
9	Aromatic amino acid inhibitors (EPSPS inhibitors)
10	Glutamine synthetase inhibitors
13	Carotenoid biosynthesis inhibitors
14	Cell membrane disruptors (PPO inhibitors)
15	Very long chain fatty acid inhibitors (Shoot inhibitors)
22	Cell membrane disrupotrs (PSI inhibitors)

in the row middles. Cultivation should be done early in the growing season. Avoid ridging of soil because this contributes to combining difficulty and harvest loss.

Cover crops- are more of a novel management practice that can be integrated into production systems to aid in weed control. Detailed information can be found in PSS-2792, Cover Crops for Weed Management in Oklahoma. Cover crops work in two different ways to help suppress weeds, either physical or allelopathic suppression. Physical suppression is the more effective and consistent way. Physical suppression involves limiting resources, i.e. sunlight, nutrients, water and space to weed growth. To be successful in physical suppression, rapid canopy coverage is required. This can be accomplished through crops with rapid growth (such as Brassicas or grasses) or through increased seeding rates. Allelopathic suppression is a little more challenging. Most plants produce allelopathic chemicals that can inhibit the growth and development of neighboring plants. Cover crops, such as rye or Brassicas, have been documented to have varying degrees of allelopathy to some plants. The challenging with allelopathic weed suppression resides on cover-crop growth stage at termination and environmental conditions. Cover crops varies their allopathic compounds production under different soil water and temperature conditions. The effectiveness of cover crops uses as weed control method is still questionable in Oklahoma.

Herbicides - Herbicides must be applied in a timely manner to maximize weed control and minimize yield loss due to weed competition. Consult the product label for optimal application timing for each herbicide. No single herbicide solves every weed problem for the entire growing season. Generally, a weed control "systems approach" is required that includes use of pre-plant, pre-emergence and/or post-emergence applications. Herbicides may not be needed at all three stages, but often applications at two or more of these stages are necessary for an effective program. This often involves the use of one herbicide or a mixture of multiple herbicides as either a pre-plant or pre-emergence application to control germinated and early season weeds. Later, post-emergence herbicides are applied as needed to control weed escapes or larger-seeded weeds that soil-applied herbicides do not adequately control. While weed control programs that use only post-emergence applications can be successful, soil-applied herbicides with residual activity included with the pre-plant burndown or pre-emergence application will improve early-season weed control and provide greater flexibility for the timing of post-emergence applications (Tables 13 and 14). This can be especially useful should weather conditions prevent timely post-emergence applications. Another benefit of including a soil-applied herbicide is the opportunity to use multiple herbicides with different modes of action (Table 14). This is an important proactive approach to preventing the development and spread of herbicide-resistant weeds, particularly where Roundup® Ready (glyphosate-resistant) crops are part of the rotation and glyphosate is repeatedly used.

Selection of herbicides must be based on the weeds present, their size at the expected time of application and the presence of herbicide-resistant weeds. For pre- and post-emergence weed control, there are many options available for the spectrum of weeds often found in soybean fields. Crop rotation should also be considered to avoid herbicide carryover issues with subsequent crops.

Glyphosate-resistant soybean varieties have greatly simplified weed control. However, proper application timing is still important to achieve maximum weed control and minimize yield loss due to weed competition. For post-emergence weed control in glyphosate-resistant soybeans, glyphosate should be applied when weeds are 4 inches tall or less in narrow rows (15 inches or less) and 6 inches tall or less in wide rows (15 to 36 inches). For most applications in glyphosate-resistant soybean, the recommended glyphosate rate is 0.75 lbs of acid equivalent per acre. Depending on the glyphosate product, use rates could range from 20 to 32 fluid ounces of glyphosate per acre (Table 15). Be sure to check the glyphosate label to determine the formulation, appropriate rate to apply and necessary adjuvants to improve weed control. Additionally, be sure to check the label for the maximum amount of glyphosate that may be applied in a single application and during the entire growing season. When using glyphosate, always add spray grade ammonium sulfate (AMS), or a suitable AMS replacement, at a rate of 8.5 to 17 pounds per 100 gallons of spray solution to the spray tank before adding glyphosate. The sulfate component of AMS is negatively charged and will bind to positively charged hard water ions, such as calcium, magnesium and iron. This prevents the hard water ions from binding to the glyphosate molecule, decreasing its activity in the plant. Again, using soil-applied herbicides with residual activity can be useful in glyphosate-resistant soybean production to reduce early season weed competition and prevent the development and spread of herbicide-resistant weeds.

If herbicide-resistant weeds are a problem, it is important to take the appropriate steps to prevent further spread of resistant weeds. Integrating chemical, mechanical and cultural weed control methods into the production system will help in the management and control of herbicide-resistant weeds. If glyphosate-resistant weeds are suspected, be sure to include an additional herbicide that has activity on the resistant weed. Preventing weeds from going to seed is another important tool for herbicide-resistant weed management.

Table 15. Use rates for glyphosate products with various active ingredient (ai) and acid equivalent (ae) concentrations.

Glyphosate formulation		*0.75 lbs ae/acre*	*1.13 lbs ae/acre*	*1.5 lbs ae/acre*
lbs ai/gal	*lbs ae/gal*		*fl oz/acre*	
4	3	32	48	64
5	3.7	26	39	52
5.4	4	24	36	48
5	4.17	24	34	48
5.5	4.5	22	32	44
6	5	20	30	40

WEED IDENTIFICATION

Generally, summer annual weeds are the most problematic in soybean production. However, as no-till production increases, shifts toward increased populations of winter annual and perennial weeds have been observed. Regardless of production practice, weeds must be identified and controlled when they are small to ensure adequate control with herbicides.

Photos of common weeds follow.

Annual morningglory species.

Common Names	Scientific Name
Summer annual weeds	
Annual morningglory species	*Ipomoea* spp.
Pigweed species	*Amaranthus* spp.
Common lambsquarters	*Chenopodium album*
Eastern black nightshade	*Solanum ptycanthum*
Jimsonweed	*Datura stramonium*
Prickly sida	*Sida spinosa*
Hophornbeam copperleaf	*Acalypha ostryifolia*
Hemp sesbania	*Sesbania exaltata*
Sicklepod	*Cassia obtusifolia*
Pennsylvania smartweed	*Polygonum pensylvanicum*
Common cocklebur	*Xanthium strumarium*
Velvetleaf	*Abutilon theophrasti*
Tropic croton	*Croton gladulosus*
Giant ragweed	*Ambrosia trifida*
Crabgrass	*Digitaria* spp.
Barnyardgrass	*Echinochloa crus-galli*
Texas panicum	*Panicum texanum*
Winter annual weeds	
Marestail	*Conyza canadensis*
Henbit	*Lamium amplexicaule*
Common chickweed	*Stellaria media*
Perennial weeds	
Honeyvine milkweed	*Ampelamus alibidus*
Field bindweed	*Convolvulus arvensis*
Pokeweed	*Phytolacca americana*
Johnsongrass	*Sorghum halepense*
Yellow nutsedge	*Cyperus esculentus*

Barnyardgrass.

Common chickweed (Photo credit: Erin Taylor).

Common cocklebur.

Common lambsquarters.

Crabgrass.

Field bindweed.

Giant ragweed.


Hemp sesbania.


Henbit (Photo credit: Erin Taylor).


Honeyvine milkweed.


Hophernbeam copperleaf.


Jimsonweed.


Johnsongrass.


Marestail.

Palmer amaranth.

Pennsylvania smartweed.

Pokeweed.


Prickly sida.


Sicklepod (Photo credit: Sarah Lancaster).


Texas panicum.


Tropic croton.


Velvetleaf.


Waterhemp.


Yellow nutsedge.

D. INSECT MANAGEMENT

Soybeans have few serious insect pests compared to other cultivated crops. However, an abundance of non-pest and beneficial insects are typically present in soybean fields. Beneficial insects usually keep harmful insect populations below economic thresholds. The potential for economic loss is possible each growing season and growers should inspect fields regularly to check for insect damage. Good pest management is the result of sampling fields, evaluating plant damage, correctly identifying insects and determining insect populations. Thresholds vary with the development of the crop. Treatment for insects should occur only when plant damage or insect counts exceed economic thresholds.

1. Scouting for Insects

Before employing chemical control measures for insects in soybeans, growers should be relatively sure that yield increases and/or the elimination of further damage will offset insecticide and application costs. Evaluation of the extent of insect infestations and timing insecticide applications are best accomplished by regularly surveying fields. Economic thresholds have been established for the major pests and applying insecticides should be based on careful scouting and using thresholds for the various pests. Economic thresholds may be based on insect counts or plant damage. Percent defoliation is often used for foliage feeders.

From mid season to pod fill, scouting for insects feeding on foliage or pods can be conducted by shaking plants over a drop cloth or shake sheet. This method is often referred to as the **drop cloth method**. This plant-shaking method is a useful tool for weekly survey of soybeans after the beans obtain 1 foot in height. The equipment needed for this method consists of a piece of white or off-white cloth that measures 24 by 42 inches. Each end of the cloth is stapled to a thin strip of wood, approximately 1/2 to 1 inch wide and 24 inches long.

To begin the survey, select a random site in the field, kneel between the two rows and unroll the cloth from one row over to the opposite row. Extend each arm forward, parallel with the row on either side. The surveyor then shakes the plants over the cloth. Their arms, from elbows to fingertips, will allow approximately 1 1/2 row feet of plants on each side of the row. Thus, a total of 3 row feet may be sampled at each side. Count the insects that fall to the cloth. This process should be repeated until approximately 10 sites have been sampled per field (up to 50 acres in size). Infestations are then evaluated as to the number of various species per 30-inch row foott. This method provides good information for making treatment decisions about defoliating caterpillars (loopers, earworms, armyworms, etc.) and stink bugs.

Another method for scouting fields is the **sweep net method,** which is most effective for younger soybean plants as this method can be damaging at more advanced reproductive stages. A standard 15-inch diameter sweep net is used to make 10 consecutive sweeps (180 degrees) while walking through the field. The net is swung from side to side with each step. After 10 successive sweeps, the insects should be identified and counted as they are removed from the net. Repeat this process five times for a total of 50 sweeps. Compare counts with economic thresholds established for individual pests. This method is particularly useful on seedling and broadcast beans.

Estimating percent defoliation is another way to determine when to treat for foliage feeders. Determine the percent defoliation of the plants in the entire field (not of individual plants) by taking several leaves at random from several random plants, then estimate the amount of leaf that has been eaten by foliage feeders.

2. Suggestions for Soybean Insect Control

A. Stem and Seedling Feeders

These pests are not usually a problem if there is a good stand of beans. Stem and seedling feeders will generally do most of their damage before the soybeans are 12 inches tall. Growers must make well-timed applications of insecticides. Isolated infestations can normally be tolerated because soybeans usually compensate if there are at least four plants per row foot.

Threecornered Alfalfa Hoppers

Spissistilus festinus

These leafhoppers feed on stems in the adult and nymphal stage. They girdle stems at or a few inches above the soil level. This girdling activity frequently causes lodging when the plants get larger. They are mainly of economic concern in the early season. Before bloom, treatment is suggested if 10% to 15% of the plants are girdled and nymphs are still present. At pod set, treat if three nymphs or one adult per row foot are recovered using the drop cloth method. Another recommendation suggests treatment when counts exceed one adult per sweep at post bloom.

Cutworms

Various species

Cutworms are erratic, but usually occur early in the growing season. Stands may be destroyed if heavy numbers exist. Rescue treatment is suggested when 30% or more of young plants are lost.

Lesser Cornstalk Borers

Elasmopalpus lignosellus

These caterpillars girdle stems and roots of soybean plants. This bluish-green worm is found at the soil surface or beneath the surface in tubes or sacs that are made of soil particles woven together with silken material. It reaches up to 2/3-inch long and is very active when touched. Treat when 30% stand reduction occurs.

False Cinch Bug

Nysius raphanus

This insect rarely achieves pest status in Oklahoma. Often preferring to feed on several different weed species, such as composite flowers like the great-flowered gaillardia, also on stink-grass or strong-scented lovegrass, thyme-leaved spurge, carpet-weed, shepherd-spurse, Russian thistle, sage-brush and pepper-grass. Under drought conditions, large populations will migrate into cultivated crops and begin feeding on many different plants. They have been commonly found on alfalfa, soybeans and other crops grown in Oklahoma. These insects congregate in large numbers on a few plants and cause the plant to wilt. Adults of the false chinch bug are about 1/8 inch long and 1/20 of an inch wide. It omits an offensive odor when disturbed. It is more slender than the chinch bug and there is no black coloration on the wing covers. It is black beneath and half covered by whitish wings above. Seedling plants are particularly susceptible. Use of insecticides to combat this pest should be considered as a last resort. If extreme populations occur early in the season and plant wilting is evident, insecticides may be needed. In conventionally tilled beans, target the field margins where populations of the bugs have begun on wild hosts. Keep weed growth around field margins minimized throughout the year. In reduced tillage systems, or where Roundup Ready® soybeans are used, the possibility exists for false chinch bugs to build up on weeds within the field, then move onto soybean plants after controlling the weeds. Growers should be aware of this possibility and treat their fields accordingly when these insects are present in high numbers.

B. Foliage Feeders

Treat defoliators as a group. In sampling populations of these insects, an estimate of percent leaf loss is the best way to assess the damage as a basis for initiating control of defoliators. Research in various states has shown that soybean plants can withstand 35% foliage loss up to one week before blooming. After bloom and during pod fill, no more than 20% defoliation should be allowed. After full pod, defoliation of 35% can be tolerated.

Bean Leaf Beetles

Cerotoma trifurcata

These 1/4-inch-long beetles are usually yellow (can be red, orange, tan or gray) with black markings, eat round holes in leaves and sometimes feed on small pods. Bean leaf beetles also transmit bean pod mottle virus. Treatment is based on defoliation unless pod feeding is involved. Treat them when feeding damage is found on 10% of the pods.

Blister Beetles

Various species

Blister beetles are soft-shelled, have an elongated body shape and usually infest isolated parts of the field. They are generally most prevalent from mid-June to late July. They feed on foliage, flowers and other plant parts. They usually are noticed when several rows are entirely defoliated. Spot treatment is usually effective in controlling this pest.

Fall Armyworm

Spodoptera frugiperda

Infestations are most common from July through September. This caterpillar ranges in color from tan to green to black, with thin yellow and red stripes, but is identified by an inverted "Y" on the head capsule. During the late season it can be very damaging.

Garden Webworms

Achyra rantalis

Webworms usually occur from July through August on late-planted soybeans. Heavy infestations of this small, spotted larvae can destroy entire fields. Double-cropped beans are especially susceptible. They feed inside webs they have spun on the leaves and terminals.

Severe infestations may cause complete loss of the field. Replanting is sometimes required as a result of heavy infestations of this pest.

Grasshoppers

Various species

Grasshoppers are a threat because of the heavy defoliation caused by large infestations. They are erratic and may occur throughout the season. Infestations are greatest during hot, dry weather. Border treatments can be effective for hoppers migrating into soybean fields.

Green Cloverworms

Hypena scabra

These caterpillars consume whole leaves. They often are found during June or July, but the biggest population usually develops in mid August. The larvae have three pair of prolegs. These slender green larvae with longitudinal fine white stripes are almost always present in soybean fields in populations below economic thresholds.

Loopers

Trichoplusia ni, other species

Loopers are long, pale green worms that move with a looping motion. Larvae have two pair of prolegs. They are a mid- to late-season pest. Control is based on percent defoliation or when eight worms (1/2 inch in length) are found per foot of row. When using the sweep net method, treat when 150 larvae are collected from 100 sweeps.

Mites

Tetranychus urticae, other species

Mites have eight legs and are more closely related to spiders than insects. They are usually accompanied by hot, dry weather. They extract sap from foliage and cause the plants to turn reddish brown.

Soybean aphid

Apphis glycines

Although this potentially devastating pest has not been recorded in Oklahoma, it was found as close as Missouri and throughout several Midwestern states. Soybean aphid populations build and peak during the period between late seedling stage (V2, two fully expanded trifoliate leaves) to blooming stage (R1-R2) of soybean. Colonies concentrate on new terminal trifoliate leaves and new leaves on side branches. Aphid infestations peaking at R1 to R2 growth stages of the host may cause stunted plants with reduces pod and seed counts, resulting in lower yields. Later in the growing season, heavily infested plants may have distorted and have yellowed leaves. Charcoal-colored residue on stems, leaves and pods is sooty mold that grows on honeydew, a by-product excreted by aphids. Although this aphid is capable of transmitting viruses to host plants, no documented cases of such a transmission on soybeans has been noted. Economic thresholds for this pest have not been established. Early indications suggest numbers around 1,000 per plant and/or heavy infestations with evidence of some honeydew as a threshold for treatment.

Velvetbean Caterpillars

Anticarsia gemmatalis

These caterpillars may occur from mid to late season. They can grow to about 1 1/2 inches in length and vary in color from green to brown or black, with light and dark stripes running along their backs and sides. They thrash vigorously when disturbed. The economic threshold is three per sweep using the sweep net method or 8 feet of row using the drop cloth method.

Yellow Striped Armyworms

Spodoptera ormthogalli

These armyworms are dark gray to black, with two distinct yellow stripes down the center of the back. They are another foliage feeder on soybeans that should be considered.

C. Pod Feeders

The greatest loss to soybeans is caused by insects that attack the pods. Only a few insect pests actually attack the pods. Control is based on numbers of insects present when scouting. It is very important to scout closely during pod set until maturity to protect beans from pod feeders.

Corn Earworms

Helicoverpa zea

Corn earworms are also called soybean podworms, cotton bollworms, sorghum headworms and tomato fruitworms. They grow to about 1 3/4 inches in length and are yellow-green, pink, brown or black with irregular light and dark stripes along the length of their bodies. The moths usually fly into soybean fields and lay eggs in August. Peak populations generally occur in mid-August. Small worms hatch from the eggs and start feeding on foliage, later moving to pods. Research has found that one worm will damage approximately 20 pods. This is probably the most destructive pest of soybeans because of direct yield loss. Fields should be treated when populations exceed two worms per row foot using the drop cloth method.

Stink Bugs
Various species

Stink bugs lower the quality of soybeans when the feeding activity of nymphs and adults is heavy. Major types of stinkbugs include: green, brown, red-banded and marmorated. The major stinkbugs for the state are typically green and brown; however, red-banded stink bugs are possible within the state and can be devastating in infestations are high. They are 3/8 inch to 3/4 inch long, shield-shaped, broad-shouldered and color will vary based on type and life stage. There are many other types of stink bugs that are predators of pest insects. Plant-feeding stink bugs suck sap from bean pods and the insertion of digestive juices into the bean may cause deterioration. Developing beans are susceptible until maturity. Control is recommended when one or more stink bugs per row foot are found using the drop cloth method or whenever 36 bugs per 100 sweeps are collected with the sweep net method.

3. Insecticide Treatments

Treatment for the various pests should be made after evaluating plant damage, insect numbers, stage of soybean development and beneficial populations present. Since the insecticides recommended for many insect pests change frequently, no specific recommendations are included in this handbook. For current recommendations and rates contact the local county Extension office.

4. Precautions

All insecticides are toxic and must be handled with caution. Before handling an insecticide, read and follow all label directions. Pay special attention to all safety precautions and handle insecticides in such a way as to prevent spillage and avoid breathing the vapors. If spillage occurs and any personal contamination occurs, wash the contaminated area thoroughly with soap and large quantities of water immediately, then change clothing. If contamination is extensive or involves one of the more toxic materials, contact a local physician.

Insecticides should always be stored in a dry, well-ventilated area that is kept locked when not in use. All insecticides are to remain in their original containers. Keep labels as legible as possible.

E. SOYBEAN DISEASES

Fungi, bacteria, nematodes and viruses are pathogens that cause soybean diseases in Oklahoma. These pathogens attack seed, seedlings, roots, foliage, pods and stems. Diseases result in various symptoms such as stand loss, leaf spots, wilting and premature plant death. Some diseases are minor and cause only cosmetic injury, while others can cause yield loss and poor seed quality. The severity of disease is influenced by the presence and amount of the pathogen, variety selection and environmental conditions. Disease management involves using cultural practices (crop rotation, residue management, etc), resistant varieties and chemical control (fungicides) when needed. Crop management that integrates several different disease control strategies generally improves success and the potential for profitable soybean production. Monitoring soybean fields to detect the early stages of disease and pest outbreaks as well as keeping good records on their occurrence and distribution allows for timely and economical application of management inputs.

1. Diseases Identification

Correct identification of soybean diseases is essential for effective disease management. For example, fungicides do not control bacterial diseases, therefore it is important to distinguish between diseases such as bacterial blight and soybean rust, a fungal disease that potentially reduces yield. The following list describes the most common diseases of soybeans in Oklahoma and general control recommendations. Some diseases such as frogeye leaf spot are easy to identify, while others require microscopic examination in the laboratory. Contact your local OSU Extension educator for information on submitting samples to the OSU Plant Disease and Insect Diagnostic Laboratory.

a. Seed, Seedling and Root Diseases

Seed Rot (*Pythium* spp., *Rhizoctonia solani, Phytophthora sojae, Fusarium* spp.)

With seed rot, the soybean seed physically rots and fails to emerge from the soil, resulting in poor germination and stand establishment. The problem usually results from poor-quality (low germ or moldy) seed, planting too deep or from wet and cold soils after planting. Control strategies include planting high-quality seed (more than 85% germination) when soil temperature and moisture favor rapid seed germination and seedling growth as well as use a fungicide seed treatment when seed quality or planting conditions are not ideal.

Seedling Disease/Damping Off (*Pythium* spp., *Phytophthora sojae, Rhizoctonia solani, Fusarium* spp.)

Plants wither and die after emergence or are stunted and grow slowly. Dark and firm or watery and soft decay of the roots and stem occurs at or below the soil line. Control strategies include planting high-quality seed (>85% germ) when soil temperature and soil moisture favor rapid seed germination and seedling growth and use a fungicide seed treatment when seed quality or planting conditions are not ideal.

Phytophthora Root Rot (*Phytophthora sojae*)

The disease occurs during cool, wet weather in soils with high clay content, in poorly drained soils or in low spots in a field. A wet, dark brown decay of stem and lower branches occurs first near the soil line and moves upward on the lower stem. Affected plants turn yellow and wilt. Roots are dark brown and rotted. The disease may occur at any stage of growth, but it is more common on young plants. Control strategies include planting resistant varieties, use tillage practices that promote good soil drainage and treatment of seed and/or soil with products containing metalaxyl or mefenoxam.

Charcoal Rot (*Macrophomina phaseolina*)

Disease associated with hot dry weather in mid to late season. Charcoal rot usually appears in patches, with droughty areas developing the first visible symptoms. Plants loose vigor, turn yellow, wilt and die with leaves remaining attached (Figure 10). Internal discoloration of tap root and upper stem is silver to gray in color. Numerous black, pepper-like sclerotia form under the bark of lower stem and roots (Figure 11). Control strategies include maintaining adequate soil fertility, irrigation to reduce moisture stress and avoiding high seeding rates.

Root-knot Nematode (*Meloidogyne* spp.)

Symptoms consist of stunting, poor growth, yellowing, general decline and early maturity. Galls of various sizes develop on infected root systems in response to nematode feeding giving the roots a swollen, deformed or excessively branched root system depending on the species involved (Figures 12 and 13). Symptoms are

Figure 10. Charcoal rot.

Figure 11. Charcoal rot.

often irregularly distributed, occurring in patches. Crop rotation with corn, sorghum or grassy forages should be considered. Resistant varieties are available, but resistance to root-knot nematode is distinct from that for cyst nematode.

Southern Blight (*Sclerotium rolfsii*)

Generally a minor problem on scattered or localized patches of plants in mid- to late season. Plants wilt and die. Base of stems covered with white, stringy mold that may extend onto the surrounding soil. Small, mustard seed-like reproductive structures (sclerotia) develop on the white mold. Crop rotation with non-host crops such as corn, sorghum and cotton will reduce disease levels.

Soybean Cyst Nematode (*Heterodera glycines*)

Symptoms range from none to various degrees of plant stunting and yellowing, often occurring in ir-

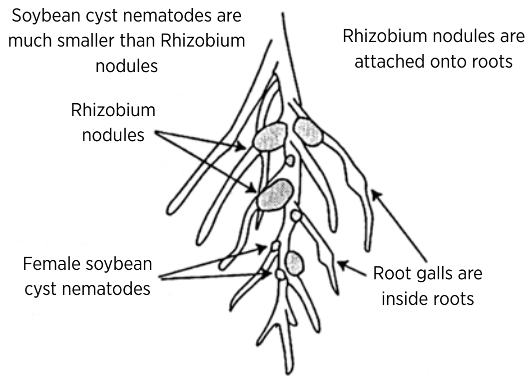

Figure 12. Comparison of Rhizobium (N-fixing) nodules, soybean cyst, nematode and root-knot nematode galls.

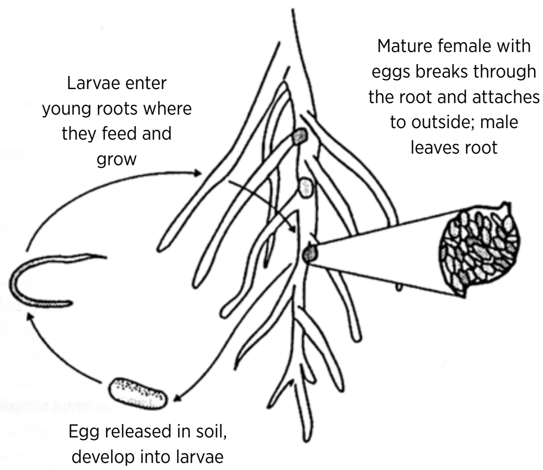

Figure 13. Life cycle of the soybean cyst nematode.

regularly shaped in patches. Symptoms may resemble nutrient deficiencies, herbicide injury, or drought stress. Yield losses of 15% to 20% may occur without visible symptoms, yet visible symptoms may appear as evidence of a problem that has developed over several years. By late season, root systems contain white to yellow colored cysts that are much smaller than the nitrogen-fixing nodules (Figures 11 and 12). Use of resistant varieties and crop rotation with corn, cotton, sorghum, or grassy forages is recommended.

Sudden Death Syndrome (*Fusarium solani* f. sp. *glycines*)

This root rot disease is not common in Oklahoma, but can occur mid to late season under cool, wet conditions. It is often associated with soybean cyst nematode and deep, fertile river bottom soils that are under irrigation. Leaves develop yellow blotches between the veins that enlarge and turn brown. Defoliation occurs, but the petioles remain attached to the stem. Internal areas of lower stems and roots turn gray-brown but the stem pith (hollow area) remains white. Controls include improving drainage, planting resistant varieties and using cultural practices that reduce soybean cyst nematode.

Sting Nematode (*Belonolaimus* ssp.)

This nematode pest is most common in the sandy soils in the Arkansas River Valley. Plants are yellowish and often severely stunted. Dark, sunken lesions girdle roots, resulting in a stubby root system. Root tips may be blackened with a proliferation of root growth above the damaged root tip. Relatively low densities of sting nematodes are damaging and the nematode is best detected in soil samples when damage is first noticed on young crops from 30 to 45 days after planting. Because of its wide host range which includes corn and grain sorghum as susceptible crops, crop rotation is less effective than fallow.

b. Foliar Diseases

Bacterial Blight (*Pseudomonas glycines*)

Small, angular, brown spots surrounded by a yellow border (Figure 14). Spots appear water-soaked on the undersides of leaves when wet. Spots fall out and leaves become ragged in appearance. Infected seed may be shriveled, slightly discolored or may not show any symptoms at all. Control strategies include the use of high-quality seed, crop rotation to avoid disease build-up and use of tillage to bury diseased crop residue.

Brown Spot (*Septoria glycines*)

Brown spot is the most common foliar disease in Oklahoma. The disease is most severe in old soybean fields and on early planted soybeans. Lower leaves develop pinpoint sized, brown spots that may enlarge to ¼-inch in diameter and be surrounded by a yellow border (Figure 15). Heavily spotted leaves turn yellow and drop, leading to significant defoliation in the lower canopy and mid-canopy. Control practices in rotation, incorporate diseased crop residue into soil and use fungicide seed treatments to prevent seed transmission.

Figure 14. Bacterial blight

Figure 15. Brown spot

Downy Mildew (*Peronospora manshurica*)

Downy mildew is a common foliar disease of soybeans that appears following periods of cool, wet weather. However, it is considered a minor disease that does not affect yield. Symptoms appear on younger (upper) leaves as pale green, then yellow spots (Figure 16). Spots enlarge to up to ½-inch in diameter; the centers die and turn tan colored with a yellow or light green border. In humid weather, tufts of tan-colored moldy growth are visible through a hand lens on the undersides of developing spots, often this is described to look like dryer lint. Control strategies include crop rotation, tillage of diseased crop residue into soil and use of fungicide seed treatments to prevent seed transmission.

Frogeye Leaf Spot (*Cercospora sojina*)

This is a sporadic disease that can reduce yield when severe. Reddish brown, circular to angular leaf spots are up to ¼-inch in diameter. The center of the spots turn gray as spots age, but the borders remain

Figure 16. Downy mildew

Figure 17. Frogeye leaf spot

purple to reddish brown (Figure 17). Plant resistant varieties, practice crop rotation, use fungicide seed treatments to prevent seed transmission and incorporate diseased crop residue into soil. Application of a foliar fungicide may provide an economic return.

Soybean Rust (*Phakospora pachyrhizi*)

Faint pale green to yellow flecks appear on leaves in the low and middle canopy during reproductive stages. Spots become angular and brown or reddish brown in color. Spots remain small but become numerous. Rust can be confused with brown spot and bacterial leaf spots. A key feature is the raised pustules (pimples) on the undersides of spots visible through a hand lens (Figure 18). Tufts of tan-colored spores also may be present. A fungicide program for rust control may be economical during reproductive stages in fields where the disease has been identified or threatens.

Cercospora Blight/Purple Seed Stain (*Cercospora kikuchii*)

Cercospora blight affects leaves, stems, pods and seed. Foliar symptoms first appear at the beginning of seed set (R5 growth stage) on upper leaves. Infected leaves become leathery and the upper surface develops dark, purplish to bronze colored discoloration (Figure 19). Dark purple spots develop on leaf petioles. Heavily infected leaves rapidly turn yellow and drop from the plant, mimicking natural leaf fall. Lower leaves remain green and attached to the plant. Round purple spots may develop on pods and seed with pink to dark purple stained areas may develop and become severe (Figure 20). There is no consistent correlation between the development of foliar symptoms and the occurrence of stained seed as they are two different strains.

Figure 18. Soybean rust

Figure 19. Cercospora blight

Figure 20. Purple seed stain

c. Pod and Stem Diseases

Pod and Stem Blight, Seed Decay (*Diaporthe* and *Phomopsis* spp.)

Plants are infected early in the growing season, but symptoms on the pods and stems do not appear until the plants are mature. Small black reproductive structures (pycnidia) develop in linear rows on mature stems or scattered on the pods (Figure 21). Affected seed may be covered with white mold or may be dull, cracked or shriveled. Diseased seed often will not germinate or will produce weak seedlings infected with the pod and stem blight pathogen. Practice crop rotation, plant high quality seed, use a fungicide seed treatment, harvest promptly and incorporate diseased crop residue into soil. Application of a foliar fungicide may provide an economic return.

Anthracnose (*Colletotrichum* spp.)

While anthracnose can affect plants at all stages of growth, it is most damaging on maturing plants during warm and rainy weather. Brown spots develop

Figure 21. Pod and stem blight

on leaves, stems and pods causing their premature death. Dark streaks develop on petioles and leaves prematurely roll and die. Numerous minute black fruiting structures appear spiny develop on the infected pods and stems that resemble pod and stem blight (Figure 21). Seed may be stained brown and appear moldy and shriveled. Control strategies include rotation with non-legume crops, incorporation of diseased crop residue into soil and use fungicide seed treatments to prevent seed transmission. Application of a foliar fungicide may provide an economic return.

Stem Canker (*Diaporthe phaseolorum* var. *caulivora*)

This disease is damaging when severe, but has not been common in Oklahoma. Reddish-brown spots appear at nodes of the main stem during reproductive stages (Figure 23). Spots enlarge into elongated cankers, girdling plants. Leaves develop yellow and brown areas between the veins, which resemble sudden death syndrome. Affected leaves roll inward, die and remain attached to stems. Yield losses occur when plants are killed prior to pod fill. Control strategies include crop rotation, management of crop residue and planting resistant varieties.

Figure 22. Anthracnose

Figure 23. Stem canker

d. Virus Diseases

Bean Pod Mottle (Bean pod mottle virus)

The bean leaf beetle spreads the virus to soybean crops from plants grown from infected seed, nearby infected perennial weeds and from overwintering beetles carrying the virus. Upper leaves become green to yellow mottled and may be puckered and distorted in shape (Figure 24). Stems of infected plants may remain green after the pods mature. Mixed infection with soybean mosaic virus can cause severe virus symptoms and yield loss. Little can be done except to plant high quality seed to help prevent virus introduction with contaminated seed.

Bud Blight (Tobacco ringspot virus or Tobacco streak virus).

The viruses are spread in contaminated seed and by thrips and nematodes. When plants are infected before flowering, terminal buds and shoots turn brown, curve down and become dry and brittle. Younger leaves often develop a rusty flecking. Plants are stunted and produce little seed. After flowering, infection results in aborted or poorly filled pods. Plants may remain green late at the end of growing season. Planting of

Figure 24. Bean pod mottle virus (Courtesy Laura Sweets, Univ. Missouri)

Table 16. Seed treatment fungicides for soybeans.

Disease	*Common name (MOA Group):* *Formulation and rate /100 lb Seed*	*Remarks*
Seed rot Seedling disease Damping off Phytophthora root rot	azoxystrobin (11):	
	Protégé-FL 0.2 to 0.27 fl oz	Slurry or mist type treatment.
	Dynasty 0.8F 0.15 to 0.46 fl oz	
	azoxystrobin + metalaxyl (11):	
	Soygard 0.32 to 0.43 fl oz	Slurry or mist type treatment.
	Bacillus subtilis:	Biological treatment.
	Kodiak HB 0.3D 4 to 8 oz	Planter box treatment.
	Integral 0.146 fl oz	Slurry or mist type treatment.
	captan (M):	
	Captan 400 4F 1.5 to 2.5 fl oz	Slurry or mist type treatment.
	Dyna Shield Captan 4F 1.5 to 2.5 fl oz	
	Captan Moly 50D 3.5 oz	Planter box treatment.
	Hi Moly/Captan-D 50D 3.3 oz	
	captan (M) + carboxin (7) + metalaxyl(4)	
	Bean Guard/Allegiance 41.25D 3.3 oz	Dry planter box treatment.
	captan (M) + carboxin (7):	
	Enhance 40D 5 oz	Dry planter box treatment.
	carboxin (7):	Slurry or mist type treatmet.
	Vitavax 34 3 to 4 fl oz	
	carboxin (7) + thiram (M):	
	Vitavax CT or Vitavax M 12 fl oz	Slurry, mist type or planter box treatment.
	Vitavax M or Vitaflo 4 fl oz	
	cloroneb (14) + mefenoxam (4):	
	Catapult XL 3.09F 5.5 to 7 fl oz	Slurry, mist type or planter box treatment.
	fludioxanil (12):	
	Maxim 4FS 0.08 to 0.16 fl oz	*Rhizoctonia* and *Fusarium* only. Slurry or mist type treatment.
	ipconazole (3):	
	Rancona 3.8FS 0.085 fl oz	*Rhizoctonia, Fusarium* and *Phomopsis* only. Slurry or mist type treatment.

Table 16. Seed treatment fungicides for soybeans. (cont'd)

Disease	*Common name (MOA Group):* *Formulation and rate /100 lb Seed*	*Remarks*
	metalaxyl or mefenoxam (4): Acquire 2.6F Acceleron DX309 Allegiance FL 2.6F Belmont 2.7FS, Metastar ST Dynashield Metalaxyl, Sebring 2.65SR, or Sebring 318 FS 0.75 to 1.5 fl oz Apron XL 3F 0.16 to 0.64 fl oz	Slurry or mist type treatment.
	Allegiance Dry 12.5D 1.5 to 2 fl oz	Planter box or dry seed treatment.
	metalaxyl (4) + PCNB (14) + carboxin (7): Prevail 33.1D 3.3 to 6.7 oz	Planter box or dry seed treatment.
	metalaxyl (4) + thiram (M): Protector L/Allegiance 6.7 fl oz	Planter box or dry seed treatment.
	pyraclostrobin (11): Diamir 1.67F 0.4 to 1.5 fl oz Acceleron DX109 1.67F 0.4 to 0.15 fl oz	Slurry or mist type treatment.
	mefenoxam (4) + fludioxonil (12): ApronMaxx RFC 0.52F 1.5 fl oz ApronMaxx or Warden RTA 5 fl oz Maxim XL 2.7F 0.17 to 0.33 fl oz	Slurry or mist type treatment.
	thiabendazole (1): Mertect 340F 0.08 tp 0.16 fl oz	Slurry or mist treatment for Phomopsis seed rot and damping off. Apply with another fungicide for broad-spectrum control.
	thiram (M): Flosan or 42S Thiram 4F 2 fl oz Thiram 75DF 2.2 oz Thiram Granuflo 75WDG 2.2 oz Protector-D 35D 3.3 oz	 Slurry or mist type treatment. Slurry or mist type treatment. Slurry or mist type treatment. Planter box treatment.
	trifloxystrobin (11): Trilex Flowable 0.32 fl oz	Slurry or mist type treatment.
	trifloxystrobin (11) + metalaxyl (4): Trilex AL 5.7 fl oz Trilex 2000 1.15F 1.0 fl oz	 Slurry or mist type treatment. Slurry or mist type treatment.

high quality seed helps prevent virus introduction with contaminated seed.

Soybean Mosaic (Soybean mosaic virus)

This virus is spread with contaminated seed and by aphids. Infected seed may not germinate or produce weak, spindly plants with crinkled unifoliate leaves. Infected older plants are stunted with crinkled or mottled leaves (Figure 25). Seed may be distinctly discolored brown or black as the hilum color bleeds out over the seed. Planting of high-quality seed to helps reduce the chances of virus introduction if contaminated seed is used.

Seed Treatment

Fungicide seed treatment can be beneficial in Oklahoma, especially with low seeding rates, use of seed with poor germination (85% or lower), under cool and wet conditions associated with early planting dates and where Phytophthora root rot is a problem. However, yield responses to seed treatments are unlikely to provide an economic return when conditions favor rapid seed germination and seedling growth. In addition, soybean plants are innately able to compensate for a wide range of plant populations, so much so that for some varieties, a field with 50% of a desired plant population may yield as well as a field with a full plant stand. However, early maturing varieties (MG III and IV) tend to branch less than full season varieties (MG V and VI) and yield better where higher plant populations are achieved. Registered seed treatment fungicides for prevention of seed rot and seedling diseases are listed by active ingredient and their mode of action (MOA) group below (Table 17). Pre-treated seed can be ordered, or seed treatment fungicides can be purchased for use with slurry or mist-type equipment, auger systems, or planter box applications. Thorough and uniform application to seed is essential for maximum performance. Metalaxyl and mefenoxam provide enhanced (systemic) control of water molds, such as Pythium and Phytophthora. However, they do not have activity against other seedling disease pathogens and should be applied in combination with another seed treatment fungicide such as captan, thiram, carboxin or fludioxanil to provide broad-spectrum disease control.

Figure 25. Soybean mosaic virus (Courtesy Laura Sweets, Univ. Missouri)

2. Soilborne Diseases and Nematodes

Crop rotation with non-host plants should be considered for preventing the build-up of soil-borne diseases and nematode problems in soybeans and for reducing pathogen populations in problem fields. Resistant varieties also are available for soilborne

Table 17. Fungicides for control of soilborne diseases of soybeans.

Disease	*Common name (MOA group): Formulation and rate/ 1000 ft row*	*Remarks*
Phytophthora root rot Pythium damping off	mefenoxam (4): Ridomil Gold 4E or SL 4F 0.08 to 0.28 fl oz Ridomil Gold 2.5G 1.5 to 6 oz Twist 2E 0.16 to 0.56 fl oz Metastar 2E 0.3 to 1.1 fl oz	At planting treatment. Apply the high rate as a surface application in a 7-inch band and incorporate or water into soil or apply any of the rates in furrow.

problems such as Phytophthora root rot, soybean cyst nematode and root knot nematode. However, single gene resistance is commonly employed in soybean breeding programs. While single gene resistance initially provides a high level of disease control, repeating cropping of the same resistance gene my lead to a new strain or "race" capable of damaging previously resistant varieties. Nematodes are frequent problems in soybean fields, but often overlooked as a cause of low yield. When nematode problems are suspected, soil samples should be submitted for analysis to the OSU Plant Disease and Insect Diagnostic Lab through a local OSU Extension office.

Phytophthora root rot: Phytophthora root rot is a problem on finely textured (clay) soils with poor drainage, in fields with hardpans or in low areas that collect water. The seed rot and damping off phases of Phytophthora root rot may be mistaken for Pythium damping-off. The fungus is highly variable and numerous races have developed in response to the planting of varieties with single-gene (specific) resistance. Once a Phytophthora problem is identified, crop rotation is of little value because the fungus survives indefinitely in soil. Ideally, varieties with single gene (race specific) resistance should be matched to the prevailing race in a problem field. However, race identification is not readily available. Variety selection must be based on local variety performance or the selection of varieties with a high probability of success, i.e. the Rps1-c or Rps1-k genes in a high-yielding variety. Tolerant (partially resistant) varieties also are available that are not race specific. However, tolerance is not effective against the disease at the seedling stages and their use should be combined with a seed treatment containing metalaxyl of mefanoxam (Table 16). Mefenoxam also can be applied to soil or in-furrow at planting (Table 17).

Soybean Cyst Nematode: Soybean cyst nematode (SCN) is a significant problem in some old soybean fields. The nematode is probably more widespread than thought, because aboveground symptoms are usually not distinct and yield loss can occur without symptoms. SCN should be suspected where yields have declined for no other obvious reasons. Soybean cyst nematode is best managed by planting resistant varieties in a crop rotation program with non-host crops to limit nematode reproduction. The goal is to reduce nematode numbers below damaging levels. Rotational crops should be summer crops that are grown during periods where nematodes are active. Non-host crops include alfalfa, corn, cotton, forage grasses and sorghum. Avoid other legumes such as southern peas, beans and forage legumes. Resistant soybean varieties use mainly two sources of resistance genes, one from "Peking" the other from "PI 88788." Most SCN-resistant varieties use PI 88788 as source of resistance. A third source of resistance, from PI 437654 contained in the public variety "Hartwig" (some are marketed with a CsytX trademark), is available in a few varieties and may be effective in more fields. Cyst nematode populations are highly variable and a particular source of resistance may perform better in one area than another. Seed dealers can recommend varieties that perform best in a particular area. However, repeated cropping of a resistant variety with the same source of resistance can lead to development of new races of the nematode for which the resistance is no longer effective. A certain percentage of cyst nematodes will reproduce on resistant varieties. If sources of resistance are not rotated, these individuals will increase and produce a race shift. The same SCN-resistant variety should not be planted in the same field for two consecutive years. If possible, rotate sources of resistance. Inclusion of susceptible varieties may also be beneficial for countering race shifts. Table 18 lists some rotation sequences recommended for growing soybeans where SCN is a problem. A listing of the sources of the resistance used in SCN-resistant varieties has been maintained yearly at http://www.ag.uiuc.edu/%7Ewardt/cover.htm by the University of Illinois.

Root-knot nematode: Root-knot nematode (RKN) may not be as widely distributed as SCN, but can cause very severe yield losses where it occurs. It is generally found at damaging levels in sandy soils. Selection of resistant varieties to manage root-knot nematode is the simplest method of control. There are several well-adapted varieties available that have high levels of root-knot nematode resistance. Growing a root-knot nematode-resistant variety for one to three years usually lowers the root-knot nematode population significantly. It should be noted that growing the same root-knot nematode-resistant (RKN) variety continuously for several years might result in a root-knot nematode population capable of damaging the resistant variety. Rotation to non-host crops is a good method of control, but because southern, northern and peanut root-knot nematodes occur in Oklahoma, it is difficult to select a non-host crop where the species of nematode is not known. Only grass crops such as corn, grain sorghum and forage grasses are non-hosts for the southern root-knot nematode. In fields with northern

Table 18. Some suggested crop rotation sequences for managing soybean cyst nematode using resistant (R) and susceptible (S) soybean varieties.

Year	*Rotation A*	*Rotation B*	*Rotation C*
1	Non-host crop	Non-host crop	Non-host crop
2	Soybean (R)	Soybean (R)	Non-host crop
3	Non-host crop	Non-host crop	Soybean (S)*
4	Soybean (R) – different source from year 2	Soybean (S)*	Non-host crop
5	Non-host crop	Repeat cycle	Non-host crop
6	Soybean (R) – different source from year 4 or (S)*		Soybean (S)*
7	Repeat cycle	Repeat cycle	

* A soil test should be done to ensure egg counts are below damaging levels (300 eggs per 100 cc soil for sandy soils; 1,200 eggs per 100 cc soil for clay soils) before planting a susceptible variety.

and peanut root-knot nematode, cotton or the grass crops are suggested.

Foliar Diseases

Foliar diseases are generally a minor problem except for frogeye leaf spot and soybean rust. Frogeye leaf spot is a sporadic disease that can reduce yields significantly. Soybean rust was identified in Oklahoma for the first time in 2007 and has the potential to reduce yields by up to 50%. Other foliar diseases, such as anthracnose, pod and stem blight and Cercospora blight have adverse effects on seed quality and may reduce yields when rainfall and humidity are high during reproductive stages and where harvest is delayed by wet weather. Consider a foliar fungicide program when yield potential is high, soybeans are grown under irrigation, soybeans are grown for seed and when early maturing varieties are grown (Group III and IV). Use the point system for forecasting the need for a fungicide program on soybeans. The expected price of soybeans also should be considered in making a decision on whether or not to use foliar fungicides. Generally, a single application from growth stage R3 to R5 is sufficient for control of diseases that affect seed quality. Rust is potentially damaging and a fungicide program should be beneficial for high yielding soybeans when rust becomes severe. Because rust will not overwinter in Oklahoma, it will likely be a sporadic problem affecting soybeans in years where airborne spores move into the state and weather is favorable for rust development. Currently, Oklahoma and surrounding states are part of a national network for monitoring rust development and spread. The current status of rust development in Oklahoma and other soybean growing states can be followed at http://sbr.ipmpipe.org. Consider a fungicide application for soybean rust when soybeans are at growth stages R1 to R5, yield potential is good (more than 25 bushels per acre) and when rust threatens or is identified in the field.

Table 19. Fungicides for control of foliar diseases of soybeans.

Disease	*Common name (MOA group): Formulation and rate/A*	*Remarks*
Anthracnose Brown spot Frogeye leaf spot Pod and stem blight Cercospora blight Seed quality diseases Soybean rust	azoxystrobin (11): Quadris 2.08F 6.0 to 15.4 fl oz	Apply at first sign of frogeye leaf spot during R growth stages or from R3 to R5 for seed quality protection. For soybean rust, apply from growth stages R1 to R5 when rust threatens. A second application may be made from 14 to 21 days after the first if needed.
	cyproconazole (3): Alto 100SL 0.83F 4 to 5.5 fl oz	Apply at first sign of frogeye leaf spot during R growth stages or from R3 to R5 for seed quality protection. For soybean rust, apply from growth stages R1 to R5 when rust threatens. A second application may be made from 14 to 21 days after the first if needed.
	azoxystrobin (11) + cyproconazole (3): Quadris Xtra 2.34F 4 to 6.8 fl oz	Apply at first sign of frogeye leaf spot during R growth stages or from R3 to R5 for seed quality protection. For soybean rust, apply from growth stages R1 to R5 when rust threatens. A second application may be made from 14 to 21 days after the first if needed.
	flutrianfol (3): Topguard 1.04F 7 to 14 fl oz	Apply at first sign of frogeye leaf spot during R growth stages or from R3 to R5 for seed quality protection. For soybean rust, apply from growth stages R1 to R5 when rust threatens. A second application may be made from 14 to 21 days after the first if needed.
	myclobutanil (3): Laredo EC 2E 4 to 8 fl oz Laredo EW 1.67E 4.8 to 9.6 fl oz	For soybean rust, apply from growth stages R1 to R5 when rust threatens. A second application may be made from 14 to 21 days after the first if needed.
	propiconazole (3): Tilt, Bumper or Propiconazole 3.6E 4 to 6 fl oz	Apply at first sign of frogeye leaf spot during R growth stages or from R3 to R5 for seed quality protection. For soybean rust, apply from growth stages R1 to R5 when rust threatens. A second application may be made from 14 to 21 days after the first if needed.
	propiconazole (3) + azoxystrobin (11): Quilt or Avaris 1.66F 14 to 20.5 fl oz Quilt Xcel 2.2F 14 to 21 fl oz	Apply at first sign of frogeye leaf spot during R growth stages or from R3 to R5 for seed quality protection. For soybean rust, apply from growth stages R1 to R5 when rust threatens. A second application may be made from 14 to 21 days after the first if needed.
	propiconazole (3) + trifloxystrobin (11): Stratego 2.08E 7 to 10 fl oz Stratego 731 4.18F 4 to 4.65 fl oz	Apply at first sign of frogeye leaf spot during R growth stages or from R3 to R5 for seed quality protection. For soybean rust, apply from growth stages R1 to R5 when rust threatens. A second application may be made from 14 to 21 days after the first if needed.
	pyraclostrobin (11): Headline 2.08F 6 to 12 fl oz	Apply at first sign of frogeye leaf spot during R growth stages or from R3 to R5 for seed quality protection. For soybean rust, apply from growth stages R1 to R5 when rust threatens. A second application may be made from 14 to 21 days after the first if needed.

Table 19. Fungicides for control of foliar diseases of soybeans. (cont'd)

Disease	*Common name (MOA group): Formulation and rate/A*	*Remarks*
	prothioconazole (3): Proline 480SC 2.5 to 3 fl oz	For soybean rust, apply from growth stages R1 to R5 when rust threatens. A second application may be made from 14 to 21 days after the first if needed.
	tebuconazole (3): Folicur, Monsoon, Muscle, Orius, Tebu, Tebucon, Tebusha, TebuStar, Tebuzol, Toledo, or Uppercut 3.6F 3 to 4 fl oz	For soybean rust, apply from growth stages R1 to R5 when rust threatens. A second application may be made from 14 to 21 days after the first if needed.
	tetraconazole (3): Domark 230 ME 1.9E 4 to 5 fl oz	Apply at first sign of frogeye leaf spot during R growth stages or from R3 to R5 for seed quality protection. For soybean rust, apply from growth stages R1 to R5 when rust threatens. A second application may be made from 14 to 21 days after the first if needed.
	thiophanate-methyl (1): Topsin or T-methyl 70W 0.5 to 1.0 lb Thiophanate Methyl 85WDG 0.4 to 0.8 lb Topsin , Thiophanate Methyl, or T-Methyl 4.5F 10 to 20 fl oz	Apply at first sign of frogeye leaf spot during R growth stages or from growth stage R3 to R5 for seed quality protection.
	thiophanate-methyl (1) + tebuconazole (3): Topsin XTR 4.3F 16 to 20 fl oz	Apply at first sign of frogeye leaf spot during R growth stages or from R3 to R5 for seed quality protection. For soybean rust, apply from growth stages R1 to R5 when rust threatens. A second application may be made from 14 to 21 days after the first if needed.

F. PESTICIDE APPLICATIONS AND SAFETY

1. Pesticide Types

Pesticide is a general term for any chemical used to kill, control, or prevent a pest from causing damage. Pesticides are classified by the types of pests they control. Important pesticides for soybeans are:

Fungicide	Fungi
Herbicide	Weeds
Insecticide	Insects
Miticide	Mites
Nematicide	Nematodes

Some chemicals are identified by function:

Attractant	Attracts pests
Repellent	Keeps pests away
Desiccants and Defoliants	Removes or kills leaves and stems
Plant Growth Regulators	Stops, speeds up, or alters normal plant processes

To use pesticides effectively without injuring plants, animals or agricultural products always follow the directions on the label. Use only for the specified purpose.

2. Mode of Action

Mode of action — How a pesticide works.

Contacts — Kill simply by coming in contact with the pest.

Systemics — Kill by being taken into the blood of an animal or sap of a plant, including consumption of infected plants.

Protectants — Applied to plants, animals, structures and/or products to prevent entry or damage by a pest.

Sterilants — Make plants unable to reproduce or kill all plants and seeds in the soil.

Growth regulators — Alters the growth of the infected.

Selective pesticide — Kill a particular type of pest without harming others.

Non-selective pesticide — Kill a general type of pest.

Biologicals — Living microorganisms (viruses, bacteria, fungi) applied to a host to cause a disease in the pest living on that host.

3. Terms Describing Pesticide Use

Band — Applied to a strip over or along each crop row.

Broadcast — Applied uniformly to an entire, specific area.

Directed — Pesticide is aimed at a portion of a plant, animal or structure.

Early pre-plant (EPP) — Applied onto the soil and early emerging weeds up to a week before planting the crop.

Foliar — Applied to the leaves of plants.

In-furrow — Applied to or in the furrow in which a seed is planted.

Pre-emergence (PRE) — Applied onto soil before or after crop planting, but before crops or weeds emerge from the ground.

Pre-plant (PPS) — Applied onto the soil or any early emerging weeds before the crop is planted.

Pre-plant-incorporated (PPI) — Mixed into soil before crop is planted.

Post-emergence-overtop (OTS) — Applied onto weeds after the crop and weeds have emerged.

Post-directed (DIR) — Applied onto small weeds in rows of taller crops.

Sidedress — Applied alongside crop row.

Spot treatment — Applied to small areas.

4. Formulations

Formulation — the specific way a product is made.

1) The active ingredient-the chemicals that work and
2) The inert, or inactive, ingredient-the carrier for the active ingredients.

Formulations are usually made and applied as a liquid, gas or solid.

Each has a specific abbreviation frequently used on labels and in recommendations.

Dry Flowable (DF) or Water Dispersible Granules (WDG) — Aggregates of granules made of finely ground particles. When mixed in water, particles disperse and remain suspended during application.

Dusts (D) — Active ingredients added to a fine inactive powder. Dusts must be used dry.

Emulsifiable Concentrates (EC or E) — Can be mixed with water to form an emulsion (a mixture in which one liquid is suspended as tiny drops in another liquid, such as oil in water).

Granules (G) or Pellets (P) — Active ingredients added to coarse particles, or granules, of inactive material. Granule particles are much larger than dust particles, smaller than pellets, applied dry and cannot be mixed with water. In general, granules are spread mechanically and pellets are spread by hand for spot treatments.

Soluble Powders (SP or WSP) — Dry, finely divided solids that dissolve completely in water.

Water Dispersible Liquid (WDL or L) or Flowable (F) — Liquid system containing finely ground particles that dissolve completely in water to form a suspension (a mixture of finely divided solid particles in a liquid).

Water Soluble Liquids (S or LS) — Mixture of one or more substances that dissolve completely in water forming a solution. Ready to use.

Wettable Powders (WP or W) — Made by combining the active ingredient with a fine powder and a wetting agent (a chemical that causes a liquid to cover a surface more thoroughly). Wettable powders look like dusts, but are mixed with water. A continuous agitation is needed to maintain a suspension.

5. Spray Additives or Adjuvants

Additives or Adjuvants — Any substance added to a pesticide to improve performance or handling. Note: If the pesticide label does not specifically identity other types of carriers, then water is the only carrier that can be used. The label must state that crop oils and concentrates can be used with the pesticide before these carriers are legal for use.

Antifoaming Agents — Reduce foaming in a sprayer system so pumps and nozzles perform properly.

Buffering Agents — Adjust and/or prevents changes in solution pH.

Compatibility — Facilitate the suspension of a pesticide when combined in tank mixes with other pesticides or fertilizers.

Crop Oils and Concentrates — Light oils that also contain surfactants that allow the oil compounds to mix or emulsify in water. Oil compounds added to aqueous solutions enhance their effectiveness.

Drift Control Agents — Reduce the fine particles in a spray that cause drift.

Emulsifiers — Promote the suspension of one liquid in another.

Foam Suppressants — Suppress surface foam and trapped air.

Petroleum Oils — Spray oils classified by their content of hydrocarbons; known as paraffins, naphthenes, aromatics and unsaturates.

Liquid Fertilizers — Such as 10-34-0 and 28-0-0.

Surfactants — Modify wetting, spreading, dispersing, emulsifying, or other liquid-surface-modifying properties.

Spreaders — Increase the area a liquid will cover on another liquid or solid.

Stickers — Cause compounds to adhere to plant foliage; reduce spray runoff during application and rain wash off.

Wetting Agents — Increase surface coverage by lowering the surface tension between a liquid and solid.

6. Calibrating Sprayers

Calibration is necessary to adjust equipment so the correct rate of pesticide is applied. Applying too much is dangerous, costly, wasteful and harmful to the environment. Applying too little may not provide effective control.

Always read the operator's manual supplied by the manufacturer for instructions on adjusting equipment for the product and application rate being used. For even and accurate coverage, the sprayer must move at a constant speed and pump out at a constant pressure. All nozzles must be checked often and be in good condition. Although there are many ways to calibrate sprayers, a basic method is given here. Contact your local Extension office for additional information on other calibration methods for liquids, granulars and dusts.

Ounce Method (liquid formulations)

1. Measure the correct distance in the field shown in Table 20.
   Select the distance that matches the nozzle spacing for broadcast or the row spacing for band applications.
2. Drive the measured distance at the speed desired for application and record the time in seconds.

Table 20.

Row or nozzle spacing (inches)	*Distance (feet)*
40	102
38	107
36	113
34	120
32	127
30	136
28	146
26	157
24	170
22	185
20	204
18	227
16	255
14	291
12	340
10	410
8	508

3. Place a container graduated in fluid ounces underneath one nozzle or nozzle group. Operate the sprayer in place at the selected pressure. Catch the discharge for the same amount of time as was recorded in Step 2.
4. The total discharge from the nozzle or nozzle group equals the total gallons per acre applied by the sprayer (broadcast). If row spacing was used in Step 1, measure all nozzles directed on the row to find gallons per acre.
5. Repeat the test for each nozzle. Nozzles should not vary more that 5% across the boom.
6. To determine the number of acres that can be treated with a full sprayer tank (broadcast), divide the total capacity of the sprayer tank by the gallons-per-acre value from Step 4.

7. To adjust for band spraying, modify the gallons per acre from Step 4 and the pesticide rate as follows.

   Band rate (gal/ac) =

   $$\frac{\text{broadcast rate [gal/acl X band width (in)]}}{\text{row spacing (in)}}$$

8. Always recalibrate when pressure, speed and/or nozzles are changed.

NOZZLE TYPES

Each of the three basic nozzle types has a special spray pattern. There are also some special nozzle patterns.

1. Solid Stream

A single jet used in handguns to spray a distant target. It can be fixed in a nozzle body to apply a narrow band or inject into the soil. There is little drift with this nozzle.

2. Flat Fan

a. Regular flat fan — Nozzles make a narrow oval pattern with lighter edges. Used on booms for broadcast spraying. Nozzles should be mounted so that the spray overlaps 30% to 50% for even distribution. Used with pre- and post-emergence herbicides and some insecticides.

b. Even flat fan — Nozzles make a uniform pattern across its width. Used for band spraying and spraying walls and other surfaces.

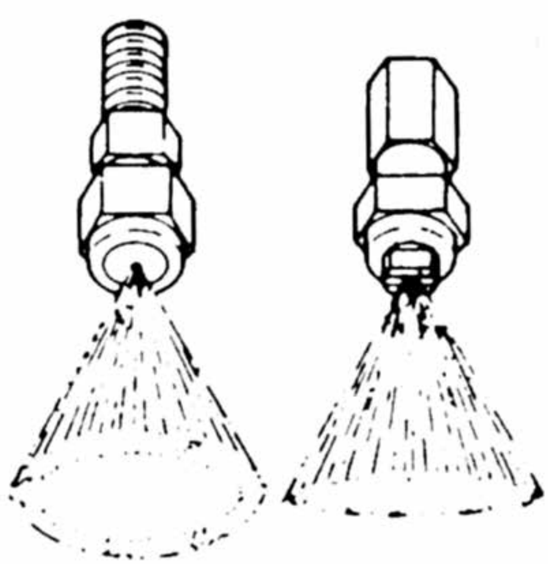

Figure 26. Hollow cone nozzle (left), regular flat-fan nozzle (right).

c. Flooding — Nozzles make a wide-angle flat spray pattern. Works at lower pressures than other flat fan nozzles. Pattern is fairly uniform across its width. Used with pre- and post-emergence herbicides where drift is a problem.

3. Cone

a. Solid cone — Nozzles form a circular pattern with the spray well distributed throughout the pattern. Used for spraying at higher pressures and flow rates.

b. Hollow cone — Nozzles form a pattern that is circular with tapered edges and little or no spray in the center. The core and disk and the whirl chamber are two types of hollow cone nozzles. Used with most insecticides and fungicides.

Nozzle heights and pattern angles

Spray pattern angle (degrees)	*Nozzle height above crop (inches)*
60	21 to 23
70	20 to 22
80	17 to 19
90	15 to 17
100	10 to 12

7. Reading Labels

Droplet Size Considerations

Droplet size will influence coverage and drift. The nozzles typically used to apply herbicides produce droplets that vary greatly in size. Large droplets, which will help mitigate spray drift, may not provide good coverage. Very small droplets lack the momentum needed toward the target and are prone to drift under windy conditions. The range of droplets from a nozzle is also affected by liquid flow rate (size of orifice), liquid pressure and physical changes to nozzle geometry and operation.

To help applicators select nozzles and use them at the most optimum droplet size range for a given situation, the American Society of Agricultural and Biological Engineers has developed a classification systems. Nozzles are classified as: very fine, fine, medium, coarse, very coarse and extremely coarse.

Currently, medium to coarse spray droplets (approximately 300 to 500 microns) are recommended by nozzle manufactures for application of herbicides.

Some herbicide companies indicate droplet size on the label so special attention should be given to fully reading the label.

Because chemical control is a common part of pest management, it is important to know how to work with these materials safely. When using any type of pesticide, it is very important to **ALWAYS** read label directions thoroughly and follow them exactly. It is unlawful to use any pesticide product in any manner or for any purpose other than those specified on its label. Label information is often contained inside the packaging. Remember that the entire label is important even though only a small amount is given on the front panel.

Chemical labels include:

- Brand or Trade name of product
- List and percentages of active and inert ingredients
- The type of pesticide
- EPA registration number
- Directions for use
- Product effects on the environment and other organisms
- Plant back restrictions

Growers must know more about the above information before safely using a pesticide. They must be acutely aware of potential environmental risks, such as water or off-target effects, the pesticide may pose. Growers also must know the plant back restrictions to avoid potential crop damage or illegal residue to crops to be planted after soybeans.

Applicators must read and follow directions in the Agricultural Use Requirement box. This is the area that provides information on how to comply with the Worker Protection Standard. Whether applied by the farmer or commercial applicator, this information is to be followed. The two important pieces of information are the Restricted-Entry Interval (REI) and the personal protective equipment (PPE) needed to mix, load, apply and clean the spray equipment.

Agricultural Use Requirement

Use this product only in accordance with its labeling and with the Worker Protection Standard, 40 CFR part 170. This Standard contains requirements for the protection of agricultural workers on farms, forest, nurseries, greenhouses and handlers of agricultural pesticides. It contains requirements for training, decontamination, notification and emergency assistance. It also contains specific information and exceptions pertaining to statements on this label about personal protective equipment (PPE) and restricted-entry interval. The requirements in this box only apply to uses of this product that are covered by the Worker Protection Standard.

Do not enter or allow worker entry to treated areas during the restricted-entry interval (REI) of 12 hours.

PPE required for early entry to treated areas that is permitted under the Worker Protection Standard and that involves contact with anything that has been treated, such as plants, soil or water, is:

- Coveralls
- Waterproof gloves
- Shoes plus socks

Signal Words

Signal words indicate how toxic a pesticide is to humans. They are located on the front panel of labels. There are three categories of signal words:

Class I

- Labeled DANGER or DANGER-POISON
- Extremely toxic when absorbed through the mouth, skin and/or through breathing
- Can cause severe eye and skin burning

Class II

- Labeled WARNING
- Moderately poisonous to humans

Class III

- Labeled CAUTION
- Slightly toxic to humans

8. Safety Guidelines Checklist

a. First and foremost, always read and follow the label directions exactly. Label directions include but are not limited to:

Pre-harvest interval — The time required between applying the pesticide and the date when the crop can be safely harvested.

Safe re-entry — The time needed between when a pesticide is applied to an area and the time you need to wait before the area can safely be entered again.

b. Before applying any pesticide, remove all people
c. Never smoke, eat,or drink when handling pesticides
d. Always use protective clothing and equipment
e. Mix products with equipment specifically reserved for this purpose

f. Clean yourself, clothing and equipment well, as directed by the label or Material Safety Data Sheet (MSDS)
g. Store equipment and pesticides properly.

Remember, pesticides may be absorbed through the skin, eyes, ears, inhaled and swallowed. Always handle them carefully.

9. Disposal of Pesticides

Mix the correct amount of solution for each application to avoid disposing of any extra chemical. Any extra must be disposed by safely following EPA guidelines.

- Carefully follow label instructions.
- NEVER pour pesticides down the drain, into sewers, onto the ground or into drainages.
- Apply extra solution on other areas listed on the label.

Disposal of Pesticide Containers

- Pressure or triple rinse all pesticide containers immediately upon emptying the container. Pour rinse water into the spray tank.
- Dispose of containers either through a recycling program or at an approved sanitary landfill.
- Do not burn or bury pesticide containers.
- Oklahoma has programs to assist in disposal of clean plastic containers.
- Oklahoma has a program to assist all applicators in disposal of unwanted pesticides.

To get help with questions and problems concerning the safe disposal of pesticides and containers contact:

Oklahoma Department of Agriculture
Plant Industry Division & Consumer Services
P.O. Box 528804
Oklahoma City, OK 73152-8804
405-522-5993

or

Pesticide Coordinator
Oklahoma State University
127 NRC
Stillwater, OK 74078-3033 405-744-5531

or

National Pesticide Telecommunication Network
1-800-858-7378

10. First Aid Procedures

When pesticide poisoning has occurred, ALWAYS ACT IMMEDIATELY. The time between the poisoning and getting proper medical attention may make the difference between life and death.

1. Stay calm and take quick action.
2. Protect yourself from contamination before assisting someone else.
3. Promptly contact the Poison Control Center or a doctor and administer first aid procedures as indicated on label or MSDS.
4. Keep the pesticide label handy for reference.
5. First aid kits need to be easily accessible, kept up-to-date and the supplies clean and dry.

Emergency Numbers

Oklahoma Poison control
1-800-222-1222

National Pesticide Telecommunication Network
1-800-858-7378

The following publications can be ordered through the local county OSU Extension office our website at extension.okstate.edu. Many other titles are also available.

EPP-322 Pesticide Record Keeping Requirements for Crop Production
EPP-7451 Agricultural Pesticide Storage
EPP-7457 Pesticide Applicator Certification Series: Toxicity of Pesticides
EPP-7462 Rinsing and Disposing of Pesticide Containers

VI. HARVESTING SOYBEANS

Field studies in soybeans have shown that 4-bushels-per-acre machine losses can be common. However, field experience and research studies have shown that machine losses of soybeans can be reduced to less than 1 bushel per acre. The results of a study conducted at The Ohio State University found the average machine loss in soybeans was 1.4 bushels per acre, but the highest loss was 4.1 bushels per acre. About 40% of the operators studied had losses below 1 bushel per acre, while almost 20% had losses exceeding 2 bushels per acre. To reduce losses, combine operators need to know where harvesting losses occur; how to measure losses; what loss levels are reasonable; and the equipment, adjustments and operating practices that will help reduce losses.

A. Estimating Harvest Losses

Where Losses Occur

Soybean losses can occur before harvest as preharvest loss or during harvest as machine loss. Preharvest loss can be high and it can only be minimized by harvesting in a timely fashion. Making sure you have enough combine capacity is the best way to minimize preharvest loss. Machine loss can occur at several places in the combine, but the most common for soybeans is at the header during cutting and gathering. Cleaning and separating losses are generally minimal compared to gathering loss. Soybeans are fragile and shatter easily so close attention should be paid to header adjustments and operation.

Measuring Harvesting Losses

While there are detailed methods for measuring losses, most operators do not take the time to use them in the rushed harvest season. However, they should at least take the time to determine the where loss is occurring so they can identify the cause and take corrective action. This procedure discussed here is not intended to help measure loss. It is simply a systematic way to assess loss and the potential cause.

Determine total loss: Operate combine under typical operating and field conditions. Stop the combine and back up about 20 feet. In the harvested area behind the combine, look for beans on the ground. Remember these may be concentrated in the area right behind the combine. Approximately four soybeans per square foot is one bushel per acre. The total loss should be no greater than 3% of your average yield. So if you are harvesting 40 bushels per acre of soybeans, the total loss should be less than 1.2 bushels per acre (40 bushels per acre times 3%). In this example, if you think the average is more than five to six soybeans per square foot, continue this procedure to pinpoint the source of loss. If the total loss is less than 3% of yield, keep on harvesting.

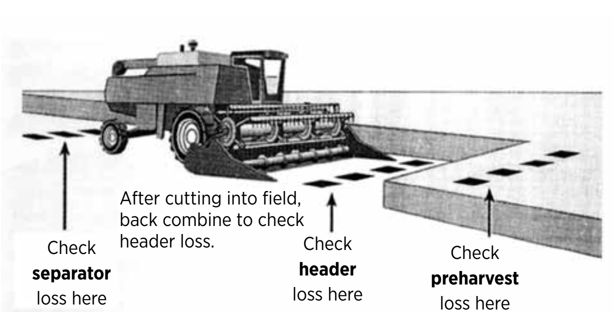

Figure 27.

Determine preharvest loss: In the unharvested area in front of the combine, count loose beans on the ground and beans in pods lying loose on the ground. Using the four soybean estimate from step one, determine loss in bushels per acre.

Determine machine loss: Machine loss is calculated by subtracting the preharvest loss from total crop loss. If machine loss is less than 3% of yield, keep on harvesting. If machine loss is more than 3%, proceed to check gathering unit losses.

Determine gathering unit loss: Check the area in front of the combine where the header has crossed, but does not contain any discharge from the rear of the combine. Again using the four bean rule, count and categorize beans according to the type of loss below. Gathering unit loss is the sum of these four losses.

Shatter loss: Loose beans on the ground and beans in loose pods on the ground minus the preharvest loss count.

Loose stalk loss: All beans in pods attached to stalks that were cut but not gathered into the machine.

Lodged stalk loss: All beans in pods attached to soybean stalks that were lodged and are still attached to the ground.

Stubble loss: All beans in pods still attached to stubble.

Determine cylinder and separation loss: Subtract the gathering unit loss from the machine loss.

Compare harvest loss levels to goal loss levels. Once you have identified the source of combine loss, concentrate on machine adjustments and operating practices that will give the least total loss.

Gathering Equipment

While soybeans can be harvested with a conventional rigid platform header, gathering loss may be excessive. Loss may be minimal on flat ground with good harvest conditions. The challenges occur when these aren't the conditions. Most soybeans are harvested with row crop or flexible platform headers. The row crop header can only be used when soybeans are planted in 30-inch rows. While gather loss from these headers can be minimal, they do require more maintenance. These headers also can be used to harvest grain sorghum, but it must be planted in 30-inch rows.

The flexible platform header allows the cutter bar to operate very close to the ground. The cutter bar flexes to follow the ground contour. When compared to a rigid platform, the flexible header will have lower loss. A flexible header is best when used on a combine with automatic header height control. This reduces operator fatigue from constantly monitoring and adjusting header height. If soybeans are grown on sloped or terraced fields, using a combine with a tilting feeder house also will reduce gather losses.

Although specialized gathering equipment for soybeans can significantly reduce harvesting losses, make sure the equipment is economically justifiable. Some key factors in this decision are acreage farmed, present machinery and other crops. The flexible header will work in wheat and grain sorghum. The row-crop head works well in grain sorghum in rows. A comparison can be made to see if the improved gathering efficiency would justify an additional investment in some of the specialized gathering equipment for soybean harvesting.

Combine Adjustment and Operation

Reel speed and position are extremely important in harvesting soybeans. The reel should be positioned for minimum disturbance of standing plants. Reels with pick-up fingers will cause the least disturbance to the standing plants. When the reel is positioned properly, the soybean plants will be conveyed smoothly across the cutter bar, along the auger and into the combine feeder house.

Gathering losses are minimized when the reel speed is set about 25% to 50% faster than ground speed. The reel will cause shatter loss when operated too fast and too many stalks may be dropped or recut if it turns too slowly. Position the center of the reel 8 and 12 inches ahead of the sickle. A bat reel should be operated just low enough to tip the stalks onto the platform.

Before the combine goes to the field, there are a number of other adjustments that should be made using the operator's manual as a guide. These include cylinder/rotor speed, concave clearance, chaffer/sieve settings and fan adjustment. If the operator's manual is followed closely, the operator usually needs to make only minor adjustments in the field. The operator's manual is also a good place to make notes regarding settings that seem to work well.

If the crop has matured properly, threshing is generally not a problem. However seed damage can occur during threshing. Seed damage is affected more by cylinder/rotor speed than by concave clearance. It is important to reset the cylinder/rotor speed as conditions change throughout the day and the harvest period. The best place to assess threshing performance is evaluating the grain in the bin. Cracked beans and small pieces of foreign material are sure signs of excessive cylinder speed. If weedy conditions are encountered during harvest, especially when weeds are green, reduce travel speed to maintain low threshing and separating losses. Do not increase cylinder speed because this will only cause excessive damage to the beans and more trash in the grain tank.

B. Post Harvest Guide for Drying and Storing Soybeans in Oklahoma

Introduction

Soybeans require special handling, drying and storage in order to maintain market quality from field to processor. Soybeans mature at different rates from one year to the next. Producers often harvest as soon as possible in order to avoid excessive shattering losses from beans that are too dry and storm damage from lodging due to wind and rain.

Producers often prefer to dry and store soybeans for several months in order to take advantage of market shifts, rather than be at the mercy of the market by having to sell at harvest and pay shrinkage and drying costs and/or storage costs at elevators.

Although insects are not usually a pest problem in stored soybeans, storage of soybeans requires knowledge of how the beans react from handling into and out of storage and how to handle and dry them with minimum split damage. Another storage problem is how to avoid the core of fines and trash accumulation under the fill point that causes aeration and natural air drying problems.

1. Handling and Cleaning Soybeans

Because soybeans have a natural crack, which creates a weak spot, so beans must be conveyed and handled gently to minimize "splits." Convey relatively slowly, preferably with drag or bell conveyors. If tubular or u-trough auger conveyors are used, beans should be handled in large diameter, slow speed conveyors and operating with the conveyor full.

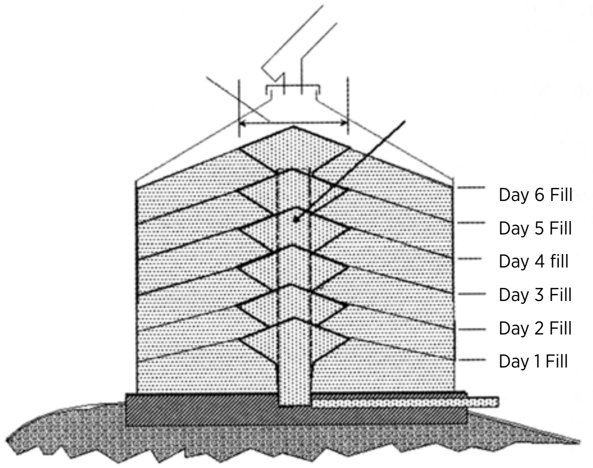

Figure 28. Coring soybeans at selected depth (2 to 4 feet) or time (once or twice daily) intervals is an easy way to "clean" dockage and foreign matter when grain spreaders or levelers are not used during drying. The final draw-down cone should be about 1/4 to 1/3 of the bin diameter as a rough "leveling" process to maintain center airflow.

Drop heights should be minimized to keep impact damage to a low level. A "bean ladder," a device that allows beans to slow down and exit at slow speed from a tube with holes in it inside the bin, is an excellent investment. These eliminate high-speed drop height impact that shatters beans.

Cleaning beans before storage using a rotary cleaner or scalper/cleaner with airflow is ideal, but many producers cannot afford cleaners. One way to "clean" the beans as they are transferred into storage is shown in Figure 28. This method is called "coring" the beans to remove fines, dockage and trash from the center core by removing the peak grain several times during the loading of the bin. This "pull-down" method removes a high percent of fines and dockage while re-handling only 3% to 5% of the total grain.

Peaked grain is difficult to cool with aeration. Peaks should be pulled down by operating the unload conveyor to remove a few hundred bushels periodically from the "core" of the bin. This process of periodic removal of grain while the bin is being loaded is called "coring" the bin. Coring removes a high percentage of dockage and fines from soybeans. At the end of the filling process, the final peak should be pulled down to form an inverted cone with the top diameter of about 1/4 to 1/3 of the bin diameter. This crater or inverted cone will help "level" the grain surface and can speed up the aeration cycle by 15% to 25%. Removing peaks improves overall storability of soybeans and other grains. "Free storage" in grain bin peaks can be very expensive.

2. Storing Soybeans

Soybeans must be stored as a dry stable seed at or below the safe moisture condition for all seeds and grains. A kernel moisture that will maintain a maximum grain mass air relative humidity of 70% RH or less. This inter-kernel air relative humidity is called the equilibrium relative humidity (ERH) of the air with grain at its equilibrium moisture content (EMC). Grain moistures that sustain 70% ERH is the target moisture for soybeans.

The air and grain in any grain mass that has an ERH below 70% will not activate or sustain most grain fungi or mold spores. That is why 70% is listed as the critical ERH for all grains and seeds.

Example 1. Table 20 lists the equilibrium moisture content of soybeans at several grain temperatures and air ERH. At 70% ERH at 41 F, the soybean EMC is 12.9%, wet basis. As the grain temperature rises, the soybean ERH drops. At 59 F, the EMC is 12.4%, while at 77 F the EMC is 12.1% to 12.2% (a second line for 77 F, shown at the bottom of the table is data from a second researcher).

Soybean EMC (and other cereal grain) values drop as temperature increases because mold spores develop more at higher air temperatures. Moistures must be lower when stored at higher temperatures. Once soybeans are stored at a safe moisture level, grain temperatures should be maintained at a stable, uniform level throughout the bulk volume to minimize convection air currents that cause moisture migration to the top surface. Moisture migration causes surface and peak grain moistures to increase, which causes sustaining air RH to increase to 75% to 100% RH. With moist surface grain from moisture migration and roof condensation, warm bin head space temperatures will cause molds to germinate and start growing.

3. Aeration of Soybeans

To minimize convection currents and moisture migration in soybean bins, warm grain must be cooled and the grain mass temperature must be kept close to the same temperature throughout the grain mass during storage. Temperature-monitoring

Table 20. Equilibrium moisture content for soybeans.

Temperature		*Relative Humidity (%)*								
°C	*°F*	*10*	*20*	*30*	*40*	*50*	*60*	*70*	*80*	*90*
5	*41*	*5.2*	*6.3*	*6.9*	*7.7*	*8.6*	*10.4*	*12.9*	*16.9*	*22.4*
15	*59*	*4.3*	*5.7*	*6.5*	*7.2*	*8.1*	*10.1*	*12.4*	*16.1*	*21.9*
25	*77*	*3.8*	*5.3*	*6.1*	*6.9*	*7.8*	*9.7*	*12.1*	*15.8*	*21.3*
35	*95*	*3.5*	*4.8*	*5.7*	*6.4*	*7.6*	*9.3*	*11.7*	*15.4*	*20.6*
45	*113*	*2.9*	*4.0*	*5.0*	*6.0*	*7.1*	*8.7*	*11.1*	*14.9*	–
55	*131*	*2.7*	*3.6*	*4.2*	*5.4*	*6.5*	*8.0*	*10.6*	–	–
25	*77*	–	–	–	*7.0*	*8.0*	*10.1*	*12.2*	*16.0*	*20.7*

Source: Equilibrium Moisture Content of Grains and Seeds (Percent Wet Basis), Moisture Relationships of Grains, ASAE 0245.4. Dec 92, ASAE Standards 1993, Standards of Engineering Practices Data, American Society of Agricultural Engineers, St. Joseph, MI, p. 414.

cables are the preferred method of checking grain temperatures throughout the mass. If cables are not available, temperature probes should be used and/or aeration fans should be run for three to five minutes and exhaust air temperatures measured.

Although soybeans do not have serious stored grain insect problems like corn and other small grains, aeration is needed to cool the beans down initially and to re-cool the outer and top surface beans during fall and winter, especially if bean moisture is marginal — 13% or more. Aeration is typically done with small, low-powered vane-axial fans that supply much lower airflow than drying fans, typically in the range of 1/10 cfm/bu to 1/5 cfm/bu. However, if drying fans with airflow rates of 1 cfm/bu to 2 cfm/bu are available, they can be used to aerate the soybeans very quickly. Aerating soybeans at 1/10 cfm/bu in the fall requires about 150 to 200 fan hours. If a drying fan that delivers 1.0 cfm/bu is used, cooling will be completed 10 times faster, so the total cooling time would be only 15 hours to 20 hours. Thus, soybean operators with drying fans have an ideal built-in aeration system — just pick a cold day and run the fans.

Some seed moisture is removed when soybeans are aerated, but excessive aeration should be avoided. About 0.25% to 0.4% moisture is removed during each cooling cycle (150 hours at 1/10 cfm/bu), at or below safe storage moisture levels, depending on soybean moisture and seed temperature before cooling.

Example 2. If 10,000 bushels or 600,000 pounds of soybeans at 13% moisture content (m.c.) are aerated 300 hours at 1/10th cfm/bu (standard steel bin aeration rates) instead of 150 hours, excess shrinkage may reduce market weight by 0.3% in moisture level, which would represent 0.3 pts. x 1.15%/pt. = 0.345% 25. loss, or 600,000 x 0.00345 = 2.070 pounds of excess moisture removed, or 34.5 bushels (market weight lost) reduced by excessive aeration.

As noted in Table 20 on EMC and ERH values, safe moisture levels are higher when grain is cooled to lower temperature levels. In the soybean regions of Oklahoma, weather begins to cool in September. Soybeans should be cooled as soon as practical in September and October to 50 F or lower. If soybeans are cooled to 35 F to 40 F and maintained near that level, soybeans at 13% to 13.2% m.c. can be safely stored through the winter and into spring months.

Keep in mind that if a drying fan that delivers 1.0 cfm/bu, a bin of soybeans can be cooled in 12 hours to 15 hours, if the beans have been "cored" and the peak has been pulled down. Monitor the grain temperature by probing with a thermocouple sensor or monitor the exhaust air carefully with a mercury thermometer. On up-flow (push) aeration systems, check the grain just below and at the grain surface at several locations in the bin. If the peak has not been pulled down, check the center peak grain very carefully.

Peak grain is almost impossible to keep cool due to the large surface volume compared to the grain volume. If the peak grain is drawn down to an inverted cone, it is much easier to keep cool. Monitor the beans by physically checking the surface and peak for hot spots at two- to three-week intervals. Don't assume that once the grain is cool it will remain cool. If a wet spot develops in the bin, mold and spontaneous heating/combustion can cause serious burn damage and endanger the drying and storage facility.

4. Drying Soybeans with Natural Air and Low Heat Forced Air Drying

Drying soybeans with natural air is possible in Oklahoma. The ideal drying situation is to dry with relatively constant temperature and relative humidity conditions that are at or slightly below the target moisture level of beans preferred for storage. Table 20 lists the equilibrium moisture contents for soybeans at a variety of air temperature and relative humidity conditions.

Although the USDA grading standard for soybeans does not list soybean moisture as a grade factor, the nominal market moisture for soybeans is 13%. If a producer wants to dry soybeans to a target moisture of 13%, with air temperatures in the 60 F to 90 F range, the air relative humidity would need to be about 72% to 73% RH.

However, the daily air temperature and relative humidity cycles vary considerably due to the psychrometric relationship between temperature and humidity. A helpful rule of thumb for grain drying is: **for each 20 F rise in air temperature, the percent RH of the air is cut in half.**

Example 3: If air at 60 F and 100% RH is warmed 20 F, it will be 80 F at about 50% RH. If the same air is warmed 10 F, the percent RH is reduced by 1/4, so 60 F air at 100% RH raised to 70 F would be about 75% RH.

When ambient air forced through soybeans is well below the equilibrium relative humidity (ERH), the air will absorb moisture from soybeans. Likewise, when ambient air cools and relative humidity rises above the ERH during the daily diurnal cycle, soybeans will absorb moisture, which is counter productive. So, natural air drying is somewhat complex to manage.

A humidistat and control relay wired to the fan starter can be set to shut the fan(s) off when the ERH setting is reached. For 13% m.c. soybeans, the ERH is about 72%. The fan would likely shut off from early evening to mid-morning. When direct drive vane-axial fans are used, air flowing over the motor picks up about 1 F to 2 F rise from motor heat. An electric heater (that will provide a 5 F to 10 F rise) placed in front of the fan can be turned on/off by the humidistat, allowing supplemental heat to be added at night.

This drying fan and heater arrangement can provide natural air and low heated air drying for soybeans without re-wetting the soybeans at night. A producer or grain manager can accomplish the same procedure by watching a hygrometer (humidity indicator) and turning the heater on and off manually. This involves more management and is hard to accomplish.

Moisture Removed in Drying

How much moisture and weight is removed during drying?

Example 4: Using Table 21, if soybeans with initial moisture of 18% wet basis are dried to 13%, or 5% points of moisture, the percent weight reduction will be 5.74% (0.0574 as a decimal). Thus, if a semi-load of soybeans weighing 100,000 pounds at 18% are dried to 13%, the water removed will be 100,000 x 0.0574 = 5,740 pounds the dried weight of the load of soybeans will be 100,000 - 5,740 = 94,360 pounds.

Drying Airflow vs Grain Moisture and Depth

Drying airflow for natural air and low heat drying of soybeans is primarily a function of grain moisture. To prevent mold, high moisture soybeans require more airflow than lower moisture beans. Table 22 lists air flow conditions vs grain moisture and grain depths. Allowable grain volumes are related to fan HP. Table 23 lists grain depths of moist grain that can be added to previously dried grain. This allows most or all of the bin to be filled and dried.

Table 21. Grain moisture shrinkage rates*.

% Initial	*Final% moisture of grain*										
Moisture	*8.0*	*9.0*	*10.0*	*11.0*	*12.0*	*13.0*	*14.0*	*15.0*	*16.0*	*17.0*	*18.0*
***% wt.** =* *pt. moist.*	*1.083*	*1.099*	*1.111*	*1.124*	*1.136*	*1.149*	*1.163*	*1.176*	*1.190*	*1.205*	*1.220*
10.0	2.17	1.10	0.0	–	–	–	–	–	–	–	–
11.0	3.25	2.20	1.11	0.0	–	–	–	–	–	–	–
12.0	4.33	3.30	2.22	1.12	0.0	–	–	–	–	–	–
13.0	5.42	4.40	3.33	2.25	1.14	0.0	–	–	–	–	–
14.0	6.50	5.50	4.44	3.37	2.27	**1.15**	0.0	–	–	–	–
15.0	7.68	6.60	5.55	4.50	3.41	2.30	1.16	0.0	–	–	–
16.0	8.66	7.70	6.66	5.62	4.54	3.45	2.33	1.18	0.0	–	–
17.0	9.75	8.80	7.77	6.74	5.68	4.60	3.49	2.35	1.19	0.0	–
18.0	10.83	9.90	8.88	7.87	6.82	**5.74**	4.65	3.53	3\2.38	1.20	0.0
19.0	11.91	11.0	9.99	8.99	7.95	6.89	5.82	4.70	3.57	2.41	1.21
20.0	13.00	12.1	11.11	10.12	9.09	8.04	6.98	5.88	4.76	3.61	2.41
21.0	14.08	13.2	12.21	11.24	10.22	9.19	8.14	7.06	5.95	4.82	3.62

Table 22. Minimum recommended airflow rates for natural air drying.

what's missing in the table column headings?

Grain type	*Grain moisture (%, wt basis)*	*cfm/bu*	*Natural Air Drying*, depth/ft*	*Max. Bu Dried/Fan HP*****	*Cooling/ Holding** cfm/bu*
Wheat	20	3.0	4	830	0.6
			6	440	
	18	2.0	4	1,880	0.4
			8	600	
	16	1.0	8	2,300	0.2
			10	1,500	
Corn & Soybeans***	25	**4.0*** **	4	1,250	0.8
			6		590
	20	3.0	6	1,360	0.6
			8	830	
	18	2.0	8	1,430	0.4
			10	1,000	
	16	1.0	8	3,330	0.2
			12	1,580	

* Recommendations for drying with unheated. Farmers bulletin 2214, USDA, 1965.

** McKenzie, et al. 1966.

*** Based on field experience, Noyes recommends 4.0 cfm/bu at 22% and 5.0 cfm/by at 25% mc.

**** Based on 3,000 cfm/HP at 1.0 inch w.c. static pressure.

Example 5: To dry 20% m.c. soybeans, the depth for the maximum recommended drying volume would be 6 feet with 1,360 bushels per fan HP. A 5-HP fan should be satisfactory to dry 6,800 bushels of 20% m.c. soybeans at that depth. Table 22 shows that 7.150 bushels of 18% m.c. soybeans at 8 feet depth can be dried with a 5-HP drying fan. For this drying management plan, 7,150 bushels at 8 feet falls between 36- and 40-foot diameter bins. Since 7,150 bushels is only 9.8% more than the 6,512 bushels loose fill, or 8.8 feet depth, the 36-foot bin would probably be selected.

Keep in mind that the airflow rates listed in Table 22 are minimum recommended airflows based on grain moisture level. The data in Table 22 are reproduced from a 1965 USDA bulletin. This author recommends 4.0 cfm per bushel be used for 22% and 5.0 cfm per bushel as minimum airflow for 25% m.c. soybeans.

For managing the fill rate and volume of soybeans added to the drying bin, Table 24 lists the initial fill depth in the first column, Depth of Dry Grain (<14 percent m.c.). Once moist soybeans are dried to 14% or below, a layer of moist soybeans can be added based on the table values. However, fans that will deliver the airflow rates based on moisture levels listed in Table 23 must be used with the soybean depths listed in Table 24.

Example 6: A producer needs a bin drying facility to dry and store 35,000 bushels of soybeans in corrugated steel bins. He plans to start drying the first layer of beans at 20% moisture and the next layer at 18% or less. To minimize drying airflow restrictions, a 16-foot-bin-sidewall height is used. Three, 36-foot-diameter bins are used to keep bin and fan sizes down due to electric power restrictions. From Table 24, a 36-foot-diameter bin holds 13,024 bushels level at 16 feet, so three, 13,000-bushel bins would provide 39,000 bushels of level storage. Inclined drag conveyors are the preferred bin fill method to minimize impact damage.

For 20% moisture in Table 21, the recommended airflow is 3 cfm per bushel. at a maximum grain depth of 8 feet, or about 6,500 bushels. At 3 cfm per bushel x 6,500 bushels = 19,500 cfm; however since it is likely that 18% grain will be dried in the rest of the bin, the minimum design airflow should be 2 cfm per bushel x 13,000 bushels = 26,000 cfm. A 36-foot-diameter bin has about 1,000 square feet of perforated floor area, so the airflow rate would be about 26,000/1,000 = 26 cfm per square foot.

Table 25 lists static pressures for soybeans at airflow rates ranging from normal and high speed aeration of 0.1 through 0.75 cfm per bushel, through

Table 23. Bin loading schedule for natural air drying*.

Dry grain depth (h) (< 14% m.c.)	*Percent Moisture of Soybeans Added to Bin*						
	22	*21*	*20*	*19*	*18*	*17*	*16*
	Maximum Moist Grain Depth Added to Dried Grain Depth						
0-(1st fill)	8.9	10.2	12	13.2	16.5	16	17.2
4	7.8	9.2	11	12.1	14.5	14.9	16.2
6	7.3	8.6	10.4	11.5	13.0	14.4	15.6
8	6.7	8.1	9.8	11.0	12.5	13.7	15.0
10	-	7.5	9.3	10.5	12.0	13.2	14.5
12	-	-	8.7	10.0	11.5	12.7	14.0
14	-	-	-	-	10.8	12.2	13.5
16	-	-	-	-	-	-	13.0

* **Source:** Abstracted from: Table: Natural Air Drying Schedule. Estimating Yields & Harvest Losses. Kansas Soybean Field Guide, 1996, Kansas Soybean Association and Kansas State University, Cooperating. Funded by Kansas Soybean Association and Kansas Soybean Commission.

Table 24. Level storage capacity of round steel bins*.

Diam. (ft)	Bu/ft depth	Bin Capacities at Selected Depths (feet)									
		4	*8*	*12*	*16*	*20*	*24*	*28*	*32*	*36*	*40*
14	123	492	984	1,476	1,968	2,460	2,952	3,444	3,936	4,428	4,920
18	203	812	1,624	2,436	3,248	4,060	4,872	5,684	6,496	7,308	8,120
21	277	1,108	2,216	3,324	4,432	5,540	6,648	7,756	8,864	9,972	11,080
24	362	1,448	2,896	4,344	5,792	7,240	8,688	10,136	11,584	13,032	14,480
27	458	1,832	3,664	5,496	7,328	9,160	10,992	12,824	14,656	16,488	18,320
30	565	2,260	4,520	6,780	9,040	11,300	13,560	15,820	18,080	20,340	22,600
33	684	2,736	5,472	8,208	10,944	13,680	16,416	19,152	21,888	24,624	27,360
36	814	3,256	6,512	9,768	13,024	16,280	19,536	22,792	26,048	29,304	32,560
40	1,005	4,020	8,040	12,060	16,080	20,100	24,120	28,140	32,160	36,180	40,200
48	1,448	5,792	11,584	17,367	23,168	28,960	34,572	40,544	46,336	52,128	57,920
54	1,832	7,328	14,656	21,984	29,312	36,640	43,968	51,296	58,624	65,952	73,280
60	2,262	9,048	18,096	27,144	36,192	45,240	54,288	63,336	72,384	81,432	90,480

* Note: Compaction for overburden not considered. Bins will hold 10% to 15% more grain by weight due to compaction in depths greater than 20 feet.

Table 25. Approximate static pressure vs. airflow per foot of depth for soybeans.

Grain Depth	*Airflow Rate, cfm/bu*							
	0.1	*0.25*	*0.5*	*0.75*	*1.0**	*2.0**	*3.0**	*4.0**
5	0.2	0.3	0.4	0.5	0.7	0.9	1.1	1.4
10	0.4	0.5	0.7	0.9	1.2	2.3	3.8	5.7
15	0.5	0.7	1.1	1.4	2.3	5.5	9.7	-
20	0.7	1.0	1.5	2.2	4.1	10.9	-	-
25	0.8	1.3	2.2	3.3	6.7	-	-	-
30	0.9	1.6	3.0	4.8	9.8	-	-	-
35	1.1	2.1	4.1	6.7	-	-	-	-
40	1.3	2.7	5.4	9.1	-	-	-	-
50	1.7	4.0	9.8	-	-	-	-	-
60	2.2	5.9	-	-	-	-	-	-

Source: ASAE engineering data, 0272.2, OEC 92, Resistance 10 airflow of grains, seeds, other agricultural products and perforated metal sheets, ASAE Standards 1993, American Society of Agricultural Engineers, p. 433.
Note: * 0.5 inches w.c. static pressure added 10 grain flow resistance static pressures for airflows from 1.0 to 4.0 cf per bushel 10 account for frictional resistance at high airflows through transition ducts, perforated floors and/or ducts and exhaust vents.

natural air drying rates of 1.0 through 4.0 cfm per bushel are listed. Notice that static pressures increase rapidly with depth for each air flow rate. For air flow rates greater than 1.0 cfm per bushel and for depths greater than 20 feet, centrifugal fans must be used. Low speed (1,750 to 1,800 RPM) direct drive centrifugal fans are more efficient than high speed (3500 to 3600 RPM), high pressure centrifugal fans for static pressures (s.p.) below 10 inches water column (w.c.).

Selecting Fan Types and Sizes

Example 7. If the grain manager selected a design airflow rate of 2 cfm per bushel for a depth of 16 feet, he can estimate the static pressure of his fan(s) from Table 25. The static pressure for 2 cfm per bushel at 15 feet is 5.5 inches w.c. and at 20 feet, 10.9 inches w.c. Interpolating between these values for 16 feet would provide an estimated static pressure of about 6.6 inches w.c.

An estimate of total fan HP required for a given bin of grain can be estimated using the rule of thumb footnoted in Table 22: 3,000 cfm/HP at 1.0 inch w.c. This can be written as an equation where:

Total Fan HP = Total CFM/(3,OOO/S.P.), or Total Fan HP = Total CFM x SP/3,000

For 13,000 bushels of soybeans with an airflow rate of 2.0 cfm per bushel, the total airflow required would be 26,000 cfm. Using 6.6 inches water column static pressure, total fan HP = 26,000 cfm x 6.6/3,000 = 26 x 6.6/3 = 57.2, or 60 HP. Notice the difference in HP required by reducing the grain depth from 16 feet to 10 feet with 8,125 bushels, or 16,250 cfm at 2.0 cfm per bushel with 2.3 inches static pressure. Total fan HP at 10 feet would be 16,250 x 2.3/3,00 = 12.46 = 12.5 HP, or two 7.5 HP fans.

At 12-foot depth and 9,750 bushels, with an estimated static pressure of 3.5 inches, the total airflow would be 2.0 x 9,750 = 19, 500 cfm. The total fan HP for 12 feet of soybeans would be 19,500 x 3.5/3,000 = 22.75 or about 22.5 HP. By reducing the depth by 25%, only 38% as much fan HP is required. Instead of six 10-HP fans, three 7.5-HP fans are required to provide the same airflow rate of 2.0 cfm per bushel.

Direct drive high speed (3,450 RPM) vane-axial fans are suitable for pressures up to about 4 inches water column. Vane axial airflow rates change much faster with increased pressure than centrifugal fans. If a grain manager expects to dry small grains like wheat, oats or barley at more than 3- to 4-feet depths, centrifugal fans should be installed instead of vane-axial fans. Static pressures for small grains will be two to three higher for the same depth of large seed grains like soybeans or corn.

Table 26. Soybean moisture conversion chart*.

% moisture	*pounds per bushel*	*% moisture*	*pounds per bushel*	*% moisture*	*pounds per bushel*
7.0	56.13	13.5	60.34	20.0	65.25
7.5	56.43	14.0	60.70	20.5	65.66
8.0	56.74	14.5	61.05	21.0	66.08
8.5	57.05	15.0	61.41	21.5	66.50
9.0	57.36	15.5	61.78	22.0	66.92
9.5	57.68	16.0	62.14	22.5	67.35
10.0	58.00	16.5	62.52	23.0	67.79
10.5	58.32	17.0	62.89	23.5	68.23
11.0	58.65	17.5	63.27	24.0	68.68
11.5	58.98	18.0	63.66	24.5	69.14
12.0	59.32	18.5	64.05	25.0	69.60
12.5	59.66	19.0	64.44	25.5	70.07
13.0	60.00	19.5	64.84	26.0	70.54

NOTE: * Corrected to 13.0% moisture content, wet basis.
This chart computed using the dry mailer formula, **Grain weight = 52.2 x 100/(100 - % m.e.)**
where: 52.2 = dry mailer in 60 pounds of 13.0% soybeans.

Table 27. Official U.S. standards for soybeans*.

Grade	Minimum test weight per bu (pounds)	Moisture (%)	Maximum limits of damaged kernels: Heat damaged (%) of total	Total (%)	Material (%)	Foreign Splls (%)	Soybeans of other colors (%)
U.S. No. 1	56.0	13	0.2	2.0	1.0	10.0	1.0
U.S. No. 2	54.0	14	0.5	3.0	2.0	20.0	2.0
U.S. No. 3	52.0	16	1.0	5.0	3.0	30.0	5.0
U.S. No. 4	49.0	18	3.0	8.0	5.0	40.0	10.0

U.S. Sample Grade --
U.S. Sample grade is soybeans that:

(a) Do not meet the requirements for U.S. Nos. 1,2,3 or 4: or

(b) Contain four or more stones which have an aggregate weight in excess of 0.1 % of the sample weight, one or more pieces of glass, three or more Crotalaria seeds (*Crotalana* spp.), two or more castor beans (*Ricinus communis* L.), four or more particles of unknown foreign substance(s) or a commonly recognized harmful or toxic substance(s), 11 or more total other material; or

(c) Total other material exceeding len of any combination of animal filth, castor beans, crotalaria seeds, glass, stones and unknown foreign substances is sample grade.

(d) Have a musty, sour or commercially objectionable foreign odor (except garlic odor), or

(e) Are heating or otherwise of distinctly low qualify.

Source: * USDA, Federal Grain Inspection Service, Official United States Standards for Grain, January 2000, Reproduced for California, Nebraska, North Dakota, Oklahoma Grain Grading Schools by Nebraska Grain & Feed Association, 1233 Lincoln Mall, Lincoln, NE 68508, p. 39.

Example 8: : A 60,000-pound semi-load of 18% m.c. soybeans would be equivalent to: 60,000/63.66 = 942.5 bushels of 13.0% soybeans.

VII. ADDITIONAL RESOURCES

Fact sheets are available online at extension.okstate.edu

.

- EPP-7660, Seedling and Root Diseases of Soybean
- EPP-7662, Stem and Pod Diseases of Soybean
- EPP-7167 - Management of Insect and Mite Pests in Soybean
- EPP- 7156 - Field Key to Larvae in Soybeans

Web Resources

OSU Soybeans
www.oilseeds.okstate.edu

Oklahoma Soybean Board
www.oksoy.org/

Conversion Factors

Acres (A)	x 0.405	Hectares
Acres	x 43,560	Square feet
Acres	x 4047	Square meters
Acres	x 160	Square rods
Acres	x 4840	Square yards
Bushels (bu)	x 2150.42	Cubic Inches
Bushels	x 1 .24	Cubic feet
Bushels	x 35.24	Liters
Bushels	x 4	Pecks
Bushels	x 64	Pints
Bushels	x 32	Quarts
CaC03	x 0.40	Calcium
CaC03	x 0.84	MgC03
Calcium (ca)	x 2.50	CaC03
Centimeters (cm)	x 0.3937	Inches
Centimeters	x 0.01	Meters
Centimeters	x 10	Millimeters
Cord (4' x 4' x 8')	x 8	Cord Feet
Cord foot (4' x 4' x 1')	x 16	Cubic feet
Cubic centimeter (cm^3)	x 0.061	Cubic inch
Cubic feet (ft^3)	x 1728	Cubic inches
Cubic feet	x 0.03704	Cubic yards
Cubic feet	x 7.4805	Gallons
Cubic feet	x 59.84	Pints (liq.)
Cubic feet	x 29.92	Quarts (liq.)
Cubic feet	x 25.71	Quarts (dry)
Cubic feet	x 0.084	Bushels
Cubic feet	x 28.32	Liters
Cubic inches (in^3)	x 16.39	Cubic cms
Cubic meters (m^3)	x 1,000,000	Cubic cms
Cubic meters	x 35.31	Cubic feet
Cubic meters	x 61,023	Cubic inches
Cubic meters	x 1.308	Cubic yards
Cubic meters	x 264.2	Gallons
Cubic meters	x 2113	Pints (liq.)
Cubic meters	x 1057	Quarts (liq.)
Cubic yards (yd^3)	x 27	Cubic feet
Cubic yards	x 46,656	Cubic inches
Cubic yards	x 0.7646	Cubic meters
Cubic yards	x 21.71	Bushels
Cubic yards	x 202	Gallons
Cubic yards	x 1616	Pints (liq.)
Cubic yards	x 807.9	Quarts (liq.)
Cup	x8	Fluid ounces
Cup	x 236.5	Milliliters
Cup	x 0.5	Pint
Cup	x 0.25	Quart

Cup	x 16	Tablespoons
Cup	x 48	Teaspoons
° Celsius (°C)	(+ 17.98) x 1.8	Fahrenheit
° Fahrenheit (°F)	(-32) x 0.5555	Celsius
Fathom	x6	Feet
Feet (ft)	x 30.48	Centimeters
Feet	x 12	Inches
Feet	x 0.3048	Meters
Feet	x 0.33333	Yards
Feet/minute	x 0.01667	Feet/second
Feet/minute	x 0.01136	Miles/hour
Fluid ounce	x 1.805	Cubic inches
Fluid ounce	x2	Tablespoons
Fluid ounce	x6	Teaspoons
Fluid ounce	x 29.57	Milliliters
Furlong	x 40	Rods
Gallons (gal)	x 269	Cubic in. (dry)
Gallons	x 231	Cubic in. (liq.)
Gallons	x 3785	Cubic cms
Gallons	x 0.1337	Cubic feet
Gallons	x 231	Cubic inches
Gallons	x 3.785	Liters
Gallons	x 128	Ounces (liq.)
Gallons	x8	Pints (liq.)
Gallons	x4	Quarts (liq.)
Gallons of water	x 8.3453	Pounds of water
Grains	x 0.0648	Grams
Grams (g)	x 15.43	Grains
Grams	x 0.001	Kilograms
Grams	x 1000	Milligrams
Grams	x 0.0353	Ounces
Grams/liter	X 1000	Partslmillion
Hectares (ha)	x 2.471	Acres
Hundred wt (cwt)	x 100	Pounds
Inches (in)	x 2.54	Centimeters
Inches	x 0.08333	Feet
Inches	x 0.02778	Yards
K,O	x 0.83	Potassium (K)
Kilogram (kg)	x 1000	Grams (g)
Kilograms	x 1000	Grams
Kilograms	x 2.205	Pounds
Kilograms/hectare	X 0.8929	Pounds/acre
Kilometers (K)	x 3281	Feet
Kilometers	x 1000	Meters
Kilometers	x 0.6214	Miles
Kilometers	x 1094	Yards
Knot	x 6086	Feet
Liters (l)	x 1000	Milliliters
Liters	x 1000	Cubiccms
Liters	x 0.0353	Cubic feet

Liters	x 61.02	Cubic inches
Liters	x 0.001	Cubic meters
Liters	x 0.2642	Gallons
Liters	x 2.113	Pints (liq.)
Liters	x 1.057	Quarts (liq.)
Liters	x 0.908	U.S. dry quart
Magnesium (Mg)	x 3.48	MgC03
Meters (m)	x 100	Centimeters
Meters	x 3.281	Feet
Meters	x 39.37	Inches
Meters	x 0.001	Kilometers
Meters	x 1000	Millimeters
Meters	x 1.094	Yards
MgC03	x 0.29	Magnesium (Mg)
MgC03	x 1.18	CaC03
Miles	x 5280	Feet
Miles	x 1.69093	Kilometers
Miles	x 320	Rods
Miles	x 1760	Yards
Miles/hour	x 88	FeeVminute
Miles/hour	x 1.467	FeeVsecond
Miles/minute	x 88	FeeVsecond
Miles/minute	x 60	Mileslhour
Milliliter (ml)	x 0.034	Fluid ounces
Ounces (dry)	x 437.5	Grains
Ounces (dry)	x 28.3495	Grams
Ounces (dry)	x 0.0625	Pounds
Ounces (liq.)	x 1.805	Cubic inches
Ounces (liq.)	x 0.0078125	Gallons
Ounces (liq.)	x 29.573	Cubic cms
Ounces (liq.)	x 0.0625	Pints (liq.)
Ounces (liq.)	x 0.03125	Quarts (liq.)
Ounces (oz.)	x 16	Drams
P,O,	x 0.44	Phosphorus (P)
Parts per million (ppm)	x 0.0584	Grainslgallon
Parts per million	x 0.001	Gramslliler
Parts per million	x 0.0001	Percent
Parts per million	x 1	Milligramlkg
Parts per million	x 1	Milligramlliter
Pecks	x 0.25	Bushels
Pecks	x 537.605	Cubic inches
Pecks	x 16	Pints (dry)
Pecks	x8	Quarts (dry)
Phosphorus (P)	x 2.29	P,O,
Pints (p)	x 28.875	Cubic inches
Pints	x2	Cups
Pints	x 0.125	Gallon
Pints	x 473	Milliliters
Pints	x 32	Tablespoons
Pints (dry)	x 0.015625	Bushels

Pints (dry)	x 33.6003	Cubic inches
Pints (dry)	x 0.0625	Pecks
Pints (dry)	x 0.5	Quarts (dry)
Pints (liq.)	x 28.875	Cubic inches
Pints (liq.)	x 0.125	Gallons
Pints (liq.)	x 0.4732	Liters
Pints (liq.)	x16	Ounces (liq.)
Pints (liq.)	x 0.5	Quarts (liq.)
Potash (K,O)	x 0.83	Potassium (K)
Potassium (K)	x 1.20	Potash (K,G)
Pounds (I b)	x 7000	Grains
Pounds	x 453.5924	Grams
Pounds	x 16	Ounces
Pounds	x 0.0005	Tons
Pounds	x 0.45359	Kilograms (kg)
Pounds of water	x 0.01602	Cubic feet
Pounds of water	x 27.68	Cubic inches
Pounds of water	x 0.1198	Gallons
Pounds/acre	x 1.12	Kilogramslha
Quarts (qt)	x 946	Milliliters
Quarts (dry)	x 0.03125	Bushels
Quarts (dry)	x 67.20	Cubic inches
Quarts (dry)	x 0.125	Pecks
Quarts (dry)	x2	Pints (dry)
Quarts (liq.)	x 57.75	Cubic inches
Quarts (liq.)	x 0.25	Gallons
Quarts (liq.)	x 0.9463	Liters
Quarts (liq.)	x 32	Ounces (liq.)
Quarts (liq.)	x2	Pints (liq.)
Rods	x 16.5	Feet
Square feet (ft')	x 0.000247	Acres
Square feet	x 144	Square inches
Square feet	x 0.11111	Square yards
Square inches (in')	x 0.00694	Square feet
Square meters (m')	x 0.0001	Hectares (ha)
Square miles (mi')	x 640	Acres
Square miles	x 28,878,400	Square feet
Square miles	x 3,097,600	Square yards
Square yards (yd')	x 0.0002066	Acres
Square yards	x9	Square feet
Square yards	x 1296	Square inches
Tablespoons (Tbsp)	x 15	Milliliters
Tablespoons	x3	Teaspoons
Tablespoons	x 0.5	Fluid ounces
Teaspoons (tsp)	xO.17	Fluid ounces
Teaspoons	x 0.333	Tablespoons
Teaspoons	x5	Milliliters
Ton	x 907.1849	Kilograms
Ton	x 32,000	Ounces

Ton (long)	x 2240	Pounds
Ton (short)	x 2000	Pound
U.S. bushel	x 0.3524	Hectoliters
U.S. dry quart	x 1.101	Liters
U.S. gallon	x 3.785	Liters
Yards (yd)	x3	Feet
Yards	x 36	Inches
Yards	x 0.9144	Meters
Yards	x 0.000568	Miles

EXTENSION