DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
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Soybean Growth and Development

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The progenitor of soybean grows wild throughout eastern China, Korea, Japan and the far eastern portion of Russia. Domestication of soybean is believed to have occurred in the Yellow or the Yangtze River valleys of central or southern China somewhere between 3,000 and 5,000 years ago. There are numerous references to soybean in some of the earliest Chinese literature.

An important characteristic of soybean is that it is a legume and forms a symbiotic relationship with *Bradyrhizobium japonicum* (commonly referred to as rhizobia) bacteria that results in nodules forming on the roots (Figure 2-1). These nodules reduce atmospheric nitrogen gas to a form that the plant can utilize. A major advantage of soybean is that because of nitrogen fixation, it does not require any nitrogen fertilizer.

Figure 2-1. A well-nodulated root system of a young soybean plant.

A second important characteristic of soybean that has important implications for crop management is that it is a short-day plant. That is, soybean is triggered to flower as the day length decreases below some critical value. These critical values differ among maturity groups (MGs). Both nitrogen fixation and the response of soybean to day length are discussed with regard to their importance on crop management in more detail later in this chapter.

Seed

Soybean seeds are living organisms and should be treated with care. Avoid unnecessary dropping of seed through augers and conveyers as this can damage the seed coat. Also, seed should be kept in a cool, dry environment to preserve seed quality and vigor. Hot and humid conditions can result in rapid deterioration of seed quality, which can decrease seed germination especially under stressful conditions.

Soybean seeds vary in shape but are generally oval. A soybean seed consists of a large embryo enclosed by the seed coat. There are large variations in seed coat color (light yellow, green, brown, black, mottled), but commercial soybean is nearly always yellow. The embryo is comprised of two cotyledons (Figure 2-2), which upon germination produce a plumule with two simple leaves (unifoliate leaves) and a hypocotyl (which is green or purple depending upon whether the variety produces white or purple

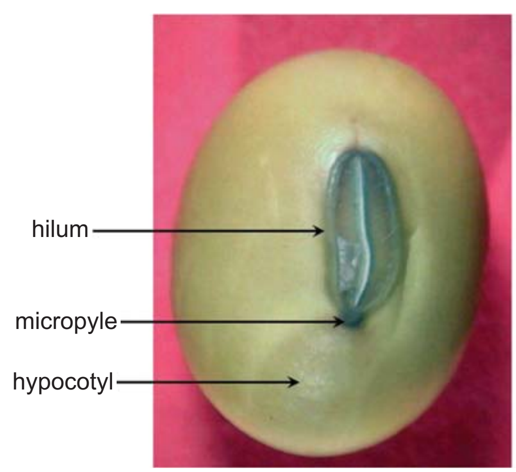


Figure 2-2. A mature soybean seed.

flowers). The embryo also consists of the radicle (root). The hilum (seed scar) is easily visible on the surface of the seed coat and is classified by color (i.e., black, imperfect black, brown, buff and clear). The micropyle is a very small hole located near the hilum that is formed during seed development. The micropyle accounts for nearly all of the gaseous exchange between the seed and its environment, whereas water can be absorbed through the entire seed coat surface.

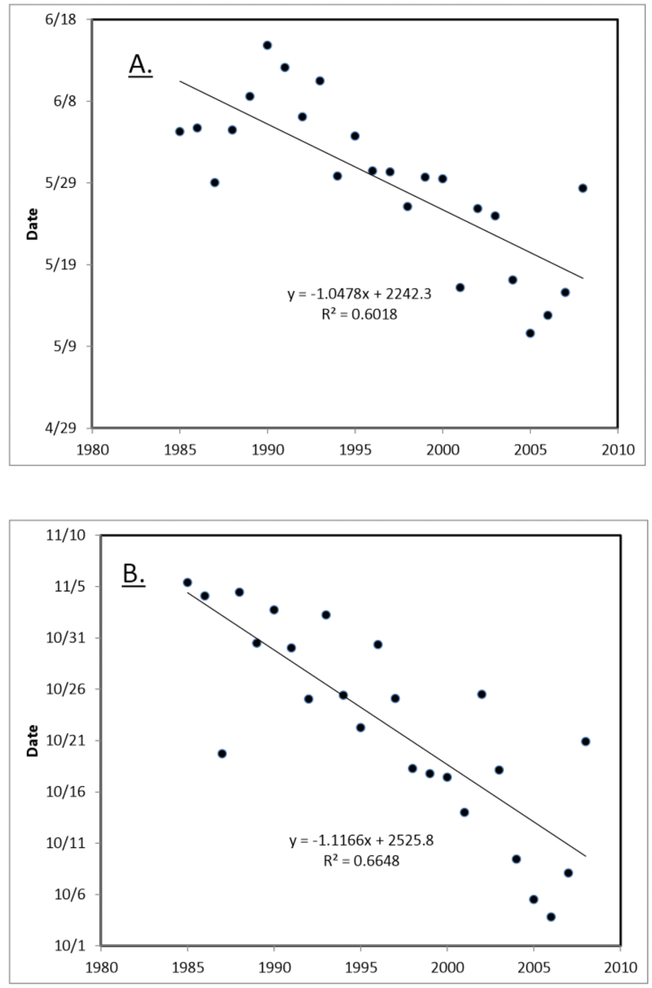
Germination and Seedling Establishment

The soybean crop has a wide planting window, typically from early spring, after the danger of frost has passed, until mid- to late-June. The trends for soybean production in Arkansas in recent years are for planting to occur earlier each year. On average, since 1985, planting has occurred one day earlier each year (Figure 2-3). In conjunction with earlier planting, the average soybean harvest date has also been about one day earlier each year. The combination of early planting and early maturity has advantages for avoiding late-season drought and disease and insect pressure. The predominant MGs grown in Arkansas today are 4 and 5, whereas MGs 5, 6 and 7 were predominant prior to 1985.

Soybean seed is typically planted at a depth of about 1 inch. Many seed companies provide fungicide and insecticide treatments on their seed, which can be especially beneficial to soybeans emerging and growing slowly in early spring due to cool temperatures. In fields where soybeans have not been grown in 3 or more years, a rhizobium inoculant (specific for soybeans, *Bradyrhizobium japonicum*) should be applied as a seed treatment or in furrow at planting. There is little supporting research to show that inoculation improves yield in fields where soybeans have been grown in recent years.

High-quality seed requires three appropriate conditions for germination – soil moisture, temperature and oxygen. Provided that the soil is not saturated, oxygen concentration is not a limitation, but germination will not occur in flooded soil due to lack of oxygen. Within 24 hours of planting, assuming that soil moisture is adequate, seed size doubles and seed moisture content increases up to 50%. During this time period, proteins become active and respiration increases. Respiration is temperature sensitive and requires oxygen, and germination rates range from 2 weeks or more in cold soil (50°F or less) to about 4 days under optimum soil temperatures (82° to 85°F).

Figure 2-3. The date when 50% of Arkansas soybeans were (a) planted and (b) harvested from 1985 to 2008. Data compiled from statewide averages of the Crop Reporting Service.



The radical (root) is the first structure to emerge from the germinating seed, usually within 48 hours of planting under optimum conditions. The radical grows downward rapidly and can provide moisture to the germinating seed if the soil surrounding the seed becomes dry. If a seed begins to germinate and the soil dries around the radical before it reaches soil moisture, the seed will most likely die.

The hypocotyl is the seedling structure that emerges from the soil surface (Figure 2-4a). The hypocotyl is either greenish or purplish in color reflecting differences in white or purple flowers that will be evident later in the season. As the hypocotyl emerges from the soil, it forms a crook as it pulls the cotyledons from the soil (Figure 2-4b). This is a critical stage in seedling emergence. In a crusted soil, the hypocotyl may be unable to push through the soil surface, resulting in a swollen hypocotyl, or the cotyledons may break from the hypocotyls, leaving

Figure 2-4a. Stages of soybean germination, emergence and seedling establishment. *(Drawing by Chris Meux)*

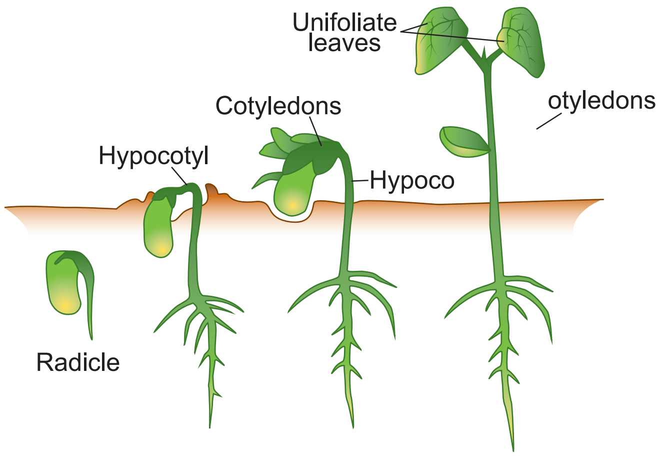


Figure 2-4b. Different stages of seedling emergence in the same field at the same time. The two soybean seedlings on the left have swollen hypocotyls due to a crusted soil surface. The two seedlings in the middle emerged normally in an area without crusting. The hypocotyl of the two seedlings on the far right has straightened and the cotyledons are beginning to unfold. *(Photo by Ryan J. Van Roekel)*

the cotyledons and terminal beneath the soil. Under these conditions, crust-busting equipment such as a rotary hoe may be able to fracture the soil crust and improve seedling emergence.

Once through the soil surface, the cotyledons unfold, synthesize chlorophyll and begin to photosynthesize. The cotyledons are rich in protein and oil and are the primary source of nutrients for the developing seedling for the first 7 to 10 days. Once the cotyledons are through the soil surface, the plant is said to be at the VE stage of development.

Two unifoliate leaves emerge opposite from one another on the main stem as the cotyledons unfold and expand. Once cotyledons and the edges of the unifoliate leaves are not touching (leaf unrolled), the plant is considered to be in the VC development stage.

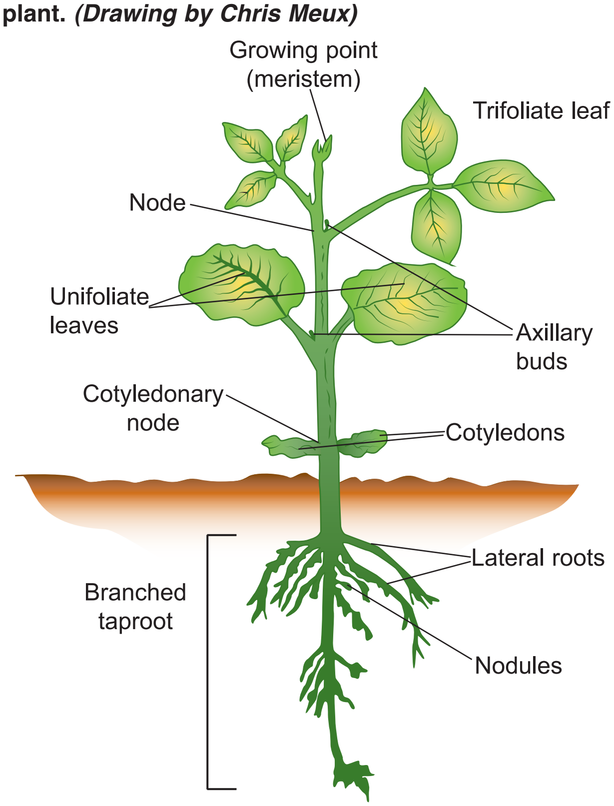
Germination Management Tips

- An example of the effect upon yield due to the loss of various plant parts during seedling development is as follows: the loss of cotyledons at VC is around 8% to 9%; the loss of the unifoliate leaves plus cotyledons at V1 is around 7%.
- Consider using fungicide and insecticide seed treatments, especially when planting in cool soils.

Vegetative and Root Development

Once the unifoliate leaves are fully expanded, the plant is described as being at the V1 stage of development. To determine when a leaf is fully expanded, examine the young leaf at a node above. If the edges of the leaf at the node above the leaf in question are not touching, the leaf at the node below can be considered fully expanded and that node is counted. For example, Figure 2-5 illustrates a soybean plant with unifoliate leaves and with two trifoliate leaves. In this figure, the edges of the young developing trifoliate are not touching. Therefore, the unifoliate node is counted and the first trifoliate node is counted, and the plant is at V2.

Figure 2-5. Vegetative structures of a young soybean plant. *(Drawing by Chris Meux)*



The nodes above the unifoliate leaves have trifoliate leaves, and vegetative development is identified from V2 (the node with the first trifoliate leaf) to the topmost node of the plant (Vn, Table 2-1). Trifoliate leaves are arranged in an alternate pattern up the stem. When temperatures are warm and soil moisture is adequate, new nodes will appear about every 4 days. Cool temperatures and drought can slow and even halt node and leaf development. The time required to reach full canopy closure decreases as rows are narrowed and populations increased, resulting in a crop more competitive against weeds.

Under good environmental conditions, the root depth increases faster than shoot height during the vegetative development phase, but the dry weight of the aboveground parts exceed the root dry weight. By V3, small root nodules are usually visible on the main root, but if there is substantial carryover of N in the soil, nodule development may be delayed. Three to four weeks after emergence, nodules begin providing nitrogen to the plant. A nodule continues to increase in size until it is about 8 weeks old, and after this, it loses activity. As nodules die and lose activity, new nodules are formed, often on branch roots, and provide a continued N supply throughout seed fill. Active nodules have a dark reddish color on the inside, whereas inactive nodules are black, gray or greenish on the inside (Figure 2-6).

Both root and vegetative development depend on a good environment such as adequate soil moisture and nutrition (including adequate nodulation for nitrogen fixation) and the absence of high levels of disease and nematode infection. During vegetative development, roots can grow 0.5 to 0.75 inch per day. Figure 2-5 depicts above- and below-ground vegetative development of a young soybean plant.

Management Tips

- At full growth, more than 80% of the roots are in the upper 4 inches of soil with a restrictive pan. This creates a situation in which deep cultivation (root pruning) or drought may reduce yields and increase the need to maintain adequate soil moisture (irrigation).
- Decreasing row spacing to 20 inches or less results in faster canopy coverage and lessens the dependence on post-emergence herbicides.

Growth Habit

The growth habit of soybeans is described as being either determinate or indeterminate. Traditionally, determinate varieties have been from MGs 5 to 10 and indeterminate varieties have been from MGs 000 to 4. In more recent years, however, this division has become less distinct, and there are numerous MG 4 varieties that are determinate and MG 5 varieties that are indeterminate.

Determinate soybean varieties stop vegetative growth and producing nodes on the main stem soon after flowering starts, whereas indeterminate varieties continue producing nodes on the main stem until the beginning of seed fill (growth stage R5). Determinate varieties, however, will continue producing nodes on branches until the beginning of seed fill. While determinate varieties have a relatively short flowering period of nodes on the main stem (~3 weeks), the entire flowering period when including branches is similar to indeterminate varieties of the same maturity. The total length of the flowering period will depend upon planting date and maturity but may range from 3 to 6 weeks.

Figure 2-6. Cross section of soybean nodules (a) actively fixing nitrogen, (b) beginning to senesce and lose nitrogen fixation activity and (c) senescent. Note that the active nodule has a deep red color compared to the gray and dark green color of the senescent nodule.

Determinate varieties are characterized as having a terminal raceme that results in a cluster of pods under good growing conditions at the uppermost main stem node. Under stressful conditions, some or all of the pods may abort and the terminal raceme appears as a notched spine at the top of the plant. Determinate varieties also typically have leaves at the topmost three or four nodes that are similar in size. In contrast, indeterminate varieties lack a terminal raceme, and the nodes at the top of the plant tend to form a zigzag pattern. Leaves of indeterminate varieties progressively decrease in size beginning at about the fifth node from the top to the plant's terminal.

Table 2-1. Description of vegetative stages.

Stage No.	Abbreviated Stage Title	Description
VE	Emergence	Cotyledons above the soil surface
VC	Cotyledon	Unifoliate leaves unrolled sufficiently so that the leaf edges are not touching
V1	First node	Fully developed leaves at unifoliate node
V2	Second node	Fully developed trifoliate leaf at node above the unifoliate node
V3	Third node	Three nodes on the main stem with fully developed leaves beginning with the unifoliate node
Vn	n^{th} node	n number of nodes on the main stem with fully developed leaves beginning with the unifoliate node

Reproductive Development

When a soybean plant begins to flower, it is classified as being in a reproductive (R) growth stage. Each reproductive stage from flowering until maturity is designated in the reproductive growth stage scheme as indicated in Table 2-2. The length of time for plant development (both vegetative and reproductive) varies depending on several factors including temperature, MG and day length. The main effect of day length on soybean development is that of floral induction. Soybeans are referred to as short-day plants because short days (i.e., long nights or dark periods) initiate flowering (floral induction).

Reproductive stages are based on flowering, pod development, seed development and plant maturation. Each stage description is given a reproductive stage (R) number and an abbreviated title (Table 2-2).

Table 2-2. Description of reproductive stages.

Stage No.	Abbreviated Stage Title	Description
R1	Beginning bloom	One open flower at any node on the main stem
R2	Full bloom	Open flower at one of the two uppermost nodes on the main stem with a fully developed leaf
R3	Beginning pod	Pod 3/16 inch long at one of the four uppermost nodes on the main stem with a fully developed leaf
R4	Full pod	Pod 3/4 inch long at one of the four uppermost nodes on the main stem with a fully developed leaf
R5	Beginning seed	Seed 1/8 inch long in a pod at one of the four uppermost nodes in the main stem with a fully developed leaf
R6	Full seed	Pod containing a green seed that fills the pod cavity at one of the four uppermost nodes on the main stem with a fully developed leaf.
R7	Beginning maturity	One normal pod on the main stem that has reached its mature pod color
R8	Full maturity	95% of the pods have reached their mature pod color; 5-10 days of drying weather are required after R8 before the soybeans have less than 15% moisture

The main stem is used for determining reproductive stages. When the main stem of a plant is broken or cut off, reproductive development on the new branches may be retarded. Plants that have intact main stems are used to determine stage development.

The R1 stage begins when there is one flower at any node on the plant. Usually the first flower is located between the fourth and sixth nodes. The R2 stage occurs when there are open flowers at one of the two uppermost nodes. Between R1 and R2, open flowers appear at nodes from the bottom of the plant toward the top. In a late-planted soybean crop (e.g., double-crop soybeans), R1 and R2 may occur almost simultaneously or be separated by as much as 6 days. For full-season soybeans (e.g., MG 5 variety planted in early May), the time period between R1 and R2 ranges between 3 and 10 days.

After flowering begins, plants continue to grow vegetatively, producing new nodes on both the main stem and branches. The time between R2 and beginning pod stage (R3) depends upon planting date, growth habit (determinate or indeterminate), MG, temperature and other factors that affect plant growth (e.g., drought). Indeterminate varieties may spend 2 or more weeks at R2 because new nodes are produced on the main stem after first reaching R2.

The beginning of the seed fill period is designated as R5. At this time, seed are 1/8-inch long in full-size pods at one of the uppermost four nodes. Flowering ends and plants reach their maximum vegetative weight at the beginning of R5. During the flowering and early pod formation stages (R1 through R4), plants adjust the number of flowers and young pods in response to the environment. Flowers and young pods may abort when conditions are stressful for a few days, but then fewer flowers and young pods may abort later if environmental conditions improve. Soon after plants reach R5, however, there is little pod abortion, and stress (e.g., drought, prolonged flooding, etc.) results in a short seed-filling period, early maturity and small seed.

The R5 development stage ends and the R6 development stage begins when the seed fills the pod cavity from a pod at one of the uppermost four nodes on the main stem. Because much of seed dry weight accumulates during R6, it is critical to ensure that the crop continues to be managed for irrigation and pests. Toward the end of R6, the canopy begins to yellow and leaves begin to senesce.

The R7 development stage begins when there is one mature-color pod at any node on the plant. Mature pod color in soybeans differs among varieties. The pod wall color in commercial varieties is usually tan but may be brown. Additionally, the pubescence (small hair-like structures on the plant) of varieties may be either gray or tawny (brown). The mature pod color of soybeans, therefore, varies from light gray to dark brown. At R7, seed moisture is still high, but the seed has reached its maximum dry weight. Seeds can still be damaged by stinkbugs at this stage. The R7 stage is also referred to as physiological maturity. Once 95% of the pods turn a mature pod color, the plant has reached R8 and can be harvested once seed moisture is less than 15%.

Management Tips

- Having a full canopy by R2 is important in setting a maximum number of pods.
- Begin scouting soybeans regularly for diseases and pod-feeding insects (especially bollworms and stinkbugs) beginning at R3 and continuing through seed fill.
- Irrigation should be continued at least until the crop is in the R6 development stage. If soil moisture is high when leaves first begin to turn yellow, irrigation can be terminated.

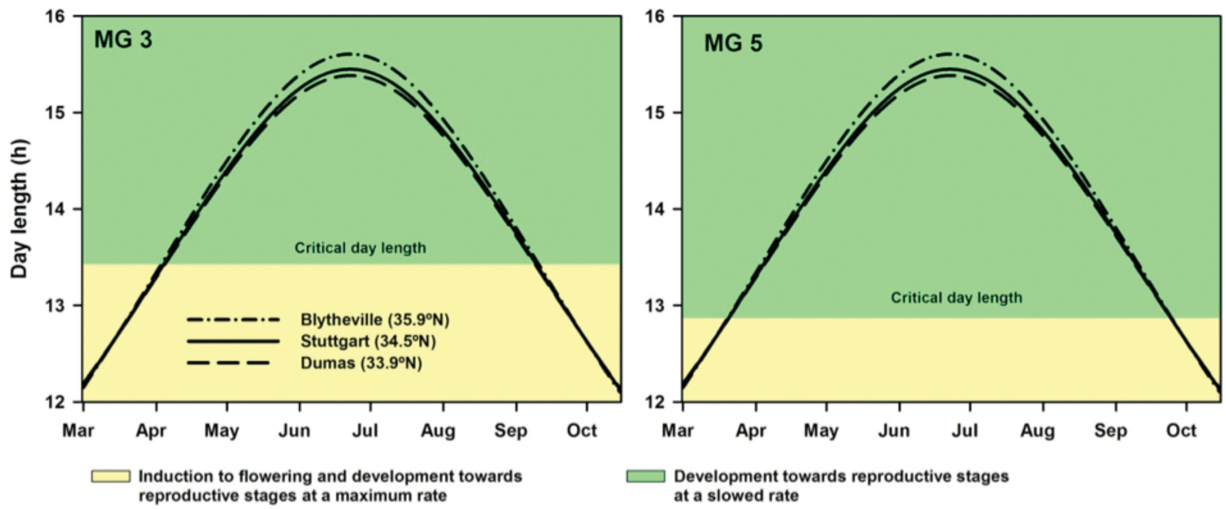
Days Between Growth Stages

Soybean development is influenced by temperature and day length and will also be affected by soil moisture conditions, plant nutrition and other factors. The number of days between stages will also vary greatly depending on the MG and variety used. Therefore, the timing of development stages will be different depending on the variety, climate and planting dates.

Emergence will depend primarily on temperature under correct moisture conditions. Plants will emerge when soil temperatures are higher than 41°F, and higher temperatures will enhance a faster emergence. For instance, emergence can take about 14 days at 46°F but only 4 days at 59°F. During the vegetative period, the plant will produce nodes at an average rate of 1 node every 4 days. The total number of nodes will vary between approximately 16 and 23, depending on the cultivar and length of the vegetative period.

The beginning of flowering and subsequent reproductive development is greatly affected by photoperiod. The soybean is a short-day plant, meaning that days shorter than a critical value will induce the plant to flower. Figure 2-7 shows the day length across the growing season for Dumas (33.8° latitude), Stuttgart (34.5° latitude) and Blytheville (35.9° latitude), Arkansas. The yellow-shaded region near the bottom of the figures show the critical day length at which the development rate toward flowering is at a maximum. For MG 3 varieties, the critical day length that induces soybeans to flower at a maximum

Figure 2-7. Day length versus date for three locations in Arkansas. The yellow-shaded regions indicate the day lengths that result in MG 3 (left panel) and MG 5 (right panel) varieties' rapid progression toward flowering. As the day length becomes longer (green region), the rate of progression toward flowering decreases.



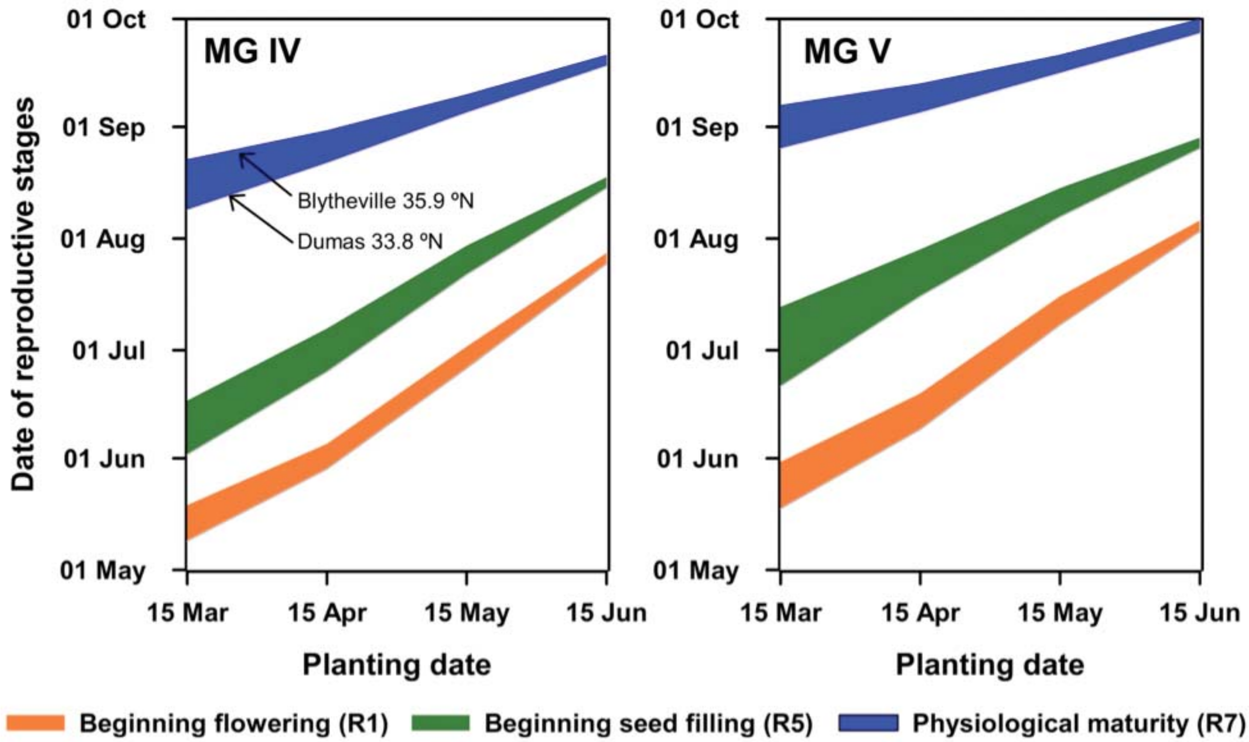
rate is about 13.4 hours, whereas for a MG 5 variety, the critical day length is about 12.8 hours. When day length is longer than these critical values, plants will continue to be induced to flower but at a progressively slower rate (green region in Figure 2-7).

For example, a MG 3 variety will be induced to flower at a maximum rate whenever the day length is less than 13.4 hours, which corresponds to dates earlier than April 1 (Figure 2-7). For a MG 5 variety, plants will be induced to flower at a maximum rate whenever the day length is less than 12.8 hours, which corresponds to dates earlier than March 15 (Figure 2-7). Note that if planting is delayed until mid-May, the photoperiod is longer than the critical day length for both MG 3 and 5 varieties (green region of Figure 2-7), which means that the progress toward flowering will take considerably longer. For double-crop or late-planted soybeans (late June or early July), the day length is shorter each day, which means that the development rate toward flowering is increasing. From a practical standpoint, these scenarios mean that early-planted or late-planted soybeans should be planted in more narrow rows (< 20 inches or twin rows) and at a higher population density than soybeans planted in mid-May. Likewise, MG 3 and early MG 4 soybean varieties will have less time for vegetative growth compared to MG 5 varieties, which may require more narrow rows and a higher population density.

In addition to photoperiod, higher temperatures will accelerate reproductive development. Using long-term weather data for Blytheville and Dumas, Arkansas, we have estimated dates when flowering (R1), beginning seed fill (R5) and physiological maturity (R7) are expected to occur over a range of planting dates using a computer simulation model (CropGro, Figure 2-8). Assuming average temperatures for early plantings on March 15, the time from planting to flowering (averaged across the two locations) will be about 60 (May 14) and 70 (May 24) days for MG 4 and 5 varieties, respectively. As planting date is delayed, the number of days to flowering is shortened. For instance, with late planting on June 15, the number of days from planting to flowering will be about 42 (July 27) and 50 (August 14) days for MG 4 and 5 varieties, respectively. The development rate toward flowering and the subsequent reproductive stages will be faster in years with higher temperatures and/or locations in south Arkansas.

The beginning of seed filling, or the R5 stage, will occur about 27 (June 10) and 39 (July 2) days after beginning of flowering for MG 4 and 5 varieties planted on March 15, but it will shorten to 21 (August 17) and 23 (August 27) days for MG 4 and 5 varieties when planted on June 15.

Figure 2-8. Estimated dates of beginning flowering (R1), beginning seed filling (R5) and physiological maturity (R7) based upon planting date for MG IV and V soybeans. The lower edge of each colored region represents dates for Dumas, AR (latitude 33.8°N), and the upper edge represents estimates for Blytheville, AR (latitude 35.9°N). Estimates were made using a crop simulation model (CropGro) and using long-term weather data for each location.



Finally, the expected number of days from beginning of seed filling to physiological maturity (R7) will be about 67 (August 16) and 61 (September 1) days for MG 4 and 5 varieties with an early planting on March 15, and the R7 date is expected to be about 34 (September 20) and 32 (September 28) days after R5 for MG 4 and 5 varieties with a planting date in mid-June.

The number of days from R7 until all the pods are mature and the crop is ready to harvest (R8) can range from 6 to 13 days depending on the cultivar and weather conditions. Under non-irrigated conditions or dry years, the soybean crop can reach maturity about 7 to 10 days earlier than the reported expected dates. Conditions of prolonged drought during flowering through early seed fill (R5) followed by favorable growing conditions may result in few pods on the plant, a delay in maturity, and green leaves and stems when pods are mature. Likewise, insect infestations resulting in a large loss of pods can also delay maturity and result in green leaves and stems when pods are mature.