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University of Kentucky
College of Agriculture, Food and Environment
Cooperative Extension Service

A Comprehensive Guide to

Soybean Management in Kentucky

Cooperative Extension Service | Agriculture and Natural Resources | Family and Consumer Sciences | 4-H Youth Development | Community and Economic Development

A Comprehensive Guide to

Soybean Management in Kentucky

Cover: Soybeans in field just east of Calhoun, Kentucky, on Highway 136.

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Chapter 1

Introduction

Carrie Knott

Soybean is used to produce hundreds of consumer, industrial, and feedstock products. Some of the most recognized products include vegetable oil, soymilk, animal feed products, and biodiesel. Other products made from soybean, which may be less well known, include spray foam insulation, plastics, paint, ink, wax, and wood adhesive.

Soybean is an important crop to Kentucky's rotation. Among the four most common crops in Kentucky, it has remained the second most valuable crop for Kentucky from the mid-2000s until 2016, when it was the most valuable crop in Kentucky (Figure 1-1).

In general, most Kentucky producers maintain either a soybean-corn or soybean-corn-winter wheat rotation. Since 1960, soybean acreage has increased from about 200,000 acres to about 1.8 million acres in 2016. During that same time period, Kentucky's average soybean yield, which includes both full-season and double-crop yield, has steadily increased from about 20 bu/A to about 50 bu/A (Figure 1-2).

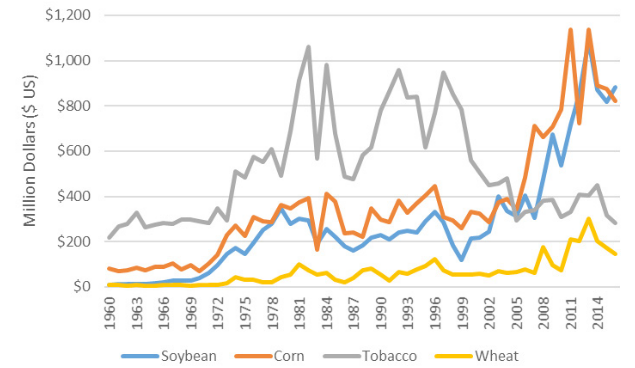
This publication provides information on soybean growth and development, principles of variety selection, and management practices to maximize soybean profitability in Kentucky.

Resources

United Soybean Board, 2017. Soy Products Guide. http://reader.mediawiremobile.com/USB/issues/200233/viewer?page=1.

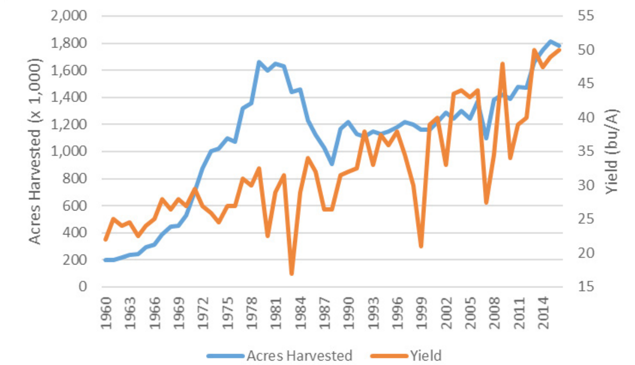
United States Department of Agriculture National Agricultural Statistics Service. Kentucky Statistics. https://www.nass.usda.gov/Statistics_by_State/Kentucky/.

Figure 1-1. Kentucky crop values per year: 1960-2016.



Source: United States Department of Agriculture National Agricultural Statistics Service.

Figure 1-2. Average soybean yield and harvested area in Kentucky from 1960 to 2016.



Source: United States Department of Agriculture National Agricultural Statistics Service.

Chapter 2

Growth and Development

Carrie Knott, Chad Lee, and Montse Salmeron

Identifying growth stages of any crop is important to effectively manage the crop and maximize yield and profitability. The most common soybean growth stage system divides plant development into two phases: vegetative (V) and reproductive (R) (Table 2-1). The **vegetative** growth stages are identified by the number of fully developed leaves on the main stem. The **reproductive** growth stages of soybean are primarily identified by flowering, pod size, seed size and pod color.

Specific growth stages of soybean are identified by examining the plant for specific characteristics: number of leaves, presence of flowers, size of pods, etc. Growth staging individual plants is relatively easy; a plant either has the key characteristic of a specific growth state or it does not. However, when managing soybean for commercial production, determining the growth stage of every individual soybean plant is not feasible. Instead, growth staging at least 30 to 40 plants at numerous **representative** areas within a field is necessary. ***At least 50 percent*** of the representative plants examined must be at (or beyond) the same stage to specify a field a specific growth stage.

The time between growth stages and the number of leaves that a soybean plant develops is highly dependent upon genetics (variety), maturity group (MG), planting date, location, and environment. In most cases, environmental stress can influence the duration of growth stages differentially depending on the growth stage of the soybean plant when the stress occurs. For example, drought stress typically extends vegetative growth stages whereas drought stress can shorten reproductive growth stages.

Adapted for Kentucky from Pedersen, 2009.

This chapter describes key features and the importance of identifying soybean growth stages. For detailed descriptions of soybean development, including growth stages, refer to the Iowa State University's *Soybean Growth and Development* (Pederson, 2009; http://extension.agron.iastate.edu/soybean/production_growthstages.html) and *Stages of Soybean Development* (Fehr and Caviness, 1977).

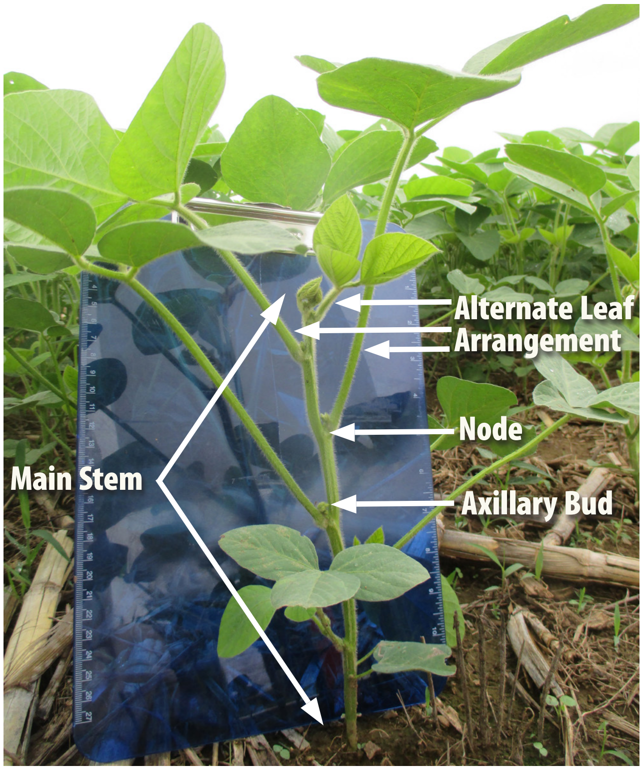


Figure 2-1. Soybean plant with **alternate leaf arrangement**, dormant **axillary buds**, and **nodes** on the **main stem**.

Table 2-1. Key soybean growth stages, approximate timing, descriptions, and importance for Kentucky soybean production.

Growth Stage (50% or more of field)		Typical Timing in Kentucky Full-Season†	Double-Crop†	Description/Importance
Vegetative Stages				
VE	Emergence	early to mid-May	mid-June to early July	The cotyledons and growing point are **above** the soil surface. Full-season soybean typically emerge 1 to 2 weeks after planting. Double-crop soybean typically emerge 5 days after planting.
VC	Cotyledon	May	June/July	The two unifoliolate leaves are fully developed (the leaf edges are no longer touching). Nitrogen (N)-fixing (*Bradyrhizobium japonicum*) root nodules may be visible, but not functional.
V1	1 Trifoliolate Leaf	May	June/July	The first trifoliolate leaf is fully developed. N-fixing root nodules may be visible, but not functional.
V2	2 Trifoliolate Leaves	May/June	June/July	Two trifoliolate leaves are fully developed. N-fixing root nodules are typically functional.
V3	3 Trifoliolate Leaves	June	July	Three trifoliolate leaves are fully developed. Typically occurs 2-3 weeks after emergence for full-season soybean and 2 weeks after emergence for double-crop soybean. This is final growth stage when several herbicides can be applied.
V4 To V(n)	4 Trifoliolate Leaves To n^{th} Trifoliolate Leaves	June	July	Four to n trifoliolate leaves are fully developed. The number of trifoliolate leaves is determined by variety and environmental conditions.
Reproductive Stages				
R1	Beginning Flowering	late June to mid-July	early Aug	One flower at any node on the main stem is open. Environmental stress or plant injury typically has minimal effect on seed yield.
R2	Full Flowering	July	Aug	A flower on the main stem opens at one of the two top nodes with a fully developed trifoliolate leaf. Beginning of rapid growth and nutrient accumulation in vegetative plant parts. Environmental stress or plant injury typically has minimal effect on seed yield.
R3	Beginning Pod	mid-July to Aug	Aug	A 5 mm (3/16 inch) long pod on the main stem at one of the four top nodes with a fully developed trifoliolate leaf. Environmental stress or plant injury typically has minimal effect on seed yield at this stage. Typically **last pesticide applications** occur.
R4	Full Pod	early Aug	Aug	A 2 cm (3/4 inch) long pod is on the main stem at one of the four top nodes with a fully developed trifoliolate leaf. Beginning with this growth stage, **seed yield can be greatly reduced** due to environmental stress and/or plant injury.
R5	Beginning Seed	Aug	late Aug	A 3 mm (1/8 inch) long seed is in a pod on the main stem at one of the four top nodes. Begins a period of **rapid seed growth and fill**. Plant stress at this stage typically results in aborted seed. Environmental stress and/or plant injury can result in **significant yield reductions**.
R6	Full Seed	early Sept	Sept	Green seed fill the pod cavity at one of the four top nodes on the main stem with a fully developed trifoliolate leaf. Plant stress at this stage typically results in pod and seed abortion, which can **significantly reduce yields**.
R7	Beginning Maturity	Sept	late Sept to Oct	One normal pod on the main stem is mature and has turned brown or tan. Soybean seed has essentially reached physiological maturity, which means the seed has attained maximum dry weight. Rapid leaf yellowing begins. Stress that occurs at this stage has essentially no effect on seed yield.
R8	Full Maturity	mid-Sept to Oct	late Oct to Nov	95% of pods have turned brown (mature pod color). Stressful conditions at this stage have no effect on seed yield, unless hail or other factors that remove pods from the stem.

† Estimated timing of developmental stages for full season soybeans planted in late April to early May, and double-crop soybeans planted in mid-June to early July.

Vegetative Growth Stages

Soybean vegetative stages are defined by the number of fully developed leaves and occur prior to flowering (R1 growth stage). Production of new leaves can occur until about R5 growth stage in indeterminate varieties (MG 000 to MG IV) and for some time after R1 growth stage in most determinate varieties (MG V to X).

To accurately identify vegetative growth stages, several key terms are essential.

Alternate leaf arrangement occurs when two leaves develop at different positions on the main stem (Figure 2-1).

Axillary buds occur at every node of a soybean plant. Each axillary bud has the potential to develop into a branch or flower cluster (raceme), or remain dormant (Figure 2-1).

Fully developed leaf is a leaf that has unfolded so no portion of the leaflet edges are touching (Figure 2-2).

Main stem is the primary stem of the soybean plant and is attached to the roots (Figure 2-1).

Node is the location at which the leaves are attached to the main stem (Figure 2-1).

Nodules are nitrogen-fixing root structures that are formed by the soil bacterium *Bradyrhizobium japonicum*. The interior of functional nodules is bright pink (Figure 2-3); non-functional nodules can be white, brown, or green (Figure 2-4).

Opposite leaf arrangement occurs when two leaves develop directly opposite from one another on the stem. In soybean the two first nodes of the main stem have an opposite leaf arrangement: cotyledons and unifoliolate leaves (Figure 2-2).

Trifoliolate leaf is a leaf that consists of three leaflets (Figure 2-2).

Undeveloped leaf is a leaf that has any portion of the leaflet edges touching (Figure 2-5).

Unifoliolate leaf is a leaf that consists of a single leaflet (Figure 2-2).

The vegetative growth stage of a soybean plant can be determined, even after leaves have fallen or been broken off the stem. Simply look at the base of the plant and identify the cotyledon (VE) and unifoliolate leaf (VC) scars (or node scars), which remain visible throughout the growing season and are in the opposite leaf arrangement. Once the two sets of opposite leaf scars are identified, then the singular, alternate leaf pattern of the trifoliolate leaves can be identified and counted to determine vegetative growth stage.

At each leaf node (Figure 2-1) a soybean plant has axillary buds that can develop into a branch or a flower cluster (raceme), or remain dormant. The growing point (apical meristem) typically produces growth hormones that suppress axillary bud development. When resources are available, axillary buds can develop into branches (Figure 2-6) that ultimately produce more nodes and pods, particularly as row spacing increases and plant populations decrease or when resources become available following an environmental stress or plant injury.

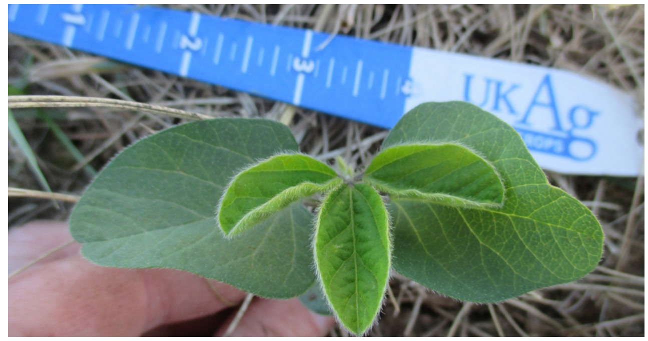


Figure 2-2. Soybean plant with one **fully developed** (leaflet edges no longer touching) **trifoliolate leaf** above the **unifoliolate leaves**. The unifoliolate leaves develop in an **opposite leaf arrangement**.

Figure 2-3. Functional soybean root nodules (white arrows).

Figure 2-4. Non-functional soybean root nodule (at white arrow).

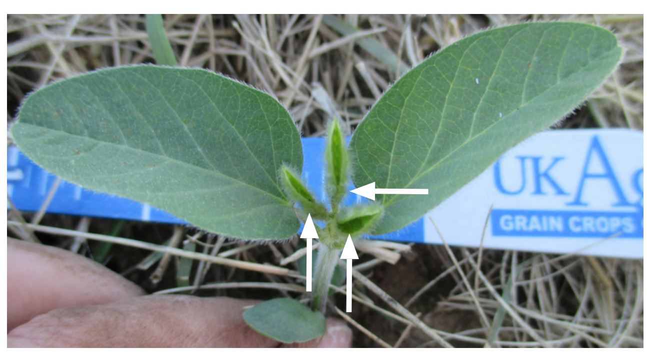


Figure 2-5. Soybean plant with an **undeveloped leaf**. The leaflet edges are still touching at the white arrows.

This ability to produce branches, nodes, and pods at the axillary buds allows soybean to produce similar yields over a wide range of plant populations and row spacings, and following environmental stress and/or plant injury, assuming adequate water and nutrients are available.

VE Growth Stage

The VE, vegetative emergence, growth stage occurs as soon as the cotyledons are above the soil surface (Figure 2-7).

During the emergence stage, the cotyledons unfold to expose the epicotyl, which consists of leaves, stem, and growing point (Figure 2-7). The growing point of soybean is located just above the cotyledons, which makes soybean vulnerable to damage as soon as it emergences from the soil. This is different from other crops grown in Kentucky such as corn and wheat that have growing points that remain below the soil surface for at least several weeks after emergence. At the VE stage, hail, frost, insect, or mechanical damage can cause significant yield reductions.

The cotyledons supply nutrients and food reserves for the developing seedling up to 10 days after emergence and are the first soybean plant part capable of photosynthesis. From seed germination to the VE growth stage, the cotyledons will lose a significant amount of their dry weight to support the developing seedling. Typically, loss of one cotyledon has little to no effect on the developing soybean plant. In contrast, if significant damage or complete loss of both cotyledons occurs, seedlings can die or be severely stunted, which can ultimately reduce seed yield.

In Kentucky, soybean planted in April usually emerge within 7 to 11 days of planting, whereas emergence can occur after only 5 days for double-crop soybean planted in late June and early July, assuming good planting conditions. Good planting conditions exist when soil temperature is at least 50°F (10°C), there is adequate soil moisture, seed are planted to a depth of 1.0 to 1.5 inches, and good seed-to-soil contact is achieved.

VC Growth Stage

The VC, vegetative cotyledon, growth stage begins when the unifoliolate leaves are fully developed (unfolded and with leaflet edges no longer touching) (Figure 2-8). In soybean, two unifoliolate leaves develop in an opposite leaf arrangement (Figures 2-2 and 2-8). The unifoliolate leaves are the first true leaves of a soybean plant.

Figure 2-7. Soybean plant at VE growth stage. The cotyledons ('bean') of the plant are separating to expose the developing unifoliolate leaflets, stem, and growing point of the plant (epicotyl).

Figure 2-6. Branches that developed at one cotyledon node (white arrow) and one unifoliolate node (black arrow) after the cotyledons and one unifoliolate leaf of the soybean plant fell off the main stem in normal growing conditions. This plant is at the R1 growth stage; there is one open flower out of the field of view.

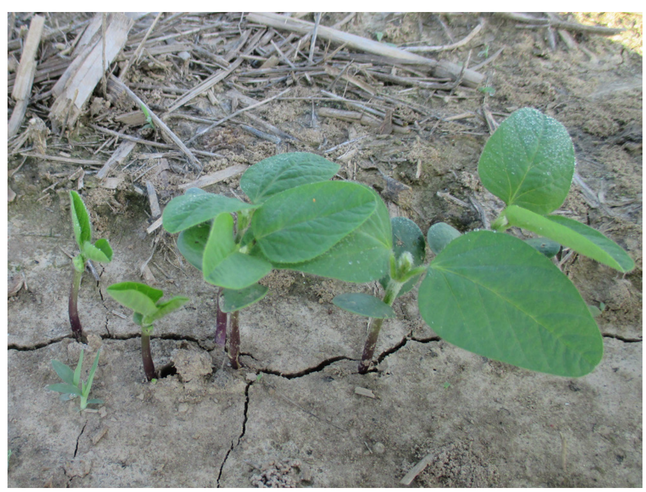


Figure 2-8. Soybean plants at VC growth stage. Although the first two plants from the left are much smaller than the other plants, they are also at the VC growth stage because the leaves are fully developed (leaflet edges are no longer touching).

V1 Growth Stage

Beginning with the V1 growth stage (Figure 2-9), trifoliolate leaves (Figure 2-2) are formed by the soybean plant. At this stage the soybean plant is still deriving a portion of its nutrient and food reserve from the cotyledons. Root nodules containing the nitrogen (N)-fixing bacteria *Bradyrhizobium japonicum* may be visible as early as the V1 growth stage; however, they are likely not functional at this stage. Functional root nodules, which are actively fixing nitrogen, are pink (Figure 2-3) whereas non-functional root nodules are not pink and can be white, brown, or green (Figure 2-4).

V2 Growth Stage

By V2 (Figure 2-10) the soybean plant is capable of producing all its energy via photosynthesis in existing leaves. In most cases the root nodules will be actively fixing nitrogen by V2. Root nodulation and N-fixation can be reduced at this stage if soil nitrate-nitrogen levels are high.

Figure 2-9. Soybean plant at V1 growth stage; one trifoliolate leaf is fully expanded.

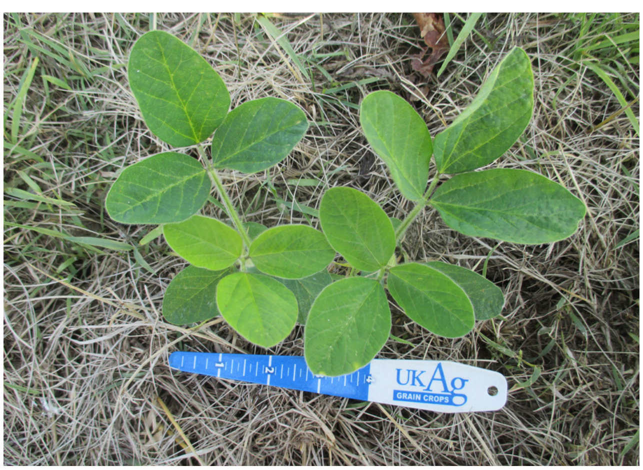


Figure 2-10. Soybean plants at V2 growth stage; two trifoliolate leaves are fully expanded.

V3 to V(n) Growth Stages

The V3 growth stage (Figure 2-11) is the final stage that several herbicides are labelled for application.

By V6 the cotyledons and unifoliolate leaves have typically matured and have fallen off the soybean plant (Figure 2-12). The leaf scars for both cotyledon and unifoliolate leaves remain visible. Damage or stress in the vegetative growth stages typically has little effect on final seed yield unless the entire plant is destroyed.

For example, only about 3 percent yield reductions occur when half of the leaves are lost at V6.

Figure 2-11. Soybean plant at V3 growth stage; three trifoliolate leaves are fully developed.

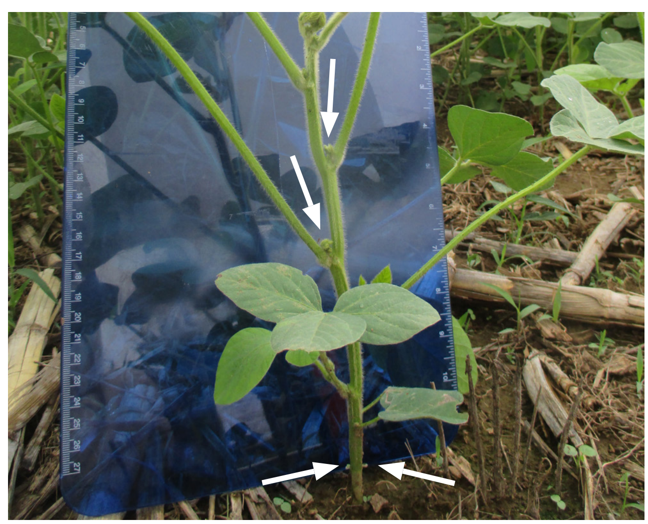


Figure 2-12. Soybean plant at V6 growth stage with axillary buds visible at the arrows. Note that the cotyledons are gone (bottom two arrows) and axillary buds are developing.

Reproductive Growth Stages

The reproductive growth stages of soybean start with the initiation of flowering. There are two growth habits of soybean which differ beginning at the reproductive stage: indeterminate and determinate. Indeterminate soybean plants continue to produce vegetative growth and new nodes while reproductive growth is occurring until approximately the R5 growth stage. Most soybean varieties from maturity group (MG) 00 to IV are indeterminate. In contrast, the determinate growth habit completes vegetative growth prior to initiation of reproductive growth or shortly thereafter. Most determinate soybean varieties are MG V to IX.

During the reproductive growth stages, soybean has tremendous capability to compensate for adverse growing conditions or plant injury. This is in part due to the long flowering period and prolific flower production of soybean. In fact, more than half of the flowers each soybean plant produces are typically aborted prior to pod development. These unique features of soybean have led to considerable interest from crop physiologists to understand and predict soybean growth, development, and yield for different environmental conditions. Prediction of key developmental stages for soybean grown in Kentucky is of particular interest given the wide range of soybean maturity groups that can be used for full-season and double-crop systems. Estimation of the time to key developmental stages can help producers and agronomists make management decisions and develop agronomic recommendations that minimize yield limitations in Kentucky.

A crop simulation model that has been widely used for soybean is DSSAT-CROPGRO. It uses daily temperature, daylength, and soybean MG to estimate soybean development. It was used to generate the expected dates of several key reproductive growth stages for four planting dates and six locations across Kentucky with the most recent 15 years of historical weather data (Figure 2-13; Tables 2-2 to 2-4).

For most full-season soybean in Kentucky reproductive growth stages begin approximately 55 days after planting, while double-crop soybean typically begin reproductive growth stages approximately 38 days after planting (Figure 2-13; Table 2-2).

R1 Growth Stage

Beginning flowering, R1 growth stage, occurs when one flower opens at any node on the main stem (Figures 2-14). Flowering typically begins on the third to sixth node and progresses up and down the plant. Petals will fall off the flowers and pods will begin to elongate three to four days after the flower opens.

Figure 2-14. Soybean plants with open flowers

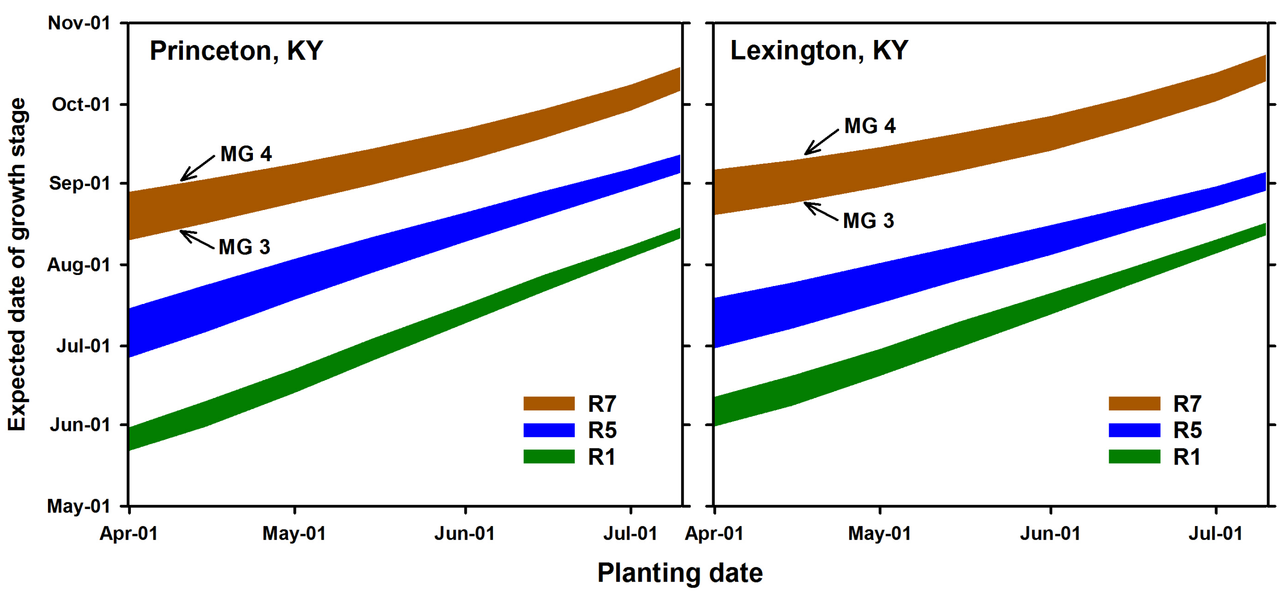


Figure 2-13. Expected date of beginning flowering (R1), beginning seed (R5) and physiological maturity (R7) growth stages for a range of planting dates at Princeton, KY (left) and Lexington, KY (right). The shaded areas represent the range in expected dates of growth stages for maturity group (MG) III and IV varieties. Data obtained from simulations with DSSAT-CROPGRO (Jones et al., 2003) across 15 years of historical weather data and with variety coefficients based on (Salmeron and Purcell, 2016). These data also appear in Tables 2-2, 2-3 and 2-4.

Branches flower a few days after flowering begins on the main stem.

Short-term environmental stress or plant injury typically has minimal effect on seed yield at this stage.

For full-season soybean, the R1 growth stage typically occurs 45 days after planting for relative maturity group 3 soybean varieties and 55 days after planting for relative maturity group 4 soybean varieties (Figure 2-13; Table 2-2).

For double-crop soybean the R1 growth stage generally occurs 34 days after planting for relative maturity group 3 soybean varieties and 38 days after planting for relative maturity group 4 soybean varieties (Figure 2-13; Table 2-2).

R2 Growth Stage

Full flowering, R2 growth stage, occurs when a flower on the main stem opens at one of the two top nodes with a fully developed trifoliolate leaf (Figure 2-16).

Soybean plants rapidly produce new flowers from R2 to R3 and root nodule N-fixation increases.

This is the beginning of a period of rapid growth and nutrient accumulation, which ends around R6. Initially nutrients are stored in vegetative plant parts (leaves, stems, petioles, and roots), which gradually shift to pods and seeds around R5.

Environmental stress or plant injury typically has minimal effect on seed yield at this stage. Defoliation of half the plant can reduce yield approximately 6 percent. Environmental stress or plant injury at this stage (R1 to about R3) can increase the number of seeds per pod and seed size, which can compensate for aborted flowers and pods.

Figure 2-15. Soybean plant at R1 growth stage, beginning flowering, with one flower open (white arrow) anywhere on the main stem. For this plant the open flower is at the seventh node.

Table 2-2. Estimated dates for occurrence of R1, beginning flowering, for relative maturity group (MG) 3 and 4 soybean varieties at four planting dates and six locations in Kentucky. Data obtained from simulations with DSSAT-CROPGRO (Jones et al., 2003) across 15 years of historical weather data and with variety coefficients based on Salmeron and Purcell, 2016.

	Planting date and Maturity Group							
	1-Apr		1-May		1-Jun		1-Jul	
Location	MG 3	MG 4	MG 3	MG 4	MG 3	MG 4	MG 3	MG 4
	Expected Day of R1 (beginning flowering)							
Mayfield	24-May	2-Jun	15-Jun	24-Jun	10-Jul	17-Jul	3-Aug	7-Aug
Princeton	22-May	31-May	13-Jun	22-Jun	9-Jul	16-Jul	3-Aug	8-Aug
Henderson	24-May	3-Jun	15-Jun	25-Jun	11-Jul	19-Jul	4-Aug	9-Aug
Bowling Green	23-May	31-May	13-Jun	22-Jun	9-Jul	16-Jul	3-Aug	7-Aug
Bardstown	27-May	6-Jun	17-Jun	27-Jun	11-Jul	19-Jul	4-Aug	9-Aug
Lexington[1]	31-May	11-Jun	19-Jun	29-Jun	12-Jul	21-Jul	5-Aug	10-Aug

[1] Lexington weather data was from Spindletop Research Farm.

Table 2-3. Estimated dates for occurrence of R5, beginning seed, for relative maturity group (MG) 3 and 4 soybean varieties at four planting dates and six locations in Kentucky. Data obtained from simulations with DSSAT-CROPGRO (Jones et al., 2003) across 15 years of historical weather data and with variety coefficients based on Salmeron and Purcell, 2016.

	Planting date and Maturity Group							
	1-Apr		1-May		1-Jun		1-Jul	
Location	MG 3	MG 4	MG 3	MG 4	MG 3	MG 4	MG 3	MG 4
	Expected Day of R5 (beginning seed)							
Mayfield	29-Jun	17-Jul	19-Jul	3-Aug	9-Aug	20-Aug	29-Aug	6-Sep
Princeton	26-Jun	15-Jul	18-Jul	3-Aug	9-Aug	20-Aug	29-Aug	6-Sep
Henderson	30-Jun	20-Jul	21-Jul	6-Aug	11-Aug	23-Aug	30-Aug	7-Sep
Bowling Green	27-Jun	15-Jul	18-Jul	2-Aug	9-Aug	20-Aug	29-Aug	5-Sep
Bardstown	3-Jul	23-Jul	23-Jul	8-Aug	12-Aug	23-Aug	31-Aug	7-Sep
Lexington[1]	8-Jul	28-Jul	25-Jul	10-Aug	13-Aug	24-Aug	31-Aug	8-Sep

[1] Lexington weather data was from Spindletop Research Farm.

Figure 2-16. Soybean plant at R2 growth stage, full flowering, with an open flower on the main stem at one of the top two nodes with a fully developed trifoliolate leaf. The open flower (white arrow) is at the second node from the top on the main stem.

Table 2-4. Estimated dates for occurrence of R7, beginning maturity, for relative maturity group (MG) 3 and 4 soybean varieties at four planting dates and six locations in Kentucky. Data obtained from simulations with DSSAT-CROPGRO (Jones et al., 2003) across 15 years of historical weather data and with variety coefficients based on Salmeron and Purcell, 2016.

	Planting date and Maturity Group							
	1-Apr		1-May		1-Jun		1-Jul	
Location	MG 3	MG 4	MG 3	MG 4	MG 3	MG 4	MG 3	MG 4
	Expected day of R7 (beginning maturity)							
Mayfield	11-Aug	29-Aug	25-Aug	9-Sep	9-Sep	21-Sep	28-Sep	8-Oct
Princeton	10-Aug	28-Aug	24-Aug	8-Sep	9-Sep	21-Sep	28-Sep	8-Oct
Henderson	14-Aug	1-Sep	27-Aug	11-Sep	11-Sep	24-Sep	30-Sep	10-Oct
Bowling Green	10-Aug	28-Aug	24-Aug	7-Sep	8-Sep	20-Sep	27-Sep	7-Oct
Bardstown	16-Aug	3-Sep	28-Aug	12-Sep	12-Sep	24-Sep	1-Oct	11-Oct
Lexington[1]	19-Aug	6-Sep	30-Aug	14-Sep	13-Sep	26-Sep	2-Oct	13-Oct

1 Lexington weather data was from Spindletop Research Farm.

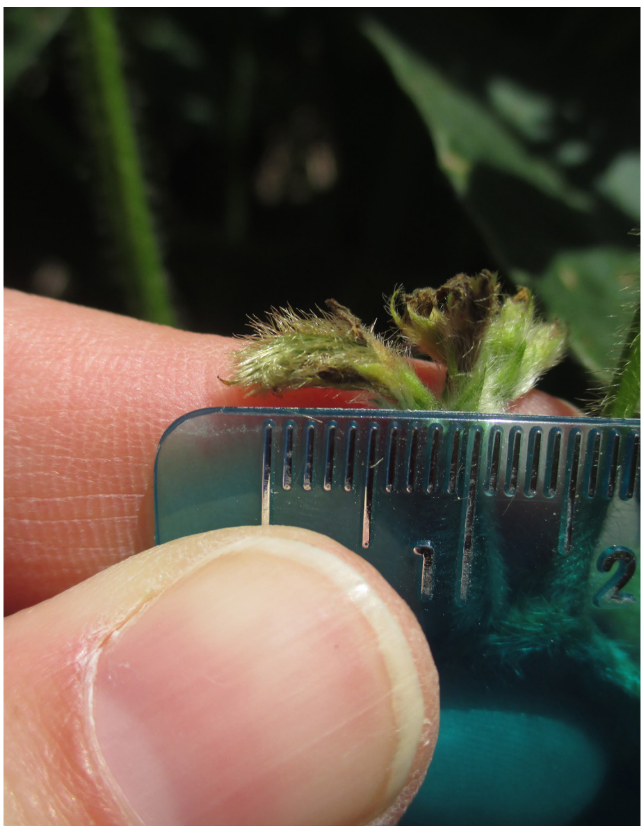


Figure 2-17. Soybean pod that is approximately 5 mm (3/16 inch) long.

R3 Growth Stage

Beginning pod, R3, has a pod that is 5 mm (3/16 inch) long (Figure 2-17) at one of the four top nodes on the main stem with a fully developed trifoliolate leaf.

At R3, developing pods, shriveled flowers, open flowers and flower clusters (racemes) are commonly found on the same plant. Developing pods are typically first found at nodes closest to the soil line, where flowering started.

Environmental stress or plant injury typically has minimal effect on seed yield at this stage.

Figure 2-18. Soybean pod that is approximately 2 cm (¾ inch) long.

R4 Growth Stage

Full pod, R4, occurs when a pod is 2 cm (¾ inch) long (Figure 2-18) at one of the four top nodes on the main stem, with a fully developed trifoliolate leaf.

During this growth stage, rapid pod growth and initiation of seed development is occurring. Pods near the bottom of the plant may already be full size or very nearly full size at this point.

The R4 growth stage is the beginning of the most sensitive period of soybean growth and development. Mid-R4 (beginning of seed swell of any pod) to the mid-R5 (full seed of any pod) is especially sensitive to environmental stress or plant injury because flowering is complete (new flowers cannot be produced) and young pods are more likely to abort than older pods. Seed yield reductions are likely to occur if environmental stress or plant injury occurs. Seed yield is typically reduced at this stage due to reduced pod numbers.

R5 Growth Stage

Beginning seed, R5, occurs when the seed is 3 mm (⅛ inch) long (Figure 2-19) at one of the four top nodes on the main stem with a fully developed trifoliolate leaf.

The R5 growth stage is a period of rapid seed growth and fill. Nutrient and dry weight are redistributed from the vegetative portions of the soybean plant to the seeds. Root growth reduces markedly once seed development begins. Late-R5 the plant reaches it maximum height, has developed all its nodes, and has attained maximum leaf area. Nitrogen fixation rates from the root nodules have reached their highest rates and are beginning to rapidly decline.

Seed yield can be greatly affected from R5 to R6. At this stage leaf area is very important for seed yield. A 100 percent leaf loss, possibly due to hail, during R5 can reduce soybean yields by 75 percent. This stage is also the beginning of the seed fill period, which has a huge effect on seed yield potential. If favorable conditions exist and seed fill can be extended seed yields will be greater than if stressful conditions (or plant injury) occur that reduce length of seed fill. Stress at this stage generally aborts seed.

For full-season soybean, the R5 growth stage typically occurs about 81 days after planting for relative maturity group 3 varieties and about 95 days after planting for relative maturity group 4 varieties.

For double-crop soybean, R5 generally occurs about 60 days after planting for relative maturity group 3 varieties and about 67 days after planting for relative maturity group 4 varieties.

Figure 2-19. Soybean pod with seeds that are approximately 3 mm long.


Figure 2-20. Soybean pod with green seed filling the pod cavity.

R6 Growth Stage

Full seed, R6, occurs when green seed fill the pod cavity (Figure 2-20) at one of the four top nodes on the main stem with a fully developed trifoliolate leaf.

The root system may have grown as deep as 6 feet deep depending upon soil conditions. In Kentucky not all soils have 6 feet of rooting depth. Even in soil that deep, if the growing season received considerable rainfall or in irrigated fields the roots are unlikely to grow to this depth.

R7 Growth Stage

Beginning maturity, R7, occurs when one normal pod on the main stem has turned brown or tan (Figure 2-21).

At R7 soybean seed has essentially reached physiological maturity. Most agronomists and physiologists consider R7 physiological maturity because it is easily recognized and studies have shown that the seed yield of R7 harvests do not differ from those harvested at approximately 13 percent seed moisture. The moisture content of soybean seed at physiological maturity is about 55-60 percent.

Rapid leaf yellowing begins at R7. Leaf maturing, yellowing, and loss begin with the oldest nodes near the bottom of the plant and progresses up the plant. Root growth is complete.


Figure 2-21. Soybean pods with colors ranging from green (bottom), yellow (second from bottom), tan (second from top), and brown (top). One tan or brown (second from top and top pod) pod anywhere on the plant is considered R7 growth stage.

Stressful conditions at this stage have no effect on seed yield, unless hail or other factors remove pods from the stem.

For full-season soybean, the R7 growth stage typically occurs about 116 days after planting for MG II varieties and about 130 days after planting for relative MG IV varieties.

For double-crop soybean R7 generally occurs about 89 days after planting for MG III varieties and about 100 days after planting for MG IV varieties.

R8 Growth Stage

Full maturity, R8, occurs when 95 percent of pods have turned brown (mature pod color) (Figure 2-22 and 2-23).

Soybean harvest is typically targeted when seed moisture content is between 15 and 13 percent. Harvesting soybean seed above 13 percent moisture content will require seed drying, while harvesting below 13 percent will increase the risk of harvest losses due to pod shattering and split beans. Soybean should be stored at 13 percent.

Stressful conditions at this stage have no effect on seed yield, unless hail or other factors remove pods from the stem.

Additional Information

The information provided above details key features of soybean growth and development. For additional information on growth staging and development of soybean see the original *Stages of Soybean Development* (Fehr and Caviness, 1977) guide. For specific discussion of indeterminate soybean plants see the Iowa State University Extension's *Soybean Growth and Development* (PM1945) publication, which details growth and development of maturity group II soybean plants in Iowa.

Figure 2-22. Soybean seed and pod at R8 growth stage.

Resources

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Figure 23. Soybean plants at R8 growth stage.

Chapter 3

Variety Selection

Claire Venard, Carrie Knott, and Chad Lee

An important step in profitable soybean production is selecting the best varieties for each crop production system. Soybean variety selection is one of the most important and most difficult management decisions a producer must make each year. Genetic improvements over time have contributed greatly to yield increases, therefore identifying the correct varieties will add to the profitability of a farming operation.

Yield Potential

To ensure that producers have access to unbiased soybean yield estimates, the University of Kentucky conducts Soybean Variety Trials each year (Figure 3-1). The Soybean Variety Trials evaluate the yield potential of soybean varieties in replicated trials under the same testing conditions at at multiple locations in Kentucky. Yield performance over multiple years and environments is the best method to identify variety adaptability and performance across Kentucky.

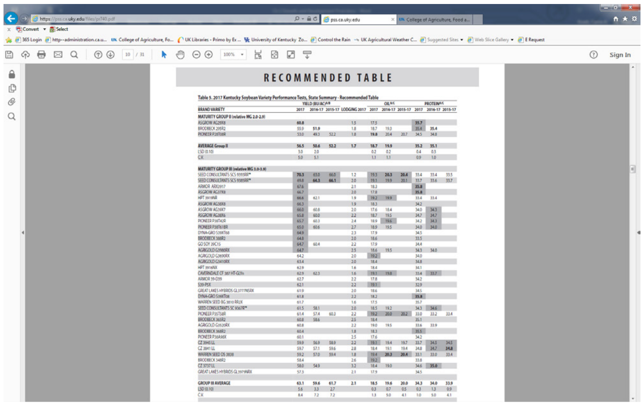

Figure 3-1. Example of Soybean Variety Trial State Summary of soybean yield, lodging, oil content, and protein content.

The soybean variety test reports are available at http://pss.ca.uky.edu/extension/soybean-variety-trials. Similar tests are conducted by surrounding states.

Although yield potential is typically the first trait examined when selecting soybean varieties, it is only one of ***many*** factors that must be considered when selecting varieties.

Relative maturity, lodging, disease resistance, weed control, and economics all need to be considered. Identifying the proper traits for a field, including disease tolerance and/or herbicide resistance, along with yield potential are needed to maximize profitability.

Relative Maturity

Soybean flowering is triggered mostly by photoperiod. Time of planting and temperature will affect flowering to some degree, but the overwhelming trigger for flowering is the length of the night. A soybean variety that matures rather quickly or "early" is sensitive to a shorter night and requires fewer hours of darkness to begin flowering; a slower-maturing or "late-maturing" variety requires more hours of darkness to begin flowering.

Soybean varieties are divided into thirteen maturity groups (MG) ranging from 000 to X. Soybean in MG 000 are the earliest maturing varieties, and MG X varieties are the latest. The early maturing varieties are adapted to the northern United States and Canada; up to MG VIII are adapted to the southern United States. Historically, MGs III, IV, and V are best suited for Kentucky. When planted on May 1 in Kentucky, soybean in MG III will flower about 10 days before soybean in MG IV, which will flower about 8 days before soybean in MG V. The differences in flowering shorten as soybean are planted later.

As more soybean varieties were developed, a numerical system was adopted to further describe the relative maturity of soybean varieties within a MG, or the relative maturity group (rMG). For example, rMG 3.0 to 3.9 are within MG III; therefore, when planted on the same day a 3.0 variety will flower sooner than a 3.9 variety. Similarly, rMG of 4.0 to 4.9 are in the MG IV and varieties designated as 4.0 will mature sooner than 4.9.

The majority of soybean varieties grown in Kentucky are MG III and IV with rMG ranging from 3.0 to 4.9. Some producers in the far western part of the state have grown MG V soybean with a rMG of 5.0 and greater. In addition, there have been a few acres of MG II soybean grown with relative maturities of 2.5 to 2.9. These MG II soybean are planted with the goal of an early harvest to capture historically higher commodity prices in August and September. Another advantage of using early maturing varieties is the possible avoidance of drought conditions in late July or August.

Relative maturities of 4.0 to 5.0 are common in far western and southern Kentucky, which includes the Purchase Area and areas south of the Western Kentucky Parkway, and are typically planted from mid-April to early June. In northern and eastern Kentucky, which would include the areas north of the Western Kentucky Parkway, the Central Bluegrass and Eastern Kentucky, relative maturities from about 3.5 to 4.5 are common. Typical planting dates in northern and eastern Kentucky are late April to early June (Figure 3-2).

Soybean varieties with rMG of about 4.0 to 5.0 are capable of producing high yields across a wide range of planting dates in Western and Southern Kentucky, while varieties with rMG of 3.5 to 4.5 have a large planting window in Northern and Eastern Kentucky (Figure 3-2). However, varieties with extremely long or short relative maturities typically produce high yields within a much smaller planting window. The planting window shortens to about one month for varieties with rMG less than 4.0 and greater than 5.0 in Western and Southern Kentucky, while varieties with rMG less about 3.5 and greater than 4.6 have the shortest planting window in Northern and Eastern Kentucky (Figure 3-2).

Double-crop soybean are planted after a winter crop, typically wheat, is harvested. Most double-crop soybean fields are planted between early June and early July. The rMG group of most double-crop soybean planted in Kentucky range from 4.0 to 4.9 in Western and Southern Kentucky and about 3.5 to 4.5 in Northern and Eastern Kentucky.

If, for any reason, soybean planting, full-season or double-crop, extends beyond early-July, then a producer may want to reduce the rMG of the soybean variety by 0.5 to 1.0 to reduce the risk of frost damage in the fall (Figures 3-2 and 3-3).

Weather varies from year to year and even across fields within the same farm. Therefore, planting soybean varieties with a range of adapted relative maturities reduces the risk that environmental factors will negatively impact yield of an entire soybean crop.

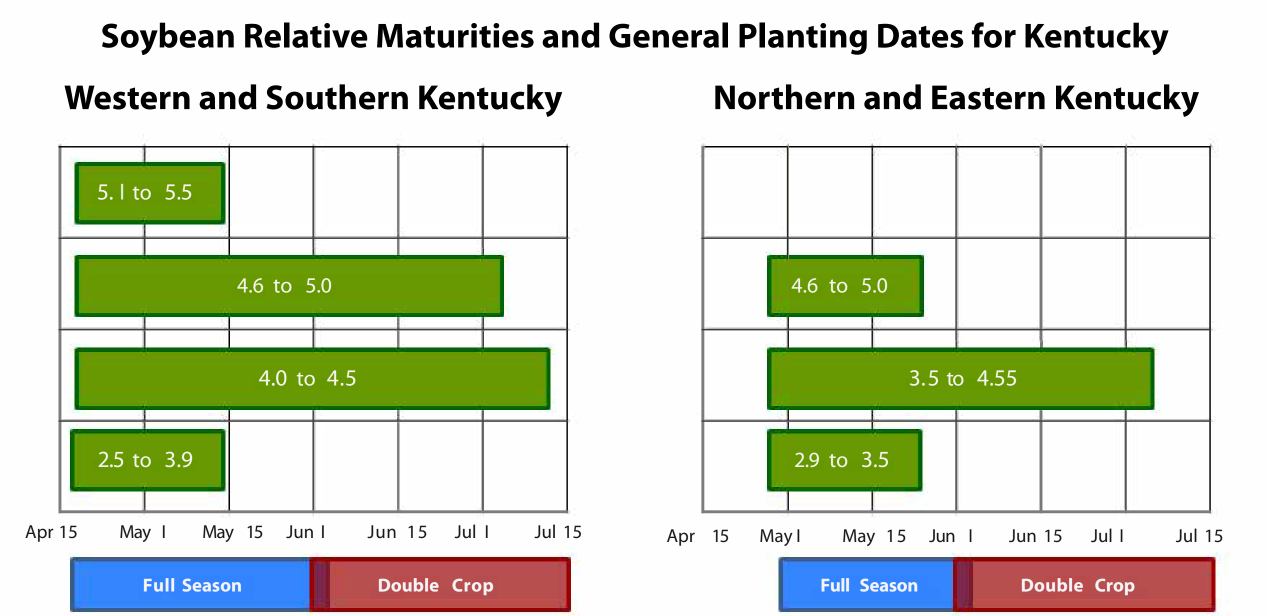

Figure 3-2. Soybean relative maturities and general planting dates for Kentucky. This graphic is intended to provide general planting dates for relative maturities in Kentucky.

Figure 3-3. A soybean maturity group study at Lexington, Kentucky. The dark green soybean plants in the center were MG V and damaged from a fall frost.

Lodging

Lodging in soybean is when the stems of a plant bend or break, resulting in plants falling over and becoming flattened onto the ground. This can result in pre-harvest yield loss and makes harvest more difficult. Historically, soybean lodging was a problem. Today, most soybean lodging is related to management practices, such as very high plant populations, excessive fertility, and row widths of 7.5 inches or less.

Lodging can also occur when wet springs promote excessive vegetative growth and in some instances, although rare in Kentucky, the soybean stem borer can also cause lodging. The larva can girdle or tunnel into the main stem of the plant, which make it more likely to break. See *Chapter 8: Insect Pests* for additional information on soybean (Dectes) stem borer.

Planting soybean varieties with good lodging ratings and avoiding high plant populations can help reduce the incidence of soybean lodging. When harvesting lodged soybean, carefully adjusting and operating the combine can help reduce harvest losses. See *Chapter 10: Harvesting, Drying, and Storing* for additional information.

Shattering Potential

Shattering loss was a problem with older varieties but is less of an issue today. Shattering among current soybean varieties is mostly affected by weather conditions with multiple periods of pod wetting and drying. The wetting periods can occur from rain or even heavy dew or fog events. Timely harvest can help maximize soybean yields because significant shattering loss typically increases as the time between full maturity (R8) and harvest increases.

Disease Resistance

Planting disease-resistant or disease-tolerant varieties will help eliminate yield losses due to plant pathogens. Soybean cyst nematode (SCN) and frogeye leaf spot resistance are of particular importance in Kentucky, because both are widespread annual problems in most, if not all, of Kentucky's soybean fields. The majority of seed companies report disease resistance ratings for many diseases. However, each company has its own method for reporting disease tolerance. For instance, one seed company may report resistance as a "1," while another company may use a "1" to signify extreme susceptibility.

Chapter 7: Diseases and Their Management provides a complete list and discussion of common soybean diseases in Kentucky.

Weed Management

To aid producers with managing weeds, some soybean varieties have herbicide resistance traits that allow the soybean plant to survive when certain herbicides are applied to fields. The first of these herbicide resistance traits was introduced in the United States in 1996. Since then, herbicide resistant soybean have been extremely popular with growers, with estimates of as much as 90 percent of all soybean in Kentucky containing at least one gene for herbicide resistance. While herbicide resistance may be a driving factor in variety selection, yield, disease tolerance, lodging and shattering potential are important factors as well. The herbicide resistance gene only confers herbicide resistance and does not indicate yield potential of that soybean variety. Evaluating the yield potential, disease tolerance, and other traits of herbicide tolerant varieties is extremely important.

Chapter 6: Weed Management provides discussion of common soybean weeds and their management in Kentucky.

Grain Composition

In some markets, soybean varieties with elevated oil or protein levels are eligible for premium prices. When selecting varieties for these markets, it is best to first identify varieties that meet agronomic needs and then identify the varieties with the greatest oil or protein concentration. This approach should identify a variety that has the best chance of producing acceptable yield and meeting oil and protein standards. However, grain composition is influenced by both weather and production practices.

On average, soybean seed produced in the United States contains roughly 19 percent oil and 34 percent protein. However, as oil concentration increases, the protein concentration decreases. In addition, soybean produced in the south, like Kentucky, have higher protein concentration than soybean produced in northern latitudes of North America. Genetics, climatic conditions, and some agronomic management practices all may influence the difference in protein content from south to north.

Specialty Varieties

Certain soybean varieties are in the specialty category, meaning that they normally sell for a premium over the standard price. This category can include edamame (vegetable soybean), natto, and non-GMO soybean. Soybean labeled as non-GMO refers to any soybean variety that was not developed with biotechnology or genetic engineering techniques. Most soybean acres in the specialty category are grown with a contract buyer. Some edamame varieties are grown for local farmers' markets and may not have prior contracts. Again, agronomic performance within the specialty category should be the first priority when selecting these varieties.

Double-Crop Soybean

Research in Kentucky has shown that high-yielding double-crop varieties are identified in full-season yield trials (i.e. single-crop soybean) (Pfeiffer, 1987). Therefore, selecting double-crop soybean varieties is as simple as selecting a full-season soybean variety.

Conclusion

Good soybean variety selection is essential to maximize profitability. Each year new soybean varieties enter the market and older varieties leave the market, which means that variety selection decisions must be made each and every year. Carefully selecting soybean varieties that possess high yield potential, disease tolerance, nematode tolerance, and appropriate relative maturity needed for individual production systems will result in the greatest profits.

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Chapter 4

Cultural Practices

Carrie Knott and Chad Lee

Crop Rotation

There are two common soybean rotations in Kentucky: full-season and double-crop soybean. Full-season soybean rotations produce two crops in two calendar years: soybean in year one and corn in year two. Double-crop soybean rotations produce three crops in two calendar years: corn planted in year one, winter wheat planted that fall and harvested the following June, and soybean immediately following wheat harvest.

Only about 30 percent of the total soybean acres in Kentucky are double-cropped with winter wheat, which corresponds to more than 85 percent of wheat acres double-cropped with soybean. This is due to many factors including soil type, environment, commodity prices, and time management for the producers.

Differences in management between the two soybean systems includes planting date, seed treatments, seeding rate, and potentially planting depth, which are discussed in subsequent sections.

Seed Quality

Soybean seed quality is important for crop establishment. In general, seed quality is an indicator of a seed's ability to produce a seedling in field conditions and includes both seed germination and seed vigor. Most producers are familiar with seed germination since they have seen it on a seed tag. Fewer are familiar with seed vigor, which is not included on the seed tag.

Seed germination is the percent of seeds that produce a normal seedling within 7 to 10 days in ideal conditions (68° to 86°F or 20° to 30°C), which is similar to seedling emergence when field conditions are ideal. Most soybean seed sold in Kentucky has a germination of at least 90 percent. However, germination is affected by production environment and harvesting and handling conditions as well as storage environment, therefore seed lots of the same variety can vary considerably for seed germination.

Knowing the seed germination for each seed lot can help the producer adjust the seeding rate to get the desired initial plant population. For example, if a producer wants a plant population of 100,000 plants per acre and the seed to be planted has 95 percent germination, then 105,263 seeds per acre should be planted: 100,000/0.95=105,263. If the seed lot has 80 percent germination, then the producer needs to plant 125,000 seeds per acre (100,000/0.80=125,000) to obtain a plant population of 100,000 plants per acre.

Using the same seeding rate on seed lots with different seed germination percentages will result in different final plant populations. For example, only 95,000 plants per acre are possible when the seeding rate is 100,000 seeds per acre with 95 percent seed germination while only 80,000 plants per acre are possible for the same seeding rate with 80 percent seed germination.

In addition to differences in seed germination among seed lots, seed lots with the same standard germination percentage can produce two very different plant populations when planted in the field with less than ideal seedbed environments. This is often due to differences in seed vigor. Seed vigor is the ability of soybean seed to produce normal seedlings when environmental conditions are not ideal. Seed vigor is not required on seed tags and is typically not stated. However, it can be an important indicator of initial plant populations in the field.

Two tests are commonly used to determine soybean seed vigor: accelerated aging and cold germination. Both of these tests apply a controlled set of stressful conditions to the soybean seed prior to germination. The accelerated aging test places soybean seed in high temperature (106°F; 41°C) and relative humidity (near 100%) for 3 days. After that time the seeds are germinated in ideal conditions (68° to 86°F or 20° to 30°C) and total seed germination is determined after 7 to 10 days. The cold germination test begins when the seed are planted into wet soils (greater than 70% water holding capacity) and placed at 40°F to 50°F (4 to 10°C) for 7 days prior to germination in ideal conditions for 7 to 10 days. Both of these tests provide insight into how the seeds will perform under stressful conditions.

Although the tests conducted to evaluate seed vigor produce percentage germination data, seed vigor is typically categorized as either "high" or "low." High seed vigor would suggest that a high percentage of soybean seedlings will successfully establish in stressful field conditions. As soybean seed vigor declines, soybean seedling emergence in the field also declines, which can result in reduced plant populations. Soybean seed vigor is not required for the seed label, therefore is unknown to the purchaser in most cases. Reputable seed companies typically offer seed with high vigor; however many factors affect seed vigor, and not all seed sold is equal.

Soybean seed vigor can vary dramatically among seed lots of the same soybean variety because the environmental conditions under which the seed was produced and storage conditions of the seeds can alter seed vigor. Most of the time, soybean seed production fields are not subjected to severely stressful conditions, thus soybean seed vigor is typically high. However, there are years in which severe environmental stresses—such as frequent precipitation after seed has matured (about R7 growth stage) and harvest delays--occur which can reduce seed vigor. The more common threat to soybean seed vigor is seed storage conditions. Dr. Dennis TeKrony and Dr. Dennis Egli at the University of Kentucky completed much of the research to understand the impact of storage conditions on soybean seed vigor. They found that seed quality decreases in storage as seed moisture content and air temperature increase and the rate that seed vigor declines is dependent upon the seed moisture and air temperature. The impact of storage environment on seed vigor is quite complex due to all the possible differences in initial seed germination and vigor and storage conditions. The most important fact is that seed vigor always decreases before seed germination is decreased. Therefore, a seed lot with acceptable seed germination will not always have acceptable seed vigor.

Farmers intending to plant soybean seed into more stressful conditions should get those seed lots tested for seed vigor, either at Regulatory Services at the University of Kentucky (www.rs.uky.edu/seed/) or at a private laboratory. Soybean vigor tests results may vary among laboratories; therefore, it may be best to use the same laboratory to obtain comparable results.

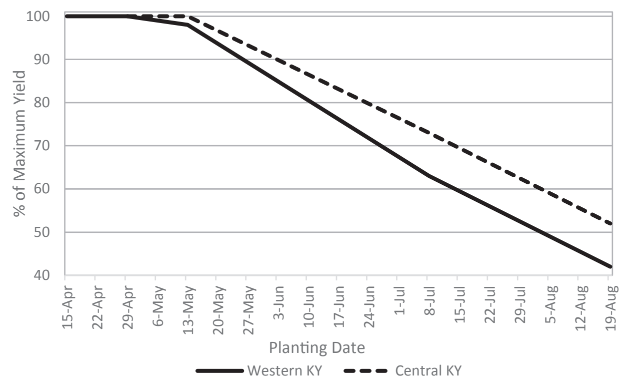

Figure 4-1. Effect of soybean planting date on grain yields for Maturity Group (MG) IV soybean varieties in Kentucky. Approximately 0.50% yield loss occurs each day after early-May in Western Kentucky and mid-May in Central Kentucky.

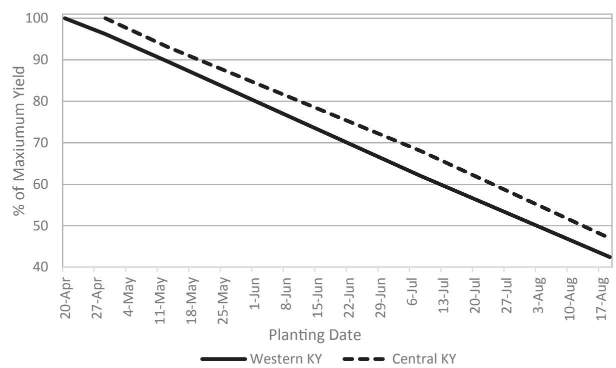

Figure 4-2. Effect of soybean planting date on grain yields for maturity group (MG) II soybean varieties in Kentucky. Approximately 0.42% yield loss occurs each day after mid-April in Western Kentucky and late April in Central Kentucky.

Planting Dates

Soybean planting dates are determined by soil temperature and moisture, and the weather forecast in combination with the calendar. Soybean seed should be planted as soon as soil temperatures are 50 to 60°F (10 to 15.5°C), with adequate soil moisture to promote rapid seed germination, but not wet enough for heavy equipment to cause soil compaction, and a weather forecast to maintain soil temperatures above 50°F. Soybean should **not be planted** when soil temperature is expected to be **less than 50°F** because reduced seedling emergence will produce inadequate plant population.

Historically, soybean were planted when soil temperature was closer to 60°F in Kentucky. More recently, soybean have been planted closer to 50°F to maximize yield. This change is based upon observations and considerable research that earlier planting dates (with soil temperatures at least 50°F) resulted in greater soybean yield.

In Western Kentucky, a six-year study found that the optimum planting date for full-season soybean is mid-April to early May for MG IV soybean varieties and mid- to late April for MG II soybean varieties (Figures 4-1 and 4-2).

In Central Kentucky, the optimum planting date for full-season soybean was found to be mid-May for MG IV soybean (Figure 4-1). Data indicate that if a late group II soybean variety is produced in Central Kentucky then a late April planting would optimize yields (Figure 4-2); however, group II soybean varieties are rarely grown in central Kentucky.

Double-crop soybean are planted after wheat is harvested, which is much later than the optimum planting dates. It is essential to plant as soon as possible because the yield potential for soybean is reduced by 0.50 percent per day after mid-May for group IV soybean varieties and 0.42 percent for the late group II soybean after late April (Figures 4-1 and 4-2). Therefore, as little as a 10-day delay can reduce yield potential by 5 percent.

For soybean planted into soil with temperatures closer to 50°F rather than 60°F, additional management decisions are necessary:

- **Risk of a late spring freeze.** The last freeze (50% probability) generally occurs in late April for Western Kentucky, while the last freeze typically occurs in early May for Central Kentucky (Table 4-1). Soybean can be planted prior to the last spring freeze as long as the plants do not emerge from the soil before the last freeze occurs. In most cases, it will be about 14 days before soybean emerge when soil temperatures are about 50°F. Therefore, planting 10 to 14 days before the last expected freeze (Table 4-1) at the probability level that makes the producer most comfortable can reduce the risk of a late spring freeze damaging the crop.
- **Seed treatments.** Soybean seed treated with a fungicide is recommended, because seedlings are more prone to fungal pathogens at these soil temperatures. If there is a field history of Sudden Death Syndrome (SDS), additional seed treatments to help control SDS and tolerant varieties are recommended. Delayed planting for fields with a history of SDS is no longer recommended, because in most cases delayed planting dates will reduce yield potential more than SDS. However, if possible, planting fields with a history of SDS after planting fields with no field history of SDS could reduce the risk of infection.
- **Seed quality.** Soybean seed with high vigor is essential. All seed lots should be tested for vigor. Seed with low seed vigor should not be used when planting into soils with temperature expected to remain near 50°F. See the *Seed Quality* section above. Some farmers may be tempted to assume high seed vigor. However, the time and effort to replant and possible yield loss can be substantial and greatly reduce profitability.
- **Seeding rates.** Seeding rates may need to be increased for early season plantings. In Kentucky, field emergence of soybean seedlings has been found to be reduced by about 15 percent for early planting dates (mid-April in Western Kentucky and early May in central Kentucky), while reductions of about 5 percent are found a few weeks later (late April/early May in western Kentucky). As such, a seeding rate of approximately 130,000 seeds per acre will be needed if a seed lot with 90 percent germination is used for an April 17 planting in Western Kentucky with a desired final plant population of 100,000 plants per acre.
    - To adjust seeding rate for seed germination rate: 100,000 ÷ 0.90 seed germination = 111,111 seed per acre
    - To adjust seeding rate for early planting date: 111,111 seed per acre ÷ 0.85 (to increase seeding rate by 15%) = 130,719 seed per acre

Table 4-1. Probabilites for the date of the last spring freeze (32°F or less) in Kentucky based upon data from 1981 to 2010 (Arguez et al., 2010 provided by S. Foster, State Climatologist for Kentucky).

Kentucky Location	Date of Last Spring Freeze (32°F or less) in Kentucky by Probability Level[1]		
	90%	50%	10%
	Western Kentucky		
Bowling Green	5-Apr	21-Apr	7-May
Glasgow	10-Apr	24-Apr	10-May
Henderson	4-Apr	18-Apr	3-May
Hopkinsville	5-Apr	20-Apr	4-May
Mayfield	4-Apr	19-Apr	4-May
Murray	29-Mar	13-Apr	26-Apr
Princeton	8-Apr	24-Apr	9-May
Russellville	6-Apr	23-Apr	12-May
	Central Kentucky		
Ashland	19-Apr	3-May	19-May
Bardstown	11-Apr	25-Apr	11-May
Covington	13-Apr	27-Apr	13-May
Danville	7-Apr	22-Apr	7-May
Leitchfield	24-Apr	8-May	26-May
Lexington	10-Apr	25-Apr	10-May
Monticello	16-Apr	30-Apr	16-May
Nolan River Lake	15-Apr	1-May	18-May
Shelbyville	23-Apr	7-May	25-May
Somerset	15-Apr	1-May	17-May

1 Probabilities that the last spring freeze will occur on or after the date listed. For example, for 90% probability the last spring freeze will occur on or later than the date listed 90% of the time (nine out of ten years), while at the 10% probability level the last spring freeze will occur on or later than the dates listed 10% of the time (one out of ten years).

Table 4-2. Seeding rates for full-season and double-crop soybean at several seed germination and assumed stand loss rates.

Assumed Stand Loss[1]	Full-Season Soybean (100,000 plants/A Harvest Population)				Double-Crop Soybean (140,000 plants/A Harvest Population)			
	Standard Germination (from seed tag)							
	80%	85%	90%	95%	80%	85%	90%	95%
	Seeding Rate (seeds per acre)							
5%	132,000[2]	124,000	117,000	111,000	184,000	173,000	164,000	155,000
10%	139,000	131,000	123,000	117,000	194, 000	183,000	173,000	164,000
15%	147,000	138,000	131,000	124,000	206,000	194,000	183,000	174,000
20%	156,000	147,000	139,000	132,000	219,000	206,000	194,000	184,000
25%	167,000	157,000	148,000	140,000	233,000	220,000	207,000	196,000
30%	179,000	168,000	159,000	150,000	250,000	235,000	222,000	211,000

1 Assumed stand loss is the anticipated loss in stand due to planting date, field conditions, field history, or any other known cause that can reduce final plant populations.
2 Seeding rates are rounded to the nearest thousand.

Table 4-2 provides seeding rates for various seed germination rates and assumed stand losses to obtain final plant populations of 100,000 and 140,000 plants per acre.

Plant Populations and Seeding Rates

Soybean can produce similar yield at many different plant populations, because of its ability to branch and produce nodes and pods when resources are available. In Kentucky, full-season soybean typically attain maximum yield when the harvested plant population is a minimum of 100,000 plants per acre. The only exception is when severe droughts occur. In these conditions, lower plant populations produce the greatest yield (as low as 40,000 plants per acre have been documented in Kentucky). For double-crop soybean maximum yield is usually attained when final plant populations are 140,000 to 180,000 plants per acre. The higher plant populations for double-crop soybean is related to the fact that seed is often planted into drier soils that reduce emergence and there is less time between emergence and flowering, resulting in smaller double-crop plants than full-season soybean plants. Given that yield of double-crop soybean is often less than full-season soybean, the lower population of 140,000 plants per acre is generally more profitable than higher plant populations.

Harvest plant populations are directly influenced by initial seeding rate, seed germination, seed quality, seedbed conditions, and environmental conditions. Therefore, all should be considered when determining seeding rates. Most soybean seed will have 90 percent or greater germination rate, which is listed on the seed tag. When soybean will be planted in April, it is essential that only high quality seed, as determined by seed vigor tests, be used.

Seedbed and environmental conditions also greatly affect final plant populations. In general, soybean seedling losses are greater in heavy clay soils than silt loam soils, because clay soils are more prone to surface crusting after a rain event. Soil temperature and moisture also has an effect on final plant populations. Planting into cool (50 to 59°F or 10 to 15°C) and wet soils can reduce soybean seed germination and seedling emergence.

Table 4-2 provides a list of seeding rates for full-season and double-crop soybean at several seed germination and assumed stand loss rates.

Seed Inoculant

A soybean crop that yields 70 bushels per acre will remove about 378 pounds of nitrogen per acre; 210 pounds of nitrogen per acre will be in the seed. Yet, in most fields, fertilizer nitrogen is not necessary for high yields. Soybean is a legume so it gets help from a soil bacterium, *Bradyrhizobium japonicum*, that forms nodules on the roots and converts nitrogen from the atmosphere into plant-available nitrogen (Figure 4-3). In exchange, the bacterium uses photosynthate from the soybean as an energy source for fixing N and to survive. The interior of root nodules that are actively fixing nitrogen, i.e. "functional," are pink to bright pink (Figure 4-4). When root nodules are not fixing nitrogen, "non-functional," the interior of the nodules will be white, brown, or green instead of pink (Figure 4-5).

In most cases, residual nitrogen in the soil and healthy root nodules will provide all the nitrogen the soybean plant requires to produce high yields. There may be isolated cases where excessive residual nitrogen reduces nodulation and these soybean could require fertilizer nitrogen. However, these cases are rare and applications of 20 to 40 pounds of nitrogen per acre have minimal to no effect on nodulation.

If root nodulation does not occur, then fertilizer nitrogen rates could be extremely high for competitive yields. A soybean crop will remove about 3 pounds of nitrogen for each bushel of seed produced. A 50-bushel crop would remove 150 pounds of nitrogen. Applying such a high rate may not be economical. See *Chapter 5: Nutrition Management* for more details.

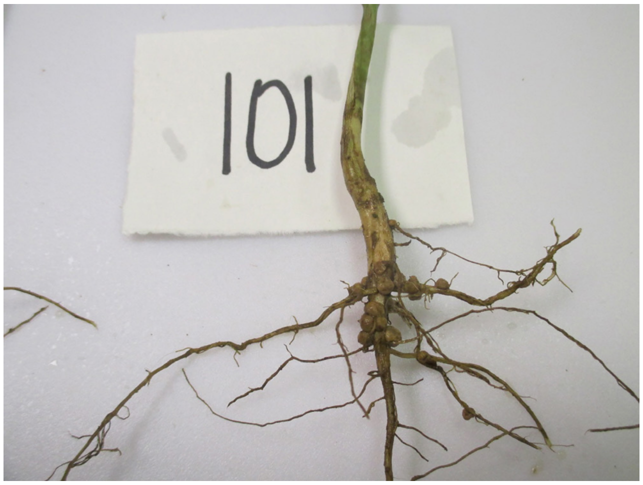

Figure 4-3. Soybean root with numerous round nitrogen-fixing root nodules

Figure 4-4. The interior of functional soybean root nodules (blue arrows) are bright pink.

Figure 4-5. The interior of non-functional soybean root nodules (at blue arrow) are not pink and are typically white or brown.

In Kentucky, the most commonly used *B. japonicum* inoculants are applied to the seed at the time of planting. There are numerous commercially available inoculants, which can be dry, peat-based products or liquid formulations. While both formulations are effective, the liquid formulations generally provide better seed coverage. When using dry forms, some type of sticking agent should be used to help the dry material adhere to the surface of the seed.

For most of Kentucky, annual use of a seed inoculant is not necessary. Considerable research found that, except for the situations listed below, seed inoculants do not increase soybean yield. Some producers prefer to inoculate soybean each year, regardless of field history, because most seed-applied inoculants cost just a few dollars per acre.

B. japonicum seed inoculants are known to be essential for high soybean yields in the following cases:

- **A new soybean field.** In most cases following label recommendations for the inoculant will result in satisfactory nodulation. However, some producers choose to inoculate the seed of the crop preceding soybean, as well as the soybean seed. See *Chapter 5: Nutrition Management* for more details.
- **Fields that have not recently produced soybean.** A field that has not produced soybean for three to five years
- **Fields with a history of poor nodulation.** A field in which the previous soybean crop had poor nodulation

  Low soil pH can impair nodulation. If the previous soybean crop had poor nodulation, pH of soil should be tested and adjusted as necessary. See *Chapter 5: Nutrition Management* for more details.
- **Fields that remain saturated for extended periods.** A field that has remained excessively saturated for extended periods may have reduced populations of *B. japonicum* and therefore benefit from annual *B. japonicum* seed treatments

Nitrogen-fixing root nodules are formed only if bacteria in the inoculant are alive. Therefore, it is essential that extreme temperatures and dry conditions are avoided. Most companies include expiration dates on their packages to ensure that the inoculant contains living bacteria. Many companies also include time limits once an inoculant package is opened as well as time limits once the inoculant is applied to the seed. Some of those limits are as short as 24 hours. In most cases, the best practice is to plant the seed immediately after it is inoculated to ensure that *B. japonicum* remain viable and capable of producing N-fixing nodules.

Fungicides and molybdenum can impair *B. japonicum*, and producers should avoid premixes containing all three. Instead, seed treated with either fungicides or molybdenum should be inoculated and planted immediately. If the time between inoculation of the treated seed and planting is more than a few hours, the viability of the bacteria may be impaired.

Seed Treatments

Soybean seed are often treated with fungicides and insecticides in Kentucky. The greatest benefit from fungicide treatments is likely to occur in early plantings when cool, wet conditions slow germination and encourage seedling diseases. A fungicide seed treatment will likely increase seedling emergence, which can result in acceptable plant populations and seed yield. Insecticide seed treatments may also be beneficial for early plantings because cool conditions cause slower plant growth which, in some cases, could increase damage caused by insect feeding. An insecticide seed treatment might protect seedlings from some of these insects, especially the adult overwintering bean leaf beetle.

In most years, seed treatments do not increase soybean yield when planted in early May or later in Western Kentucky and mid-May or later in Central Kentucky. If soybean seed is treated with a fungicide and a seed inoculant is used it is important to plant immediately following seed inoculant application.

Planting Depth

Soybean seed should be planted about 1 to 1.5 inches (2.5 to 3.8 cm) deep into moist soil with good seed-to-soil contact to ensure maximum seed germination and emergence. Shallow seed placement increases the risk that fluctuating soil moisture levels will reduce germination or negatively impact seedling growth and development. Deep seed placement delays emergence and increases the risk that the soybean seedling will not reach the soil surface. Variations in soil texture, temperature, and moisture will dictate slightly different planting depths (Table 4-3).

Seeding depth should be checked at the start of each field and modified if soil conditions change during planting. Planters equipped with soybean cups or air delivery generally provide more accurate seed depth and placement and better soil-to-seed contact than drills. Planters also provide more accurate seeding rates and are easier to calibrate than drills. For these reasons, soybean planted in 15-inch rows with a planter is better than soybean planted with a drill in 7.5-inch rows.

Row Width

Extensive research has shown that soybean grown in 15-inch rows yield more than or at least as much as soybean grown in 30-inch rows. Conversely, soybean in 30-inch rows almost never yield more than soybean in 15-inch rows. Soybean in 15-inch rows generally produce greater yield because of a more rapid canopy closure, which intercepts more sunlight. To maximize seed yield, it is essential to have complete canopy cover by R1 growth stage or shortly thereafter. Greater light interception increases plant growth, dry matter accumulation, and thus seed yield. More rapid canopy closure and the shading of the soil surface reduces weed emergence and growth of existing weeds and can, in some cases, also reduce soil moisture loss.

Table 4-3. Recommended soybean seeding depth based upon soil conditions.

Soybean Seeding Depth	Soil Conditions
1 inch (2.5 cm)	Soils that are cool and moist, which will delay germination and seedling growth
1 to 1.5 inches (2.5 to 3.8 cm)	Most conditions and soil types including heavy clays prone to surface crusting
2 inches (5 cm)	Sandy soils, which often lose soil moisture quickly and become droughty Dry soil conditions, if possible delay planting until after a rainfall event and plant 1 to 1.5 inches deep

Soybean can be drilled in 7.5-inch rows in Kentucky. In general, the yield of drilled soybean is similar to those planted in 15-inch rows. However, as mentioned above, planters generally provide more accurate seed depth and placement and better seed-to-soil contact than drills.

Replanting

Except for extreme cases soybean re-planting is generally not profitable because soybean plants can compensate for low populations and gaps in stands by branching and thereby produce similar yields with reduced plant populations.

For full-season soybean, replanting generally will not be profitable until the initial stand drops below 50,000 plants per acre. The relatively low yield loss from a final stand greater than 50,000 plants per acre combined with the expected yield loss of a later planting date and additional cost of replanting normally does not justify replanting.

When considering a replant, the first thing to determine is the yield potential of the replanted soybean crop. This can be accomplished by estimating the yield loss based upon planting date. For example, assume the field in question is in Western Kentucky and a group IV soybean variety will be planted on July 24. The expected yield loss for a group IV soybean in Western Kentucky is 0.50 percent per day beginning May 9. If the typical yield of this field is 80 bushels per acre then the maximum yield expected would be 49.6 bushels per acre:

22 days in May + 30 days in June + 24 days in July
= 76 days past the optimum planting date

0.50% yield loss per day x 76 days past the optimum planting date = 38% yield loss

80 bu/A field average x (100-38% yield loss) = 49.6 bu/A

While seed is sometimes free to replant, costs associated with replanting should be considered such as fuel, machinery, labor, and potential yield loss.

There are certain situations in which a replant would be desirable, regardless of profitability. These may include the proximity of the field to your home, your neighbors, and/or landlords.

Estimating Soybean Grain Yield

Estimating soybean yield while the crop is still standing in the field can be challenging.

Proceed with caution. Variability in yield components such as plant population, seeds per pod, and seed size can drastically affect the final estimate. Yield estimates may be inaccurate when conducted before seed fill is complete, because assumptions of final pod number, seeds per pod, and seed size may not accurately reflect those values at maturity. The best estimate can be achieved at reproductive growth stage R6 (full seed) or later. Estimates of yield components should be made in five to ten random locations across the field to get a more accurate yield estimate. Each of the locations should be typical of the surrounding areas. Sampling from multiple locations in the field will improve the overall yield estimate. Soybean yield is estimated by completing the terms in the following equation:

Table 4-4. Estimated soybean plants per acre. For 30-, 20-, and 15-inch rows, determine plants per foot of row by counting the number of plants in a 10-foot section of a row and divide the number of plants by 10. For 7.5- and 7.0-inch rows, determine the number of plants in 40-feet of row by counting plants in 10 feet of four separate rows.

Soybean Plants per Foot of Row	Row Width (inches)			Soybean Plants in 40 Feet of Row	Row Width (inches)	
	30	20	15		7.5	7
	Estimated Plants per Acre				Estimated Plants per Acre	
0.5	8,712	13,068	17,424	5	8,712	9,340
1	17,424	26,136	34,848	10	17,424	18,679
1.5	26,136	39,204	52,272	15	26,136	28,019
2	34,848	52,272	69,696	20	34,848	37,358
2.5	43,560	65,340	87,120	25	43,560	46,698
3	52,272	78,408	104,544	30	52,272	56,037
3.5	60,984	91,476	121,968	35	60,984	65,377
4	69,696	104,544	139,392	40	69,696	74,716
4.5	78,408	117,612	156,816	45	78,408	84,056
5	87,120	130,680	174,240	50	87,120	93,395
5.5	95,832	143,748	191,664	55	95,832	102,735
6	104,544	156,816	209,088	60	104,544	112,074
6.5	113,256	169,884	226,512	65	113,256	121,414
7	121,968	182,952	243,936	70	121,968	130,753
7.5	130,680	196,020	261,360	75	130,680	140,093
8	139,392	209,088	278,784	80	139,392	149,432
8.5	148,104	222,156	296,208	85	148,104	158,772
9	156,816	235,224	313,632	90	156,816	168,111
9.5	165,528	248,292	331,056	95	165,528	177,451
10	174,240	261,360	348,480	100	174,240	186,790
10.5	182,952	274,428	365,904	105	182,952	196,130
11	191,664	287,496	383,328	110	191,664	205,469
11.5	200,376	300,564	400,752	115	200,376	214,809
12	209,088	313,632	418,176	120	209,088	224,148

Soybean Yield Estimate Equation:

bu/a = (plants/a) x (pods/plant) x (seeds/pod) ÷ (seeds/lb) ÷ (lb/bu).

Step 1. Estimate plants per acre.

The number of plants per acre must be determined at each location in the field. Use the data in Table 4-4 to quickly convert stand counts into plants per acre. Count the number of plants in 10 feet of one row and divide that number by 10 to determine plants per foot for row widths of 30, 20, and 15 inches. For row widths of 7.5 and 7 inches, count the number of plants in 40 feet of one row (or 10 feet of four separate rows) to determine plants per acre.

Example:

In 15-inch rows, you count an average of 3.5 plants per foot of row.

According to Table 4-4, 3.5 plants per foot in 15-inch rows equal 121,968 plants per acre.

If you would prefer to count plants in 1/1,000th acre, you can use Table 4-5 to determine the row lengths needed. When using this method, count the number of plants within 1/1,000th acre, and multiply that number by 1,000 to estimate plants per acre for each location.

Step 2. Estimate pods per plant.

Count the pods on each plant for 10 consecutive plants in one row, regardless of plant size. Determine the average number of pods per plant.

Example:

At one location, 220 pods were counted on a total of 10 consecutive plants.

The total number of pods (220) is divided by 10, so the average number of pods per plant is 22.

Step 3. Estimate seeds per pod.

Healthy soybean plants will average about 2.5 seeds per pod. For healthy soybean, multiply pods per acre from Step 2 by 2.5 seeds per pod to estimate seeds per acre. For soybean under stress, the seeds per pod could drop to 2, 1.5, or even less under high stress situations. You can count the seeds per pod from the same soybean plants used in Step 2.

Example:

The majority of pods appear to have three seeds while some have two seeds. The overall estimate of seeds per pod is 2.5.

Step 4. Estimate seeds per pound (seed size).

Table 4-5. Row width and length of row needed to equal 1/1000th acre.

Row Width (inches)	Length of Row Needed to Equal 1/100th Acre
6	87 feet 1 inch
7	74 feet 8 inches
7.5	69 feet 8 inches
15	34 feet 10 inches
30	17 feet 5 inches

Seeds per pound may be the most difficult estimate to make. Research in Kentucky indicates that 2,500 seeds per pound is an average seed weight estimate, but seeds per pound can be as high as 3,400. If the soybean plant experienced stress, the seed size may be smaller, meaning that a larger seeds-per-pound number should be used for the estimate. The original seed size from the seed bag may provide a reasonable indication of soybean seed size. When the seed tag is not available, use 2,500 seeds per pound. You may want to adjust the seed size if the final yield estimate seems unusually high or low.

Example:

Without knowing the actual seeds per pound, you estimate 2,500 seeds per pound.

Step 5. Estimate bushels/acre.

One bushel of soybean weighs 60 pounds.

Example:

Using the numbers obtained and the yield calculation formula, the following yield estimate is determined: (plants per acre) x (pods per plant) x (seeds per pod) ÷ (seeds per pound) ÷ (pound per bushel) = (bushels per acre)

121,968 x 22 x 2.5 ÷ 2,500 ÷ 60 = 44.72 or 45 bushels per acre

Step 6. Repeat yield estimate at other locations.

The yield estimate should be repeated five to ten times across the field. Use Table 4-6 as a worksheet to record the values estimated for each yield component. If the first five yield estimates are relatively close to each other, additional yield estimates at more locations may not be necessary. If the first five yield estimates vary widely, additional yield estimates at more locations are necessary.

Keep the Yield Estimate in Perspective

Remember that the yield estimate is only as good as the numbers put into the equation. Yield estimates made closer to harvest are typically more reliable than yield estimates made earlier in growth and development of the soybean plant. If you have additional questions regarding soybean yield estimates, contact your county Cooperative Extension agent.

Second Year and Continuous Soybean

It is not uncommon for river and creek bottoms in Kentucky to produce soybean several years in a row. Most often soybean are grown in these areas because flooding prevents timely corn plantings and because soybean has lower production costs than corn, thus reducing risk of further losses should a flood occur during the growing season.

Before considering second year or continuous soybean, test for soybean cyst nematode (SCN). If nematodes are present in low numbers (less than 500 eggs per half pint of soil) then those fields may be candidates for a second year of soybean production. If continuous soybean are established in these fields it will be necessary to monitor SCN populations because SCN will likely increase over time. It is also important to choose SCN resistant varieties for the HG type (formerly race) present, which can also be determined from the SCN test. Once nematode levels exceed 500 eggs per half pint of soil, continuous soybean will likely result in significant yield losses due to SCN and probably are not good candidates for additional years of soybean production.

Once SCN levels are determined and fields for second year or continuous soybean are identified, there are several additional management decisions that will need to be considered:

- **Yield loss.** An eight-year (2009 to 2016) study at the University of Kentucky found that, on average, there was about a 2 percent yield reduction for second-year soybean in the absence of soybean cyst nematode. The yield loss across the eight years ranged from a 5 percent yield increase for second year soybean to a 13 percent yield loss when compared to soybean following corn. In three years yield increases were found.

Table 4-6. Worksheet for yield estimates. Use this table to fill in the yield components for each location in a field. Average the yields of each location together for a yield estimate of the entire field. Use the following equation to calculate yield at each location in the field. (plants per acre) x (pods per plant) x (seeds per pod) ÷ (seeds per pound) ÷ (pound per bushel) = (bushels per acre)

Location	Plants per Acre	x	Pods per Plant	x	Seeds per Pod	÷	Seeds per Pound	÷	Pound per Bushel	=	Bushels per Acre
1		x		x		÷		÷		=	
2		x		x		÷		÷		=	
3		x		x		÷		÷		=	
4		x		x		÷		÷		=	
5		x		x		÷		÷		=	
6		x		x		÷		÷		=	
7		x		x		÷		÷		=	
8		x		x		÷		÷		=	
9		x		x		÷		÷		=	
10		x		x		÷		÷		=	
Average										=	

The three years in which yield increases were observed for second year soybean were droughty years or years following an extreme drought that was unusually cool. These conditions likely reduced disease levels and resulted in yield increases.

When those three years of yield increases were excluded from the data, an average yield loss of 5 percent was found, which is similar to national estimates of yield loss of continuous soybean.

- **Seeding Rate.** Seeding rates should be increased to compensate for reductions of seedling emergence that can occur in second year/continuous soybean production. It is best to assume a 25 to 30 percent stand loss, which will result in a seeding rate of about 160,000, with a 90 percent seed germination rate.
- **Seed Treatment**. Seed treatments will also be important to help with seed germination and seedling establishment. Fungicide seed treatments, in particular, will help protect seeds and seedlings against pathogens that cause seedling diseases (i.e. Pythium and Fusarium seedling blights). Make sure to use high quality fungicide and insecticide seed treatments at the highest recommended rates for effective control.
- **Soil Fertility**. Ensuring adequate soil fertility is also a key component to a profitable continuous soybean production system. See *Chapter 5: Nutrition Management* for further details.
- **Other pathogens.** In additon to SCN there are a couple of other diseases that overwinter on soybean stubble and can become particularly problematic in second year and continuous soybean. These diseases are frogeye leaf spot (caused by *Cercospora sojina*) and southern stem canker (caused by *Diaporthe aspalathi*). Selecting varieties with high levels of resistance to these diseases and SCN (as described above and in *Chapter 7: Diseases and Their Management*) is essential in minimizing yield reductions under second year or continuous soybean production scenario.
- **Insects**. For fields with a recent history of Dectes stem borer, do not plant into continuous soybean. Crop rotation is the only way to control the Dectes stem borer. If you happen to have a problem with this pest, timely and even early harvesting have been suggested as strategies to mitigate yield loss. See *Chapter 8: Insect Pests* for additional details.
- **Weeds**. Continuous soybean production can also lead to greater weed pressure from specific weeds. In the study above, marestail (*Conyza canadensis L.*) became particularly problematic. Aggressive weed management programs will be needed to control weeds and ensure that herbicide-resistant populations do not develop. Refer to *Chapter 6: Weed Management* for more information.

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Chapter 5

Nutrition Management

Edwin Ritchey, John Grove, and Josh McGrath

Introduction

Soybean grows best on well-drained, fertile soils that are free of weed and disease pressure, but are also successfully produced on marginal ground. We often think soil fertility and pH management are less critical for soybean than other crops, but that is not true. The University of Kentucky has conducted numerous field studies to establish the relationship between soil nutrient supply, added nutrients, and soybean yield. Soybean removes more nutrients per bushel of grain than corn, sorghum, or any small grain (Table 5-1). On average, soybean removes 3 lb nitrogen (N), 0.7 lb phosphate (P_2O_5), and 1.1 lb potash (K_2O) per bushel of grain, but even greater nutrient uptake is required to provide the nutrients needed for growth and development of soybean root, leaf, stem, and pod tissues. This chapter will discuss the role of nutrients in soybean growth and the fundamentals of nutrient management in soybean production.

Table 5-1. Nutrient removal in soybean, corn, wheat, and sorghum grain

Crop	Nutrient content (lb/bu)		
	N	P_2O_5	K_2O
Soybean	3.0	0.7	1.1
Corn	0.7	0.4	0.35
Wheat	1.2	0.5	0.3
Sorghum	1.0	0.4	0.3

[1] Adapted from University of Kentucky Extension publication *Lime and Nutrient Recommendations* (AGR-1)

Soil pH Management

Soil pH is the foundation of a soil fertility program due to the influence of pH on nutrient availability, root growth, and herbicide activity. As pH drops below 5.5, the availability of aluminum (Al), manganese (Mn), and iron (Fe) increase. With increasing availability, Al damages plant roots, reducing nutrient and water uptake. At lower pH values Al and Fe will complex phosphorus (P), reducing P availability. As pH increases above 7, calcium (Ca) will complex P, also reducing P availability. Most micronutrients have greater availability at lower pH values, except molybdenum (Mo). The availability of Mo rises with increasing soil pH.

Most soils in Kentucky are naturally acidic because rainfall is greater than evapotranspiration, annually, causing leaching of basic cations (especially Ca) and soil acidification. Additionally, nitrification of ammonium (NH_4^+) causes soil acidification. Ammoniacal nitrogen (N) fertilizers and the mineralization of organic N provide NH_4^+-N to the soil. Nitrification, a biological process, converts NH_4^+-N to nitrate-N (NO_3^-), resulting in soil acidification according to the equation:

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+$$

So, natural soil acidification combined with additional acidity resulting from use of N containing fertilizers, cover crops and manures, causes pH to fall and a need for lime.

Soybean grows best at a pH of 6.2 to 6.8. Ideally, lime should be applied 6 months prior to soybean establishment and at a rate to raise soil pH to a target of 6.4. The most common liming material used in Kentucky is agricultural limestone (ag lime). Ag lime can either be calcitic (largely Ca carbonate) or dolomitic (both Ca and magnesium [Mg] carbonates) limestone. The recommended lime rate depends on the current soil pH and the soil buffer pH, which soil testing labs use to characterize the level of soil acidity, and ag lime quality, measured as the relative neutralizing value (RNV). Limestone RNV is determined by ag lime purity (amount of Mg and Ca carbonate relative to impurities) and fineness (particle size). Ag lime of higher purity and finer particle size will have a higher RNV than ag lime of lower purity and with a coarser grind. Limestone rate recommendations from the University of Kentucky soil testing labs assume an RNV of 100 percent. This level of ag lime quality is unusual, so actual lime rates will usually be adjusted upwards to account for the generally lower quality of commercial liming products. To use the RNV to adjust the recommended limestone rate, multiply the rate of RNV_{100} material by 100/RNV of the ag lime for the quarry where the ag lime was purchased. For example, if the recommended rate of 100 percent RNV lime is 2 ton/acre, and the available product has an RNV of 67 percent, then 2 x (100/67) ≈ 3 ton/acre of the RNV_{67} material. Quarries in Kentucky selling ag lime are sampled each spring and fall to assess purity and fineness and determine RNV. The RNV values for each quarry are found at the University of Kentucky Regulatory Services webpage (http://soils.rs.uky.edu/technical_Info/).

Macronutrients–Primary

The primary macronutrients are N, P, and potassium (K). These nutrients are required in large amounts. The N supply is usually adequate when soybean is properly inoculated. Soils naturally differ in their soil fertility status and many times supplemental P or K will be required for optimal soybean growth and development. The amount of nutrients present, as well as the ability of the soil to supply the nutrients to the plant, are both important.

Nitrogen

Nitrogen is contained in all living cells and is a constituent of chlorophyll, which gives plants their characteristic green color. Chlorophyll is vital for photosynthesis, the process that coverts carbon dioxide (CO_2) and sunlight into fixed plant carbon, i.e., plant growth. Nitrogen is also a constituent of protein, so production of amino acids, the building blocks of protein, is dependent on plant N.

Next to plant available water, N is often the most limiting factor to worldwide crop production. Fortunately, soybean forms a symbiotic relationship with a specialized bacterial species, *Bradyrhizobium japonicum* (*B. japonicum*), which biologically fixes the dinitrogen (N_2) gas that makes up 78 percent of the atmosphere as ammonia (NH_3). The NH_3 quickly becomes the NH_4^+ utilized by the growing plant. Well nodulated soybean (Figure 5-1) grown in soils of adequate pH (greater than 6.2) should not need additional fertilizer N.

Soybean will also take up NH_4^+ and nitrate (NO_3^-) released during the mineralization of organic N in the soil. Soil organic N can result from several different sources, including atmospheric deposition (typically less than 10 lb N/acre/year), N remaining from previous N applications, and N from mineralization of plant residues, all immobilized as humic organic N contained within soil organic matter (SOM). None of these soil pools or processes contributes the entire N needed by soybean, but when coupled with N fixed by *B. japonicum*, soybean's N supply is usually sufficient–assuming no other environmental or management conditions limit N uptake. Although soybean typically does not need supplemental fertilizer N, the crop has a high N demand. There are approximately 3 pounds of N in each

Figure 5-1. Soybean roots with excellent (left) and poor (right) nodulation.

bushel of soybean grain and more N is needed for roots, stems, and leaves. A 50 bushel per acre soybean yield will require about 270 lb N/acre in the growing season, with roughly half removed at grain harvest.

Nitrogen is a mobile nutrient within the plant, so early deficiency symptoms (Figure 5-2) typically occur on older leaves. Soybean lacking adequate N will have pale green leaves, slower growth, and leaves that will eventually turn yellow and brown, senescing and defoliating plants prematurely. The most common cause of N deficiency is little to no nodulation. Soybean grown in stressful environments (drought, flooding) can show several nutrient, including N, deficiency symptoms. These "induced" symptoms are not typically due to inadequate levels of N or other nutrients but are instead due to soybean's inability to utilize the existing nutrients. Water limited plants are not able to take up N and other nutrients and also may show symptoms of drought stress. Flooding reduces the amount of soil oxygen, causing plant stress. Furthermore, soybean is unable to take up water from saturated soil. Flooding or drought can potentially reduce *B. japonicum* viability and function.

There are different ways to address soybean N deficiency. First, examine soybean root systems to determine if they are well nodulated and if the nodules are functioning properly. A healthy nodule, after being split open, should be pink to bright red. If not, the nodule is not actively fixing N. Nodules on plants experiencing drought or flooded soil stress may not be pink or red. If the nodule appears healthy, you should evaluate if other nutrients or growth factors are the cause of the symptoms. If soybean lacks nodulation, root growth is not restricted and the deficiency is detected early (prior to flowering), N fertilizer may be recommended. Since the soybean N requirement is high, 200 to 250 lb N/acre will be required to produce a normal yield. All N sources are equally effective, though N volatilization losses are possible with surface broadcast urea. Another approach, less well documented in terms of success, has been to create a suspension of inoculant in water which is then sprayed over the crop just prior to a rainfall or irrigation event.

Phosphorus

Phosphorus, known as the "energy element," is a part of compounds that store energy created by photosynthesis to drive many growth processes within the soybean plant. Phosphorus is part of DNA and RNA, carriers of the genetic code. Although P is a primary macronutrient like N and K, tissue P concentration is about one-tenth that of N and K.

Soil P consists of both inorganic and organic forms, but only a very small amount of soluble P ($H_2PO_4^-$ or HPO_4^{2-}) is found in the soil solution at any time. Soluble P reacts with many soil components, causing limited movement. In moist soil, soluble P will not move more than one inch from the application point. At normal soil P levels, a good rule of thumb is that if you are not losing soil then you are not losing P. At very high soil P concentrations, soluble P can be lost by leaching or in runoff water moving to nearby bodies of water. The latter can cause eutrophication (excessive algal growth) of the water body.

Root hairs and tips take up P either as $H_2PO_4^-$ or HPO_4^{2-}, depending on soil pH. A soil pH near 6.5 maximizes P solubility/availability. Phosphorus is "tied up" by Ca as soil pH increases above 6.5, and by Al and Fe as pH decreases below 6.5. Since P does not easily move within soil, soybean roots need to "grow towards" the phosphorus. With increased soybean root exploration, P nutrition will

Figure 5-2. Nitrogen sufficiency (left) and deficiency (right) in soybean.

Figure 5-3. Phosphorus sufficiency (left) and deficiency (right) in soybean.

be adequate if the field is properly fertilized. However, early season P deficiency may be evident when soybean plants are small and root exploration is limited by cold or compacted soil, even at normally adequate soil P concentrations.

Phosphorus is mobile in soybean, and deficiency symptoms typically begin on older leaves. Phosphorus deficiency is characterized by reduced leaf expansion, shorter internode length, dark-green leaf color, delayed maturity, and stunted soybean growth (Figure 5-3).

Soybean removes approximately 0.7 lb P_2O_5/bushel of grain. Over time, soil P will decrease due to crop removal of the nutrient. In most soils outside of the Central Bluegrass, supplemental P is added to the soil after continued cropping. Soil testing is the best way to know the amount of additional P needed for crop production. The most common sources of fertilizer P in Kentucky are diammonium phosphate (DAP; 18-46-0) and monoammonium phosphate (MAP; 11-52-0). The amount of P contained in fertilizers is expressed as the oxide equivalent (P_2O_5), even though there is no P_2O_5 actually in fertilizer. Soil test results are typically expressed as lb P/acre, or in parts per million P (ppm P), while the fertilizer recommendations are typically expressed in lb P_2O_5/acre. To convert from P to P_2O_5, multiply P by 2.29. To convert P_2O_5 to P, multiply P_2O_5 by 0.44. To convert from ppm to lb/acre, multiply by 2. For example, if a sample soil test result is reported as 25 ppm P, then 25 x 2 = 50 lb soil test P/acre. Be aware of the units used in your soil test reports to avoid erroneous fertilizer rate recommendations.

Potassium

Soybean takes up more K than any other nutrient except N. Potassium also differs from most other nutrients in that K is not incorporated in any plant chemical compound. Potassium is important for enzyme activity in photosynthesis, starch and protein synthesis, and transport of sugars and nutrients within the plant. Although vital to enzyme activation, K is not consumed during this process and is "recycled" throughout the plant for continued use. Potassium is important for stomatal regulation. Internal control of K concentrations near the guard cells causes stomata to open and close.

Soybean roots take up potassium from soil solution as a cation (K^+). Potassium is the seventh most abundant mineral in the earth's crust, but a relatively small proportion is available for plant uptake at any given time. Thus, K fertility/bioavailability is influenced by the total K present, dissolution of primary K-bearing minerals, type and amount of clay minerals present, soil water status, soil temperature, and soil K buffer capacity or cation exchange capacity (CEC). Soybean genetics (cultivar choice) and age (growth stage) can also influence K acquisition.

Potassium is mobile within the soybean plant, so K deficiency is first expressed in older leaves, progressing to newer leaves as deficiency becomes more severe. Potassium deficiency is characterized by yellowing on the leaf tips/edges that moves toward the center of the leaf (Figure 5-4). Yellowing is followed by browning/firing and necrosis (tissue death). Other symptoms include reduced stalk strength that can lead to lodging, slow growth, reduced disease resistance, and smaller seed.

Soybean removes approximately 1.1 lb K_2O/bushel of grain. Even though total K levels are relatively high in most Kentucky soils, plant available K concentrations can be low enough that soybean will respond to added K from fertilizer or manure applications. The most common and economical fertilizer K source for Kentucky soybean production is "muriate of potash," also known as potassium chloride or 0-0-60. Other available fertilizer sources are generally not economically competitive. The amount of K in K fertilizers sold in the U.S. is expressed as the oxide equivalent (K_2O), even though no K_2O is contained in fertilizer. Soil test results are typically expressed as lb K/acre or ppm K. To convert from K to K_2O, multiply K by 1.20; to convert from K_2O to K, multiply K_2O by 0.83. Be aware of the unit that you are dealing with to avoid erroneous fertilizer rate recommendations.

Macronutrients–Secondary

Secondary macronutrients include Ca, Mg, and sulfur (S). The soybean requirement (tissue concentration) for these nutrients is similar to that of the primary macronutrients, but deficiencies are quite rare, making the need for fertilization with these nutrients "secondary." With proper pH management, soybean will not exhibit Ca or Mg deficiency. Sulfur deficiencies are rare in Kentucky, but with stricter emission standards for coal-fired power plants and internal combustion engines, atmospheric S deposition has decreased and so we should monitor crop S nutrition more closely in the future.

Figure 5-4. Potassium sufficiency (large green plants) and deficiency (small chlorotic plants) in soybean.

Calcium

Calcium is a structural nutrient element found in soybean leaf and stem cell walls that contributes structural support to the plant. Calcium is necessary for cell division and elongation, promotes root and leaf development, regulates the translocation of carbohydrates within the plant, and is important to pod set. Finally, Ca is important in nodule formation and Rhizobia function. Plant roots take up calcium as the divalent cation Ca^{2+}.

Calcium is immobile in plants, and deficiency symptoms (Figure 5-5) are first exhibited on newer leaves. Soybean Ca deficiency is rarely observed, but when seen, younger leaves appear short and wrinkled, while stems are weak/brittle. Good pH management eliminates the need for fertilizer applications of Ca.

Magnesium

Magnesium is essential for chlorophyll formation. Magnesium is also involved with the formation of plant sugars, proteins, and oils, regulation of nutrient uptake (especially P), and translocation of carbohydrates. Plant roots take up Mg as the divalent cation Mg^{2+}.

Magnesium is mobile, so the typical interveinal yellowing deficiency symptoms begin on older soybean leaves (Figure 5-6), turning purple as severity increases. Most soils in Kentucky have adequate topsoil or subsoil Mg and fertilizer Mg additions are seldom needed. Conditions that increase the potential for Mg deficiency include sandy soils naturally low in Mg that have received large N and K fertilizer applications.

Dolomitic limestone contains Mg carbonates (6-12% Mg) and is a good Mg source. Other Mg sources include magnesium sulfate; sold either as Epsom salt ($MgSO_4 \cdot 7H_2O$; 11% Mg) or kieserite ($MgSO_4 \cdot H_2O$; 17% Mg), potassium magnesium sulfate (sul-po-mag; $K_2Mg(SO_4)_2$; 11% Mg), and magnesium oxide (MgO; 45% Mg). Dolomitic limestone is by far the most economical Mg source, if available.

Sulfur

Sulfur is important for chlorophyll synthesis and is involved in vitamin, hormone, and amino acid production. Sulfur is found in plant proteins as disulfide, which helps maintain enzyme structure. Sulfur is sparingly mobile within the plant, so deficiency symptoms would be noticed on upper portions of the leaf canopy, spreading downward if the problem continues (Figure 5-7). Deficiency symptoms start with an overall light green color that becomes yellow as S deficiency continues. Sulfur deficiency can be mistaken for N deficiency as both may initially cause light green to yellow leaves, but N deficiency will begin in the lower leaf canopy.

Soybean S deficiency has not been reported in Kentucky, but producers should be aware of conditions under which S deficiency would be observed. Low SOM, sandy and/or eroded soils and cool, wet conditions favor S deficiency. Mineralization of organic S increases with increasing temperature and adequate moisture, so S deficiency potential is higher with cool conditions early in the growing season.

Soil S is contained in SOM, crop residues, and a few inorganic forms, especially the divalent anion, sulfate (SO_4^{2-}). Organic S must be mineralized to give SO_4^{2-} for root uptake. Roughly 1 to 3 percent of soil organic S is mineralized each year, with the remainder of plant available S coming from atmospheric S deposition and residual inorganic S in the soil profile. Plant available soil S is often retained in the subsoil. Kentucky topsoils are primarily negatively charged, retaining cations (positively charged ions like K^+, Ca^{2+}, and Mg^{2+}). However, many Kentucky subsoils exhibit enough positive charge to retain anions like SO_4^{2-} and NO_3^-.

Figure 5-5. Calcium deficiency in soybean.

Figure 5-6. Magnesium deficiency in soybean.

Figure 5-7. Sulfur sufficiency (left and right) and deficiency (center) in soybean.

Despite what is known about soil S, soil testing for S is not yet reliable as a tool to predict crop response to S and determine crop S need. Commonly used topsoil sampling procedures will not predict the level of subsoil S. Further, soil S concentrations found with the most commonly used extraction procedures have not been correlated with crop response to soil S availability and are not predictive of either the need for S fertilizer or the rate of S fertilizer to be recommended. This is simply because S deficiency is rare in Kentucky and field study sites appropriate to S correlation and calibration research have not been identified.

Currently, the best methods to determine soybean S need are monitoring/scouting for deficiency symptoms and routine plant tissue sampling and analysis. Other crops in the rotation that have higher S demand than soybean (e.g. alfalfa), higher removal rates (e.g. corn/corn silage), or make the majority of their growth at times when mineralization rates are low (e.g. winter wheat) are potential indicators of a field's potential for S deficiency. A detailed discussion of soybean tissue sampling follows later in this chapter.

Soybean removes approximately 0.18 lb S/bushel of grain and several common fertilizers will meet this need. Historically, P fertilizer was produced using sulfuric acid and SO_4-S remained in the finished product as an impurity. Current fertilizer production practices are much more efficient, and little S is left as a fertilizer impurity. Gypsum ($CaSO_4{\cdot}2H_2O$) is either mined or a byproduct of coal-fired power plant scrubber systems. The latter is the most common source of gypsum available in Kentucky and is usually the most economical S source. Gypsum comes in a range of sizes; from powder to processed pellets. The latter are manufactured in a wide size range to allow for blending with other fertilizer materials and/or greater ease of handling and application. Within the soil pH range (5.5 to 6.8) most common for row crop production, gypsum does not change soil pH. Another common S source, elemental S (S^0) is used to provide S nutrition and to reduce soil pH as the S^0 is oxidized to form SO_4^{2-}, a process that can take months. Other S sources include ammonium sulfate ($(NH_4)_2SO_4$), ammonium thiosulfate ($(NH_4)_2S_2O_2$), magnesium sulfate ($MgSO_4{\cdot}7H_2O$), and potassium sulfate (K_2SO_4) but are not appropriate or economical for soybean production.

Micronutrients

Micronutrients are essential to soybean growth and development and include boron (B), chlorine (Cl), copper (Cu), Fe, Mn, molybdenum (Mo), nickel (Ni) and zinc (Zn). Although needed in very small amounts, micronutrients are just as critical to soybean growth as the macronutrients. Soil micronutrients are generally adequate for high soybean yield in Kentucky, with the exception of Mo, Mn and B (each deficient in limited areas of the Commonwealth). Proper pH management will usually result in sufficient levels of available micronutrients. Most micronutrients are present in or on SOM and become available as SOM is mineralized. Fertilizer micronutrient addition is recommended when soil test results indicate deficiency is likely. **NOTE:** *There is a very fine line between sufficiency and toxicity with B, Cu, Mn, Mo, and Zn, and care must be taken to avoid over-application and potential yield loss.*

Boron

Soil B is contained in SOM and the mineral tourmaline. Boron comes in several soluble forms, many of which are anions ($H_2BO_3^-$, HBO_3^{2-}, BO_3^{3-}, $B_2O_7^{2-}$) when soil pH is above 7.0, but uncharged H_3BO_3 predominates when soil pH falls between 5 and 9. All soluble forms may be adsorbed on certain soil minerals but are otherwise mobile in the soil and somewhat prone to leaching. Boron is not very mobile in the soybean plant and is required for cell wall formation, cell division, pollination, fruit set and seed development, translocation of sugars and starches, and nodule formation. Drought conditions can increase the potential for B deficiency because SOM mineralization rates are lower and there is less water movement to the roots. Excessive leaching of the soil profile can also reduce B availability. Roots take up B as H_3BO_3. Boron availability is greatest at soil pH values between 5.5 and 7.0; if soil pH is above or below these values, B availability decreases. Boron deficiency symptoms first appear at soybean growing points, resulting in stunted growth (Figure 5-8). The loss of flowers and buds can also signal B deficiency. The University of Kentucky currently does not have a recommendation for B fertilization of soybean. If B deficiency is confirmed by a hot water extractable B soil test of less than 2 lb B/acre, or by tissue testing, the addition of 1 to 2 lb B/acre may be warranted. Boric acid or a sodium borate product such as Borax are very soluble and effective sources of B.

Figure 5-8. Boron deficiency in soybean.

Chlorine

Chlorine (Cl) was only recently found to be a micronutrient. The plant available form is the mobile anion chloride (Cl^-), which maintains electrical charge balance within the plant, helps to maintain plant turgor and stomatal regulation, and participates in photosynthesis. Chlorine is the only micronutrient not associated with SOM. Most Cl is associated with soluble salts of Na, Ca, and Mg. Soybean Cl deficiency has not been documented, but Cl toxicity can occur when high levels of Cl^- are present in the soil. Toxicity is due to the plant's inability to take up water. Toxicity symptoms start with scorch at the leaf margins that spreads with time if not corrected. Drought accelerates leaf scorch. Chloride salt accumulation in soil is commonly the cause of "dead areas" where animal manure has been stored for an appreciable time.

Copper

Copper (Cu) present in some enzymes, is necessary for carbohydrate production, and required for lignin synthesis. Copper deficiencies are extremely rare for crops grown on mineral soils east of the Mississippi River. There is no Cu soil test correlated with plant growth response and calibrated to support recommended fertilizer Cu rates for Kentucky soils. Copper deficiencies can occur on muck or peat soils (organic soils) due to the high affinity of the Cu ion (Cu^{2+}) for SOM, causing formation of very stable complexes. Plant roots take up Cu^{2+} derived from naturally occurring Cu chelates found in soil solution. Copper availability decreases with increasing pH in mineral soils. Soybean Cu deficiency has not been observed. Symptoms in other plant species include leaf tip dieback, yellow leaves, and stunted growth. Fertilizer Cu sources include Cu sulfates, Cu oxides, and chelated Cu products.

Iron

Iron is a component of chlorophyll. Iron helps to catalyze reactions and is a component of enzymes associated with energy production, N fixation, and lignin formation. Iron is the most abundant element in soil and is adsorbed to SOM. Soluble Fe consists of natural Fe^{2+} and Fe^{3+} chelates, but soybean only takes up Fe^{2+}. Iron availability is influenced primarily by soil pH, SOM content, and soil aeration/wetness. Iron availability decreases with increasing soil pH, and deficiency symptoms are more often observed when soil pH is greater than 7.5. Symptoms begin with interveinal yellowing on the youngest leaves. As the severity of the deficiency increases, the leaves eventually turn completely yellow, and then white to brown, until finally the leaves senesce (Figure 5-9). Iron deficiency is unknown in Kentucky.

Manganese

Manganese is essential for photosynthesis, N metabolism, and synthesis of other compounds needed for soybean growth. Both deficiency and toxicity of Mn occur in Kentucky, depending mostly on soil pH. Manganese availability is greatest at low soil pH and Mn toxicity can damage leaves, impairing their function. Plant leaves exhibiting Mn toxicity can have a characteristic crinkled appearance (Figure 5-10). Maintaining soil pH greater than 5.8 will prevent Mn toxicity.

Figure 5-9. Iron deficiency in soybean.

Soluble Mn, like Fe, exists in more than one oxidation state (Mn^{2+}, Mn^{3+}, Mn^{4+}), with the most prevalent form determined by soil pH and moisture status. Soybean roots take up the divalent cation Mn^{2+}. Manganese deficiency is not common in Kentucky but has been observed in the Lower Green River region when soil pH is greater than 7.0. Deficiency symptoms for Mn are characterized by interveinal yellowing on the newest leaves (Figure 5-11), which may eventually develop brown necrotic spots with increasing severity. A foliar application of chelated Mn or Mn sulfate is the best approach to remedy Mn deficiency due to high soil pH soil and is more effective than soil applied Mn.

Molybdenum

Molybdenum (Mo) is found in very low concentrations in most soils. As Mo is part of the nitrogenase enzyme, Mo is essential to biological N fixation by *B. japonicum* in soybean. Molybdenum is also contained in the NO_3^- reductase enzyme. Soil Mo is associated with SOM and is adsorbed to clay, but is somewhat mobile in soil. Molybdenum deficiency is most likely to occur on acid, coarse textured soils low in SOM. Maintaining soil pH above 6.2 is a very effective way to ensure adequate Mo availability for soybean. However, some soils are naturally low in Mo and these require fertilizer Mo addition. Soluble Mo occurs in several ionic forms, but MoO_4^{2-} is the Mo ion most often taken up by plants.

Essential Mo concentrations in plants are very low, lower than those for most other micronutrients, and low pH and low soil Mo levels can cause Mo deficiency. Soybean Mo deficiency has been observed in central Kentucky. Symptoms are similar to those for N deficiency (Figure 5-12), due to the essential role Mo plays in biological N fixation. The crop is stunted and leaves are pale green to yellow. Molybdenum fertilizer can be blended with other fertilizer materials and broadcast on the soil, or applied as a seed treatment prior to planting. There can be an antagonistic reaction between seed applied Mo and the living *B. japonicum* in seed applied inoculant. When both Mo and an inoculant are needed, either plant the dual treated seed immediately or make a separate application of either the Mo fertilizer or the inoculant. A seed treatment of 1 to 2 oz of sodium molybdate/acre or 1 lb of broadcast sodium molybdate/acre is recommended when Mo is needed. No more than 2 lb of sodium molybdate/acre is recommended in a 5-year period because too much Mo can be toxic.

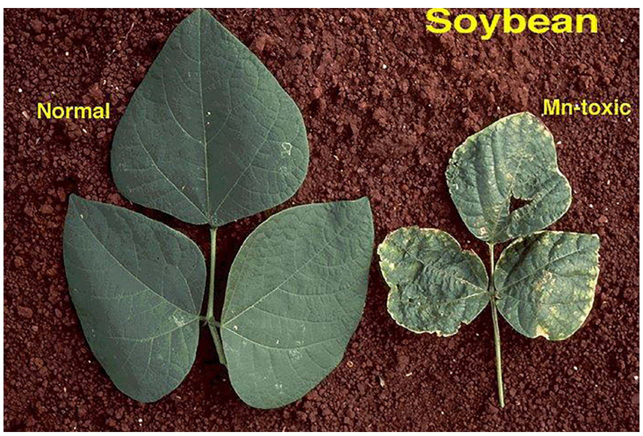

Figure 5-10. Manganese sufficiency (left) and toxicity (right) in soybean.

Figure 5-11. Manganese deficiency in soybean.

Figure 5-12. Molybdenum deficiency (left) and sufficiency (far right) in soybean.

Nickel

Nickel (Ni) is the latest element found to be essential for plant growth, as a constituent of the urease enzyme. Urease is important to plants depending upon urea for N nutrition or those where ureides are an important part of their N metabolism, especially legumes. Nickel addition can increase soybean nodule weight and yield. Soluble Ni occurs as the cation Ni^{2+}, which is also the form used by plants. Nickel deficiency has not been observed in Kentucky, but symptoms are similar to urea toxicity–the death (necrosis) of leaf tips due to urea accumulation (Figure 5-13).

Zinc

Soil zinc (Zn) availability is related to the solubility of Zn minerals and release of adsorbed Zn from SOM and clay. Plants absorb Zn as the cation Zn^{2+}. Plant Zn activates a number of enzymes, is essential to tryptophane synthesis, and promotes growth hormone synthesis. Zinc deficiency is often expressed as stunted growth due to shortened internodes (rosetting), and also as light green, yellow to white interveinal chlorosis (Figure 5-14). Soybean Zn deficiency, however, has not been confirmed in Kentucky, and although there is a good Zn soil test, the University of Kentucky does not make a Zn recommendation for soybean.

Inoculation for Soybean Nitrogen Nutrition

Soybean requires a large amount of N to produce high yields. Fortunately, as a legume, soybean has a symbiotic relationship with *Bradyrhizobium japonicum*, a relationship which results in atmospheric N being fixed and made available to the crop. In the corn/soybean or corn/wheat/double-crop soybean rotation, soybean should not need inoculation every year. *Bradyrhizobium* can survive in soil for several years without soybean production. However, due to the relatively low price of inoculant and the relatively high value of the biologically fixed N, soybean seed inoculation is recommended if the crop has not been grown in the field for three to five years. If the previous soybean crop exhibited poor nodulation, soil pH should be checked, lime applied as needed, and seed for the next crop should be inoculated. There is limited evidence that fields saturated for extended periods during winter have lower populations of *B. japonicum*. Soybean planted into these fields could benefit from seed inoculation.

The most common inoculation strategy is to apply inoculant to soybean seed prior to planting, either as part of a pre-plant seed coating or by adding inoculant over the seed in the seed box (hopper-box treatment).

Two other inoculation approaches are worth noting. The first is a "rescue" strategy sometimes used when a soybean field exhibits N deficiency that is due to poor nodulation (Figure 5-15). In this instance, a suspension of inoculant is applied to the soil surface, either broadcast or banded, so that rainfall will move the *B. japonicum* into the soil. The second is an "anticipatory" protocol, sometimes used when a field has no history of soybean production for many years. In this case seed of the crop preceding soybean, regardless of species, is inoculated with *B. japonicum*, perhaps at two to three times the recommended rate. The following soybean crop is also inoculated at two to three times the recommended rate to further ensure adequate nodulation.

See *Chapter 4: Cultural Practices* for additional details on seed inoculants.

Soil Testing and Soybean Lime and Fertilizer Rate Recommendations

The basis of all soil nutrient management programs is soil sampling and testing. Soil tests reflect the current nutrient status of the sampled area and should be used to make informed nutrient management decisions. Without a good soil testing program, the soybean producer risks either losing money by applying or over-applying nutrients that are not needed (monetary loss), or by not applying needed nutrients (yield loss).

Figure 5-13. Nickel deficiency in soybean.

Figure 5-14. Zinc deficiency in soybean.

Figure 5-15. Areas of this soybean field that are lighter green in color are N deficient because of poor nodulation.

Soil samples should be collected so as to represent the area of interest, and to the desired sample depth (0 to 4 inches in no-till fields; 0 to primary tillage depth in tilled fields)–no shallower and no deeper. The University of Kentucky Cooperative Extension Service recommends the sampled area be no larger than 10 to 20 acres. A minimum of 10 cores, more for larger areas, should be collected per sampled area. The samples should be representative of the area but should not include fencerows, waterways, old feeding areas, or any area where soil nutrient status might vary considerably from the larger sampled area. Sampling areas that differ greatly from the majority of the field can result in either an over- or under-application of nutrients.

The recommended target pH for soybean is 6.4 (*Lime and Nutrient Recommendations* [AGR-1]) and is based on measures of both active acidity and the soil's ability to resist pH change, measured separately. Recommended P and K fertilizer rates, according to soil test P and K, respectively, are given in Table 5-2.

Plant Tissue Analysis for Soybean Nutrition Diagnosis

Soybean plant tissue analysis is useful when the grower has one of the following objectives: a) confirming existing deficiency symptoms; b) verifying suspected "hidden hunger" of the crop for one or more nutrients; and c) regular, routine monitoring of the soybean nutrient management program. The last objective is the most important. Soybean tissue analysis, done well, provides a real-time assessment regarding the success (or lack thereof) of the nutrient management program for a field. Soybean tissue analysis can indicate which nutrients are deficient, sufficient, or excessive/toxic. Plant analysis cannot indicate the rate of a product needed when a nutrient element is deficient or toxic. The soil's buffer capacity (resistance to change) plays a large role in product rate determinations.

Plant analysis for a nutrient may not be well correlated to soil test values for the same nutrient. Tissue analysis alone will not identify potential contributing factors such as general soil or sidewall compaction, a soil pH or water drainage problem, or weather events that have influenced plant nutrient composition. Nutrient sufficiency ranges for soybean tissue samples are reported in Table 5-3. These ranges are good guidelines but are not absolute. If tissue sample analysis levels fall within the reported ranges, deficiencies should not occur. However, values slightly above or below these ranges do not mean that plant growth or yield will be limited. Values that deviate greatly from the reported ranges should be investigated further to understand potential yield limiting factors.

Soybean plant tissue samples can be taken at any time after emergence but are not very useful until the crop has reached a height of about 4 inches (V2). Up to a height of 12 inches (V6), the sample consists of the entire soybean plant, cut at 1 inch above the soil surface. At growth stages after V6, the sample consists of the uppermost fully developed trifoliolate leaves, usually the third or fourth set of trifoliolates from the top of the soybean plant. For further details, follow guidelines found in University of Kentucky Extension publication *Sampling Plant Tissue for Nutrient Analysis* (AGR-92).

Table 5-2. Phosphate and potash rate recommendations for soybean (lb/acre)[1]

	Full season soybean		Double crop soybean[2]		Full season and double crop soybean[2]	
Soil test category	**Soil test P:**	**P_2O_5 needed**	**Soil test P:**	**P_2O_5 needed**	**Soil test K:**	**K_2O needed**
High	>60	0	>60	0	>300	0
Medium	40-60	30	48-60	30	242-300	30
	34-39	40	45-47	40	226-241	40
	28-33	50	41-44	50	209-225	50
			38-40	60	191-208	60
			34-37	70		
			31-33	80		
Low	22-27	60	24-30	90	173-190	70
	16-21	70	17-23	100	155-172	80
	11-15	80	10-16	110	136-154	90
	9-10	90			118-135	100
	7-8	100			100-117	110
	6	110				
Very Low	1-5	120	<10	120	82-99	120
					64-81	130
					46-63	140
					<46	150

[1] Adapted from University of Kentucky Extension publication *Lime and Nutrient Recommendations* (AGR-1).
[2] Assumes fertilizer P and K will be applied before the wheat crop. This is adequate for both the wheat and the double-crop soybean.

Table 5-3. Nutrient concentration sufficiency ranges for whole soybean plants at the early vegetative growth stage and for uppermost fully developed trifoliolate leaves at flowering

Nutrient concentration (%)						Nutrient concentration (ppm)					
N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo
Early Growth											
3.5-5.5	0.3-0.6	1.7-2.5	1.1-2.2	0.03-0.6	0.3-0.8	ND*	ND	ND	ND	ND	ND
Flowering											
3.25-5.0	0.3-0.6	1.5-2.25	0.8-1.4	0.25-0.7	0.25-0.6	25-300	17-100	21-80	4-30	20-60	0.1-2.0

Adapted from University of Kentucky Extension publication *Soybean Nutrient Management in Kentucky* (AGR-213)
* ND–A sufficiency range for these nutrients has not been determined.

Delivering Needed Soybean Nutrition

The timing of nutrient delivery for soybean has changed with time. In the past, growers would add P and K for both crops in the corn/soybean rotation ahead of the corn production season. Soybean was grown with residual nutrients–no additional P and K were applied ahead of soybean production. This is no longer true–producers are more likely to apply needed soybean P and K nutrition ahead of planting. With small grain or canola/double-crop soybean, University of Kentucky recommends that the P and K needed for both crops be applied ahead of winter annual establishment.

Most nutrients can be applied in the fall, pre-plant or at-planting. Certain micronutrients (Mn, Mo) may be more cost effective if applied to plant foliage (Mn) or on the seed (Mo). Foliar micronutrients should be applied to anticipate, rather than correct, nutrient stress. Applications of any nutrient (especially P and K) after planting may correct a deficient soil condition but may not entirely maximize soybean yield potential, depending upon the length of time the crop is under nutrition stress.

Nutrient placement options for soybean are somewhat limited. Most needed nutrition is broadcast on the soil surface and then may or may not be incorporated, depending on the soil tillage management system. Incorporation to reduce nutrient stratification is not recommended. University of Kentucky research shows that the stratification of P and K commonly observed with no-tillage production systems has a positive impact on crop nutrition.

In row (pop-up) soybean fertilization is not recommended because of salt damage to soybean seed–which are very susceptible to salt injury. Because cold soil temperatures are less likely at soybean planting, banding (2 by 2, etc., placement) of P and K is less likely to be beneficial to soybean unless soil test levels for these nutrients (especially P) are low.

Foliar application of nutrients should be limited to needed micronutrients–it is not possible to apply an adequate rate of any foliar applied primary (N, P, K) or secondary (Ca, Mg, S) macronutrient, either because of crop injury or excessive cost. The exception to this is fertigation, where enough water to avoid crop injury can be applied. However, soybean fertigation nutrient applications are subject to the same timing considerations as other soil and foliar nutrient applications.

Animal Manures

Animal manures, especially poultry litter (PL), can be another good source of nutrients if properly used and economically priced. University of Kentucky research has shown a consistent soybean yield increase (about 3 bu/acre over 8 locations) to PL, even when soil test results recommended little or no fertilizer addition. Animal manures are considered a complete fertilizer in that they contain N, P, K, and appreciable amounts of secondary macronutrients and micronutrients in readily available forms. The P in animal manure is reportedly between 80 and 100 percent as available as fertilizer P, depending on animal species, manure type, and diet. Manure K is equal in availability to fertilizer K. Along with various amounts of several micronutrients, a ton of PL contains roughly 15 lb of S. When animal manures are used to provide adequate P and K nutrition, S and micronutrients should also be adequate. Additionally, PL can raise soil pH; an average RNV (see earlier section on soil pH management) value is about 10 percent. (See *Soil pH Management* section.)

Soybean should not need manure N but will utilize this N along with the manure P, K, and other nutrients. If soil test P or K is high, animal manures will probably not be the most economical fertilizer source for soybean production. A decision tool developed by Jordan Shockley in the Department of Agricultural Economics to evaluate the economics of using PL, Economic Value of Poultry Litter: Grain Crops AEC 2016-14, can be found at http://www.uky.edu/Ag/AgEcon/shockley_jordan.php.

Managing Nutrition in Organic Soybean Production Systems

A small percentage of Kentucky producers choose to grow organic soybean to capture the price premiums in a niche market. The basic principles of soil chemistry and nutrient availability are the same for organic and conventional soybean production systems. Organically produced soybean requires the same nutrients as conventionally produced soybean. However, the fertilizer products used must meet USDA organic standards. In general, products used for organic crop production are naturally produced (not synthesized) and are intended to improve or maintain soil organic matter levels in a manner that does not contribute to the contamination of crop, soil, or water resources. This section will briefly cover the main components of a soil fertility management program for organically produced soybean. Producers interested in organic soybean should read the supplemental materials below, make sure they have a viable market, and speak with a USDA representative prior to transitioning into an organic system to ensure this is an appropriate production system for their operation.

The fertilizer products allowed in organic production often have physical and chemical characteristics that are different from those used for conventional production. Nutrient additions to the soil should be based on a good soil sampling program, regardless of the production system. Currently, there is no scientific evidence that soil test methods for organic production should differ from those used for conventional production. The recommended nutrient rates will not change, but the plant availability of nutrients from organic nutrient sources can differ substantially.

Animal manures and composts are some of the best, most cost effective nutrient sources permitted for organic crop production. Although processed biosolids from wastewater treatment plants have many of the same characteristics and qualities of manure and composts, these are strictly prohibited from use in organic crop production. Manures and composts contain macronutrients and micronutrients in various concentrations, differing between and within manure types and composts. Therefore, sampling of manure and compost is highly recommended prior to purchase and application to soybean. Continued use of manure and compost can increase soil P and K levels up to, and beyond, sufficiency. Application of manure and compost above sufficiency can lead to environmental concerns about excessive N and P loading and subsequent offsite movement to nearby surface waters.

When animal manure or compost is not available to, or desired by, the organic producer, alternate organically approved products will need to be used according to soil test recommendations. Naturally produced products that are mined but not processed are generally allowable under USDA organic standards but each should be verified prior to use. Many of the products approved for organic production have lower solubility than conventional nutrient products, especially P products. For example, rock phosphate and bone meal are approved P products that are much less soluble than the diammonium phosphate (18-46-0) used in conventional production. Maintaining a lower soil pH (5.5 to 6.0) may benefit P availability in organic production as this increases P solubility from rock phosphate and bone meals. The same may be true with certain organic K products, although some of these have solubility similar to that of conventional K products. For example, mined sulfate of potash (0-0-50) and potassium-magnesium sulfate (0-0-22-10Mg-21S) are allowed in organic crop production and are very soluble. The organic soybean grower must be aware of the regulations governing nutrient inputs for organic production and the sometimes significant differences in nutrient solubility/availability among product choices.

Supplemental Materials

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Chapter 6

Weed Management

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Weed and Soybean Interactions

Implementation of effective weed control strategies is an important component of soybean production. Control efforts become economically justified because of the potential for soybean yield reduction, crop quality loss, harvesting difficulties, or other problems associated with the presence of weeds. In some situations, low weed populations may not interfere with crop yield, harvestability, or crop quality. Thus, producers could allow low populations of certain weeds to remain in the field throughout the growing season without affecting the crop. However, weed species such as smooth pigweed (*Amaranthus hybridus*), Palmer amaranth (*Amaranthus palmeri*), and common lambsquarters (*Chenopodium album*) are capable of producing thousands of seeds from single plants, thus weed seed added to the soil bank from even relatively low populations can be substantial. It is advisable to control populations of most weeds, particularly newly introduced species, before they reach maturity. Furthermore, vining weeds such as

Figure 6-1. Hophornbeam copperleaf (*Acalypha ostryifolia*), also known as three-seeded mercury, is a summer annual that emerges from June through September and can grow from 1 to 3 feet tall. The characteristic leaves are heart-shaped with finely serrated margins attached alternately on the stem. In the young seedling stage this plant can be confused with prickly sida, which has more linear leaves and more coarsely serrated margins.

Table 6-1. Estimated impact of select weed species on soybean with a 50 bu/ac yield potential.[1]

Relative weed pressure	Yield Loss potential	Foxtail spp.	Johnson-grass	Morning-glory spp.	Smooth Pigweed	Common Cocklebur	Giant Ragweed	Estimated yield loss by a single species
	-- Weed Density (plants per 100 sq ft) --							(bu/ac)
Slight	(0-5%)	5	2	1	1	<1	<1	1
Low	(5-10%)	10	5	2	2	1	1	2
Moderate	(10-20%)	20	10	5	5	4	4	6
Severe	(20-30%)	40	20	15	10	8	8	12
Very Severe	(>30%)	60	30	20	15	10	10	20

[1] These specific plant density values are based on general observations, and estimates show relative differences among weed species. Estimated values can vary greatly depending on the environment and when the weeds emerge relative to the time of crop emergence. Adapted from University of Missouri-Columbia Extension bulletin "Integrated Pest Management--Practical Weed Science for the Field Scout Corn and Soybean," Nov 2009.

burcucumber (*Sicyos angulatus*), morningglory (*Ipomeoa* spp.) and trumpetcreeper (*Campsis radicans*) can interfere with soybean harvest and reduce yield. The potential yield loss from various weed populations is illustrated in Table 6-1.

Most studies evaluating weed-soybean competition indicate weeds that emerge and grow with soybean during the first three weeks but are then removed do not reduce soybean yield under normal environmental conditions. Weeds that remain in the crop from three to eight weeks after soybean emergence have the greatest potential to reduce soybean yields. Weeds that emerge six to eight weeks after soybean emergence in fields, which have been kept weed-free up to that point, are not likely to reduce yield or have a negative economic impact relative to the cost of in-season treatment. However, these later emerging weeds may cause harvest problems, reduce crop quality, or produce more weed seeds.

Double-Cropping

Double-cropping in Kentucky typically involves planting soybean after winter wheat harvest. In this system, double-crop soybean tends to have fewer weeds compared with full-season soybean due to the delay in planting date and vegetative cover provided by the wheat residue. Nevertheless, the impact of weeds on yield can still be significant because of limited moisture typically observed with later planting dates. Fields may appear to be weed-free after wheat harvest, but a close examination could indicate otherwise. It is important to use a burndown herbicide treatment to control emerged weeds prior to planting double-crop soybean and to utilize a soil-residual herbicide to extend control of critical weeds. Examples of weeds that emerge in wheat and transition over to double-crop soybean include johnsongrass (*Sorghum halepense*), marestail. also known as horseweed (*Conyza canadensis*), common ragweed (*Ambrosia artemisiifolia*), giant ragweed (*Ambrosia trifida*), and smartweed (*Polygonum* spp). Planting soybean in narrow rows (< 15-inch-wide rows) is important for weed control in double-crop soybean.

No-Tillage

The majority of soybean in Kentucky and surrounding states are produced using no-tillage practices. No-tillage practices provide numerous benefits for weed control. Undisturbed soil, with time, reduces the germination of weed seed that are buried deep in the soil-seed bank. No-tillage limits the amount of soil disturbance and scarification (that is, physical abrasion) of weed seeds and may explain why weeds such as common cocklebur (*Xanthium strumarium*), burcucumber, and sicklepod (*Senna obtusifolia*) are observed to a lesser extent in no-tillage compared with intensive tillage situations. Furthermore, leaving the soil undisturbed for several years may lead to rotting and/or predation of weed seeds on the soil surface.

The lack of soil disturbance may, however, promote the development of populations of certain weed species. Common pokeweed (*Phytolacca americana*) and curly dock (*Rumex crispus*) are examples of perennials with large fleshy tap-roots that grow well in a no-till environment. Also, some small-seeded annual weed species such as marestail, annual fleabane (*Erigeron annuus*), and daisy fleabane (*Erigeron philadelphicus*) are noticed more frequently under no-tillage conditions. These weed species can emerge during the late fall or early winter months and maintain active growth throughout the soybean growing season. The seed-like achenes with tufts of hair contribute to the spread of these weeds by wind. Thus, they can easily invade new fields and thrive if primary tillage is not used to destroy emergence of new plants. Emergence of other small-seeded weeds, such as common lambsquarters and pigweed species, as well as annual grasses, may also be favored in no-till fields. This is likely due to their ability to emerge from shallow depths in the soil.

No-tillage leaves much of the previous crop residue on the soil surface where it can partially intercept herbicide applications. Less crop residue is present if the previous crop was soybean as compared to corn or wheat. Rainfall occurring soon after application generally moves the herbicide off the crop residue and into contact with the soil. This reflects the importance of rainfall instead of mechanical incorporation as the means by which a major portion of the soil-residual herbicide is moved within close proximity to germinating weed seeds in a no-tillage system. Some herbicides intercepted by crop residue may be subjected to loss by photodecomposition or by volatilization. In general, research data have not indicated that performance of soil-active herbicides is greatly reduced as a result of crop residue left on the soil surface. The thick surface mulch often associated with long-term no-tillage production may

Figure 6-2. Prickly sida (*Sida spinosa*), also called teaweed, is a summer annual that emerges from June through August and grows 1 to 2 feet tall. The leaves are oblong and are generally 2 inches long, have short petioles and coarsely serrated margins. The leaves covered in fine hairs are arranged alternately on the stem. In the young seedling stage this plant can be confused with hophornbeam copperleaf.



Figure 6-3. Marestail (*Conyza canadensis*), also called horseweed, is an annual that can grow 1 to 6 feet tall when it matures in late summer. Seedlings emerge as rosettes in fall, late winter, or early spring and bolt (develop elongated stems) in late spring to early summer. Stems are covered with fine hairs. Leaves are also hairy with entire or slightly toothed margins. Seed, which develop in late summer, are small achenes that are attached to a pappus (group of hairs) that can become wind borne.

however be one factor that contributes to inconsistent control of broadleaf signalgrass (*Urochloa platyphylla*) with the chloroacetamide herbicides. The mulch may also slow the warming of soil and delay emergence of weeds such as johnsongrass.

Cultural Practices

Many cultural practices contribute to weed management in soybean, and to cropping systems in general. It is important to note that use of these practices alone is not likely to result in a satisfactory level of weed control. These cultural practices represent just some of the tools that should be utilized in a program of integrated weed management.

A key objective is to prevent weed seed dispersal into fields. Most crop seed utilized today is certified and weed-free. Efforts should also be made to only plant weed-free cover crop seed, avoiding bin-run seed. As much as is feasible, all equipment should be cleaned before moving from infested fields, particularly during periods of weed seed production. Combines are major contributors for spreading resistant weed seed throughout Kentucky. Fence rows, ditchbanks, and other non-crop areas that harbor agricultural weeds that may contribute to the spread of seed to nearby production fields should be managed through mowing or herbicide applications. In some cases, hand rogueing may be necessary especially when herbicide resistant weed species are first observed; removing these before they set seed can limit their spread. A vigorous and intensive scouting program can often detect these isolated individuals at low density.

Healthy, competitive soybean plants are also key to outcompeting weeds. Select good quality seed, plant at recommended seeding rates, and use appropriate planting practices to ensure a good stand of soybean. Adjust soil pH and soil fertility according to recommendations. Plant or drill in narrow rows (< 15 inches) to ensure quick canopy closure. See *Chapter 4: Cultural Practices* and *Chapter 5: Nutrition Management* for additional details.

Rotating with other crops also contributes to weed management. The main advantage in a corn/soybean rotation or a corn/wheat/double-crop soybean rotation is the opportunity to rotate herbicide sites of action and reduce the buildup of weeds that can occur in a monoculture cropping system. The use of cover crops can also contribute to weed management in a subsequent soybean crop. Actively growing cover crops help suppress emergence of winter annuals that germinate in the fall and summer annuals that germinate early in the spring by outcompeting them. Depending on when the cover crop is killed, cover crop residues can also suppress weeds in the subsequent crop by limiting germination and emergence. The more cover crop biomass that accumulates and the thicker the mulch layer prior to soybean planting, the more weed suppression occurs and the longer this effect lasts. Cover crops should be terminated at the proper time to balance weed management goals with soybean establishment. Growers are cautioned that soybean planting issues can result from large amounts of cover crop residue, so special care must be taken when planting to avoid stand establishment problems.

Mechanical Control

Mechanical control is not practiced as much today due to no-till production practices, a variety of effective herbicide options, the use of narrow row spacing, and the adoption of herbicide-resistant varieties. However, mechanical control may still be used in an integrated weed management program. In some situations, tillage prior to planting can help with control of troublesome weeds such as marestail and perennial weeds with taproots such as common pokeweed and curly dock. Tillage is best utilized on fields with less potential for soil erosion.

Early season cultivation can take advantage of size differences between weeds and crops—especially early in the season when smaller weeds are more vulnerable to physical disruption than the larger crop plants. Operating a rotary hoe or a spring-tine harrow at high speeds is effective when weeds are in the white-thread stage–when the small stems are thin and have the appearance of a white thread. Once fully emerged soybean are generally tolerant of rotary hoeing until they reach 3 to 4 inches tall (about V2 growth stage), but they can be significantly injured by rotary hoeing as the hypocotyl forms a crook while emerging from the soil.

When soybean plants are taller, cultivation equipment that specifically works the area between the crop rows is needed but may be less practical with narrow rows (≤ 15 inches). If cultivation is feasible it should be done as shallowly as possible to minimize soil disturbance and to avoid damaging the soybean plant roots. Weeds should be targeted when they are small. Effective cultivation needs good soil conditions or soil will not flow around the tools and weeds can re-root after being removed from the soil.

Herbicide Use and Timing

Herbicides are the primary method used by producers for control of weeds in soybean. They are particularly important for combating weed problems in no-till or conservation tillage production systems. Herbicides are generally considered to be either soil-active or foliar-active. Soil-active herbicides are generally applied to the soil surface since they are most effective as weed seeds germinate, whereas foliar-active herbicides control weeds after they have emerged from the soil.

Soil-active herbicides are often applied to the soil surface (i.e. preemergence [PRE]) before the crop and weeds emerge. Herbicides applied to the soil surface are either dependent on rainfall to move the herbicide into the weed seed zone or are mechanically incorporated (i.e. preplant incorporated [PPI]). Some weeds such as Eastern black nightshade (*Solanum ptychanthum*) and yellow nutsedge (*Cyperus esculentus*) are more susceptible to herbicides when they are mechanically incorporated into the soil. However, mechanical soil incorporation is not feasible in no-till soybean production systems. Herbicide products that contain acetochlor (e.g. Warrant), S-metolachlor (e.g. Dual II Magnum) and pyroxasulfone (e.g. Zidua) are examples of soil-active herbicides generally applied at time of planting, but they can also be applied after soybean emergence. To be effective, however, they must be applied before seeds of target weeds germinate.

In no-tillage systems herbicides are usually needed to control weedy vegetation prior to or at time of crop planting (i.e. preplant foliar [PPF]). For example, paraquat (Gramoxone, etc), glyphosate (Roundup, etc.), glufosinate (Liberty, etc), and 2,4-D can be used to "burndown" the existing vegetation. With full-season soybean, the green vegetation present usually consists of cool-season annual weeds, occasionally some perennials, and/or cover crop plants. In double-crop soybean, which are planted later in the season, the existing vegetation can also consist of emerging summer annual weeds and certain warm-season perennials.

In recent years there has been greater reliance on foliar-active herbicides that are applied postemergence (POST) to the weeds and the crop. Postemergence applications became more popular with the introduction of herbicide-

Figure 6-4. Johnsongrass (*Sorghum halepense*) is a perennial warm-season grass that can emerge from rhizomes or seed and grows 2 to 8 feet tall. The stem and leaves have no hairs with a relatively large, membranous ligule with jagged edges. The wide leaves contain a prominent whitish midrib.

Figure 6-5. Common lambsquarters (*Chenopodium album*) is a summer annual that can grow up to 5 feet tall. Leaves are lanceolate to triangular shaped (2 to 2.5 inches long) with a dull to pale grayish green color covered with a white powdery coating particularly on younger leaves. Older stems are vertically grooved with red, purple or light green stripes.

Figure 6-6. Giant ragweed (*Ambrosia trifida*), also called horseweed, is a summer annual that can grow 3 to 8 feet tall or more. First true leaves are unlobed; subsequent leaves often have three prominent, deeply segmented lobes, although occasionally may have five to seven palmate lobes. Leaves are hairy, with an opposite arrangement on upright stems.

resistant soybean varieties (i.e. Roundup Ready soybean, LibertyLink soybean). Postemergence herbicide applications must be made at the proper stage of soybean and weed growth to be effective. Since most foliar-active treatments work best on small weeds, timing is extremely important. Treating weeds at the proper weed size is also important to minimize potential crop yield losses. Furthermore, actively growing weeds are more susceptible to herbicides than when weeds are under stressful environmental conditions. Since the desirable stage of weed growth to achieve the most effective control can vary by weed species and the herbicide used, read the product label for proper application timing.

Figure 6-7. Pitted morningglory (*Ipomoea lacunosa*) is a summer annual vine that can grow to lengths of 6 feet. Cotyledons are deeply indented helping to distinguish this morningglory from other species; true leaves are heart-shaped tapering to a point arranged alternately on the stem. The leaves are smooth or may be slightly hairy, and often have purplish margins.

Figure 6-8. Ivyleaf morningglory (*Ipomoea hederacea*) is a summer annual vine that can grow up to 6 feet or more in length. Cotyledons are butterfly-shaped and often narrow at the base. True leaves are three-lobed and ivy-shaped and arranged alternately on the stem. The leaves contain erect hairs on both surfaces.

Figure 6-9. Palmer amaranth (*Amaranthus palmeri*) is a summer annual that can grow 3 to 6 feet tall. Characteristics can resemble those of other pigweed species and can vary within the same population, therefore assess multiple plants within the field for proper identification. The stem and leaves are smooth with leaf petioles that are typically longer than the leaf blade. Often, but not always, there will be single hair in the leaf tip notch. Some Palmer amaranth plants have white chevron or V-shaped watermarks.

Figure 6-10. Waterhemp (*Amaranthus tuberculatus*) is a summer annual, which can grow 3 to 6 feet tall. Characteristics can also resemble those of other pigweed species and can vary within the same population, therefore assess multiple plants within the field for proper identification. The stem and leaves are smooth with long, lance-shaped leaves that are glossy or waxy in appearance. Waterhemp cotyledons are often more egg-shaped than the long, linear cotyledons of other pigweeds.

Certain weeds are best controlled with foliar-active treatments, especially perennials. However, the best overall approach is to implement herbicide programs that utilize soil-active (preemergence) herbicide applications followed by postemergence herbicide treatments. Weed control programs should also include multiple modes of herbicide activity and vary herbicide programs from year to year.

Herbicide mode of action can be defined as the way that a herbicide interferes with normal plant metabolism, inhibits plant growth, or otherwise contributes to plant death. Some herbicides interfere with photosynthesis, some cause unregulated growth, and some interfere with amino acid synthesis. Refer to University of Kentucky Extension publication *Weed Control Recommendations for Kentucky Grain Crops* (AGR-6) for a more detailed discussion of herbicide modes of action and for specific herbicide products available for use on soybean.

Herbicide Persistence and Carryover

While persistence of herbicides in soil is beneficial for maintaining season-long weed control, it can be a significant concern when it results in carryover to rotational crops. The potential risk of subsequent crop injury from herbicide carryover is dependent on several factors, including the susceptibility of the rotational crop and the persistence of the herbicide. Consult herbicide product labels for specific guidelines when planting subsequent crops.

A typical cropping sequence used in Kentucky and portions of neighboring states include corn, wheat, and double-crop soybean. In this cropping sequence crop injury from carryover seldom occurs from the most commonly used herbicides. The risk of carryover however, may be greater in double-crop soybean compared with full-season soybean due to less time for dissipation of herbicides and drier conditions at the time of application following wheat harvest. Some soybean herbicides that contain chlorimuron (e.g., Canopy, Classic, Synchrony, etc.), fomesafen (e.g. Flexstar, Prefix, etc.), imazaquin (e.g. Scepter), and imazethapyr (e.g., Extreme, Pursuit) have potential under some environmental conditions to persist long enough to injure corn. Corn herbicides that contain atrazine and simazine or wheat herbicides such as Finesse (chlorsulfuron plus metsulfuron) have precautions on their labels for rotating to soybean. Certain herbicide-tolerant crops can limit the risk of injury from herbicide carryover. For example, soybean varieties with BOLT™ technology and other STS (sulfonylurea-tolerant soybean) varieties are more tolerant to many sulfonylurea type herbicides and are recommended when certain ALS-inhibiting herbicides have been used previously.

Environmental conditions also affect herbicide persistence and rotational crop injury potential. Factors that help promote herbicide dissipation and limit carryover problems in Kentucky include: 1) an ample supply of moisture throughout the growing season, 2) mild winter temperatures, 3) relatively low levels of organic matter (usually 2 to 3 %), and 4) soils with medium soil pH levels (usually pH 6.0 to 6.8).

Herbicide Interactions

Herbicides marketed as package mixtures and premixes with more than one active ingredient have become prevalent due to the need for broad spectrum weed control activity and to introduce multiple herbicide modes of activity. Furthermore, mixing herbicides with other chemicals, including other pesticides and fertilizers, either as tank mixtures or sequential applications, is practiced widely. It is important to recognize the potential benefits as well as drawbacks for using such strategies. The "jar test" method that is described on many product labels helps determine physical compatibility of tank mixtures but will not indicate the potential for synergism (i.e., more activity) or antagonism (i.e. less activity) as it relates to weed control or crop injury.

Surfactants, crop oils, methylated seed oils, and nitrogen fertilizers, such as 28 to 32 percent liquid nitrogen, 10-34-0, or ammonium sulfate (AMS) are sometimes used as additives with foliar-active herbicides. Although the benefit of nitrogen fertilizers as additives is debatable for certain herbicides, there are situations where their use can enhance control or limit antagonism. For example, it is well known that the use of AMS as an additive enhances postemergence control of velvetleaf (*Abutilon theophrasti*). It also enhances the activity of glyphosate in hard water by preventing the reaction between the glyphosate salt and calcium ions. On the other hand, AMS should not be used with some dicamba herbicide formulations as it increases the potential for volatilization.

The risk of antagonism between herbicides varies depending on specific products, method of application, and environmental conditions. For example, when tank mixing a postemergence herbicide for grass control (e.g. clethodim) with another herbicide to target broadleaf weeds (e.g. fomesafen) the control of weedy grasses could be reduced. Furthermore, some products are not stable in water over time and should be sprayed soon after mixing. This is especially true of many of the sulfonylurea herbicides, which may degrade within 4 to 24 hours after mixing. It is important to consult the product labels of all herbicides and other additives involved in a spray mixture to avoid physical incompatibility issues with mixing as well as potential problems with crop injury or weed control.

Application Stewardship

Applying herbicides correctly is just as important as choosing the right products and the success of a herbicide treatment can sometimes be dependent on the applicator. The applicator should be knowledgeable of the herbicide being used and the conditions whereby the application will be made. Some herbicide products should be applied at low spray volumes (10 GPA) to achieve the best results, while other products require higher spray volumes (15 GPA or even greater) for good weed coverage. A significant consideration when making herbicide applications is to minimize the potential for off-site movement of spray particles. Nearby sensitive vegetation can be severely damaged or killed when herbicides move off-target. Look around, be aware of your surroundings, and know what your neighbor is growing. Crops such as tobacco, grapes, and vegetables, or greenhouses, home gardens, and landscape trees could be nearby and can be sensitive to exposure to certain herbicide products. With any herbicide application be aware of wind speed and direction since direct physical drift of spray particles can injure off-target vegetation. For the desired spray volume, use the correct spray nozzles and spray pressure to produce coarser spray droplets. Herbicide products that contain 2,4-D and dicamba have an especially high potential for damage to nearby vegetation. Therefore, label guidelines for application of these herbicides should be closely followed. It is also important to to keep the spray boom close to the target vegetation while maintaining the correct spray pattern across the spray boom.

Proper sprayer cleanout following an application is another important consideration. This is especially true when using the same sprayer for pesticide applications on subsequent crops or when applying certain herbicides to the same crop that do not have the same genetic herbicide tolerances. This may require multiple rinses of the spray tank including the hoses on the spray boom, cleaning all the strainers and spray nozzles, and in some cases using special spray tank cleaners. Most herbicide products will detail the procedures for sprayer cleanout on the label.

Herbicide-Resistant Weeds

A major concern in soybean weed management is the development of weed biotypes that are resistant to commonly used herbicides. The basis for herbicide resistance is the genetic diversity that allows biotypes within a species to survive a herbicide that is generally known to be lethal to that plant species.

There are several weeds in Kentucky that have evolved resistance to certain herbicides. The ones of greatest concern include marestail, Palmer amaranth, and waterhemp (*Amaranthus tuberculatus*). Biotypes of all three species are now resistant to glyphosate. There is mounting evidence that populations of Palmer amaranth and waterhemp have multiple resistance involving glyphosate, ALS inhibitors, and PPO inhibitor type herbicides.

The potential for weeds to evolve resistance increases with repeated use of a herbicide or herbicide products that have the same site of action on the same field for several seasons. Therefore, herbicide history should be considered and production practices implemented to prevent or reduce the potential for weed resistance to occur.

The key to avoiding development of herbicide-resistant weed populations is prevention. Examples of management strategies to help prevent or limit herbicide-resistant weeds are:

- Scout fields regularly and respond quickly to shifts in weed populations.
- Utilize cultural practices to minimize weed seed production and restrict the spread of weeds.
- Select a herbicide based on weeds present and use a herbicide only when necessary.
- Utilize the labeled herbicide rates, and apply herbicides to the recommended weed sizes with the proper spray volume.
- Apply herbicides with different sites of action as a tank mixture or sequential application during the same season.
- Avoid sole use of herbicides with the same site of action (i.e. herbicides that inhibit the same process in target weeds) for two consecutive years.
- Utilize cultural practices, such as narrow row spacing, to maximize crop competitiveness.
- Utilize cover crops where appropriate to suppress weed emergence. Treating fewer weeds with herbicides can reduce the chances that one of those individuals has developed resistance.
- Rotate crops. Crop rotation helps disrupt weed cycles, and some weed problems are more easily managed in certain crops than others.
- Utilize physical (mechanical) management if appropriate.
- Clean tillage and harvest equipment to avoid moving weed problems from one field to the next.

Herbicide-Tolerant Traits in Soybean

Much of the current weed control technology involves soybean varieties that have tolerance to specific herbicides (See Table 6-2). Herbicide-tolerant soybean varieties can be developed from two different procedures: 1) selection by traditional plant breeding methods and 2) biotechnology techniques resulting in a genetically modified organism (GMO).

Herbicide-tolerant varieties provide additional options to control some weed problems. However, there are concerns associated with their use. These include a)

Figure 6-11. Smooth pigweed (*Amaranthus hybridus*) is a summer annual that can grow 3 to 5 feet tall. Characteristics can resemble those of other pigweed species and can vary within the same population; therefore assess multiple plants within the field for proper identification. Smooth pigweed cotyledons are often long and narrow; true leaves are generally more egg-shaped. Fine hairs are generally present on the stem and leaves.

Figure 6-12. Velvetleaf (*Abutilon theophrasti*) is a summer annual with branched stems that can grow 2 to 7 feet tall. Leaves arranged alternately on the stem are often light green, orbicular to heart-shaped with dentate leaf margins. The stems and leaves are covered with very soft, velvety hairs.

Figure 6-13. Common pokeweed (*Phytolacca americana*) is a bushy perennial that can grow up to 8 feet tall. It can emerge from a large, fleshy taproot or from seed. The succulent red-purplish stems are smooth with alternately arranged large lance-shaped leaves. The fruit forms grape-like structures that produce dark purple berries in the fall.

misapplication of a herbicide to a traditional susceptible soybean variety, b) greater selection pressure for herbicide-resistant weed species or shifts in weed populations due to the repeated use of the same herbicide mode of action, c) herbicide-tolerant crops becoming weedy and difficult to control, d) marketing issues, and e) negative public reaction to biotechnology-derived crops. Herbicide-tolerant crops require a high level of management to prevent problems such as misapplication, spray drift, or further development of weed resistance.

Other Information

This publication describes general concepts of weed management in soybean. More specific information on herbicides and their use in soybean can be found in University of Kentucky Extension bulletin *Weed Control Recommendations for Kentucky Farm Crops* (AGR-6), revised annually. Additional information may be found on the University of Kentucky Weed Science website: http://weedscience.ca.uky.edu/graincrops.

Table 6-2. Crop technologies involving herbicide-tolerant traits

Commercial Launch Year	Trait	Herbicide	Method of Development
1993	Sulfonylurea Tolerant Soybean (STS)	ALS type herbicides • Synchrony STS • Permit Plus	Traditional plant breeding techniques
1996 ----- 2010	Roundup Ready Soybean (RR) • 1st Generation ----------- • Genuity Roundup Ready 2 Yield	glyphosate • Roundup PowerMax • several other products	Biotechnology techniques
2009	LibertyLink (LL)	glufosinate • Liberty, Ignite • other products	Biotechnology techniques
2015	BOLT soybean	ALS herbicides + glyphosate • LeadOff[1] / Basis Blend[1] • Finesse[2] • Synchrony STS	Traditional plant breeding and Biotechnology techniques
2016	Roundup Ready 2 Xtend soybean	dicamba + glyphosate • XtendiMax, FeXapan • Engenia	Biotechnology techniques
2018	Enlist soybean ---------- Enlist E3	2,4-D choline + glyphosate • Enlist Duo, Enlist One ------------ 2-4-D choline, glyphosate + glufosinate • Enlist Duo, Enlist One • glufosinate products	Biotechnology techniques

1 BOLT soybean can be planted zero days following application of LeadOff or Basis Blend
2 Reduced plantback to double-crop soybean following application of Finesse to wheat

Chapter 7

Diseases and Their Management

Carl A. Bradley and Kiersten A. Wise

Nearly all parts of a soybean plant can be affected by diseases. Although diseases can be found in almost every soybean field grown in Kentucky, they do not always cause economical yield reductions. All four major groups of plant pathogens (bacteria, fungi, nematodes, and viruses) cause soybean diseases. Like all plant diseases, soybean diseases will only occur when the three components of the plant disease triangle are present: a susceptible host, a plant pathogen, and an environment favorable for infection and disease development.

Proper identification of soybean diseases is the first step in disease management. In some cases, symptoms of soybean diseases may resemble those caused by abiotic factors such as drought stress, soil fertility problems, herbicide damage, etc. In addition, symptoms of one particular soybean disease may closely resemble those caused by a completely different pathogen. Working with your local county Extension Office to submit a sample to the University of Kentucky Plant Disease Diagnostic Laboratory (PDDL) will help ensure a proper diagnosis. Staff at the PDDL will evaluate plant samples for both disease symptoms and pathogen signs. A disease symptom is the plant's response to the infection by a pathogen (i.e. leaf spot, stunted plants, stem lesion), whereas, a pathogen sign is a structure formed by the actual pathogen (i.e. fungal structures inside of a leaf spot, cyst nematode on a root, bacterial cells streaming out of infected tissue). Observation of pathogen signs may require magnification with a microscope or hand lens.

There are many management practices that can be employed to reduce the amount of soybean disease inoculum present each year and to protect plant tissue from infection. In general, the major methods of managing soybean diseases fall into one of the following categories:

- **Cultural practices**: Include crop rotation with non-host crops; adjusting seeding rate, adjusting row width, adjusting planting date, etc.
- **Host resistance**. Growing varieties that are resistant or partially resistant to specific diseases.
- **Chemical**. Generally, seed-applied or foliar-applied chemicals (i.e. fungicides and nematicides) for the purpose of protecting plant tissue from infection by a pathogen.
- **Biological control**. The use of another organism to manage a plant pathogen. Biological control agents can be found in both seed-applied and foliar-applied products registered for use on soybean.

Below are some diseases of soybean that can be observed in Kentucky. This is not a complete list, and as cropping systems, soybean varieties, and the environment changes over time, diseases that are currently infrequently observed in Kentucky may become more prevalent.

Root and Seedling Diseases

Seedling Diseases

Causal agent: *Pythium* spp., *Phytophthora* spp., *Rhizoctonia solani, Fusarium* spp.

Time of occurrence: Planting to seedling stage

Conditions favoring disease: Conditions that are not favorable for quick germination and emergence, such as cool soil temperatures and wet soils. Planting poor quality seed and stress caused by some herbicides may favor seed and seedling diseases.

Symptoms: Several pathogens may cause seeds to rot and seedlings to decay. These pathogens usually cause lesions on the roots, eventual rotting of roots, and, if severe, wilting and death of plants (Figure 7-1).

Figure 7-1. Soybean seedlings dying from a seedling disease.

Figure 7-2. Wilted soybean plants affected by Phytophthora root rot. Note the dark lesion extending up the stem from the soil line.

Management: Avoid planting too early in the season, when soil temperatures are more likely to be cool. Crop rotation may provide some management benefit, but many of the pathogens that cause seed and seedling diseases have a wide host range and may also affect rotational crops. Fungicide seed treatments may provide some protection against seed and seedling diseases.

Phytophthora Root and Stem Rot

Causal agent: *Phytophthora sojae* (fungal-like oomycete)

Time of occurrence: All season.

Conditions favoring disease: Warm, wet weather. Low, poorly drained areas particularly in compacted and heavy clay soils.

Symptoms: At the primary leaf stage, affected stems look bruised and are soft; secondary roots are rotted, the leaves turn yellow, and plants quickly die (Figure 7-2). At this stage, *Phytophthora* and *Pythium* damage are very similar and can be differentiated only by a laboratory examination. In mid to late season, yellowed, wilted and dying plants appear in wetter areas of the field. Dark brown lesions form on the roots and a distinct dark brown discoloration of the stem may extend from below the soil line upward into the branches. Groups of plants are often killed in a row before plants in adjacent rows are affected.

Management: Planting resistant varieties is the best method to manage Phytophthora root and stem rot. Two types of resistance exist: single gene resistance (known as *Rps* genes) and partial resistance (often referred to as "field tolerance"). *Rps* genes can provide complete resistance, but races of *P. sojae* that can overcome some of the *Rps* genes are present in some Kentucky fields, which may render the *Rps* genes ineffective. Partial resistance is not complete, but is effective against all races. The best way to manage this disease with resistant varieties is to choose a variety with an *Rps* gene for resistance that also has a high "field tolerance" rating. Some fungicide seed treatment products contain specific products that are effective against oomycete pathogens such as Phytophthora. These seed treatments will provide some protection for a few weeks after planting but will not provide season-long protection.

Rhizoctonia Root Rot

Causal agent: *Rhizoctonia solani* (fungus)

Time of occurrence: Planting to mid-season.

Conditions favoring disease: Heavy, poorly drained soils, delayed emergence, herbicide stress.

Symptoms: Seedlings or older plants are stunted and may wilt due to a firm, dry, brown to reddish-brown decay (often sunken) of the root and stem below or near the soil line (Figure 7-3).

Management: Fungicide seed treatments will provide protection until emergence. Practice good management to reduce outside stresses, such as avoiding herbicide injury, maintaining proper soil fertility, and managing other diseases and pests.

Figure 7-3. Reddish-brown, sunken lesions on the hypocotyls and roots of soybean plants affected by Rhizoctonia root rot.

Sudden Death Syndrome (SDS)

Causal agent: *Fusarium virguliforme* (fungus)

Time of occurrence: Flowering to maturity for above ground symptoms. A root rot caused by the same fungus also may occur throughout the season.

Conditions favoring disease: Cool, moist soil at or just after planting, and high rainfall amounts through the reproductive stages.

Symptoms: Interveinal leaf tissue becomes chlorotic then necrotic (Figure 7-4). Leaflets drop off, leaving petioles attached to the stem. Leaf symptoms look similar to brown stem rot and stem canker foliar symptoms. Pod abortion can occur. Vascular tissue in the roots become gray-brown, but the pith remains white. Roots may be discolored and stunted early in the season. Later, if soil is wet, blue colored spore masses can develop on infected roots. Although the most prominent symptoms occur on the leaves, the pathogen is located in the roots and infects shortly after planting. The fungus then produces a toxin that causes the leaf symptoms.

Management: Plant the most resistant varieties available. Some fungicide seed treatments have efficacy against *F. virguliforme* and can reduce severity of SDS. Risk of SDS increases when cool and wet weather occurs at or just after planting, which is more likely to occur early in the season.

Soybean Cyst Nematode (SCN)

Causal agent: *Heterodera glycines*

Conditions favoring disease: Continuous soybeans or soybeans grown every other year in rotation, and added stress factors. SCN-resistant soybeans may be damaged by SCN under one or more of the following three conditions: 1) high SCN populations; 2) failure to rotate resistant varieties; or 3) low level of resistance in the variety grown.

Symptoms: Under good growing conditions, symptoms may not be visible. Yield may be reduced up to 30 percent in high-yield environments in the ***absence of symptoms***. Under stress conditions, heavily infected plants may be stunted and yellow (chlorotic), or may exhibit symptoms of nutrient deficiency. Drought conditions encourage symptom development. Infested areas may be oval to somewhat elliptical in outline. Such areas show the most severe damage in the center with less damage toward the margin.

Scouting procedure: All soybean fields have a high probability of SCN infestation and should be scouted at least once every six years even if no symptoms are evident.

Soil sampling: SCN populations are highest late in the growing season, but fields can be sampled for SCN at any time of year. Soil samples should be collected as follows: take soil cores to a depth of 6 to 10 inches at several locations in the field, combine the cores and mix thoroughly to break up clods, and place one quart of the mixture in a sturdy plastic bag. Avoid sampling inside the margins of "hot spots" (areas showing severe symptoms). Samples must be kept cool and submitted to a lab for analysis. Symptom thresholds for SCN vary according to local or regional conditions, so local sources should be consulted for this information. The action threshold for SCN is one cyst.

Direct examination: Begin examining fields six weeks after planting until late August. Dig (do not pull up) two or three plants from at least five locations in a field if no obvious symptoms are present. When damage is present, dig several plants from the margin of the affected area. Gently tap or soak the soil from the roots and carefully examine for the swollen female stage. Females are white to yellow, lemon-shaped bodies about 1⁄32 inch or less (Figure 7-5). Later they become brown protective structures containing up to 400 eggs (cyst stage). If no females are visible, submit a soil sample for analysis as described in the previous paragraph.

Management: Rotating with non-host crops, such as corn, will reduce SCN populations in the field over time. Growing resistant varieties will help manage SCN, but

Figure 7-4. A range of foliar symptoms caused by sudden death syndrome in this picture. This includes yellow flecking of leaves and leaves with interveinal chlorosis and necrosis.

Figure 7-5. Soybean cyst nematode females attached to soybean roots (white to yellow lemon-shaped structures on roots).

some SCN populations (known as HG Types) may still affect resistant varieties. Seed-applied products (nematicides and biological control products) are available and may help manage SCN in combination with other management practices.

Foliar Diseases

Bacterial Blight

Causal agent: *Pseudomonas savastanoi pv. glycinea* (bacterium)

Time of occurrence: All season.

Conditions favoring disease: Mainly a cool, wet weather disease; spread by wind and rain within a field as well as by moving equipment through a field when foliage is wet.

Symptoms: Small, angular, water-soaked spots turn yellow, then brown as the tissue dies. A yellow "halo" may surround the leaf spots (Figure 7-6). Several spots may merge and the dead tissue drops out giving the leaves a ragged appearance. The lesions usually do not cross leaf veins. Leaves usually remain on the plant.

Management: No in-season management options exist. Most varieties are fairly resistant to this disease, so generally no management is needed. Since this disease can be seedborne, planting high-quality seeds will help reduce the incidence of this disease. The likelihood of economic yield loss occurring due to this disease is low.

Bacterial Pustule

Causal agent: *Xanthomonas axonopodis pv. glycines* (bacterium)

Time of occurrence: All season.

Conditions favoring disease: Mainly a warm, wet weather disease.

Symptoms: Small, yellow-green spots with brown centers are noticeable mainly on the upper leaf surface. A small, raised pustule develops in the center of the lesion, particularly on the underside of the leaf. Spots may merge and tissue may fall out, giving the leaves a ragged appearance. There is no water-soaked appearance to the spots (Figure 7-7).

Management: No in-season management options exist. Most varieties are fairly resistant to this disease, so generally no management is needed. The likelihood of economic yield loss occurring due to this disease is low.

Cercospora Blight

Causal agent: *Cercospora kikuchii* (fungus)

Time of occurrence: Flowering time to maturity (July-September).

Conditions favoring disease: Warm and wet.

Symptoms: Late in the season, leathery, red-brown spots may develop on leaves, stems, and pods. These spots may merge to form large areas (Figure 7-8).

Figure 7-6. Bacterial blight lesions on soybean leaves.

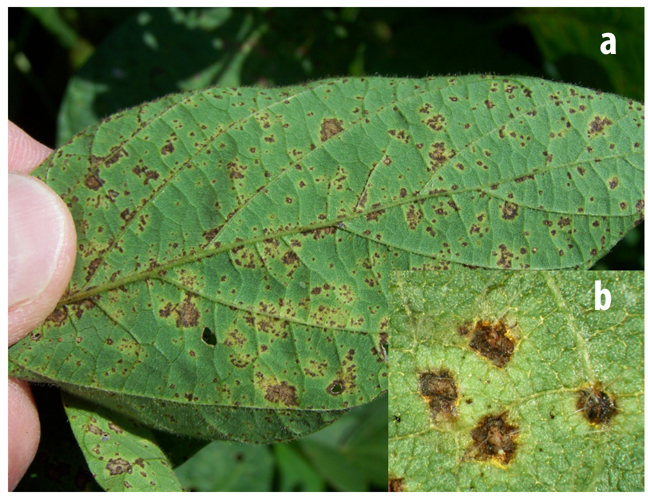


Figure 7-7. (a) Lesions on a soybean leaflet caused by bacterial pustule. (b) Raised pustules on a soybean leaflet affected by bacterial pustule visible with the aid of magnification.

Figure 7-8. Dark, leathery appearance of a soybean leaflet affected by Cercospora leaf blight.

Management: Some foliar fungicides may help protect leaves against infection. In Louisiana, strains of this fungus with resistance to different fungicide active ingredients have been identified. It is possible that fungicide-resistant strains are present in Kentucky; therefore, it is important to apply fungicides with multiple modes of action.

Downy Mildew

Causal agent: *Peronospora manshurica* (fungal-like oomycete)

Time of occurrence: Plants of all ages are susceptible.

Conditions favoring disease: Infected seeds, narrow rows, cool, moist conditions.

Symptoms/signs: Small, yellow-green areas develop on the upper leaf surface. These areas enlarge and become grayish to dark brown and surrounded by yellow-green margins. Gray velvety mold develops on lower leaf surfaces (Figure 7-9), particularly under wet, humid conditions. Infected seeds are encrusted with a white coating of spores.

Management: In general, yield losses caused by downy mildew are minimal. Foliar fungicides are not effective in managing this disease. Since this disease can be seedborne, planting high-quality seeds will help reduce disease incidence. The likelihood of economic yield loss occurring due to this disease is low.

Figure 7-9. Yellow-greenish blotches on the upper leaf surfaces caused by downy mildew (left); light to gray-colored "tufts" observed on the underside of a leaf caused by the soybean downy mildew pathogen (right).

Frogeye Leaf Spot

Causal agent: *Cercospora sojina* (fungus)

Symptoms: Symptoms on leaves are usually most prominent. Round to misshapen tan to gray spots on leaves (up to ⅛-inch diameter) surrounded by a thin, dark reddish- to purple-colored ring (Figure 7-10); reddish and elongated lesions may develop on stems and pods.

Time of occurrence: Usually after flowering.

Conditions favoring disease: Warm, wet, and humid weather.

Management: Planting resistant varieties can be an effective way to manage this disease. Crop rotation may help reduce inoculum levels in fields, since the fungus overwinters on soybean debris. Foliar fungicides can be effective in protecting leaves against infection; however, strains of this fungus that are resistant to quinone outside inhibitor (QoI; also referred to as "strobilurin" fungicides) are prevalent throughout Kentucky and surrounding states. Therefore, it is important to apply fungicides with multiple modes of action.

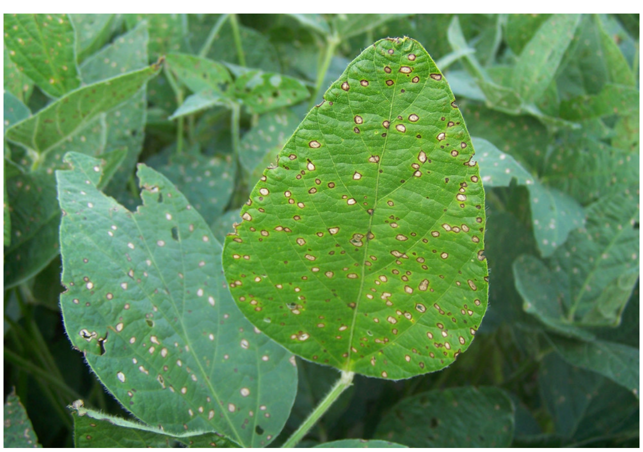


Figure 7-10. Soybean leaves affected by frogeye leaf spot.

Powdery Mildew

Causal agent: *Microsphaera diffusa* (fungus)

Conditions favoring disease: Cool weather.

Time of occurrence: After flowering, usually late in the season.

Symptoms/signs: White, powdery mold patches on aerial plant parts, especially the leaves (Figure 7-11). Defoliation may occur.

Management: This disease is rarely observed in Kentucky; therefore, it is likely that no management is needed.

Figure 7-11. Soybean leaves affected by powdery mildew.

Septoria Brown Spot

Causal agent: *Septoria glycines* (fungus)

Time of occurrence: This disease may appear on the unifoliolate leaves in the spring and progress throughout the season.

Conditions favoring disease: Warm, wet weather, continuous soybean, and minimum tillage.

Symptoms: Infections progress from the lower to the upper leaves. Diseased areas are angular to irregular and dark brown (Figure 7-12). They range in size from pinpoint to ⅕-inch diameter and may be more prominent on lower leaf surfaces. The lesions may also cross leaf veins. General yellowing may occur around the lesions but are not as distinct as the yellow halos that occur with bacterial blight. Infected leaves turn yellow and drop prematurely, progressing from the bottom upward.

Management: Since this pathogen overwinters on soybean debris, crop rotation will help provide adequate time for soybean residue to decompose and help reduce inoculum levels in a field. Foliar fungicides are effective in protecting leaves from infection. Septoria brown spot will only cause yield losses in years where rainfall is frequent, which helps assist the fungus to infect leaves in the upper-third of the canopy. In many years, this disease remains in the bottom portion of the canopy which makes it less likely to cause yield loss.

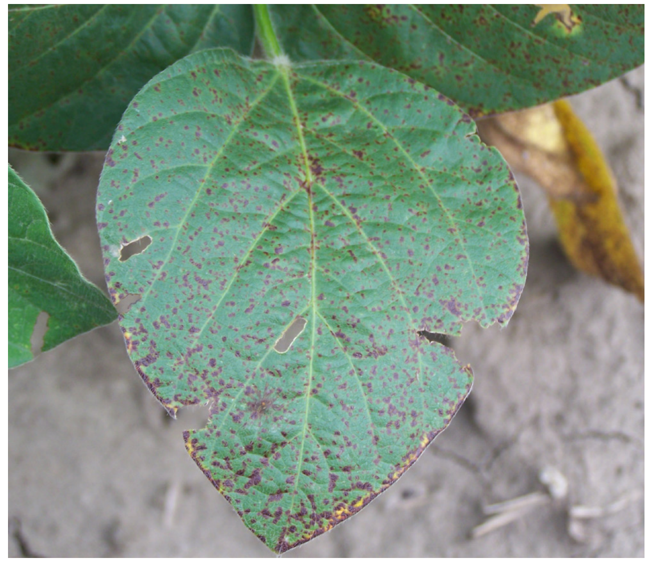


Figure 7-12. Dark lesions on a soybean leaf caused by Septoria brown spot.

Soybean Rust

Causal agent: *Phakopsora pachyrhizi* (fungus)

Symptoms/signs: Symptoms begin on the lower leaves of the plant and appear as lesions that resemble those caused by Septoria brown spot. Small pustules surrounded by necrotic areas develop on the underside of leaves (Figure 7-13). These pustules break open and release tan to brown spores that can be observed with a microscope. Pustules can look identical to those caused by bacterial pustule. Soybean rust pustules will only occur on the underside of the leaves, whereas, bacterial pustules can occur on both the upper and undersides of the leaves. In addition, bacterial pustules will not contain spores.

Time of occurrence: In Kentucky, this disease has only been observed after flowering has occurred, and generally too late in the season to cause yield losses.

Conditions favoring disease: Extended periods of cool (59°F to 85°F) and wet weather, high humidity (75 to 80%).

Management: The only available method of management is the application of foliar fungicides. Although this disease has been found almost annually in Kentucky since the mid-2000s, its appearance has generally been too late in the season to cause yield losses.

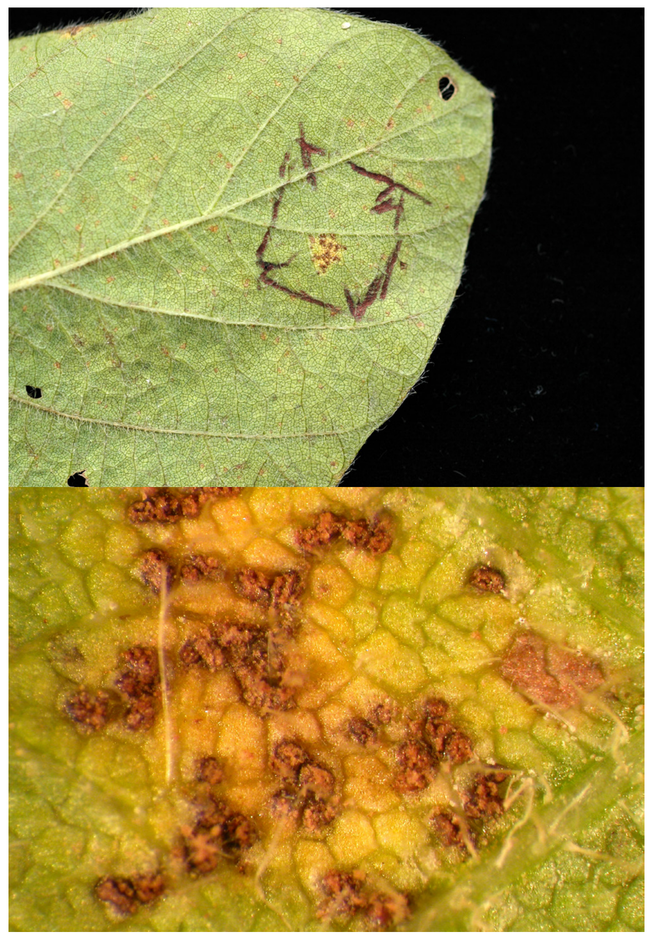


Figure 7-13. Underside of a soybean leaflet affected by soybean rust (top; inside of square box drawn on the leaf); close-up image of raised pustules on a leaflet caused by soybean rust (bottom).

Figure 7-14. Target spot lesions on a soybean leaflet.

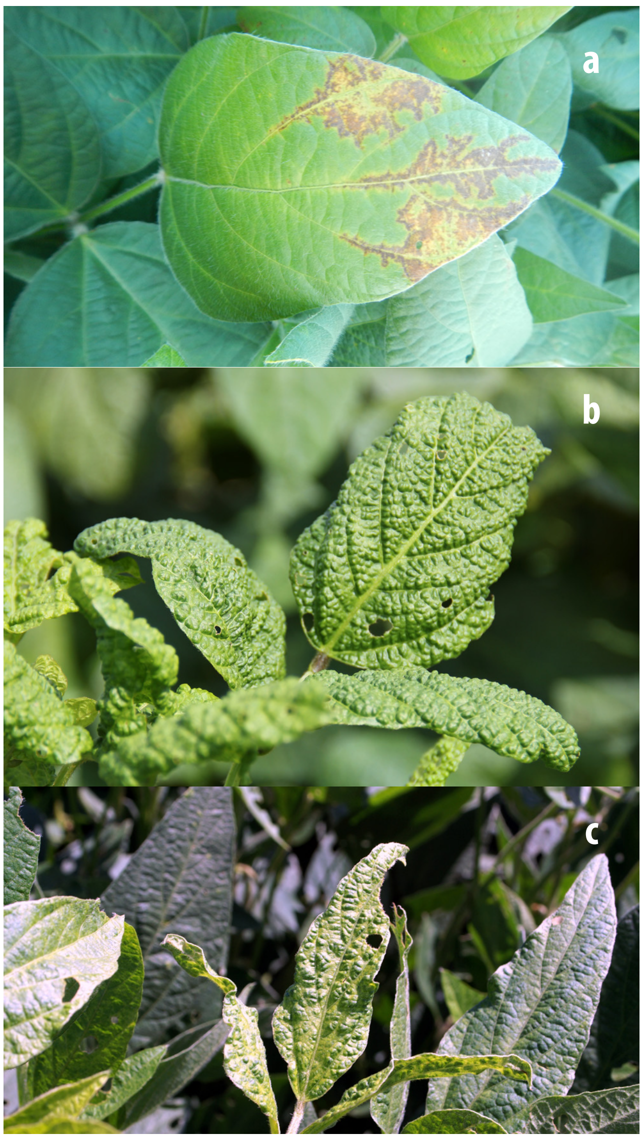


Figure 7-15. (a) Leaflet infected with *Soybean vein necrosis virus.* (b) Leaves infected with *Soybean mosaic virus.* (c) Leaves infected with *Bean pod mottle virus.*

Target Spot

Causal agent: *Corynespora cassiicola* (fungus)

Symptoms: Round to irregular-shaped spots with a zonate pattern that resembles a target. Spots are reddish-brown in color and may occur on leaves, stems, and pods, with leaf spots being the most prominent (Figure 7-14).

Time of occurrence: Usually after flowering.

Conditions favoring disease: Warm, wet, and humid weather.

Management: Although target spot is not an uncommon disease in Kentucky, finding it at damaging levels is rare. Some foliar fungicides may help protect leaves against infection.

Soybean Viruses

Causal agent: Many different viruses can affect soybean plants. Some of the more commonly observed viruses that affect soybean in Kentucky include *Bean pod mottle virus, Soybean mosaic virus*, and *Soybean vein necrosis virus*. Viruses typically are transmitted through a vector, which is usually an insect (i.e. aphid, bean leaf beetle, thrips), or in some cases, through infected seed.

Time of occurrence: Planting to maturity.

Symptoms: Symptoms caused by viruses will vary, depending on the virus (Figure 7-15). Diseased plants may be stunted with crinkled, puckered, or mottled leaves. Necrotic areas associated with the leaf veins is typical of plants infected with *Soybean vein necrosis virus*. Seeds infected with *Bean pod mottle virus* or *Soybean mosaic virus* may have black to brown mottling.

Management: The first step in managing diseases caused by viruses is getting an accurate diagnosis. Because symptoms caused by viruses can look very similar to those caused by abiotic problems (i.e. herbicide damage, etc.), diagnosing a virus disease in the field from symptoms alone is unreliable. It is important to submit a sample to a laboratory that can use immunoassays and/or molecular techniques to identify soybean viruses. The main line of defense against virus diseases is planting soybean varieties with a high level of resistance. In some cases, managing insect vectors with seed-applied and foliar-applied insecticides, may help reduce transmission of viruses.

Stem Diseases

Anthracnose

Causal agent: *Colletotrichum truncatum* (fungus)

Time of occurrence: Planting time to maturity (May to September).

Conditions favoring disease: Warm and moist.

Symptoms: Infected seeds either do not germinate or produce weak seedlings. Seedlings may have numerous, small, red-brown lesions on the cotyledons. Stems, pods, and leaves may be infected without showing external

Figure 7-17. Soybean stem split open to show pith affected by brown stem rot.

Figure 7-16. Dark lesions on soybean stems caused by anthracnose.

Figure 7-18. Epidermis of lower soybean stem scraped away to show dark-gray microsclerotia embedded in soybean tissue produced by the charcoal rot fungus.

symptoms until the weather is warm and moist. On older plants, affected tissue is covered with small scattered raised black structures called acervuli, which resemble tiny pincushions covered with black spines (observe with a hand lens) (Figure 7-16).

Management: Although the signs and symptoms of this disease are observed frequently on mature soybean plants, it is unlikely that this disease causes economic losses in Kentucky.

Brown Stem Rot (BSR)

Causal agent: *Cadophora gregata* (fungus)

Time of occurrence: The fungus infects through the roots and stem early in the growing season, but symptoms do not appear until August or September.

Conditions favoring disease: Cool, wet weather during pod-fill followed by hot, dry weather.

Symptoms: Brown stem rot can cause either foliar and internal stem symptoms or internal stem symptoms only. Yellow and brown discoloration may develop between veins on leaves, and these symptoms are similar to sudden death syndrome. Before harvest, the leaves may (not always) turn dull brown and dry, and may drop prematurely. Lodging may occur. Under some conditions only internal stem symptoms develop. To diagnose brown stem rot, split the stems late in the season. Healthy stems have white centers; infected tissue is dark reddish brown (Figure 7-17). There may be browning only at the nodes or lower stem.

Management: This disease typically does not occur in Kentucky. In states where this disease occurs regularly, resistant varieties are grown.

Charcoal Rot

Causal agent: *Macrophomina phaseolina* (fungus)

Time of occurrence: The symptoms occur after mid-season but may affect seedlings in hot, dry soils.

Conditions favoring disease: Hot, dry weather. Disease is most severe where plants have been growing under conditions of stress or injury. This fungus also attacks corn.

Symptoms/signs: Leaves of affected plants will turn yellow prematurely, resembling early senescence. Symptoms often are confused with drought stress or soybean cyst nematode damage. Small black dots (microsclerotia) and gray discoloration are found beneath the epidermis of the stems and in the woody part of the roots and lower stem (Figure 7-18) giving the stems and roots a charcoal-sprinkled appearance.

Management: In fields where charcoal rot is a recurring problem, plant varieties with the highest resistance rating available. Irrigating fields and lowering seeding rates to reduce inter-plant competition may also reduce stress and reduce the risk of charcoal rot.

Pod and Stem Blight

Causal agent: *Diaporthe/Phomopsis spp. complex* (fungi)

Time of occurrence: After mid-season. Soybeans are infected early in the growing season, but symptoms appear on pods and stems of plants nearing maturity.

Conditions favoring disease: Wet humid conditions and continuous soybeans.

Symptoms/signs: Numerous, small, black, raised dots (pycnidia) are arranged in rows on the mature stem (Figure 7-19) but scattered on the pods. They also occur on fallen petioles. Infected seed are cracked, shriveled, and dull, and may have a white mold on them. Seed infections usually take place after the pods have turned yellow. Infected seed may have reduced germination rates, which can have an economic impact in seed production fields.

Management: Although symptoms and signs of this disease are observed frequently when plants are mature, it is unlikely that this disease causes economic losses in Kentucky. Application of a foliar fungicide and harvesting as soon as possible may limit seed infection, which would be important for seed production fields.

Figure 7-19. Dark-colored structures in rows on a soybean stem caused by the pod and stem blight fungus.

Sclerotinia Stem Rot (a.k.a. White Mold)

Causal agent: *Sclerotinia sclerotiorum* (fungus)

Time of occurrence: After flowering.

Conditions favoring disease: Cool moist weather, dense soybean canopies, lack of air circulation.

Symptoms/signs: Upper leaves wilt and die from a white cottony mold on the stems. Large, irregular black bodies (sclerotia) form in the cottony growth and inside infected stems (Figure 7-20).

Management: This disease occurs very rarely in Kentucky. Due to the reduced risk of this disease occurring in Kentucky, no management is needed.

Sclerotium Blight (also known as southern blight and white mold)

Causal agent: *Sclerotium rolfsii* (fungus)

Conditions favoring disease: Hot and wet weather.

Time of occurrence: Mid-July to maturity.

Figure 7-20. Soybean stem affected by Sclerotinia stem rot (white mold). Note the white mycelia growth on the stem and small dark circular structures forming (sclerotia).

Symptoms/signs: Wilted plants with white mats of fungal mycelia wrapped around the stem. Small, spherical, tan to brown structures (known as sclerotia) will be present on infected plant tissue (Figure 7-21).

Figure 7-21. Soybean stems affected by Sclerotium blight (southern blight). Note the white mycelia growth on the stems and the small, spherical, tan-colored structures forming (sclerotia).

Management: This disease is not commonly observed in Kentucky, and when observed, incidence generally is low.

Stem Canker

Causal agent: *Diaporthe phaseolorum* var. *caulivora* (northern type) and *D. p. var. meridionalis* (southern type) (fungi)

Conditions favoring disease: Moderately warm, wet weather.

Time of occurrence: Mid-July to maturity.

Symptoms/signs: Reddish brown, slightly sunken lesions appear at the base of branches or leaf petioles. Eventually, parts above the lesions die. The leaves remain attached after death. Lesions may also be found at the soil line, making it easy to confuse this disease with Phytophthora stem rot. After plant death, tiny black dots (perithecia) may appear on the stem (Figure 7-22).

Management: Rotating to a non-host crop, such as corn, will help reduce inoculum and risk of stem canker. In fields where stem canker is a recurring problem, plant the most resistant varieties available.

Figure 7-22. (a) Interveinal chlorosis and necrosis of a soybean leaflet caused by the southern stem canker fungus. (b) Dark lesion on a soybean stem caused by the southern stem canker fungus.

Chapter 8

Insect Pests

Raul T. Villanueva, Ric Bessin, and Doug Johnson

There are a great number of insect species that occur in soybean fields; most are innocuous, or beneficial, however, a small proportion of them are pests, and on occasion can cause yield losses or reduce farmers' profits. This chapter was prepared as a reference guide for soybean farmers to recognize soybean pests and to manage these insect populations with the best available methods.

Insect Control

High populations of insect pests can reduce yields and the income of farmers. Nowadays the effective control of insect pests should rely on the combination of several tactics rather than the indiscriminate use of insecticides. These tactics include preventive cultural methods, timely scouting or monitoring, proper pest identification, and as a last resource the selective use of proven insecticides. All these tactics are known as integrated pest management (IPM). IPM should be an essential part of the grower's decisions to manage pests for sustainable agriculture. Before any use of insecticides growers should consider use of preventive tactics that are part of IPM. The use of IPM can reduce the cost of managing pests as well as the potential for pests developing resistance to pesticides.

Prevention Tactics

Cultural practices such as the use of resistant varieties for specific pests, planting short season varieties that can allow soybeans to escape high populations of pests, adequate use of fertilizers to avoid excessive vegetative growth, and destruction of weeds that may be reservoirs of insect vectors of pathogens should be the first line of defense against recurring insect pests.

Scouting for Insects

Early detection and the correct identification of a pest is probably one the most important steps for insect control. Commercial consultants and growers should check their soybean fields at least once each week from planting until maturity. To avoid biased results during sampling, samples should be spread across the field such that they represent the entire field, including areas distant from the edges. Many insect pests have high populations near the borders or edges of fields, so sampling only the edges often over estimates pest densities. Sampling in the middle of the field requires more effort but insect estimates are more representative. Scouting for insects should be done frequently from planting to near maturity of the plants. Scouting methods that can be used for this purpose include the following:

- **Visual inspection**. This method is used for small plants from emergence (VE) to V8 (eighth fully developed trifoliolate leaves). As plants become taller, this method becomes inaccurate because it is difficult to observe insects in a full canopy. A visual survey includes walking a length of row and counting and/or collecting the insects observed.
- **Sweep net**. This method is used with solid-seeded soybeans. It consists of collecting insects by swinging an open net (15-inch diameter) through the foliage on a 180-degree sweep and again in the reverse direction while walking through the field slowly. A sample consists of 25 sweeps with multiple samples taken per field. We recommend four samples in a 15-acre field and one additional sample for each additional 10 acres. The insects collected can then be counted and recorded immediately; however, it is recommended to transfer

the insect collected into a plastic zip bag for a more accurate insect identification and estimate. This method is the most convenient and fastest procedure but may not always be an accurate assessment of insect populations. Disadvantages of this sampling method includes the exclusion of sampling insects living on the bottom parts of the plant and difficulties when plants are wet or the canopies very dense.

- **Shake cloth**. This is a common method used with wide-row planted beans to sample for insects large enough to see with the naked eye. A white fabric cloth (42" x 24") with a rod at two opposite sides is placed in the row middle between two rows. An approximately two row feet of plants from each row are shaken onto the cloth. This gives an estimate from four row feet of the field. Plants should be shaken vigorously to dislodge insects from the foliage over the cloth. Then, insects are identified and counted and this process is repeated at 10 different locations in the field. The disadvantages of this method are that the shake cloth cannot be used in wet or solid-seeded fields, it is difficult to use when the foliage is dense, and insects need to be counted rapidly before they move or fly away.

Scouting is done weekly and written records maintained such that growers can compare pest levels over the season, among fields, and between years. To do this growers need to stick to standardized sampling methods so the estimates can be compared and evaluated against thresholds.

Types of Insect Damage

Insects can cause indirect or direct damage. **Indirect damage** may affect roots, stems, or leaves, parts of the plants we don't use. **Direct damage** affects the pods during formation and maturity. Several insects and arthropods can affect soybeans. However, soybean is a resilient plant, and its vegetative growth can tolerate significant insect damage without reduction in yields. In fact, low levels of defoliation can even cause a slight yield increase. Both types of damage can reduce yields. Growers are most concerned about how much yield or seed quality loss will result from insect damage. Loss of yield will result when the amount of injury exceeds the plant's tolerance. Economic loss occurs when the value of the loss exceeds the cost of control. Soybean insects are placed in one of the following categories: seedling pests, foliage feeders, and pod feeders. A brief discussion of each category is found below as well as the insect pests that may be encountered in Kentucky in each category.

- **Seedling pests**. These insects attack soybean plants above- or belowground early in the growing season. Insects in this group include the three-cornered alfalfa hopper, bean leaf beetle, wireworms, seedcorn maggot, and cutworms. Losses by these insects have been minor to date and generally non-economic. Soil insecticides may be used; however, since soil insects or seedling insects are rarely a problem, they are not recommended as a regular practice unless a history of the problem develops. The most significant pests for soybean seedlings are the seedcorn maggot, bean leaf beetle, and cutworms.
- **Foliage feeders**. This large group of insects receives the most attention and concern. Most insecticide foliar applications are used to control this group of insects. Since soybeans can withstand a small amount of leaf damage before yield losses occur, the degree of damage can often be misleading in terms of justifying control. Foliage feeders remove plant tissue and reduce yield through loss of photosynthetic surface and increased water loss in the plant. Soybeans in the vegetative growth stages can tolerate more leaf area loss without a serious reduction of yield potential than can soybeans in the reproductive stages where leaf area loss is more critical.

Evaluation of defoliation levels. Defoliation is the most common and visible form of insect damage to soybeans. When the amount of defoliation reaches a certain level, yield loss will result. Treatment recommendations are based on the percent defoliation and presence of an insect population. However, determining the percent defoliation can become difficult because the dense foliage can hide damaged leaves. Most growers tend to overestimate defoliation. A good method is to pull up plants from several locations in the field, place the leaves against a light background, and then estimate the percent defoliation.

The defoliation level needed before a control measure is applied will vary depending on insect numbers, stage of plant development, cost of treatment, market price of soybeans and anticipated yield. These factors should all be taken into account to determine defoliation required for control measures to be economically justified. Refer to *Insecticide Recommendations for Soybeans* (ENT-13) (http://pest.ca.uky.edu/EXT/Recs/ENT13-Soybeans.pdf), for tables which show the amount of defoliation required for economic injury to soybeans (damage level needed to justify treatment). These tables are based on stage of plant development, anticipated yield, soybean market price, and cost of treatment.

If you discover the following percentages of defoliation at the various soybean growth stages in your fields, then controls may be justified:

- 40 percent defoliation from planting to prebloom
- 20 percent defoliation from blooming to podfill
- 30 percent defoliation from podfill to maturity

The percentages presented above are general guidelines; however, to justify control, the economic factors (treatment cost, soybean price, and anticipated yield), pest species, and the developmental stage of the plant need to be considered.

The most common pests in this group are the green cloverworm, loopers, Mexican bean beetle, bean leaf beetles, velvet bean caterpillar, blister beetles, and grasshoppers.

Other foliar arthropod pests encountered occasionally in Kentucky are spider mites and thrips. Thrips damage plants with piercing-sucking mouthparts rather than by chewing, however their damage is not as serious as that caused in southern states.

- **Pod feeders**. Pod feeders directly affect the beans, and have the greatest potential for decreasing soybean yield and quality. They can cause serious damage both by direct seed feeding and damage to pods. Pod damage can lead to pod abortion or allow entrance of seed pathogens. Insects in this group include corn earworm, fall armyworm, stink bugs, and bean leaf beetle. Estimating the amount of **injury to pods and seeds** is more difficult. The estimate should be based on both the number of pods and/or seeds damaged as well as the loss of quality. Treatment decisions for the control of pod and seed feeders are normally based on the number of insect pests that need to be present for control measures to be justified. These estimates are compared to threshold levels (number needed to justify control) for each soybean pest and are listed in *Insecticide Recommendations for Soybeans* (ENT-13).
- **Other pests (insects and mollusks)**. Other groups of insects that may be of concern include soil insects (wireworms, grubs, seedcorn maggot, grape colaspis, and bean leaf beetle larvae) and storage insects (Indian meal moth). Seed treatments can be used to reduce stand loss where there is a risk of seedcorn maggot, wireworms, or white grubs. In addition, slugs can cause some damage when soils are cool and moist during the seedling stage.

For further information on soybean insects, go to the soybean diseases and soybean insects web page (https://ipm.ca.uky.edu/soybnlist) of the University of Kentucky's Integrated Pest Management Programs.

Seasonal Activity of Most Common Insect Pests

Two calendars are presented below on the presence of the key soybean pests in Kentucky. Table 8-1 is a general calendar for common soybean pests found in Kentucky based on the plant stage; Table 8-2 shows the abundance of insects based on the months of the Julian calendar. In both cases, the dates of most probable occurrences of insect pests listed in the tables can occur earlier or later than indicated because environmental factors can influence insect development. However, these calendars will provide a good estimate of when major insect problems might occur. The tables were developed for Kentucky IPM scouting records collected over many years.

Methods of Control

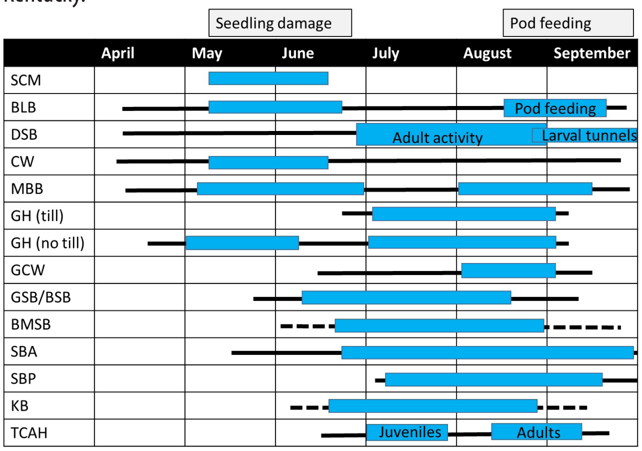
Soybean growers should rely on several methods to manage soybean pests whenever possible. Methods include cultural practices, biological control, and insecticide applications. All these methods should be considered to maintain insect pest levels below the economic threshold (that number of insect pests or level of damage capable of reducing yields and/or quality exceeding the cost of control measures). The most important component of a soybean insect management program is scouting and monitoring fields for pests and their damage on a regular basis.

Table 8-1. Soybean insect calendar based on the plant developmental stage.

PLANT STAGE*		SCM *Delia platura*	BLB *Cerotoma Trifurcata*	DSB *Dectes texamus*	CW *Agrotis spp.*	MBB *Plathypena scabra*	GH *Melanoplus spp.*	GCW *Hypena scabra*	GSB *Acrosternum hilare*	BMSB *Halyomorpha halys*	KB *Megacopta cribraria.*
Planting	-	■									
Emergence	VE	■	■		■						
Cotyledon	VC		■		■		■				
True Leaf	VC		■		■		■				
Trifoliolate	V1		■		■	■	■				
Vegatable Stages	V2-V4		▒	▒		■	▒				
Early Bloom	R1			▒		▒	▒	▒	▒		
Full Bloom	R2			▒		▒	▒	■	■	░	
Pod Set	R3-R4			▒		■	▒	■	■	░	░
Pod Fill	R5-R6			▒		■		■	■	░	░
Maturity	R7-R8							▒	■	░	░

SCM = *seedcorn maggot*, BLB = *bean leaf beetle*, DSB = *Dectes stem borer*, CW = *cutworm*, MBB = *Mexican bean beetle*, GH = *grasshopper*, GCW = *green cloverworms*, GSB = *green stinkbug*. ■= *Period when insect populations are likely to cause economic damage*, ▒=*Invasive insects partially present in some part of the state and may cause damage*, ░= *Insects present and should be watched.*

Table 8-2. Soybean insect calendar based on the Julian calendar for Kentucky.



SCM = *seedcorn maggot*, BLB = *bean leaf beetle*, DSB = *dectes stem borer*, CW = *cutworm*, MBB = *Mexican bean beetle*, GH = *grasshopper*, GCW = *green cloverworms*, GSB = *green stinkbug*, BSB = *brown stink bug*, BMSB = *brown marmorated stink bug*, SBA = *soybean aphid*, SBP = *soybean podworm*, TCAH = three cornered alfalfa hopper. ■ = *Period when insect populations are likely to cause economic damage*, (——) =*Insects present in fields and may cause damage*, (– –) = *Insects present in some parts of the state.*

- **Cultural practices**. These are preventive methods of control that are dependable and cheap; and they require some small modifications to the normal production practices. They include seed quality, optimum planting dates, resistant or tolerant varieties, destruction of crop residues, sanitation practices, trap crops, weed control, and crop rotations. Using a combination of these practices can reduce insect pest problems.
- **Biological control**. This is a method of managing several pests (insects, mites, weeds, and plant diseases) using other living organisms. These living organisms collectively are called "natural enemies." It relies on predation, parasitism, herbivory, or other natural mechanisms, but typically involves an active human management role. Typically soybeans have relatively high levels of natural enemies of pests when compared to other crops. These naturally occurring insect predators and parasites and disease pathogens aid in keeping insect pests below economic levels. Application of broad-spectrum insecticides should be done only when needed so that beneficial insects (those that feed on insect pests) are not severely affected. Broad-spectrum insecticides act indiscriminately, killing many different groups of insects. Untimely insecticide applications may reduce the beneficial insects and allow insect pest populations to increase again in their absence. Certain insect pests may also be controlled by natural diseases. Several "biological insecticides" are now labeled for use on soybean insect pests. Their action differs from traditional insecticides by causing a disease or a physiological dysfunction instead of poisoning the insect pest.
- **Chemical control**. This method of control should be used only when necessary. If economic threshold levels have been reached, insecticides are needed to stop insects from doing any further damage. On the other hand, indiscriminate use of insecticides is expensive, may result in poor pest control, and increases the potential need for additional applications. The rotation of insecticides with different modes of action should be used to reduce resistance in pests. When you select insecticides, make sure they are appropriate for the particular insect pest. Some insecticides are more effective in controlling certain insects than others. Because insecticides vary in their labeled crop uses, rates, application methods, selectivity, and toxicity, read the insecticide label and follow the directions. Care to protect pollinators is required when soybeans are in bloom as insecticides used at this time may severely impact both native and managed pollinators. Using insecticides with lower toxicity to pollinators or spraying late in the afternoon can mitigate harm to pollinators.

For current insecticide recommendations, threshold levels, and economic injury defoliation tables, consult University of Kentucky Cooperative Extension publication, *Insecticide Recommendations for Soybeans* (ENT-13).

Major Insect Pests of Soybeans

Seedcorn maggot

Delia platura (Diptera: Anthomyiidae)

Description: The immature larva of this insect has a whitish coloration and it is found feeding on developing soybean seeds. Full-grown maggots are legless, about ¼ inch (6 mm) long, cylindrical, narrow, and tapered. The maggot has a pointed head and blunt tail. The adult stage of the seedcorn maggot looks very much like a small house fly.

Occurrence: This pest is most often feeding on seeds planted early into cool, wet soil with a lot of surface residue.

Damage: Not usually noticed until "skips" appear in the newly emerging stand. To find this maggot look for ungerminated seeds; these seeds will be riddled with small holes or have the inside eaten leaving only the outer shell. If detected early, the maggots should be present.

Scouting: Look for areas of poor stand. Carefully dig up some seeds and examine for the presence of insects and/or damage.

Control: The best method of control is to delay planting soybeans until soil conditions favor a rapid seed germination. It is recommended to use an insecticide seed treatment when planting into cool wet soil. When serious damage has occurred, there are no rescue treatments and a decision to replant needs to be made.

Additional Information: Entfact-133, *Seedcorn Maggot in Kentucky Grown Soybean*. https://entomology.ca.uky.edu/ef133.

Bean leaf beetle

Cerotoma trifurcata (Coleoptera: Chrysomelidae)

Description: This is a native beetle of the U.S. This pest was reported affecting peas; however, as soybean fields have expanded the beetle has adapted to feed on seedling soybeans and on pods. Adults are about ⅛ to ¼ inch long. The body is slightly convex and the beetle is longer than wide. Color is variable, ranging from light brown to dark red; spots and/or stripes may be present or absent (Figure 8-1). All bean leaf beetle adults have a backwards-pointing black triangle behind the head. Bean leaf beetle larvae are white and segmented small worms living belowground, with a brown head and a brown hardened area at the posterior end of the body. They can be confused with the seedcorn maggot.

Occurrence: From plant emergence throughout the season. (See soybean insect calendar for probable damage dates.) Bean leaf beetle is present in most soybean fields every year but economic levels are uncommon. In some years, seedlings may be damaged heavily. Significant damage to larger plants is relatively rare.

Damage: Bean leaf beetle feeds on cotyledons, leaves, and pods. Leaf feeding consists of very distinctive almost circular holes. Feeding on cotyledons and pods usually appears as scooped-out holes in the surface.

Scouting: From plant emergence to V1 (1st completely unrolled trifoliolate leaf); then, from pod set (R3) through pod fill (R6). Look for stand reduction (cotyledon stage) and heavy leaf feeding while crossing the field. If damage is noticed, try to establish that bean leaf beetle is the problem by looking for them on the plant. In the cotyledon stage, defoliation will be an obvious characteristic. If soybeans are in the seedling stage, a control should be considered if 30 percent stand loss due to cotyledon feeding or 30 percent defoliation has occurred.

Mid-season plants may be scouted using the shake cloth procedure or the sweep net procedure. Using a 15-inch sweep net, 20 sweep samples should be taken at each location. For the ground cloth procedure, place a two-foot-wide strip of cloth on the ground between rows and bend the plants over the cloth and shake them vigorously. This provides a four-foot sample. Sampling for pod damage is done by checking five plants at each sample site for damaged pods. The number of sites you need to examine in a field is based on the size of the field.

The economic thresholds for bean leaf beetle in soybeans based on the numbers of pods injured, numbers of beetles captured with net sweep, and the numbers of beetles per foot of row are shown on the Table 8-3.

Table 8-3. Economic thresholds for bean leaf beetles in soybeans based on (a) the numbers of pods injured, (b) the numbers of beetles captured on per net sweeps, and (c) the numbers of beetles tallied per foot of row.

(a) Number of Pods Injured by Bean Leaf Beetles per 5-Plant Sample[a,b]				
Market Value/ Bushel	Management Costs/Acre			
	$7.00	$8.00	$9.00	$10.00
$5.00	30.8-36.7	35.2-42.0	39.5-47.1	43.9-52.4
$6.00	25.4-30.3	29.1-34.7	32.6-38.9	36.2-43.3
$7.00	21.6-25.8	24.8-29.6	27.7-33.1	30.9-36.9
$8.00	19.-23.3	22.3-26.6	25.0-29.8	27.8-33.2
$9.00	17.2-20.5	19.7-23.5	22.0-26.3	24.5-29.3
$10.00	15.0-17.9	17.6-21.0	19.7-23.5	22.0-26.2
(b) Number of Bean Leaf Beetles per Net Sweep[a]				
	Management Costs/Acre			
$5.00	30.8-36.7	35.2-42.0	39.5-47.1	43.9-52.4
$6.00	25.4-30.3	29.1-34.7	32.6-38.9	36.2-43.3
$7.00	21.6-25.8	24.8-29.6	27.7-33.1	30.9-36.9
$8.00	19.-23.3	22.3-26.6	25.0-29.8	27.8-33.2
$9.00	17.2-20.5	19.7-23.5	22.0-26.3	24.5-29.3
$10.00	15.0-17.9	17.6-21.0	19.7-23.5	22.0-26.2
(c) Number of Bean Leaf Beetles per Foot of Row[a,b]				
	Management Costs/Acre			
$5.00	4.6-5.5	5.3-6.3	6.0-7.1	6.6-7.9
$6.00	3.8-4.6	4.4-5.2	4.9-5.9	5.5-6.5
$7.00	3.3-3.9	3.7-4.4	3.8-4.5	4.1-5.0
$8.00	2.9-3.5	3.4-4.0	3.8-4.5	4.1-5.0
$9.00	2.6-3.1	3.0-3.5	3.3-4.0	3.7-4.4
$10.00	2.2-2.8	2.6-3.2	3.0-3.6	3.3-4.0

[a] ET range is set at 67 and 80 percent of the economic-injury level
[b] Based on a row spacing of 30 inches

Figure 8-1. There is significant color and marking variation among bean leaf beetles, but the black triangle behind the head is characteristic.

Cutworms

Agrotis sp. (Lepidoptera: Noctuidae)

Description: Cutworms can occasionally cause considerable stand loss in localized areas of a field. In Kentucky the most common species is the black cutworm. They are more likely to be found in fields with a history of cutworm damage, those planted under reduced or no-tillage practices, fair to poorly drained fields and / or 'overflow' land, or fields covered with winter annual weeds prior to planting. The black cutworm adult is a dark grey to black moth with a dark black dagger shaped mark on the front wing. The back wing is whitish grey. Cutworm moth flight may be monitored using pheromone traps. Once moths have been detected, the appearance of the cutting damage can be predicted using a day degree model (See Entfact-112 and 123 in suggested references list). Larvae are light gray to nearly black with a faint, narrow stripe down the middle of the back. The skin appears "greasy" and seems to contain tiny granules (Figure 8-2). Larvae vary from ¼ inch long just after hatch to 1¼ to 1¾ inches long when full grown. They will be coiled in a compact "C" when uncovered.

Occurrence: Black cutworm may be found from plant emergence until late June. Cutworms are active at night, feeding first on leaves.

Damage: Larger cutworms cut small plants and may pull parts of them into their burrow. Symptoms are cut or wilted, or missing plants.

Scouting: Look for stand reduction or wilted or cut plants when walking through the field. Scouting is done only if plant with these symptoms are noticed. Look for live cutworms around damaged plants. First, check under clods around the plant base. Then, dig up an area three inches in diameter and three inches deep around the plant. Use a knife blade to sift through the soil. If stand loss due to cutworms is found and live cutworms are still present, then estimate the percentage of stand loss in several areas of the field.

Control: Control may be justified if 30 percent or more of the plants are lost or damaged and live cutworms are still present. If controls are warranted, then insecticides used against cutworms can be effective.

Green cloverworm

Hypena scabra (Lepidoptera: Erebidae)

Description: Green cloverworm larva is light green, slender and grows to approximately one inch long. It has two white stripes running the length of the body (Figure 8-3). When disturbed they will wiggle violently. Smaller larval stages may drop from the leaf when disturbed and hang from a silken thread. The green cloverworm is often confused with the looper; however, cloverworm can be easily distinguished by the number of abdominal prolegs near the center of the body. Cloverworm has three pairs. Loopers have one or two pairs of abdominal prolegs and most other soybean-infesting caterpillars have four pairs of abdominal prolegs. All three of these groups of caterpillars also have three pairs of legs near the head and a pair of anal prolegs near the tail end.

Occurrence: Green cloverworm occurs in Kentucky from mid-June through August.

Damage: Green cloverworms feed extensively on soybean leaves. Early larval instars skeletonize the underside of soybean leaves, leaving the upper leaf surfaces intact. Older larval instars consume all leaf tissue, leaving only the main veins and giving the plants a ragged appearance. Normally they do not feed on pods.

Scouting: A shake cloth should be used in sampling for green cloverworm. One four-foot shake cloth sample should be taken at each scouting site. The number of sites you need to examine in a field is based on the size of the field.

Control: Larval populations of green cloverworm may not reach damaging levels because they are very susceptible to attack by parasites and diseases. Larvae that have been parasitized will be mottled brown in color and shrunken. Their bodies may be tapered at one or both ends. Diseased larvae are often found hanging from leaves and are powdery pink or white in color. Treatment decisions should consider the following:

- Number of cloverworm larvae per site
- Number of parasitized or diseased larvae
- Growth stage of the soybean plant
- Percent defoliation
- Anticipated yield
- Cost of the treatment

Mexican bean beetle

Epilachna varivestis (Coleoptera: Coccinellidae)

Description: The adult Mexican bean beetle is rounded in shape, about ⁵⁄₁₆ inch long and ⅕ inch wide. These beetles are orange-brown to copper in color with 16 black spots

Figure 8-2. Cutworm larvae usually hide underground on sunny days.

Figure 8-3. Green cloverworm has three pairs of abdominal prolegs in addition to the true legs and anal prolegs.

on their backs (Figure 8-4). They are a type of ladybug, but one that only feeds on plants. When they emerge from the pupal stage the beetles are pale yellow; later they develop the typical copper color (Figure 8-4). The females deposit their yellow eggs in irregular clusters on the undersides of the leaves. The eggs have an elongated oblong shape. Larvae are oval in shape and yellow with branched spines providing them a fuzzy appearance. The mature larvae attach themselves to the undersides of the bean leaves and transform into the pupal stage. Mexican bean beetle overwinters as adults in sheltered locations. They leave the overwintering sites when the weather warms up in mid- to late spring.

Occurrence: Mexican bean beetle occurs in Kentucky from June through August.

Damage: All stages of the Mexican been beetle feed on beans. Young larvae feed on the underside of the leaves so will only be observed by flipping over damaged leaves. Older larvae and adults eat through the leaf, leaving only the major veins. This type of feeding gives the leaves a lacy appearance. Mexican bean beetles can feed on pods but rarely damage the developing beans. Mexican been beetle feed readily on the foliage of many varieties of beans, including kidney, lima, navy pinto, snap, lima, pinto, etc. preferring these beans to soybean.

Figure 8-4. (a) Mexican bean beetle adult and (b) larva.

Figure 8-5. Soybean podworm is also known as the corn earworm.

Table 8-4. Economic thresholds for Mexican bean beetle at different soybean stages of growth.

Stage of Growth	Date	Number of Insects per 4 Row Feet Required to Justify Using Control
seedling	June	3 or more adults
prebloom	July	20 or more larvae plus adults
bloom	July-August	16 or more larvae or adults

Scouting: When scouting seedlings, look for adults feeding. When plants are taller, use the shake cloth method. Note the number of beetles per 4 feet of row observed at each scouting site. The number of sites you need to examine in a field is based on the size of the field. You will use the average number of beetles per 4 feet of row to determine if a treatment is needed. Table 8-4 presents the economic threshold for the control of Mexican bean beetle at different stages of soybean growth.

Soybean podworm

Helicoverpa zea (Lepidoptera: Noctuidae)

Description: Soybean podworm and corn earworm are two names for the same insect. The adult moth has a wing span of approximately 1½ inches, is buff colored, and has a characteristic dark "comma-shaped" pattern which is visible near the center of each of the forewings. Young larvae are very small and grow to 1½ inches in length when full grown. They are usually tan to pale green in color with several dark stripes down the back. Color may vary greatly with some appearing almost black (Figure 8-5).

Occurrence: Mid-July through August.

Damage: The soybean podworm feeds mainly on pods but may also feed on leaves, stems, and flowers. Larvae will eat the pod wall and consume the seed. Delayed maturity may also increase the risks of late-season damage. More severe damage tends to occur when large larvae are present on plants with fairly mature pods because the larvae will feed on the beans inside the pods rather than foliage.

Scouting: Sampling for the soybean podworm should be made using a shake cloth. At each sample site, using a two foot cloth, bend the plants over the cloth and shake them vigorously. Note the number of larvae in a four-foot sample area at each site. The number of sites you need to examine in a field is based on the size of the field. The economic threshold for soybean podworm is two worms (caterpillars) per row foot.

Stink bugs

Acrosternum hilare, Euschistus servus, Halyomorpha halys (Hemiptera: Pentatomidae)

Description: Adult stink bugs are shaped like a shield and about one-half inch long. The green and brown are identified by their uniform color while the brown marmorated can be identified by the dark body color and a pair of white bands on each antenna (Figure 8-6). Immature stages, or nymphs, look like adults but are smaller and do not have wings (Figure 8-6). Green stink bug nymphs vary in color but have some red markings.

Occurrence: Stink bugs are present in fields from July through August, generally moving into soybeans beginning around the R3 to R4 stage.

Damage: Stink bug nymphs and adults feed on plant sap rather than chewing on vegetation. As pod feeders, stink bugs feed on soybean pods with their piercing, sucking mouthparts. This damage causes discolored, shriveled beans and reduces the yield and quality of the beans.

Scouting: Stink bugs usually appear first in field margins and border rows. When scouting a field for stink bugs, first check the two field borders closest to woody vegetation. Using a sweep net, take 50 sweeps along each border. Note the number of stink bugs collected at each field border. If the samples contain 25 or more stink bugs per 50 sweeps then sample again with a shake cloth.

Control: Chemical treatment may be needed if the shake cloth samples average two stink bugs per four foot of row. Large populations of stink bugs often appear in isolated spots within a field or along field borders. A thorough check of a field is necessary to determine the level of infestation.

Trap-cropping: The technique of trap-cropping can be used to control stink bugs. Stink bugs colonize in soybeans during the plants' reproductive periods of pod set to pod filling; therefore, early-maturing or early-planted beans tend to be more attractive to stink bugs. The population of egg-laying adult females and nymphs would be highest in the early maturing or early planted beans, thus allowing a producer to only treat this area with an insecticide. Timing, however, is critical to the control of the stink bugs. A chemical control must be applied before the nymphs develop wings and leave the area of beans serving as a trap-crop.

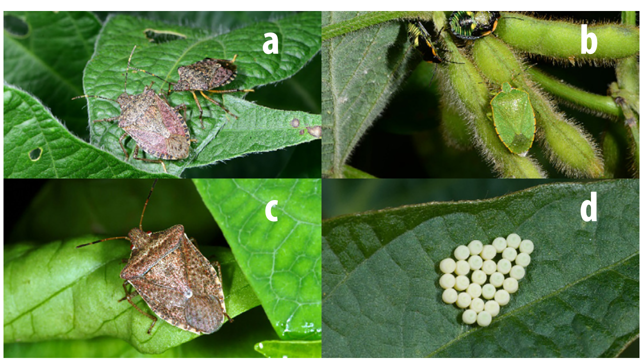


Figure 8-6. (a) Brown marmorated stink bug with white bands on antennae; (b) green stink bug and nymphs; (c) brown stink bug; (d) green stink bug eggs.

Table 8-5. Key descriptive characteristics of three most common grasshoppers affecting soybeans.

Common name	Scientific name	Description	Habitat/Size
Redlegged	*Melanoplus femurrubrum*	hind leg is red with black stripes	humid 0.59-1.38 in long (15 to 35 mm)
Two-striped	*Melanoplus bivittaatus*	a narrow yellow stripe extends from behind each eye to nearly the tip of the wing covers	humid 0.51 to 2.65 in long (55 to 35 mm)
Differential	*Melanoplus differentialis*	chevron-like black stripes on the large portion (femur) of the hind legs	humid, cultivated 1.53-1.75 in long (38.1 to 44.5 mm)

Grasshoppers

Melanoplus spp. (Orthoptera: Acrididae)

Description: There are numerous species of grasshoppers present in soybean fields in Kentucky but the most common species are shown on Table 8.5 and Figure 8-7. All these species overwinter as eggs in the soil near the surface in areas surrounding soybean fields. The nymphs will begin to feed on grasses and weeds in these areas; and when the vegetation is consumed or becomes dry, grasshoppers will move to soybeans. This is the reason why damages are first detected on border rows. Later in the season, grasshoppers can be found feeding over the entire field. Drought conditions that reduce natural vegetation increase the movement of grasshoppers into cultivated crops. The population of grasshoppers fluctuate from year to year. Nymphs hatch from mid-May to June. Nymphs generally resemble adults

Figure 8-7. (a) Red legged grasshopper; (b) differential grasshopper; and (c) grasshopper nymphs.

although their wings are not completely developed (Figure 8-7). In adults the front pair of wings are narrow, and leathery. The hind pair are thin, broadly triangular, transparent, or sometimes brightly colored. Some species never get larger than ½ to ¾ inch. It is the small species that usually cause the most damage.

Occurrence: Grasshoppers are likely to occur in at least two situations depending upon the tillage used. In no-tillage systems, grasshoppers may occur very early in the season, and be evenly distributed across the field. This is true especially if the field was pasture or fallow before planting. With conventional-tillage, grasshoppers usually are not a problem until mid-summer when they move into fields from pastures or grassy areas.

Damage: Grasshoppers are mainly foliage feeders which usually appears as very ragged holes beginning first on leaf margins. Under severe cases, petioles and stems will be eaten.

Scouting: Grasshoppers are active and very difficult to count. Watch for large numbers of grasshoppers as you move through the field. If defoliation is occurring record percentage of defoliation, estimate the number of grasshoppers per square yard and consult Entfact-13 *Insecticide Recommendations for Soybeans* (http://entomology.ca.uky.edu/files/ent13.pdf) for tables which show the amount of defoliation required for economic injury to soybeans (damage level needed to justify treatment).

Additional information. See Entfact-116 *Three Common Kentucky Grasshoppers and Their Natural Enemies*. http://www.uky.edu/Agriculture/Entomology/entfacts/pdfs/entfa116.

Two-spotted spider mite

Tetranychus urticae (Acari: Tetranychidae)

Description: This organism is not an insect nor a spider but a mite. The most common species is the two-spotted spider mite. This is a very occasional pest. Egg are spherical, less than 0.1 mm in diameter, whitish and translucent; the larva (stage after egg hatch) has three pair of legs, and nymphal instars and the adult have four pairs of legs. The adults have two characteristic dark spots on the back (Figure 8-8). The female is 0.5 mm long (0.02 in), and the male is smaller and slender (0.3 mm long). By the end of the summer or fall overwintering females are known by their orange coloration. The two-spotted spider mite is one of the most polyphagous pests feeding on vegetables, ornamentals, trees and field crops. Economic infestations are always associated with extreme heat and drought conditions. In soybeans, the most important time is during the reproductive stages of R1 (beginning bloom) through R5 (beginning seed). Females can lay up to 10 eggs/day; this leads to a rapid population growth with each generation taking about five to seven days to complete. In fields where synthetic pyrethroids are used spider mites are more abundant; hormoligosis (increased egg laying after the use of insecticides) has been detected in the two-spotted spider mite with pyrethroids and neonicotinoid insecticide use.

Figure 8-8. Two-spotted spider mite with characteristic spots on each side.

Occurrence: July through August, during the reproductive stages of soybean R1 (beginning bloom) through R5 (beginning seeding).

Damage: Spider mites feed on leaves penetrating the plant tissue with their stylets and sucking out cell contents. The empty cells turn into a white or yellow spot due to the mites removing the cell's green chlorophyll. The damage first appears as white flecks on the undersides of leaves causing "stippling." Later, leaves will turn bronze, and in some varieties necrotic lesions will occur. If the spider mites are not controlled leaves will change their color from green, yellow and to orange as damage progresses. Eventually, this abundant feeding can cause leaf drop.

Scouting: To sample in soybeans, shake plants over a piece of white paper and look for tiny, black, moving specks. You will need a hand lens to determine if the specks are actually mites. It is recommended to carefully monitor field edges as infestations begin as a patchy distributions around borders.

Additional information: *Spider mites beginning to appear on soybeans, can corn be far behind?* https://graincrops.blogspot.com/2012/07/spider-mites-beginning-to-appear-on.html.

Spider mites may be active in drought-stricken soybean fields. http://news.ca.uky.edu/article/spider-mites-may-be-active-drought-stricken-soybean-fields.

Dectes stem borer

Dectes texanus texanus (Coleoptera: Cerambycidae)

Description: The adult Dectes stem borer, is a long horned beetle approximately ⅜ inch long and gray in color. It has long, slender antennae that can be one and a half times longer than the length of its body. In Kentucky, adults can emerge from June to August. After mating, a female beetle chews a small hole in the leaf petiole or the stem and then typically lays a single egg inside. The oviposition period can be up to 45 days. Both adult and larval stages of Dectes are known to feed on soybean, with the larvae stage being the

Figure 8-9. (a) Dectes stem borer larva in a green stemp; (b) larva in bottom of plant; and (c) stem girdled by Dectes larva.

Figure 8-10. Adult Dectes stem borer is a long horned beetle; its antennae can be 1.5 times longer than the length of its body.

most damaging. Dectes larvae take on the appearance of an accordion, with deep segments, and are creamy white with an orange-red head (Figures 8-9 and 8-10).

Occurrence: July through September

Damage: The larva hatches and makes tunnel in the stem while feeding on it. One stem borer larva is typically found on a single soybean plant due to their cannibalistic behavior towards other larva. Later in the season Dectes larva can move to the lower part of the stem or even near the roots and girdle the plant. Dectes stem borer overwinters as larva and pupates by March to April. Dectes stem borer only has one generation per year.

Scouting: Adults can be scouted in soybean fields with sweep nets in late June or early July. Signs of larvae infestation can often be mistaken as sudden death syndrome caused by the fungus *Fusarium virguliforme*. When scouting for larvae cut open the stems and petiole of the soybean in order to determine if any feeding damage has occurred.

With no currently available resistant varieties of soybean or effective insecticides, the best method to avoid yield losses is cultural control. Early harvesting of soybean once it has matured is recommended in order to avoid girdling and lodging when fields show a high number of larvae infestation. Fall tillage and crop rotation can also limit the occurrences of Dectes since these beetles are not strong fliers.

Additional information. *Dectes Stem Borer (aka Soybean Stem Borer) in Kentucky Grown Soybeans.* https://entomology.ca.uky.edu/ef149.

Soybean Pest Management: Dectes Stem Borer. http://extension.missouri.edu/p/g7152.

Distribution of the long-horned beetle, Dectes texanus, in soybeans of Missouri, Western Tennessee, Mississippi, and Arkansas. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3016958/pdf/031.010.14138.pdf.

Suggested References and Related Publications

AGR-6, Chemical Control of Weeds in Kentucky Farm Crops.

ENT-13, Villenueva, R.T. *Insecticide Recommendations for Soybeans.* http://pest.ca.uky.edu/EXT/Recs/ENT13-Soybeans.pdf.

Scout Info: Soybean Insects. http://www.ukyedu/Ag/IPM/scoutinfo/soybean/insects/inslist.htm.

Kentucky Integrated Crop Management Manual for Field Crops: Soybeans. http://ipm.ca.uky.edu/files/ipm3soy2.pdf.

ENTFACT-112, *Using Pheromone Traps in Field Crops.* http://entomology.ca.uky.edu/ef112.

ENTFACT-113, *Procedure for Selecting Random Sites for Sampling.* http://entomology.ca.uky.edu/ef113.

Chapter 9

Economics of Production

Greg Halich and Jordan Shockley

Introduction

Managing the economics of any commodity, including soybean production, begins with understanding the costs and returns. Given a production plan for the upcoming cropping season, enterprise budgeting is an economic tool that allows a producer to outline projected input costs of production and anticipated returns from soybean sales. Given the project costs and returns for the upcoming year, enterprise budgets estimate the profitability of the existing production plan. In addition to estimating profitability, enterprise budgeting can determine what commodity price or yield is required to cover the costs of production. This technique is referred to as a breakeven analysis. Outlining these costs also allows a producer to determine which inputs are the costliest and manage those accordingly. On rented ground, the biggest cost is typically land rent. Enterprise budgeting allows a producer to determine what one could aff ord to pay for rented ground and still be profitable.

When making a production plan for the upcoming cropping season, a producer has the choice to plant full-season soybean or double-crop soybean. Therefore, it is important to capture the economic differences between each system in two separate enterprise budgets to allow for accurate comparisons. These differences include yield potential and required fertilizer rates. In a typical season, full-season soybean traditionally yield more than double-crop soybean. Therefore, anticipated returns from the sale of soybean should be higher. Also, a double-crop soybean system requires nitrogen (unlike full-season soybean) and higher rates of phosphorous and potassium. This results in great fertilizer costs for double-crop soybean compared to full-season soybean. Understanding these diff erences not only allows for accurate comparison when utilizing enterprise budgets but also when utilizing other economic tools that are available to aid in soybean management and improving profitability.

Soybean Enterprise Budget

Enterprise budgets for both full-season and double-crop soybeans are easily accessible online at the link below. Full-season soybean budgets can be found with the corn enterprise budgets and are available for both central and western Kentucky production areas. Double-crop soybean budgets can be found with the wheat enterprise budgets. Both are Microsoft Excel–based budgets that outline all the costs and revenues on a per acre basis for soybean production and are updated annually. These budgets represent a typical operation in Kentucky and should be adjusted to more accurately represent a particular farm. These adjustments can be made by changing the inputs highlighted in blue to depict the user's soybean operation and production plan accurately. The inputs that can be modified include both costs of production and anticipated revenues. Examples for 2016 full-season and double-crop soybeans can be found in Tables 9-1 and 9-2.

Soybean Enterprise Budgets: http://www.uky.edu/Ag/AgEcon/halich_ greg_rowcropbudgets.php.

Variable Costs of Production

Variable costs of soybean production include operating expenses that typically last one production season. Most enterprise budgets reflect costs on a per acre basis since the size of individual farms will vary by users. An example of a cash operating expense in the soybean production is fertilizer. The enterprise budgets allow the user to customize the spreadsheet to reflect the variable cost of their operation by changing the quantity of the input or the unit price of the input (items are highlighted in blue on the budget). The first variable cost in the soybean enterprise budget is seed. Seed costs are reflected in the number of bags used to plant one acre and the cost for each bag of seed.

Next is the fertilizer cost, specifically phosphorus and potassium required for full-season soybean production. Both fertilizer quantities are actual (100%) fertilizer required (regardless of fertilizer source) and unit price for one pound of fertilizer. To aid in determining the unit price given a particular source, a fertilizer price calculator can be used and is available online at http://www.uky.edu/Ag/AgEcon/pubs/FertPriceCalc.xlsx. If fertilizer is only applied at the beginning of the corn production season and is enough to last through the next soybean production season, then the amount of phosphorous and potassium should be prorated. To reflect the appropriate fertilizer amount in a soybean budget, determine the amount of fertilizer in addition to the corn requirement to be available for the following soybean season and utilize these amounts within the budget. If double-crop soybean are budgeted, nitrogen costs must be reflected in the budget as well for the production of wheat. Similar to phosphorus and potassium, actual nitrogen rates per acre are used in the budget along with the dollar per pound cost of nitrogen. If other fertilizers are applied (e.g. micronutrients), they should be reflected in the budget as well. In addition to fertilizer, lime is also typically applied to fields in Kentucky and is reflected in the enterprise budget as the amount (tons) applied per acre and with a unit cost per ton.

Table 9-1. 2016 enterprise budget for no-till full-season soybeans, per acre costs and returns in western Kentucky

	Quant.	Unit	Price			Total
No-Till Soybeans, Per Acre Costs and Returns						
Gross Returns Per Acre						
Soybeans	47	bu	$9.75			$458.25
Crop Insurance Payment	1	acre	$0.00			$0.00
Gov't Program Payment	1	acre	$15.00			$15.00
Total Revenue						**$473.25**
Variable Costs Per Acre						
Seed	1.00	bags	$70.00			$70.00
Phosphorous (P_2O_5)	30	units	$0.35			$10.50
Potassium (K_2O)	55	units	$0.30			$16.50
Other Fertilizer	0	units	$0.00			$0.00
Lime - Delivered and Spread	0.7	ton	$20.00			$14.00
Herbicides	1	acre	$40.00			$40.00
Insecticides (Planting and Foliar)[1]	1	acre	$0.00			$0.00
Fungicides (Foliar)[1]	1	acre	$0.00			$0.00
Fuel and Lube	1	acre	$0.00	**Calculate**		$9.58
Repairs	1	acre	$0.00	**Machiner**	Y	$23.58
Hired Labor	1	acre	$0.00	**y Related**		$0.00
Operator Labor (Variable Only)	1	acre	$0.00	**Costs?**		$16.22
Machinery Rental	1	acre	$0.00			$0.00
Custom Work	1	acre	$0.00			$0.00
Crop Insurance[2]	1	acre	$20.00			$20.00
Cash Rent[3]	1	acre	$175.00			$175.00
Other Variable Costs	1	acre	$5.00			$5.00
Operating Interest	$379	dollars	5.0%	**# Months**	6	$9.48
Total Variable Costs Per Acre						**$409.87**
Return Above Variable Costs Per Acre						**$63**
Budgeted Fixed Costs Per Acre						
Operator Labor (Fixed Only)			$0.00	**See Question**		$0.00
Machinery Depreciation and Overhead			$0.00	**Above**		$38.50
Taxes and Insurance	1	acre	$5.00			$5.00
Other Fixed Costs	1	acre	$5.00			$5.00
Return Above All Specified Costs						**$15**
Breakeven Yield at $9.75 /bushel	**42**	**bu per acre to cover variable costs**				
Breakeven Cost at 47 bu/acre	**$8.72**	**per bu to cover variable costs**				
Breakeven Cost at 47 bu/acre	**$9.75**	**per bu to cover all specified costs**				

Pest management costs should also be reflected in the budget. Those include any costs for herbicide, insecticide, and fungicides that are applied during the cropping season to control weeds, insects, or any soybean diseases that might occur. The per acre cost of pest management products should be reflected in this portion of the budget. Application cost of either fertilizer or pest control will be reflected on the machinery side of the budget.

Machinery costs include fuel, repairs, and maintenance, and labor required for soybean production. If machinery costs are known by the user, the per acre costs can be entered into the budgets. However, if the user would like the tool to estimate machinery costs for them, they can do this by entering a "Y" in the machinery section. Field operations for which machinery costs will be calculated include the application of fertilizer and lime, a burn-down herbicide application, planting, postemergence herbicide application, and harvesting costs. The user can customize the machinery portion of the budget as well by entering the cost per gallon for diesel fuel, labor cost ($/hour), and trucking distance to the grain elevator or other delivery point. Once the machinery inputs are entered, the calculations are automatically completed in the budget. If the user deems these costs too high or too low, they can be adjusted in the machinery calculations tab on the spreadsheet by increasing or decreasing the costs by a percent. These estimated costs are based on custom machinery costs and it is advisable that most producers increase these costs by 10

Table 9-2. 2016 enterprise budget for no-till wheat and double-crop soybean, per acre costs and returns for western Kentucky

No-Till Wheat \ Double-Crop Soybeans, Per Acre Costs and Returns						
	Quant.	Unit	Price			Total
Gross Returns Per Acre						
Wheat	70	bu	$4.75			$332.50
Soybeans	35	bu	$8.50			$297.50
Direct Gov't Payment	1	acre	$0.00			$0.00
Total Revenue						**$630.00**
Variable Costs Per Acre						
Seed (Wheat)	135	lbs	$0.50			$67.50
Seed (Soybean)	1.00	bags	$65.00			$65.00
Nitrogen[1]	100	units	$0.50			$50.00
Phosphorous (P_2O_5)	75	units	$0.40			$30.00
Potassium (K_2O)	60	units	$0.40			$24.00
Other Fertilizer	0	units	$0.00			$0.00
Lime - Delivered and Spread	0.50	ton	$20.00			$10.00
Herbicides	1	acre	$90.00			$90.00
Insecticides[2]	1	acre	$5.00			$5.00
Fungicides[2]	1	acre	$5.00			$5.00
Fuel and Lube	1	acre	$0.00	Calculate		$21.56
Repairs	1	acre	$0.00	Machiner	Y	$46.71
Hired Labor	1	acre	$0.00	y Related		$0.00
Operator Labor (Variable Only)	1	acre	$0.00	Costs?		$40.20
Machinery Rental	1	acre	$0.00			$0.00
Custom Work	1	acre	$0.00			$0.00
Drying(Wheat): LP, Electric, Maint & Lal	1	gallon LF	$2.00	Pts Remove	1.0	$2.92
Crop Insurance[3]	1	acre	$35.00			$35.00
Cash Rent[4]	1	acre	$200.00			$200.00
Other Variable Costs	1	acre	$5.00			$5.00
Operating Interest	$656	dollars	4.0%	# Months	8	$17.49
Total Variable Costs Per Acre						**$715.38**
Return Above Variable Costs Per Acre						**-$85**
Budgeted Fixed Costs Per Acre						
Operator Labor (Fixed Only)			$0.00	See Question		$0.00
Machinery Depreciation and Overhead			$0.00	Above		$72.33
Taxes and Insurance	1	acre	$5.00			$5.00
Other Fixed Costs	1	acre	$5.00			$5.00
Return Above All Specified Costs						**-$168**

to 25 percent to reflect a higher cost structure. In addition, if any machines are rentals or if an operation was custom hired, there is a section on the budget below the machinery cost for those items.

Other variable costs that should be included in the soybean budget include crop insurance, cash rent, and operating interest. Crop insurance will vary substantially by policy type and contract level and should be reflected appropriately in the budget. Furthermore, cash rent can vary by parcel of land and productivity. Therefore, the averaging of all rented land should be entered into the budget if you are using one budget for all of your combined land, or use specific farm rents if evaluating at the farm level.

Fixed Costs of Production

Fixed costs (ownership cost, overhead, indirect cost, or sunk cost) of soybean production are generally considered non-cash costs and are not immediately seen or paid. An example of fixed costs in soybean production is machinery depreciation where it is slowly losing value over time. Fixed costs do not affect the decision-making in the short-term (within season); however, in the long-term all costs are variable (e.g. machinery can be sold). Fixed costs are sometimes difficult to isolate between various crops since the same tractor will be used in both corn and soybean production for example. Therefore, like the variable cost of machinery, the budget will estimate the fixed cost for the user for both operator labor as well as machinery depreciation and overhead. In addition to fixed machinery costs, taxes, insurance, and other fixed costs are reflected in the budget and can be customized by the user.

Machinery depreciation and overhead is the largest portion of fixed costs in the soybean production. Given recent record profits for grain production, it was easy for a producer to invest in new equipment that was larger than what they needed for their given operation. To determine the appropriate size of machinery, both farm size and the number of days typical for conducting an operation must be considered. Weather risk in the soybean production area for completing an operation should be considered, especially for the major operations like planting. Controlling fixed costs through appropriate machinery sizing is key for long-term profitability.

Sensitivity Analysis Using Enterprise Budgets

Enterprise budgets are not only used for determining the net returns from production, they can be used to determine what yields and prices are required to cover the cost of production. This technique is called breakeven analysis. At the bottom of the enterprise budgets online, the breakeven yield and breakeven price to cover the cost of production are calculated. As seen in Table 9-1, the breakeven soybean yield to cover variable costs is 42 bushels (at a $9.75/bu soybean price). The breakeven soybean price required to cover variable costs is $8.72/bu if 47 bu/ac were produced.

Additional Tools for Soybean Management

In addition to enterprise budgets, there are other economic tools available which aid in cost management. One key element discussed above are machinery costs and elevated depreciation and overhead. For Kentucky soybean producers, there are alternatives to acquiring machinery which could reduce or eliminate the fixed costs incurred from machinery ownership. Kentucky soybean producers can lease or custom hire machinery to complete operations on the farm. Custom hiring activities will avoid the fixed cost of machinery ownership but will increase your variable costs of production. Although the cash cost is typically higher than the cost to complete the task yourself, ownership costs are avoided when custom work is hired. Custom hire rates applicable to Kentucky can be found at the link below. These rates are based on reported surveys from surrounding states and adjusted to account for changes in fuel price, machinery costs, and wages from the time of the surveys. Each grain crop operation, including soybean, is listed along with the three rates. The average final rate, which is highlighted in blue, and then 15 percent below the average and 30 percent above the average are reported. These rates are updated annually and estimate the variable costs for hiring custom work in soybean production.

Custom Hire Rates: http://www.uky.edu/Ag/AgEcon/pubs/CustomRatesKY.pdf.

Land Rental Tools

There are various means to acquire land for soybean production. One way is to own the land, and the other is to lease the land. For Kentucky producers leasing land for soybean production, rental rates could be the largest variable cost of production. Also, the productivity of the land and quality will influence what a producer can afford to pay for the rental arrangement. However, various leasing arrangements can be used. The most common for Kentucky producers is a cash rental arrangement. For a guide, an annual cash rent survey is conducted with Kentucky Agricultural and Natural Resource county agents to estimate the land rents for their area. These results are then summarized by regions, eight in total, and reported based on good or fair cropland. See the link below to access the most recent cash rent survey conducted for Kentucky.

Cash Rent Survey: http://www.uky.edu/Ag/AgEcon/pubs/KYCashRentNew.pdf

In addition to cash rental arrangement, traditional crop share arrangements are utilized by Kentucky soybean producers. However, becoming more used is a hybrid arrangement, or a flexible cash lease (flex lease). Flex leases provide a base rent, or a floor, that is lower than what the equivalent cash rent would be. Also, the landowner receives a bonus or revenue percent based on the production and market prices for that season. There are many variations to a flex lease and it may not work for every landowner and producer. If considering a flex lease, a decision aid is available online that is designed to assist the landowner and producer regarding terms of the rental arrangement.

Flexible Cash Lease Decision-Aid: http://www.uky.edu/Ag/AgEcon/pubs/extflexiblecashaid15.xlsx.

Grain Transportation

Determining the optimal market to deliver a load of soybeans to is a complex decision. Most producers only consider one key factor when choosing a market (e.g. highest price). Other factors such as distance to market, fuel price, wait time, quality discounts, labor, and truck capacity must all be considered to minimize transportation costs and maximize net price per bushel. Most producers, particularly in western Kentucky, have multiple potential markets to sell their soybeans. This decision process begins with identifying all markets in the area. A map of Kentucky grain markets is available online which displays over 80 grain markets across Kentucky and bordering states.

Kentucky Grain Market Map: https://drive.google.com/open?id=1nUoO2dd8NCFtNLAlz4QXZoh_mnQ&usp=sharing.

Once markets are identified, determining the cost to transport a load of soybeans and each market's cash price (with basis) and quality discounts are required. Cash prices and quality discounts are available by contacting each potential market and acquiring the information. Determining the cost of transportation can be more difficult. Two tools are available online that will aid in determining these costs. One is a document that walks through the expenses of transporting grain and how to calculate both operating costs as well as fixed costs. The other is a spreadsheet tool that will determine the most profitable market based on all the key factors outlined above. The spreadsheet tool can compare up to six different markets and estimates both transportation costs and net price received for each market. Also, the discount schedules for each market are calculated based on moisture content and each market's discount schedule. The grain transportation tool can be found online at the link below.

Grain Hauling Decision Guide: http://www.uky.edu/Ag/AgEcon/pubs/extGrainHaul36.xlsx.

Summary and Conclusions

Managing soybean economics begins with understanding the costs and returns to production. Enterprise budgeting is a vital tool to outline the costs and returns for a given production plan. Outlining these costs also allows a producer to determine which inputs are the costliest and manage those accordingly. There are various other decision aids and tools available online to manage soybean production and enhance profitability.

Chapter 10

Harvesting, Drying, and Storage

Sam McNeill

Harvesting, drying, and storing soybean are some of the final steps for soybean producers each year. Often these steps occur within a relatively short period, which can require some very quick decisions should any problems be encountered. To maximize yields and profitability, sound management decisions must occur during this timeframe.

Harvesting

Soybean can be harvested when the moisture content of seed ranges from 9 to 20 percent (wet basis). In general, soybean harvested at or above 15 percent seed moisture have much less seed damage than when harvested at lower moisture levels. Cracked and damaged seed typically increases as seed moisture decreases from about 13.5 to 9 percent. An additional concern is that once seed dry down to harvestable moisture contents and rewetting occurs, the percentage of cracked and damaged seeds increases when harvested. Most producers in Kentucky harvest at between 13.5 and 15 percent seed moisture to capture the greatest amount of undamaged seed, which requires the least drying.

Operating the Combine

When harvesting soybean the most important combine adjustments, in order of importance, are 1) ground speed, 2) cutterbar height, 3) reel position and speed, and 4) cylinder speed. Ground speed should be maintained between 2.5 and 4 mph to reduce losses at the header. The cutterbar should be as low as possible for field conditions to reduce stubble loss. The reel axle should be 6 to 12 inches in front of the cutterbar and run about 1.25 times faster than the ground speed to reduce shattering. Finally, the cylinder speed should be below 500 rpm to reduce cracking and damage to the seed. Initial settings for the cylinder speed and concave/rotor spacing should always follow the operator's manual.

Harvest Losses

An average operator is estimated to leave from 2 to 4.5 bushels of soybeans per acre in the field (5 to 10% loss, assuming yields of 45 bu/A). Considering the price of soybeans (~$10/bu), reducing losses from 10 to 5 percent can result in an additional $22.50 per acre.

Measure harvest losses for each field by counting seed on the ground. Count the number of seeds on the ground in front of the combine to determine pre-harvest losses. Then count the number of seeds behind the combine to measure total loss (pre-harvest and harvest loss). About 4 seeds per square foot represents 1 bu/A loss. A good goal is to limit harvest loss to less than 3 bu/A or about 12 seeds per square foot. Inspect the soybean stubble to ensure that all pods were harvested. To reduce harvest losses, adjust ground speed, cutterbar height (if pods remain on standing stubble), reel speed and position, and cylinder speed. Inspect cutterbars for sharp knives and replace as necessary.

Drying

Soybeans are usually dried in the field or in a bin with either natural air (no heat), or with a small amount of heat (5 to 10°F) when the relative humidity of the air is above 80 percent (see Table 10-1). Generally, a drying temperature below 110°F is recommended. Drying time is dictated by airflow rate, with a minimum of 1 cubic foot per minute per bushel (cfm/bu) recommended for in-bin drying. The University of Minnesota Extension Service website (http://webapps.bbe.umn.edu/fans/) can be used to estimate the airflow rate for a given fan-bin combination.

For example, a 10 horsepower (hp) axial fan can provide 1 cfm/bu in a 30-ft diameter bin of soybeans that is 20 feet deep (11,300 bu), or 3 cfm/bu at 8 feet of depth (4,500 bu).

Refer to the equilibrium chart (Table 10-1) as a guide for the limits of drying at the average temperature (T) and relative humidity (RH) levels shown. For example, during October the average ambient T and RH in Kentucky are 60°F and 65 percent, respectively, so soybeans will dry to about 12 percent moisture. However, if left in the field until November when the average T and RH are 50°F and 75 percent, soybean moisture will be about 16 percent. Adding just 5 degrees of heat in a bin dryer lowers the RH to 65 percent and the corresponding moisture to 12 percent. Be careful not to over-dry soybeans by running fans when the RH is below 60 percent (Table 10-1). With today's price, drying soybeans to 11 percent amounts to 26.5 cents per bushel (Table 10-2). For this reason, consider installing an automated fan control system that can be programed to operate the fans when outside air conditions are favorable.

Table 10-1. Equilibrium moisture content for soybeans at various temperature and relative humidity levels.

Temperature F	Relative Humidity, %						
	40	50	60	65	70	80	85
30	7.9	9.5	11.6	12.9	14.5	19.2	23.1
40	7.7	9.3	11.4	12.7	14.3	18.9	22.7
50	7.6	9.1	11.2	12.4	14.0	18.6	22.4
60	7.5	9.0	11.0	12.2	13.8	18.3	22.0
70	7.3	8.8	10.8	12.0	13.5	18.0	21.7
80	7.2	8.7	10.6	11.8	13.3	17.7	21.3

Table 10-2. Cost of drying soybeans below the market level of 13% moisture content with test weight of 60 lb/bu, soybean price of $10.00/bu and a drying cost of 2.0 cents/bu-point.

Moisture Content	Amount of Water, lb / bu	Cost, cents/bu		
		Value of Water	Energy Cost	Total Cost
9.0	5.16	44.0	8.0	52.0
10.0	5.80	33.3	6.0	39.3
11.0	6.45	22.5	4.0	26.5
12.0	7.12	11.4	2.0	13.4
13.0	7.80	0.0	0.0	0.0

Storage

Moisture Content

Soybeans should be stored at 13 percent moisture content (wet basis) or less, depending on the temperature of the grain during storage and the length of time the crop will be held. If soybeans are to be stored over the summer months, the moisture content should be about 12 percent to eliminate the possibility of spoilage in storage.

Clean Grain

Excessive trash should be removed from soybeans before they are stored. Accumulation of trash in small pockets in a grain bin can cause heating and decay, which may lead to elevator discounts. Cleaning soybeans normally requires removing particles that are larger than the seed. Bins should also be cored after filling to remove fine material from the center and provide more uniform airflow.

Aeration

Soybeans should be cooled after they are placed into a bin. A minimum airflow rate of 1/10 cfm per bushel is recommended and the University of Minnesota WINFANS program can be used to determine fan capacities at different grain depths for each fan-bin combination. Grain should be cooled once a month by 10°F until it has been cooled to 35°F to 40°F. Estimate the time needed for aeration by dividing 15 by the airflow rate in cfm/bu.

For example at 0.1 cfm/bu it will take about 150 hours to move a cooling front through the grain. However, only 15 hours are required at 1 cfm/bu.

Safety

Flowing grain is dangerous and can be fatal. Educate all workers on the farm of the hazards associated with flowing grain and exposure to grain dust. Never enter a grain bin while the unloading auger is operating because the downward flow can pull a person below the grain surface in less than five seconds and result in suffocation. Always lock-out-tag-out the power to electrical motors on unloading augers prior to entry. Work in pairs with a person on the ground who can call for help if needed. Personal protective equipment for bin inspections includes a climbing harness with a tie-off rope and respirator at minimum. See University of Kentucky Cooperative Extension Service publication *Suffocation Hazards in Grain Bins* (AEN-39) (http://www2.ca.uky.edu/agc/pubs/aen/aen39/aen39.pdf) and the *Midwest Plan Service Grain Drying, Handling and Storage Handbook* for more details. Keeping grain in good condition is the best safety measure.

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Chapter 11

Irrigation Basics and Principles of an Approach Involving Soil Moisture Measurements

Ole Wendroth, Xi Zhang, Javier Reyes, and Carrie Knott

Introduction

Since the early times of crop production, it has been recognized that a sufficient water supply is essential to avoid crop failure. Besides weather conditions, two major components affect the decision when and how much water must be applied: the plant water need, and the capacity of soil to store and supply water.

The plant water need varies in the life of a growing soybean plant and depends mainly on the production rates and functions at the particular growing stage. During the early vegetative stages until flowering (R2) and the beginning of pod development (R3), the demand of water for the soybean can increase linearly to a maximum of 0.3 inches per day before it decreases again during seed filling and toward maturation (Kranz and Specht, 2012). Moreover, part of the decision is the production goal. Do we just want to keep the plant alive (i.e., avoid death through permanent wilting) or do we want to maximize production by keeping the "cost" or the metabolic energy for the plant to take up water at a minimum. Remember, the plant can take up water over a wide range of soil moisture conditions, but the drier the soil gets, the more stressful it becomes for the plant to take up water, and the more energy has to be invested to overcome the suction with which the soil pores hold the water. The additional metabolic energy spent for water uptake is not available for other important plant functions. Therefore, we want to keep the investment of energy for the plant to take up water as low as possible to increase the abundance of energy for other important functions.

Why don't we then flood our fields and have water always in place when the plant needs it? Of course, such an approach would not work for topographic conditions in Kentucky's farms, nor for our main crops: corn, soybean and wheat. Their root systems require oxygen, and if soil pores are blocked because they are saturated with water, oxygen cannot get to the plant roots. If that situation lasts for a long time, as in some cases in July 2016 after heavy rainfall in Western Kentucky and many other regions, the plant dies because of wilting.

The soil water holding capacity (WHC) is a complex term, and several questions arise: What is the capacity of the soil to store water and to have it available for the plant even though it may not rain for a certain time period? What is the effect of plant water uptake during one day on the water availability during the next and the following days? Are all soils the same in this regard, or do they exhibit marked differences?

There exists a huge body of literature on irrigation explaining and applying concepts related to the physiology of plant water uptake and soil processes. For irrigation scheduling, we distinguish between water balance or checkbook approaches and soil moisture–based approaches. The water balance approach is based on precise estimates of actual evapotranspiration, which is complex and more difficult than the approach based on soil moisture status measurements.

In this chapter, we focus on the latter approach and refer to the literature and to our future work regarding the water balance approach. The purpose of this contribution to the comprehensive soybean guide is to provide basic insights in fundamentals of the role of soil type on soil water relations, the appropriate timing of irrigation, and the proper amount of water to apply. The objective is to estimate the amount of plant available water in the soil profile and to derive the threshold soil moisture status at which irrigation should be turned on. Application rate considerations are focused on circular pivot irrigation systems.

Soil Water Status and Relationships

Soil moisture status can be expressed in different ways. Two of them are the volumetric soil water content θ and the soil water suction ψ. The volumetric soil water content is given in volume fraction of the total soil volume, i.e., volume per volume or v/v. For most mineral soils, the maximum soil water content filling the entire pore space is between 0.4 and 0.5 v/v. If this volume fraction is multiplied by 100, the soil water content is expressed in Vol.-%. It is rather the exception that a field soil is totally saturated with water. Soils are most of the time unsaturated. This fact implies that only some pores of the total pore space are water-filled. Others are air-filled. If one of both components—water or air—gains volume, the other one loses an equal volume. Total water saturation of the soil's pore space is a condition that is not preferred because the soil is then not sufficiently aerated and the plant roots suffer oxygen deficiency.

The soil water suction ψ reflects the energy that the plant root needs to overcome to extract water from the soil. The suction is expressed in pressure units. Several units are used for quantifying pressure (Table 11-1).

In this presentation, the unit kPa (kilo-Pascal) is used because it is the unit in which many commercial sensors express soil water suction. In many cases, the energy status of soil water is given as a negative magnitude. In that case, the energy status is expressed as soil water pressure head or as soil matric potential. Units of these two are the same as for soil water suction, but the sign is negative. Throughout this chapter, soil water status is expressed as water suction and therefore in positive values.

Table 11-1. Pressure units.

kilo Pascal (kPa)	1 kPa = 0.145 psi (psi: pounds per square inch)
bar	1 bar = 100 kPa
cm of water column head	1 cm = 0.098 kPa 10.19 cm = 1 kPa

The wetter a soil is the less resistance the plant has to overcome to take up water. And the drier a soil is the more energy the plant has to apply in order to extract water from the soil. The soil water content and water suction have typical relationships for different soil types. These relationships are shown for three soil types—silt loam, clay loam and sand—in Figure 11-1. The relationship is called the soil water retention curve, soil water release curve, or simply soil water characteristic.

The soil water suction is plotted along the x-axis, whereas the soil water content along the vertical y-axis. Notice, the scale of the ψ-axis is logarithmic because the relationship between soil water content and suction is non-linear.

In Figure 11-1, we divide the soil water suction range into compartments, depicted by colors. On the left side, the white area is marked "Fast Draining Water." This area denotes the range of water that is usually not available for plant uptake because it is present in large pores that cannot hold the water against gravity for a long time. The range of soil water contents in these fast-draining pores is for the silt loam between 0.45 and 0.33 v/v. Hence, 0.12 v/v or 12 percent of pores are large and cause fast drainage. This is one reason why many of our silt loam soils in Kentucky are classified as well-drained. We consider the lower limit of water suction for these fast draining pores to be at ≈ 10 kPa. This suction value corresponds to a pore diameter of approximately 30 μm. The volume of pores in the fast draining water range differs among soil types.

For the sandy soil, the volume of this fast draining class is much larger than for the silt loam. It is between 0.43 and 0.09 v/v, resulting in a difference of 0.34 v/v or a fast draining pore volume fraction of 34 percent. This is one of the

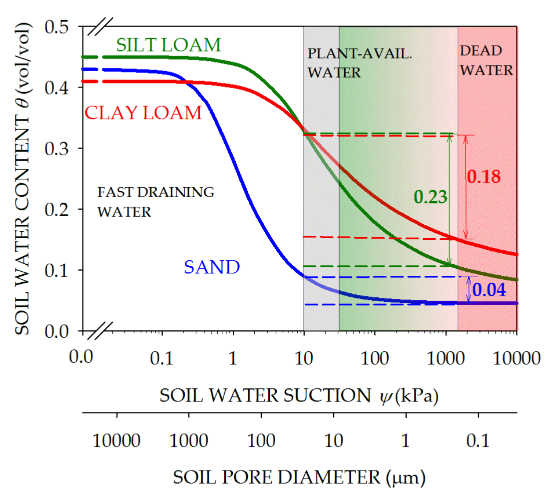

Figure 11-1. Soil water retention characteristic showing the relationship between soil water content and soil water suction for three soil types Note: Since soil water suction is directly related to the equivalent soil pore diameter, the latter is provided along the x-axis corresponding to suction.

reasons why sandy soils drain and dry so quickly and why only a few hours after a rainfall a sandy soil may already be in good moisture condition to be tilled. We do not have such extreme sandy soils in Kentucky, but in coastal and glacial till areas we may find them.

The clay loam soil represents conditions in this fast draining water content range that are different from the other two soils presented here. The pores are fast draining only between water contents of 0.41 and 0.33 v/v. Hence, the fast draining pores make about 8 Vol.-%, because clay soils do not have many large pores.

Plant available water capacity (PAWC) of a soil is the range from field capacity (FC, ψ = 10 kPa) to permanent wilting point (PWP, ψ = 1,500 kPa). In Figure 11-1, the field capacity is shown as a range of suction. This range is marked in gray color. The upper limit is at 10 kPa while the lower end of this gray range denoting field capacity is at a suction of 33 kPa or a third of a bar. There is a reason we consider a range of suction values to represent field capacity, and not a single value. In some regions—the drier regions of the U.S. —field capacity is considered to be at the higher suction value of 33 kPa while here in Kentucky, it is closer to 10 kPa. For two days following a heavy rain period in Kentucky, we observed a rapid change in soil water suction due to fast drainage, but the change of suction was negligible once the soil reached 10 kPa. This occurred two days after a rainfall period; further drying of the soil is then caused by evaporation from the soil surface or by plant water uptake. The lower limit of PAWC is called permanent wilting point (PWP) because when a plant is entirely exposed to this level of soil water suction it irreversibly wilts and dies of water shortage although there is still a measurable amount of water in the soil. At PWP, the water content in the clay loam is highest with approximately 0.15 v/v, followed by the silt loam with 0.1 v/v and the sand with 0.05 v/v. But this water is in pores that are smaller than 0.2 µm and is so tightly bound to the walls of soil pores that the plant roots cannot extract it. Nevertheless, the plant can extract water up to a suction of 1,500 kPa. That is an enormous accomplishment. For comparison, a pressure of 1,500 kPa exists inside a semi-truck tire. However, to extract water when it is so tightly bound to the soil becomes very "expensive" for the plant as it has to invest a lot of metabolic energy that is not available for other important growth processes. Notice that from field capacity to permanent wilting point, it becomes increasingly difficult for the plant to extract water from the soil. That is why the green shade of the area in Figure 11-1 becomes lighter and reddish to its right side limit, the PWP. Of course, the soil water suction range for PAWC is independent of the soil type. But the maximum amount of water that can be stored between the two limits strongly depends on the soil type.

Now we want to learn how the maximum amount of plant available water can be derived from the soil water retention curve: We begin with the clay loam soil. Its water content at FC is θ_{FC} = 0.33 v/v, and the water content at PWP is θ_{PWP} = 0.15 v/v, resulting in a difference of 0.18 v/v. See Figure 11-1 and Table 11-2.

The sand holds the lowest PAWC of only 0.04 v/v while the silt loam retains the largest amount of water with its PAWC being 0.23 v/v. Notice, the PAWC has to be considered as a capacity, not as an actual soil water content. If the soil water content did not reach at least field capacity during a rain period, then the actual soil water content has to be used minus θ_{PWP} to calculate the actual plant-available soil water content.

We also understand from the results in Table 11-2 that PAWC is only a relative measure. If we want to know the actual amount of water that is available in a certain depth increment, horizon, or an entire soil profile, we have to consider the amount of stored water in the profile which is given in length units, e.g., inch or cm. Here we use the length unit "inch" for expressing the soil water storage. In order to calculate the amount of maximum stored water in a soil, we multiply PAWC with the depth increment that we consider. Hence the resulting maximum water storage in a silt loam is 0.92 inch for a 4-inch-soil layer, 2.76 inches for a 1-foot soil horizon, and 8.28 inches for a 3-foot soil profile. Again, why "maximum" water storage? Because this is the water storage after an extended rainfall period has filled the soil to θ_{FC}, and on every day without additional rainfall, this stored water decreases through evaporation from the soil surface and transpiration by the crop, simply called evapotranspiration.

Table 11-2. Typical soil water contents at field capacity (θ_{FC}), at permanent wilting point (θ_{PWP}), plant-available soil water capacity (PAWC), and plant available water storage (PAWS) for soil layers of different thickness in different soil types

	Soil water content			Plant Available Soil Water Storage (PAWS) in a		
	Field capacity (θ_{FC})	Permanent Wilting Point (θ_{PWP})	Plant Available Soil Water Capacity (PAWC)	4 in-layer	1 ft-layer	3 ft-profile
Soil type	(v/v)	(v/v)	(v/v)	(inch)	(inch)	(inch)
Silt Loam	0.33	0.10	0.23	0.92	2.76	8.28
Clay Loam	0.33	0.15	0.18	0.72	2.16	6.48
Sand	0.09	0.05	0.04	0.16	0.48	1.44

If we want to know the amount of plant-available water that is stored in the soil profile on a day during the growing season, we need to measure either soil water content or soil water suction in different depth compartments. In case of soil water suction measurements, we must convert suction to soil water content through the soil water retention curve. We can convert suction readings to water content graphically from the curve or use an equation that describes the soil water retention curve for different soils. Upon obtaining the measured water content, the water content at permanent wilting point θ_{PWP} is subtracted, and the resulting difference multiplied by the specific depth of each vertical soil compartment to arrive at plant available water storage in each compartment. The storage values calculated for the different depth compartments are then summed up to yield the total plant-available water storage at the time of measurement.

For example, we consider soil water suction measurements at three soil depths—8, 16, and 24 inches. We neglect the upper 4 inches of soil and are only interested in the amount of stored water between 4- and 28-inch depth. Hence, each of the measurement depths represent a depth compartment that is 8 inches thick. In Table 11-3, ψ-readings are provided for each measurement depth, and the PAWS for each depth compartment is indicated in the last column as well as the sum of all three, i.e., the Total PAWS, yielding 3.52 inches of water.

Irrigation Management

When do we turn on the irrigation?

This is the question that farmers deal with during almost the entire growing season. Timing is even as important as the decision about the right amount and rate of irrigation because if irrigation is turned on too late, the crop suffers and cannot grow at a rate that would be possible under ideal water conditions. Another strong reason to not turn on the irrigation too late is the fact that once the soil dries out, it becomes increasingly harder to get the water into the soil. The drier the soil surface is, the more it acts as a seal. Similar to the soil water content–suction relationship, soils have a characteristic that describes the behavior of hydraulic conductivity vs. soil water suction (Figure 11-2). Hydraulic conductivity is a measure of permeability and it changes rapidly with soil water content or suction. The drier the soil becomes the lower the conductivity because the resistance to water flow increases.

We notice from Figure 11-2 that the conductivity curve for silt loam begins for saturated conditions at approximately 15 inches/day which is about 10 times higher than the curve of the clay loam, another reflection of the

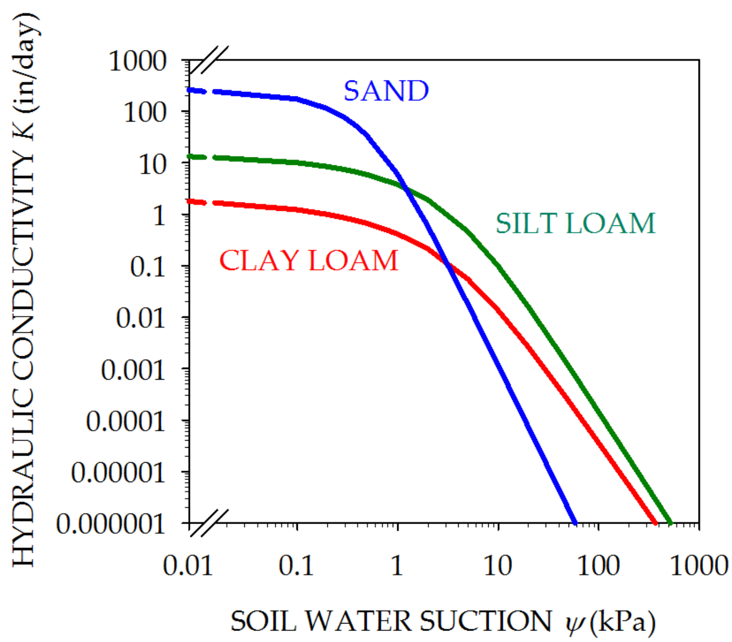

Figure 11-2. Soil hydraulic conductivity K versus soil water suction ψ for silt loam, clay loam and sand soils. Note: Notice the logarithmic scale on both axes. The relationship is strongly non-linear.

Table 11-3. Example for plant available water storage (PAWS) for a 28 inch deep silt loam soil profile.

Meas. Depth (inch)	Soil Layer (inch)	ψ-reading (kPa)	Soil Water Content, SWC (v/v)	Soil Water Content at Permanent Wilting Point, θ_{PWP} (v/v)	Plant available Water, PAW (v/v)	Plant Available Water Storage, PAWS (inch)
8	4-12	75	0.35		0.12	0.96
16	12-20	55	0.37	0.23	0.14	1.12
24	20-28	30	0.41		0.18	1.44
					Total:	**3.52**

well-drained silt loam soil that we often find in Kentucky. Between saturation and a suction around field capacity (ψ = 10 kPa), K has dropped by a factor of 100 for both the silt loam and the clay loam soil. With further drying, K drops even more rapidly for both of these soils. When the suction increases to 90 - 100 kPa, K has further declined by a factor of 100, which implies that K becomes now very low. This is why the soil should not get too dry before the irrigation water is turned on. Under such dry soil conditions, we may face a problem that the water cannot infiltrate at a sufficient rate, because K is too small.

The conductivity curve of the sand soil behaves much different. Very high K values near water saturation are followed by an extremely steep drop with the drying of the sand. At field capacity, the K value in the sand is already much lower than in the other two soils.

Under moist soil surface conditions, the K values in the silt loam and clay loam soil are high enough to allow the water to infiltrate and redistribute in the soil matrix where the roots can take it up. On the other hand, under dry surface conditions, K is low at the soil surface, and we do not get the water where we want it to be. It cannot infiltrate, and surface runoff occurs. Even open cracks developing in some soils under dry conditions do not help. If the surface runoff water infiltrates and disappears in a crack, only a small volume of soil is wetted. Moreover, within the cracks, water runs deep into the soil and probably out of the reach of plant roots. Hence, if the soil is too dry, we lose the water in many different ways, while the plant remains stressed. So, remember: Don't be late.

If on the other hand, irrigation is turned on too early, or not shut off in time, soil water abundance may exceed the field capacity. The possible consequences can be oxygen deficiency that occurs when even the largest soil pores become water-saturated. Ongoing symptoms of too much water could be observed in many places in western Kentucky in the summer of 2016, when excessive rainfall occurred. In that situation, crop damage symptoms look very similar to those observed during drought. Wilting phenomena appear under water-logging conditions because the plant roots become dysfunctional as a consequence of oxygen deficiency. Other negative effects of over-irrigation are excessive drainage of water and nutrient leaching out of the root zone as well as enhanced nitrous-oxide gas emissions.

How do we know from measurements when to turn on the irrigation?

We do not want to allow the soil water storage to be depleted close to the permanent wilting point because by then, plants suffer stress. It depends on the climatic region when plant water stress sets in. The cooler and milder the climate the farther we can allow the soil water storage to decrease before we need to turn on the irrigation. For Kentucky climate conditions and assuming that field capacity water content θ_{FC}, is precisely at ψ = 9.8 kPa, we need to turn on the irrigation when the soil water content is depleted by 50 to 65 percent of the PAWC (Table 11-4). For example, the PAWC for the silt loam soil was calculated with 0.23 v/v, equal to 2.76 in/ft. In other words, a 1-ft soil layer can hold 2.76 in of plant available water. We calculate 65 percent of PAWC to be 0.15 v/v. Subtracting 0.15 v/v from the soil water content at field capacity θ_{FC} (= 0.33 v/v for silt loam) yields a soil water content of 0.18 v/v. Therefore, when in the root zone of the silt loam, the measured soil water content reaches θ_{on} = 0.18 v/v, the irrigation should be turned on. Based on the above, we can expand this calculation for an entire soil profile by calculating 50 to 65 percent of its total PAWC. Looking at the soil water retention curve for the silt loam displayed in Figure 11-1, this water content corresponds to a soil water suction of ψ_{on} = 93 kPa. With a safety margin, we remember to turn on the irrigation as soon as the ψ reading reaches 85 to 93 kPa (Table 11-4). Remember, that such values would already be too dry for the use of a regular tensiometer which can measure up to suctions of 70 kPa. But these values of soil water suction can easily be measured with a watermark sensor. The measurement should not become higher before irrigation is turned on.

For the clay loam soil, the suction threshold range is the same (Table 11-4). However, remember that for the same plant water uptake rate this suction is reached much faster in a clay loam than in a silt loam due to the flatter soil water retention curve of the clay loam. For the sand, the threshold suction for turning on the irrigation is much lower because of the extremely steep water retention curve.

It is repeated, that the percentage of depleted PAWC given here (Table 11-4) is valid for assuming field capacity at a suction ψ of 9.8 kPa.

Table 11-4. At what soil water content (θ_{on}) or soil water suction value (ψ_{on}) should irrigation be turned on in different soil types?

Soil type	θ_{FC} (v/v)	θ_{PWP} (v/v)	PAWC (v/v)	Depleted PAWC (%) (v/v)	θ_{on} (v/v)	ψ_{on} (kPa)
Silt Loam	0.33	0.10	0.23	0.15 (65)	0.18	85 - 93
Clay Loam	0.33	0.15	0.18	0.11 (60)	0.22	85 - 93
Sand	0.09	0.05	0.04	0.02 (50)	0.07	25 - 30

Sensors

Figure 11-3 shows a tensiometer and a water mark sensor. Both sensors provide a measurement of soil water suction ψ. The tensiometer consists of a ceramic cup which is in direct contact with the soil. This ceramic has fine pores that can hold water until the suction gets higher than approximately 70 kPa. Above that threshold, air enters the system and suction measurements become unreliable. Below 70 kPa, the tensiometer is a very reliable instrument. The PVC tube and the inside of the ceramic cup are entirely filled with water up to a level that can be seen in the plexiglass. The upper inch of the PVC tube and the plexiglass reach out of the ground. The remaining length of the PVC tube and the ceramic cup are below the ground surface. With a needle manometer, the user can penetrate through the rubber septum and take a suction reading in the air gap between the water filling and the septum. The suction in the air gap is in equilibrium with the suction that the soil exerts on the ceramic cup minus the length of the water column in the PVC tube and the plexiglass while 10 cm (= 3.94 inch) refer to 0.98 kPa (see Table 11-1). Some tensiometer types have a permanent manometer instead of the rubber septum.

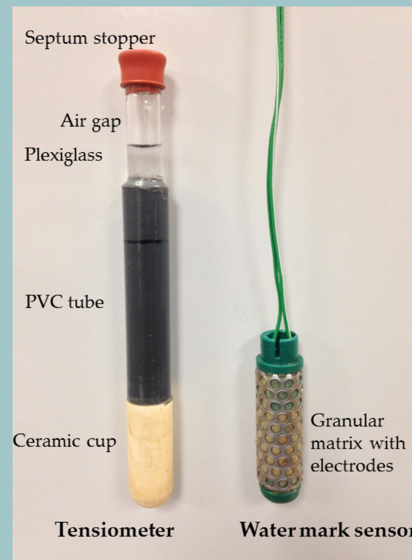

Figure 11-3. Tensiometer (left) and a water mark sensor (right)

The water mark sensor consists of a granular matrix in which two electrodes are embedded. The electrical resistivity of these two sensors depends on the wetness of the granular matrix which is in direct contact with the soil. This wetness is in equilibrium with the surrounding soil. The resistance is read with an Ohm-meter, or can be stored on a datalogger for continuous automatic readings. A correction for soil temperature is made because temperature affects the resistance. The water mark sensor is not as sensitive to low suctions as a tensiometer, but its measurements range reaches to 200 kPa which makes it applicable for sensor-based irrigation management.

How much water can we apply in one irrigation event?

This quantity is driven by many criteria. Considering circular pivot systems, one important criterion is to apply as fast as possible an amount of water that lasts for some time. Many farmers therefore, use an application rate of 5/10 to 7/10 of an inch in one turn. For many field conditions, this application is reasonable and comparable to the plant water consumption over two to three days. If a smaller amount is applied, soil water content or suction measurements will indicate that the irrigation may need to be turned on soon again. Anyway, the farmer can rely on such measurements.

The above irrigation amount works well in many cases. But for some soil conditions, the irrigation amount of 7⁄10 inches can cause problems. If this amount of water was applied to the soil over an entire day, it would be ideal because the application rate would be slow enough to let the water infiltrate into the soil. However, the pivot needs to move on to cover the entire field in a limited time. In many cases, the pivot takes a time period of about 15 minutes to pass over a given point in the field. This short time implies a huge irrigation rate, which equals a millennium rain storm intensity. For most silt loam soils that rate may still be acceptable as long as they are not structurally damaged and they are sufficiently covered by surface residue. However, in western Kentucky, a considerable fraction (30% or more) of the area of many fields is represented by eroded summits and shoulders in which the former clayey B-horizons are now the A horizons, so that field soils mapped as silt loam are in fact a mixture of silt loams, clay loams or silty clay loams. In areas with high clay content, the hydraulic conductivity is lower by at least a factor of 10 compared to silt loam zones as shown in Figure 11-2. If the same irrigation amount of 7/10 inches is applied in these clayey zones over 15 minutes, substantial surface runoff can occur and the water does not get to where it is needed. Such a situation can quickly be diagnosed by digging or drilling into the soil after irrigation. The surface soil may be wet, however, at a few inches below the surface, the soil remains dry, and the plants do not receive the water they need. At the same time, we notice puddles in local depressions where water accumulated from runoff.

To counteract this problem, the following is recommended: In fine textured soils or soils with low permeability, the rate of irrigation should be reduced. If the pivot is equipped with a variable rate irrigation system, the rates should be adjusted according to the soil map. If the system does not allow for variable-rate irrigation, clayey zones should be irrigated with a faster forward speed of the pivot to lower the rate. And the clayey zones should be irrigated more frequently at low rates, in order to apply the amount of water that is needed. Computer simulations have shown that the surface runoff can be cut by a factor of 2.5, if 5/10 inches of water were applied in two splits with two days in between as compared to one split.

A very important strategy to increase the soil water infiltration rate is to **create a soil surface as rough as possible**. Clods and substantial crop residue at the land surface increase the surface water storage, and allow more time for the soil underneath the surface layer to take up and redistribute the irrigation water than a smooth soil surface.

Summary and Conclusions

Proper irrigation management is based on soil type and hydraulic properties, crop water needs, and actual soil water status. Water has to be applied at the appropriate time and at a rate that is based on the local soil conditions.

Soil moisture sensors should be used for irrigation decisions. These sensors measure either soil water content or soil water suction while the latter has a lower demand for calibration.

For most Kentucky soils, irrigation must be turned on in time, i.e., when soil water suction is between 85 and 93 kPa.

Irrigation rate has to be managed according to soil type. The finer the soil type and the lower the hydraulic conductivity, the lower the application rate should be and the more often irrigation has to occur in order to avoid surface runoff and to let the water percolate to where it is needed.

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