How A Soybean Plant Develops

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Contents

Preface

This publication is designed to aid those involved in soybean production to more fully understand how the soybean plant develops. The content is both basic and applied. The basic information explains soybean growth and development through one life cycle. Management guides pinpoint practices needed for optimum plant growth and production.

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How a Soybean Plant Develops

Soybean growth and development are measured by the amount of dry weight (dry matter) accumulating in the plant. Dry weight consists of everything in the plant except water including carbohydrates, proteins, oils, and mineral nutrients. The soybean plant produces most of its dry weight through a unique process called photosynthesis. During photosynthesis, the sun (light energy) powers a process within the plant where carbon dioxide from the air combines to produce sugars (larger carbon compounds). These sugars produced by photosynthesis along with mineral nutrients obtained from the soil are the basic ingredients needed to make the carbohydrates, proteins, and oils of dry weight.

In more practical terms, growth, development, and yield of soybeans are all a result of a given variety's genetic potential interacting with its environment. The soybean plant is finely tuned to its environment; as the environment changes so does the plant's development.

All varieties have a maximum yield potential that is genetically determined. This genetic yield potential is obtained only when environmental conditions are perfect, but such perfect growth conditions do not naturally exist. In a field situation, nature provides the major portion of the environmental influence on soybean development and yield; however, soybean producers can manipulate this environment with proven managerial practices. It is the producer's task, therefore, to provide the best possible growth environment for the soybean plant by using such management practices as wise tillage and fertilization of the soil, selecting the most suitable varieties and plant densities, timely weed and insect control, and many other practices.

Combinations of these practices vary over different production situations and management levels. Regardless of the specific situation, however, a producer needs to understand soybean growth and development. A producer who understands the soybean plant can use production practices more efficiently to obtain higher yields and profit.

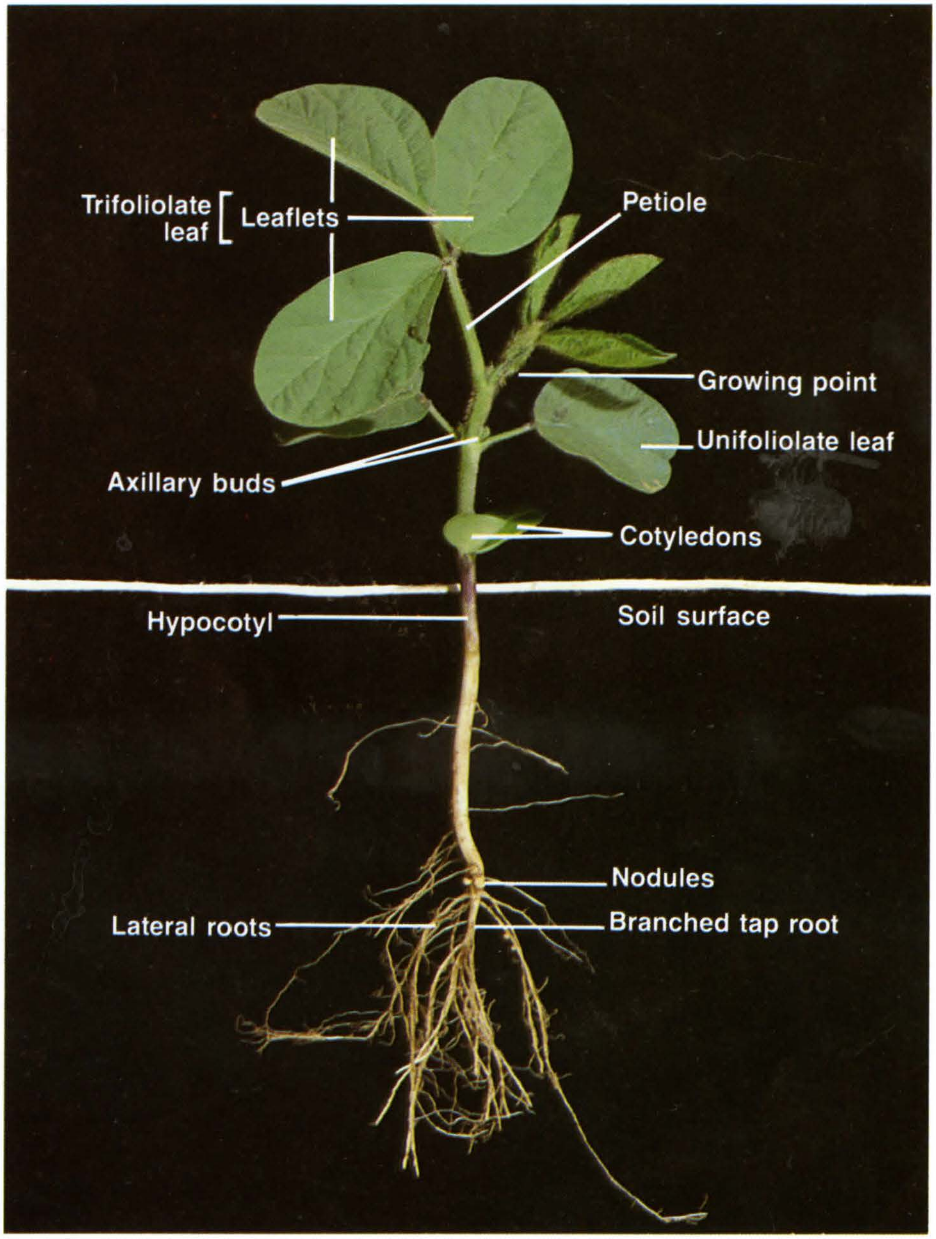

Fig. 1. Soybean seedling.

The Illustrations

Soybean varieties are classified for their morphological (form and structure) growth habit, and for their daylength and temperature requirement to initiate floral or reproductive development. The indeterminate growth habit is typical of most Corn Belt soybean varieties and is characterized by a continuation of vegetative growth after flowering begins. Determinate soybean varieties characteristically have finished most of their vegetative growth when flowering begins and are typically grown in the southern United States.

The classification for floral development is based upon the adaptability of a soybean variety to effectively utilize the growing season in a given region. These regions of adaptability are long belts east and west and relatively short 160-240 kilometer (99-149 mile) distances north and south. All soybean varieties adapted to a particular region are given a group number from 00 for the northernmost Corn Belt region in northern Minnesota and North Dakota, to VIII for the southernmost region in the United States which includes Florida and the southern parts of the Gulf Coast states. Almost all varieties in 00 to IV display the indeterminate growth habit, and varieties in groups V to VIII are of the determinate growth habit.

The pictures, charts, and discussion in this publication represent an adapted group II indeterminate soybean variety grown in central Iowa. Typical soybean plants grown in the Corn Belt follow the same general pattern of development shown and described in this publication. But the specific time between stages, number of leaves developed, and plant height may vary between different varieties, seasons, locations, planting dates, and planting patterns. For example:

1. An early maturing variety may develop fewer leaves or progress through the different stages at a faster rate than indicated here, especially when planted late. A late maturing variety may develop more leaves or progress more slowly than indicated here.

2. The rate of plant development for any variety is directly related to temperature, so the length of time between the different stages will vary as the temperature varies both between and within the growing season.

3. Deficiencies of nutrients, moisture, or other stress conditions may lengthen the time between vegetative stages, but shorten the time between reproductive stages.

4. Soybeans planted at high densities tend to grow taller and produce fewer branches, pods, and seeds per plant than those planted at low densities. High density soybeans also will set pods higher off the ground and have a greater tendency to lodge.

The pictures show plants and plant parts at identifiable stages of morphological development. All plants were grown in the field except the germination and emergence sequence, which was greenhouse grown, but were photographed in the laboratory. Scientific names of the parts of the young soybean plant are shown in fig. 1.

Identifying Stages of Development

The staging system employed here divides plant development into vegetative (V) and reproductive (R) stages (table 1). Subdivisions of the V stages are designated numerically as V1, V2, V3, through V(n) except the first two stages which are designated as VE (emergence) and VC (cotyledon stage). The last V stage is designated as V(n), where (n) represents the number for the last node stage of the specific variety. The (n) will fluctuate with variety and environmental differences. The eight subdivisions of the R stages are designated numerically with their common names in table 1.

The V stages (node stages) following VC are defined and numbered according to the uppermost fully developed leaf node. A fully developed leaf node is one that has a leaf above it with unrolled or unfolded leaflets. In other words, the leaflet edges are no longer touching as they are in fig. 2. The V3 stage, for example, is defined when the leaflets on the 1st (unifoliolate) through the 4th node leaf are unrolled. Similarly, the VC stage occurs when the unifoliolate leaves have unrolled.

The unifoliolate leaf node is the first node or reference point from which to begin counting upward to identify upper leaf node numbers. This node is unique in that the unifoliolate (simple) leaves are produced from it on opposite sides of the stem and are borne on short petioles. All other true leaves formed by the plant are trifoliolate (compound) leaves borne on long petioles, and are produced singularly (from different nodes) and alternately (from side to side) on the stem.

The cotyledons, which are considered as modified leaf storage organs, also arise opposite on the stem just below the unifoliolate node. When the unifoliolate leaves are lost through injury or natural aging, the position of the unifoliolate node can still be determined by locating the two leaf scars on the lower stem which permanently mark where the unifoliolate leaves had grown. These unifoliolate leaf scars are located just above the two opposite scars which mark the cotyledonary node position. Any leaf scars above the opposite unifoliolate scars appear singularly and alternately on the stem, and mark node positions where trifoliolate leaves had grown.

Table 1. Vegetative and reproductive stages of a soybean plant.*

Vegetative Stages		Reproductive Stages	
VE	Emergence	R1	Beginning bloom
VC	Cotyledon	R2	Full bloom
V1	First-node	R3	Beginning pod
V2	Second-node	R4	Full pod
V3	Third-node	R5	Beginning seed
•			
•		R6	Full seed
•		R7	Beginning maturity
V(n)	nth-node	R8	Full maturity

*This system accurately identifies the stages of a soybean plant. However, all plants in a given field will not be in the same stage at the same time. When staging a field of soybeans, each specific V or R stage is defined only when 50 percent or more of the plants in the field are in or beyond that stage.

Fig. 2. Top soybean leaf with curled edges touching.

Vegetative Stages and Development

Germination and Emergence

The planted soybean seed begins germination by absorbing water in amounts equal to about 50 percent of its weight. The radical or primary root is first to grow from the swollen seed (see fig. 3) where it elongates downward and anchors itself in the soil. Shortly after initial primary root growth, the hypocotyl (small section of the stem between the cotyledonary node and the primary root; see fig. 1) begins elongation toward the soil surface pulling the cotyledons (seed leaves) with it. The anchored primary root and elongating hypocotyl provide leverage for pulling the cotyledons to the soil surface for VE or emergence, fig. 3. VE occurs 5 to 10 days after planting, depending on soil moisture, soil temperature, variety, and planting depth. Lateral roots begin to grow from the primary root just prior to emergence.

Shortly after VE the hook-shaped hypocotyl straightens out and discontinues growth as the cotyledons fold down. The unfolding of the cotyledons exposes the growing epicotyl (young leaves, stem, and growing point located just above the cotyledonary node). The subsequent expansion and unfolding of the unifoliolate leaves marks initiation of the VC stage, which is followed by the numbered (nodal) V stages.

Nutrients and food reserves in the cotyledons supply the needs of the young plant during emergence and for about 7 to 10 days after VE, or until about the V1 stage. During this time, the cotyledons lose 70 percent of their dry weight. Loss of one cotyledon has little effect on the young plant's growth rate, but loss of both cotyledons at or soon after VE will reduce yields 8 to 9 percent.

After V1, photosynthesis by the developing leaves is adequate to sustain good plant health.

New V stages will appear about every 5 days from VC through V5, and every 3 days from V5 to shortly after R5 when the maximum number of nodes is developed.

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Plant soybeans at a depth of 2.5 to 3.8 cm (1 to 1½ inches) and never deeper than 5.1 cm (2 inches). The ability of the germinating soybean seedling to push through a crusted soil decreases with deeper planting. In addition, the cooler soil temperatures at greater depths cause slower growth and decreased nutrient availability.

Small amounts of fertilizer placed in a band 2.5-5.1 cm (1 to 2 inches) to the side and slightly below the seed may stimulate early plant growth if soil temperatures are still cool. Roots are not attracted to this fertilizer band, so the fertilizer must be placed where the roots will be. Fertilizer placement too near or with the seed can injure the young plant.

Weeds compete with soybeans for moisture, nutrients, and sunlight. Tillage operations, herbicides, narrow row widths (less than 102 cm or 40 inches), and crop rotations are useful methods for controlling weeds. The rotary hoe is an excellent tool for early weed control before and shortly after the soybeans have emerged. Two good rotary hoeings after VE when the weeds are still very small will kill 10 percent of the beans as well as the weeds.

Seed innoculation with *Rhizobium japonicum* bacteria is generally not recommended unless the field has never grown soybeans, or has not grown soybeans for the past 3 or more years.

Fig. 3. Germination and emergence.

V2 Stage

At the V2 stage, the plants are 15.2 to 20.3 cm (6 to 8 inches) tall and three nodes have leaves with completely unfolded leaflets (the unifoliolate node and the first two trifoliolate leaf nodes), fig. 4.

Soybean roots normally become infected with *Rhizobium japonicum* bacteria, which cause formation of round or oval shaped root growths termed nodules, fig. 1 and 5. Millions of these bacteria are located within each nodule and provide much of the soybean plant's nitrogen supply through a process called nitrogen-fixation. Through nitrogen-fixation, the bacteria change nonavailable N_2 gas from the air into nitrogen products that the soybean plant can use. The plant in turn provides the bacteria's carbohydrate supply. A relationship such as this where both the bacteria and plant profit from the other is called a symbiotic relationship. Nodules actively fixing nitrogen for the plant appear pink or red on the inside (fig. 6), but are white, brown, or green if N-fixation is not occurring.

Under field conditions, nodule formation can be seen shortly after VE, but active nitrogen-fixation does not begin until about the V2 to V3 stages. After this, the number of nodules formed and the amount of nitrogen fixed increases with time until about R5.5 (mid-way between R5 and R6) when it decreases sharply.

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Nitrogen fertilization of soybeans is not recommended because it generally does not increase or decrease grain yields. The total number of root nodules that form decreases proportionately with increasing amounts of applied N fertilizers. In addition, N fertilizer applied to a soybean plant with active nodules will render the nodules inactive or inefficient proportionately to the amount of N applied. Thus, the soybean plant can utilize both fixed N from bacteria and soil N (both mineralized and fertilizer N), but soil N is utilized over fixed N if available in large amounts through fertilization.

At V2, the lateral roots are proliferating rapidly into the top 15 cm (6 inches) of soil between the rows, and by V5 will completely reach across a 76 cm (30-inch) row. Because these roots are growing close to the soil surface, weed cultivation should be shallow.

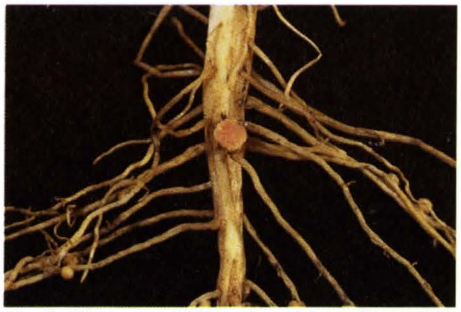

Fig. 6. Close-up of V2 root nodules with nodule sliced.

Fig. 4. V2 plant.

Fig. 5. V2 roots showing nodules.

V3 and V5 Stages

Plants at V3 are 18 to 23 cm (7 to 9 inches) tall and four nodes have leaves with completely unfolded leaflets, fig. 7.

Plants at V5 are 25.4 to 30.5 cm (10 to 12 inches) tall and six nodes have leaves with completely unfolded leaflets, fig. 8.

The upper angle junction between the main stem and a leaf petiole is called an axil. In each axil is an axillary bud (fig. 1), which is similar in nature to the main stem growing point. This bud, however, may develop into a branch, develop into a flower cluster and finally pods, or it may remain dormant (inactive).

The number of branches that develop increases with wider row spacings and lower plant densities, depending on the variety grown. From zero to six branches typically develop under field conditions. Generally the largest branch is the lowest on the main stem and progressively smaller branches develop farther up. Each branch develops trifoliolate leaves, nodes, axils, axillary buds, flowers, and pods similar in nature to the main stem. The first branch beginning to develop can be seen in the axil of the first trifoliolate leaf node in fig. 7.

At about two node stages (one week) from R1, or at V5 in this publication, the axillary buds in the top stem axils appear bushy and are beginning to develop into flower clusters called racemes. A raceme is a short stem-like structure that produces flowers and finally pods along its length, see fig. 21.

The total number of nodes that the plant may potentially produce is set at V5. The potential total number of nodes that an indeterminate type soybean plant may produce is always higher than the actual number of nodes that fully develop (have a leaf on the node above with unfolded leaflets).

Management Guides

The axillary buds of the unifoliolate and trifoliolate leaves and of the cotyledons, allow a tremendous capacity for the soybean plant to recuperate from damage such as hail. The stem apex or tip growing point normally exhibits dominance over the axillary buds (axillary growing points) during vegetative growth of the plant. If the stem apex is severed or broken off along with part of the stem, however, the remaining axillary buds are released from this dominance and branches grow profusely. The plant, therefore, has the ability to produce new branches and leaves after hail destroys almost all of the above ground foliage. Severing the plant below the cotyledonary node kills it because there are no axillary buds below this node.

V6 Stage

Plants at V6 are 30.5 to 35.6 cm (12 to 14 inches) tall, fig. 9. Seven nodes have leaves with completely unfolded leaflets and both of the unifoliolate leaves and cotyledons may have senesced and fallen from the plant at this time. New V stages are now appearing every three days.

Lateral roots are present completely across row spacings of 76 cm (30 inches) or less by this stage.

Fifty percent leaf loss at V6 reduces yield approximately 3 percent.

Fig. 7. V3 plant.

Fig. 8. V5 plant.

Fig. 9. V6 plant.

Reproductive Stages and Development

The eight R (reproductive) stages are divided into four parts: R1 and R2 describe flowering; R3 and R4, pod development; R5 and R6, seed development; and R7 and R8, plant maturation. Because vegetative growth and nodal production continue through some of the R stages, including the V stage (total number of nodes fully developed), at the R1 through R6 stages better describe plant development. Each R stage description in bold print pertains to only the beginning or initiation of the stage.

General development and timing of the vegetative growth, flowering, pod development, and seed-filling periods are outlined against the R stages in fig. 10.

R1 Stage

R1—One open flower at any node on the main stem, fig. 11.

Plants at R1 are 38 to 46 cm (15 to 18 inches) tall and are vegetatively in the V7 to V10 stage (7 to 10 nodes fully developed). Flowering begins on the third to sixth node of the main stem, depending on the V stage at the time of flowering, and progresses upward and downward from there. The branches begin flowering a few days later than the main stem. Flowering on a raceme occurs from the base to the tip, see fig. 12. Basal raceme pods are thus always more mature than pods from the raceme tip, see fig. 21. Flowering and pod set mostly occur on primary racemes, but secondary racemes may develop to the side of the primary raceme in the same axil. The appearance of new flowers peaks between R2.5 and R3, and is almost complete by the R5 stage.

At R1, vertical root growth rates sharply increase and stay relatively high to the R4 to R5 stage. Proliferation of secondary roots and root hairs within the top 0 to 23 cm (0 to 9 inches) of soil is extensive during this period also but roots in this zone generally begin to degenerate thereafter.

Fig. 11. R1 plant.

Fig. 12. Beginning of flowering on racemes.

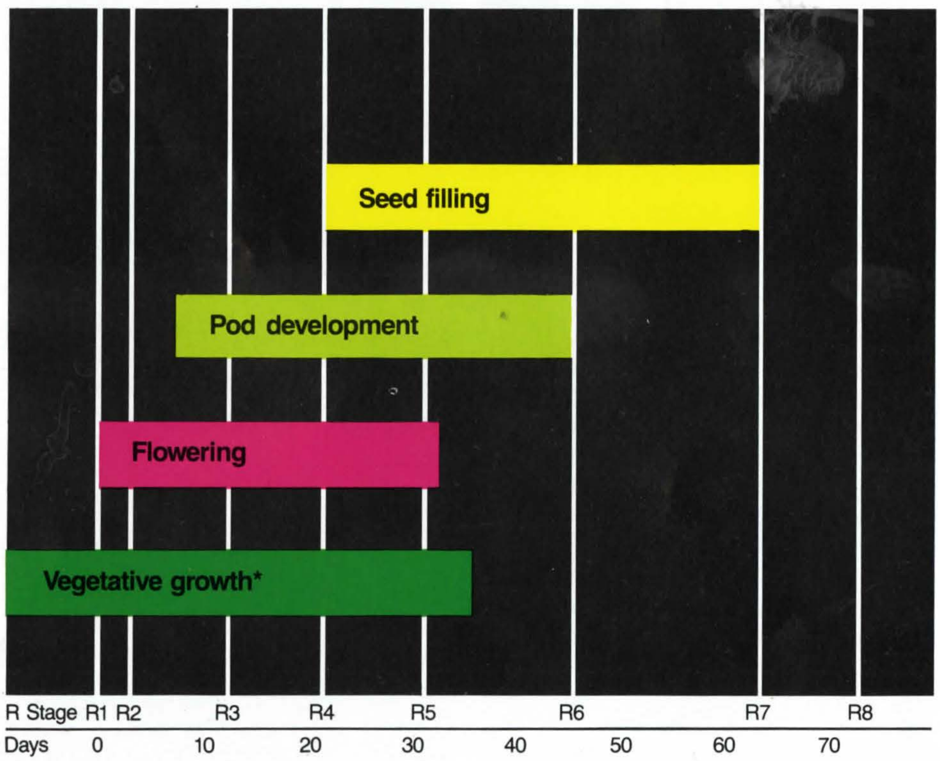

Fig. 10. Development and timing of vegetative growth, flowering, pod development, and seed filling.
*Plant height and node development

R2 Stage

R2—Open flower at one of the two uppermost nodes on the main stem with a fully developed leaf, fig. 13.

Plants at R2 are 43 to 56 cm (17 to 22 inches) tall and are in the V8 to V12 stage. At this stage the plant has only accumulated about 25 percent of its total mature dry weight and nutrients, attained about 50 percent of its mature height, and has produced about 50 percent of its total mature node number. This stage marks the beginning of a period of rapid and constant daily dry matter and nutrient accumulation rates (see figs. 38-41) by the plant that will continue until shortly after the R6 stage. This rapid accumulation of dry weight and nutrients by the whole plant initially occurs in the vegetative plant parts (leaves, stems, petioles, and roots), but accumulation gradually shifts into the pods and seeds as they begin to develop, and as vegetative parts finalize their development. In addition, the rate of nitrogen-fixation by the root nodules is also increasing rapidly by the R2 stage. Figure 14 shows that a large number of root nodules may develop on a single plant.

Roots are present completely across the inter-row space of 102 cm (40 inch) rows by R2 and growth of several major lateral roots has turned downward by this time. These major lateral roots along with the tap root continue to elongate deeply into the soil profile until shortly after the R6.5 stage.

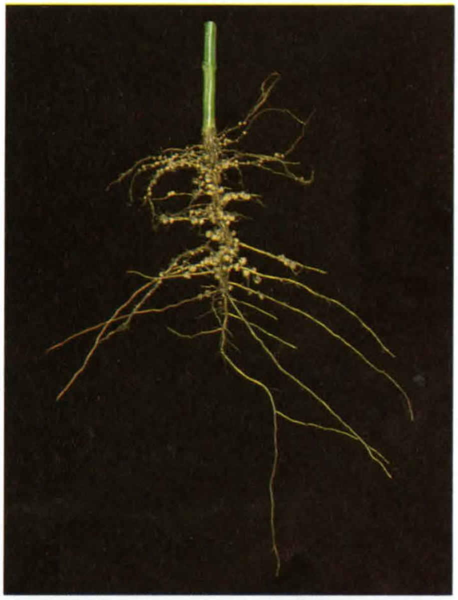

Fig. 14. Large numbers of root nodules developed on a single plant.

Fig. 13. R2 plant.

R3 Stage

R3—Pod is 5 mm (3/16 inch) long at one of the four uppermost nodes on the main stem with a fully developed leaf, figs. 15 and 16.

Plants at R3 are 58 to 81 cm (23 to 32 inches) tall and are in the V11 to V17 stage. It is not uncommon to find developing pods, withering flowers, open flowers, and flower buds on the same plant at this time. Developing pods are located on the lower nodes where flowering first began.

If plant densities are adequate, yield (total seed weight) can be divided into three components: the total number of pods produced per plant, the number of beans produced per pod, and the weight per bean (seed size). Yield increases or decreases may be described as increasing or decreasing one or more of these three components.

Yield increases most generally result from increases in total number of pods per plant, especially large yield increases. The upper limits on number of beans per pod and seed size are genetically confined; however, these two components can still fluctuate enough to produce sizable yield increases.

Stressful conditions such as high temperature or moisture deficiency reduce yield due to reduction in one or more of the components. Reductions in one component, however, may be compensated by another component so yields are not significantly changed. Which yield component is reduced or increased depends on the R stage of the plant when the stress occurs. As the soybean plant ages from R1 through R5.5, its ability to compensate after a stressful condition decreases, and the potential degree of yield reduction from stress increases.

Management Guides R1-R3

Under Corn Belt conditions, about 60 to 75 percent of all soybean flowers produced typically abort and never contribute to yield. About half of this abortion occurs before the flowers develop into young pods, and the other half is due to pod abortion. The over production of flowers and pods and the extended period of flowering (from R1 to R5) seems desirable because it offers a degree of escape from short periods of stress. Stressful conditions (which cause even higher abortion rates) from R1 through R3 generally do not reduce yields greatly because some flowers (and finally pods) can still be produced until R5 to compensate. In addition, stress at these stages may result in an increase in the number of beans per pod and weight per bean, which also help compensate for the aborted flowers and young pods.

Scientists and producers haven't learned to take full advantage of the soybean plant's potential. Practices such as fertilization, narrow rows, proper planting rates, irrigation, and weed control are all attempts to reduce the amount of floral and pod abortion and thus increase yields.

Fig. 15. Fourth node of R3 plant.

Fig. 16. R3 plant.

R4 Stage

R4—Pod is 2 cm (¾ inch) long at one of the four uppermost nodes on the main stem with a fully developed leaf, figs. 17 and 18.

Plants at R4 are 71 to 99 cm (28 to 39 inches) tall and are in the V13 to V20 stage. This period is characterized by rapid pod growth and by beginning seed development.

The period from R4 to shortly after R5.5 is a period of rapid steady dry weight accumulation by the pods. Some individual pods on the lower nodes of the main stem are full size or close to full size now (fig. 18), but many pods will be full size by the R5 stage, see fig. 25. Pods normally attain most of their length and width before the beans begin to develop rapidly, see fig. 27. Thus, toward the end of this period, some beans within the lower node pods have begun rapid growth.

Some of the last flowering to occur on the plant is at the main stem tip where a floral cluster appears, fig. 20. This cluster consists of axillary flowers bunched together from the tip nodes that haven't separated. Flowering on the upper nodes of the branches is also the last to occur on the plant.

Management Guides

The R4 stage marks the beginning of the most crucial period of plant development in terms of seed yield determination. Stress (moisture, light, or nutrient deficiencies; high temperatures, lodging, or hail) occurring anytime from R4 to shortly after R6 will reduce yields more than the same stress at any other period of development. The period from R4.5 (late pod formation) to about R5.5 is


Fig. 17. R4 plant.


Fig. 18. R4 stem.

Fig. 19. Young pod cut open.

especially critical because flowering becomes complete and can not compensate, and because young pods and seeds are more prone to abort under stress than older pods and seeds. Yield reductions at this time result mainly from reductions in total pod numbers per plant, with lesser reductions occurring in beans per pod and possibly seed size. Seed size may actually compensate somewhat if growing conditions are favorable after R5.5. However, compensation by seed size is genetically limited. Thus, the plant essentially has no way to compensate for abortion-causing stresses that occur during R4.5 to R5.5.

Where possible, irrigate to assure adequate moisture during these crucial periods.

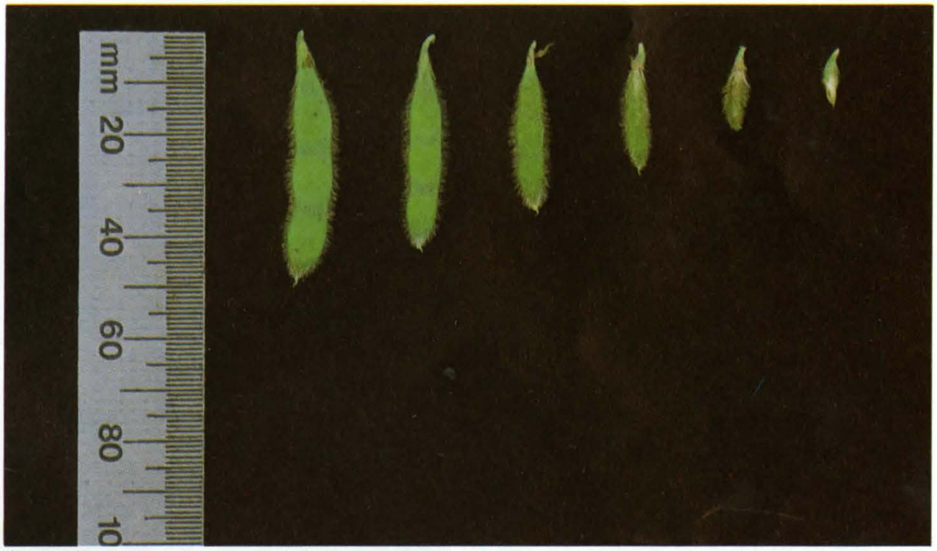

Fig. 22. Sequence of young pod development.


Fig. 21. Raceme.


Fig. 20. Floral cluster at stem tip.

R5 Stage

R5—Seed is 3 mm (⅛ inch) long in the pod at one of the four uppermost nodes on the main stem with a fully developed leaf, figs. 23, 24, 25, and 26.

Plants at R5 are 76 to 109 cm (30 to 43 inches) tall and are in the V15 to V23 stage. This period is characterized by rapid seed growth or seed-filling, figs. 27 and 28, and redistribution of dry weight and nutrients within the plant to the growing seeds, see figs. 38, 39, and 40.

At initial R5, reproductive development ranges from flowers just open to pods containing seeds 8 mm long, fig. 27. Midway between the R5 and R6 stages, several events occur close to the same time. At about R5.5: (1) the plant attains its maximum height, node number, and leaf area; (2) the high nitrogen-fixation rates peak and begin to drop rapidly; and (3) the seeds begin a period of rapid steady dry weight and nutrient accumulation. Shortly after R5.5 dry weight and nutrient accumulation in the leaves, petioles, and stems maximizes and then begins to redistribute (relocate) from these plant parts to the rapidly developing seeds. The period of rapid steady seed dry weight accumulation continues until shortly after R6.5, during which time about 80 percent of the total seed dry weight is acquired.

Seed yields depend upon the **rate** of dry weight accumulation in the seeds and the **length of time** that dry weight accumulates in the seeds. There is often relatively little difference between adapted varieties in the rate of dry weight accumulation, but they do vary in the length of time that dry weight accumulates in the seeds. Stress may influence both the rate and length of time that dry weight accumulates in seeds.

Fig. 23. R5 plant.

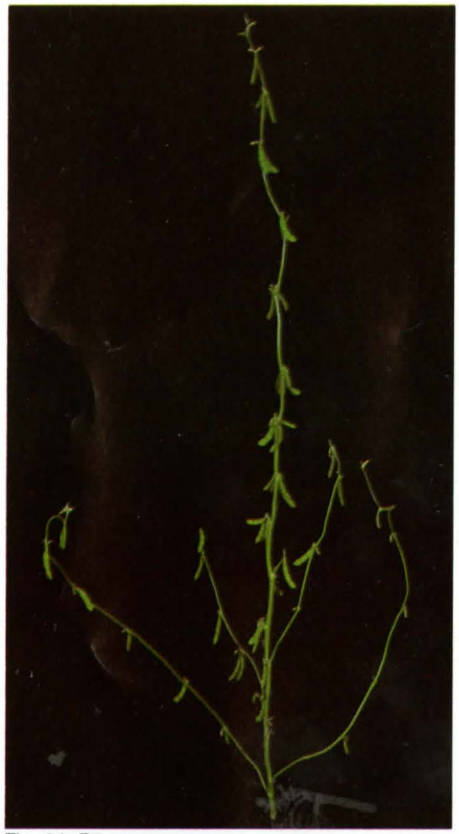

Fig. 24. R5 stem.

Fig. 25. Stem of R5 and R4 plants.

Fig. 26. Fourth node pod and bean of R5 plant.

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Demand for water and nutrients is large throughout the rapid seed-filling period. During this entire period the beans acquire about half of their N, P, and K by redistribution from vegetative plant parts, and about half by soil uptake and nodule activity. This redistribution of nutrients from plant parts occurs regardless of the soil nutrient availability. Water deficiencies may reduce nutrient availability because roots cannot take up nutrients or grow in upper soil areas where the soil dries. Thus, at least part of the P and K must be located where the soil will likely be moist and the nutrients will be available to the plant.

One hundred percent leaf loss (such as by hail) anytime between R4.5 to R5.5 can reduce soybean yields by more than 80 percent. Stress conditions occurring from the R5.5 to R6 period also may cause large yield reductions. Yield reductions during R5.5 to R6 occur mainly as fewer pods per plant and fewer beans per pod; and to a lesser degree, as less weight per bean.

Fig. 28. Side view of pod and seed development during R5. Beans are 5, 7, 8, 10, and 11 mm long.

Fig. 27. Rapid pod and seed development with beans 3, 5, 7, 8, 10 and 11 mm long during R5.

R6 Stage

R6—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, figs. 29 and 30.

Plants at R6 are 79 to 119 cm (31 to 47 inches) tall and are in the V16 to V25 stage. Because plant height and node number maximized at about R5.5, little increase in these factors is evident between R5 and R6.

The R6 bean or "green bean" (fig. 31) is characterized by width equal to its pod cavity; however, beans of all sizes, as in figs. 27 and 28, may be found on the plant at this time. Total plant pod weight maximizes at about R6.

Growth rate of the beans and whole plant at R6 is still very rapid. This rapid rate of dry weight and nutrient accumulation begins to slow in the whole plant shortly after R6, and at shortly after R6.5 in the seeds. Dry weight and nutrient accumulation maximizes in the whole plant shortly after R6.5 and in the seeds at about R7, figs. 38, 39, and 40.

Rapid leaf yellowing (visual senescence) over the plant begins shortly after R6 and continues rapidly to about R8, or until all leaves have fallen. Leaf senescence and falling begins on the older lowest node leaves, and subsequently spreads upward to the younger leaves. Three to six trifoliolate leaves may have already fallen from the lowest nodes before rapid leaf yellowing begins.

Root growth is essentially complete shortly after R6.5.

Fig. 29. R6 plant.

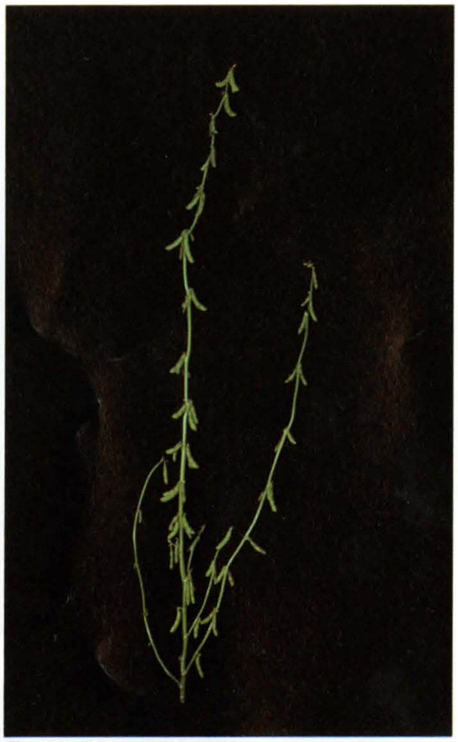

Fig. 30. R6 stem.

Fig. 31. Fourth node pod and bean of R6 plant.

R7 Stage

R7—One normal pod on the main stem that has reached its mature pod color, figs. 32 and 33.

Physiological maturity of an individual soybean seed occurs when the accumulation of dry weight ceases. This first occurs when the seed (and generally the pod) turns yellow, or has completely lost all green color. Although not all pods on the R7 plant (figs. 32 and 33) have lost their green color, the plant is essentially at physiological maturity because very little additional dry weight will be accumulated. The soybean seed at physiological maturity is about 60 percent moisture and contains all necessary plant parts to begin the next generation soybean plant.

Figure 34 displays a green R6 pod and beans, a completely yellow pod and beans at physiological maturity, and a pod and beans at mature color ready for harvest.

Management Guides R6-R7

As pods and seeds mature, they become less prone to abort. As a result, the total number of pods per plant and number of beans per pod gradually becomes set with plant maturity. Although an older seed may not abort (fall from the plant) under stressful conditions, the length of the period of rapid seed dry weight accumulation may be shortened, which in turn causes smaller seed size and reduced yields.

As the soybean plant matures past R6, the **potential** degree of yield reduction by stress gradually declines. From R6 to R6.5 stress may cause large yield reductions mostly by reducing seed size, but also by reducing pods per plant and beans per pod. Yield reductions from stress occurring from R6.5 to R7 are much smaller because the seeds have already accumulated a sizable portion of their mature dry weight. Stress occurring at R7 or thereafter essentially has no effect on yield.

Figure 35 shows the redirection of leaf growth toward the sun after a soybean plant partially lodges. The tendency for lodging increases as plants grow taller. High plant populations, narrower row spacings, irrigation, and high seasonal rainfall increase plant height and lodging. Lodging reduces yields by causing increased harvest losses and inefficient use of sunlight by the plant.

Fig. 32. R7 plant.

Fig. 33. R7 stem.

Fig. 34. Green (R6), yellow (physiological maturity), and brown (harvestable) pods with enclosed beans.

Fig. 35. R6 lodged plant.

R8 Stage

R8—Ninety-five percent of the pods have reached their mature pod color, fig. 36. Five to 10 days of drying weather are required after R8 before the soybeans have less than 15 percent moisture.

Figure 37 displays the sequence of color and size changes the soybean pod and beans undergo from the green R6 beans (left) to the mature beans ready for harvest (right). The second from right pod and beans in fig. 37 are at their mature color, but have not attained their harvest shape and moisture content. Thus, mature pod color does not always indicate harvestable readiness of the beans within. With favorable drying weather, soybeans will lose moisture quickly.

Management Guides

Sub-optimum plant densities become readily apparent at harvest time. Above-optimum plant densities cause lodged plants that are difficult to harvest, thus leaving potential yield in the field. Below-optimum plant densities cause branching and low pod set. Heavily podded branches break off and fall to the ground easily. Also, pods produced very close to the ground are difficult or sometimes impossible to harvest mechanically.

Timeliness of harvest is very crucial for soybeans. Ideal bean moisture content at harvest and for storage is 13 percent. Although harvest may begin at higher moisture percentages, some drying costs will be encountered for safe storage. In contrast, harvest delayed to less than 13 percent moisture causes increased pre-harvest shatter loss, sickle-bar shatter loss during harvest, and increased number of split beans.

To reduce harvest losses: drive slowly, check concave clearance, cylinder speed, sieves, and air velocity. Be sure reel speed and ground travel are synchronized to minimize sickle-bar shatter loss. Leave a short stubble. A 9 cm (3.5 inch) stubble contains 5 percent of the crop; a 6.5 cm (6.5 inch) stubble, 12 percent.

Fig. 36. R8 plant.

Fig. 37. Green (R6) to brown (harvestable) pod and bean sequence.

Summary

How a Soybean Plant Grows
The rate of increase in soybean plant dry weight is very slow at first but gradually increases through the V stages and R1 as more leaves develop and ground cover increases. At about R2, the daily rate of dry weight accumulation by the whole plant is essentially constant until it gradually decreases during the late seed-filling period (shortly after R6) and measurably stops shortly after R6.5, fig. 38. This dry weight accumulation is initially in the vegetative plant parts, but between R3 to R5.5 accumulation gradually shifts to the pods and beans, see figs. 10 and 38.

Rate of growth of the leaves, petioles, and stems closely follows that of the whole plant until the pods and beans begin growth, or at about R4. Shortly after R5.5, dry weight maximizes in these vegetative parts and begins to relocate in the rapidly developing beans. Leaf and petiole loss begins at V4 to V5 on the lowest node leaves and petioles and progresses very slowly upward until shortly after R6, fig. 38. At this time, leaf and petiole loss becomes rapid and continues until R8 when generally all leaves and petioles have fallen, see fig. 36.

Root growth begins upon germination when the primary root emerges from the planted seed. Under favorable conditions, the primary root and several major lateral roots grow strongly until about R5 when they may be 1.2 to 1.5 m (4 to 5 feet) deep in the soil. At this time, most of the soybean root system consists of branch and minor lateral roots that have proliferated in the upper 23 to 30 cm (9 to 12 inches) of soil. After R5, these shallower roots begin to degenerate, but the deep growing primary root and major lateral roots continue to grow deeper into the soil until shortly after R6.5 when root growth completely stops.

A portion of the nitrogen used by the soybean plant is made available by fixation of N from the air by *Rhizobium japonicum* bacteria in the root nodules. These bacteria infect the roots causing nodule production as early as the V1 stage, see fig. 1. Throughout the V stages, the number of nodules increases (see fig. 14) along with the rate of N-fixation. At about R2, the N-fixation rate increases dramatically, peaks at about R5.5, and drops rapidly thereafter.

Flowering is initiated at R1 on the third to sixth main stem node and progresses upward and downward from there. These first flowers generally appear at the base of a raceme, see fig. 13. With time, the raceme elongates (see fig. 21) while new flowers appear progressively toward the raceme tip. By the R5 stage, the plant has completed most of its flowering but a few newly opened flowers may be present on branches and upper main stem nodes. Almost all soybean flowers pollinate themselves at, or a little before, the time of flower opening.

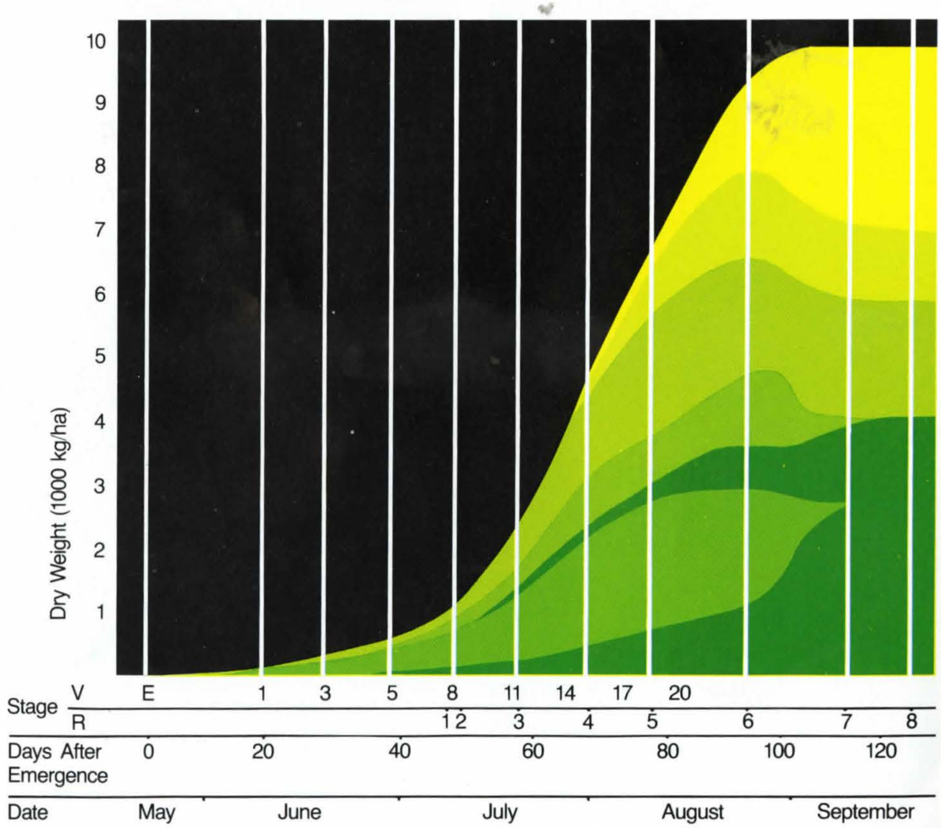

Fig. 38. Total plant dry weight

Three to 4 days after an individual flower opens, the flower petals are dried out and the pod (fruit) begins to elongate. By 2 to 2½ weeks after this individual flower opens, a full length pod has formed. Pod growth on the whole plant is rapid between R4 and R5, since only a few full length pods are present on the lowest nodes at R4, see fig. 18. Many pods have reached mature length at R5 (see figs. 24 and 25), however, and by R6 almost all pods are mature length, see fig. 30.

The beans (seeds) within an individual pod do not begin to grow rapidly until the pod is full length and the beans are 7 to 8 mm (0.3 inch) long. Since the largest individual beans on a plant at R5 are about 8 mm long, (see fig. 27) these few beans are beginning rapid dry weight accumulation at this stage. By R5.5, the combined rate of dry weight accumulation by **all** beans on a plant is rapid and essentially constant. This rapid whole plant bean growth begins to slow shortly after R6.5 and measurably stops by the R7 stage.

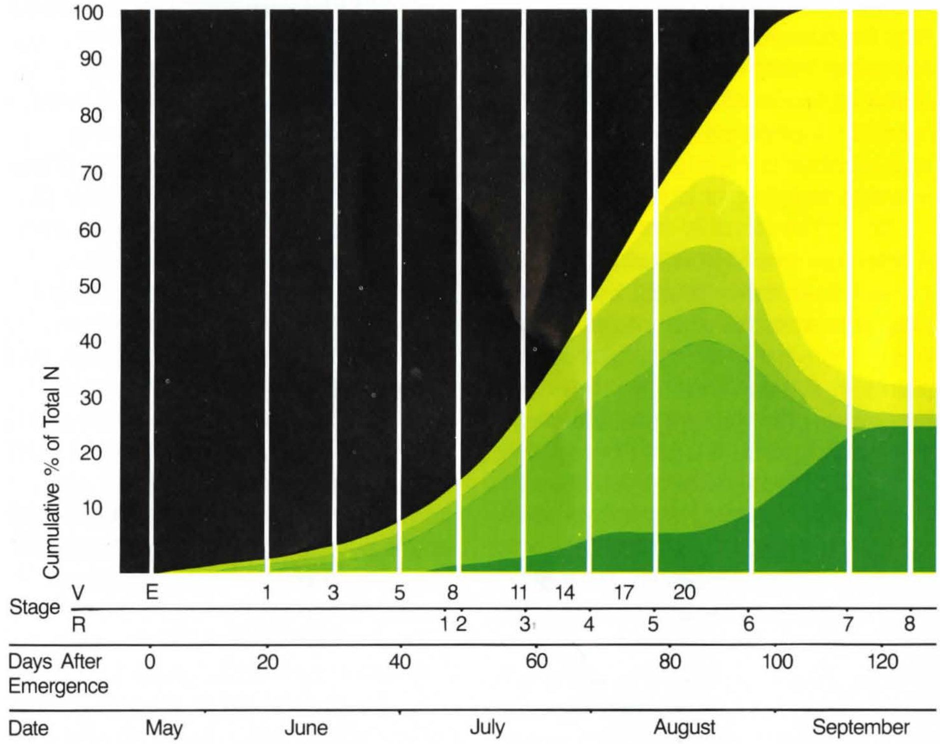

Fig. 39. Nitrogen

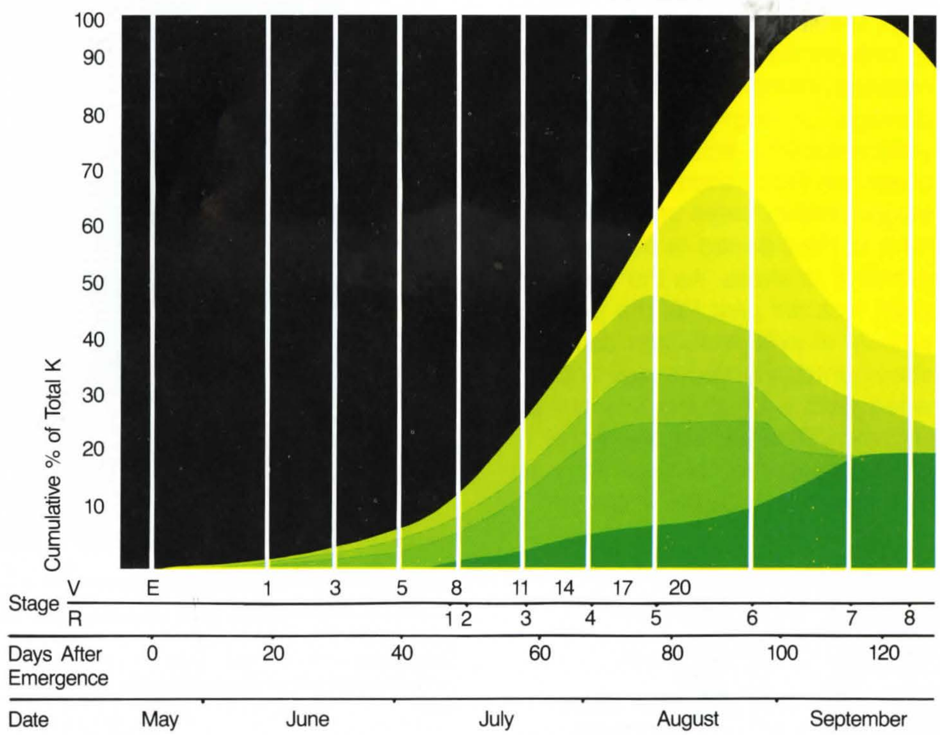

Fig. 40. Potassium

Beans
Pods
Stem
Petioles
Leaves
Fallen Leaves and Petioles

Yield (total seed weight) of soybeans may be described by the following equation: Yield = average number of plants per hectare × average number of pods per plant × average number of beans per pod × average weight per bean.

A soybean plant grown without competition from other plants will branch profusely and develop into a large plant. Increasing the number of plants in a given area (plant density) increases plant height and lodging tendencies, reduces branching and pod number per plant, but allows more pods and beans per unit area up to an optimum plant density. The optimum plant density is different for different varieties and growth environments.

The environment in which a soybean variety grows is extremely influential upon the plant's development and yield. Environmental stress occurring at any stage of soybean development will reduce yields. Stress such as nutrient deficiencies, inadequate moisture, hail damage, insect damage, or lodging cause greatest yield reductions when occurring between the R4 to shortly after R6 stages. Within these stages, the R4.5 to R5.5 period is especially sensitive to stress. As the soybean plant matures past R6, the potential amount of yield reduction caused by stress gradually decreases until R7 when yield is unaffected by stress. Highest yields are obtained only where environmental conditions are favorable at all stages of growth.

Nutrient Requirements and Uptake by Plants

Soybean plants (as well as the symbiotic bacteria associated with them) require all of the following nutrient elements: nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), magnesium (Mg), iron (Fe), boron (B), manganese (Mn), zinc (Zn), copper (Cu), and molybdenum (Mo). Most nutrients are absorbed from the soil; however, part of the N is obtained from bacterial fixation in the nodules and some S is absorbed (primarily as SO_2 and H_2S) from the air. Soil nutrients are absorbed into the plant roots with water and move up into the plant to the leaves and other vegetative plant parts.

The amounts of nutrients available vary with soil type, depth of soil, and tillage practices, and are influenced by soil temperature and moisture conditions. Roots will not grow into dry soil and moisture must be present for roots to absorb nutrients from the soil. However, excess moisture in the soil limits aeration, and roots also require air (oxygen).

The seasonal patterns of accumulation of different nutrients in the different parts of soybean plants are illustrated in figs. 39, 40, and 41. The amounts of nutrients taken up by the plants early in the season are relatively small because the plants are small. However, the nutrient concentration in individual leaves of well nourished plants are as high during

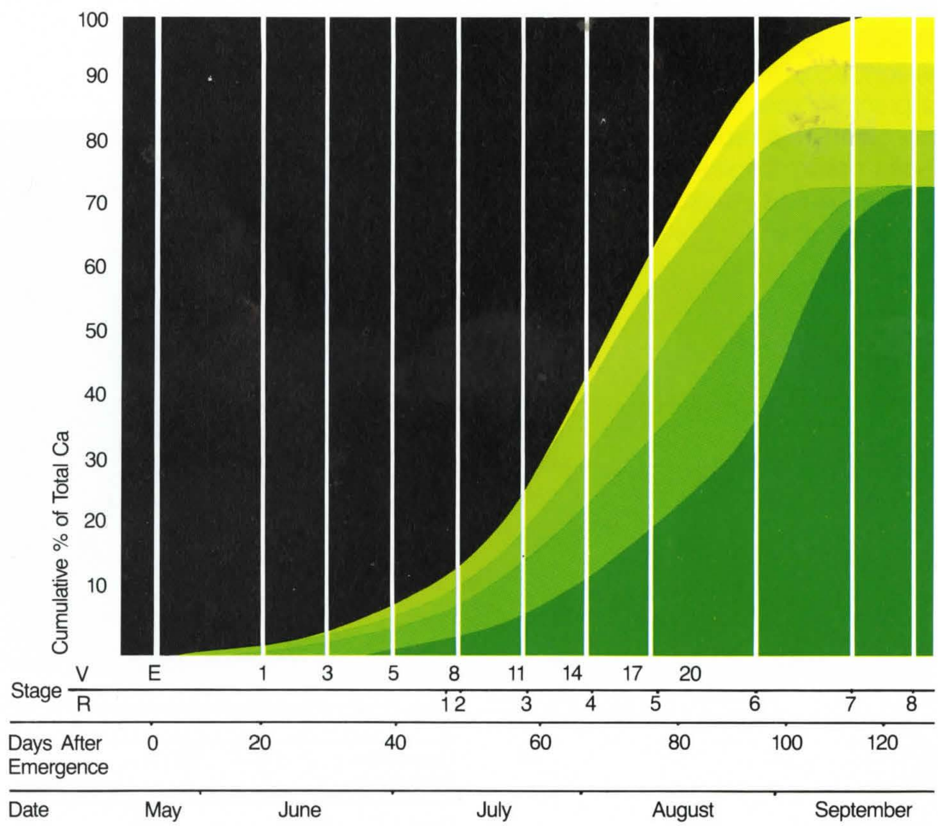

Fig. 41. Calcium

this period as individual leaves later in the season. Uptake and accumulation of some nutrients in the plants continues throughout the season until maturity (fig. 41); uptake of others is nearly completed by stage R6, fig. 39.

Redistribution of mineral nutrients from older plant parts to newer growing parts is a primary source for some nutrients. Some nutrient elements are very mobile in the plants and are readily translocated from older to newer plant parts. Redistribution of N, P, and S (shown for N in fig. 39) is a primary source of these nutrients for growth of the beans and results in severe depletion of these elements in the leaves, petioles, stems, and pods during the late seed-filling period. However, some nutrients such as calcium are very immobile in the plants and there is little redistribution of these elements from older to new plant parts. Late season redistribution of mobile materials that have accumulated in leaves and other plant parts without redistribution of Ca results in increased Ca concentration in the leaves late in the season, fig. 41.

Redistribution of other elements in the plant generally are intermediate between the extremes for very mobile N and immobile Ca. P and S are very similar to N. K is redistributed from the vegetative plant parts to the developing seeds, but is not redistributed from the pods. Zn and Cu are redistributed but not to the same degree as N. Mn, Mg, Fe, B, and Mo are relatively immobile but not as immobile as Ca. Very marked differences in mobility of Fe have been observed among different soybean varieties.

Fertilizer Use and Fertility Management

When the soil cannot supply the plant nutrient requirements, fertilizers must be added to supplement the nutrient supply. Uptake of nutrients added to soils is not always an efficient process. Under good conditions, the recovery in the year of application ranges from 5 to 20 percent for phosphorus and 30 to 60 percent for potassium.

Nutrients Most Commonly Deficient:

1. Nitrogen is fixed and made available to the plants by the bacteria in the nodules on the roots. Where soybeans have not been grown previously, inoculation is needed to supply the desired bacteria. Liming of acidic soils is usually beneficial. By making conditions favorable for N-fixation, the need for N fertilization of the soil is eliminated.

2. The availability of phosphorus and potassium in many soils is not adequate for optimum soybean yields so fertilizers to supply these nutrients should be applied where needed.

3. Applications of some of the other nutrients are desirable on some soils where deficiencies exist. S, Fe, B, Mn, or Zn are the elements that are most commonly deficient.

Pointers for High Yields

The illustrations tell us that the yield produced by the soybean plant depends upon the **rate** and **length of time** of dry weight accumulation. To produce high yields, therefore, carry out all known cultural practices to maximize the rate and length of time of dry weight accumulation in the grain. These practices include:

1. Fertilize according to soil test.
2. Prepare an adequate seedbed.
3. Select the variety best suited to your farm.
4. Plant at the optimum inter-row population and row spacing (plant density).
5. Control competition from weeds, diseases, and insects.
6. Avoid ridging when cultivating.
7. Harvest all you produce.

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