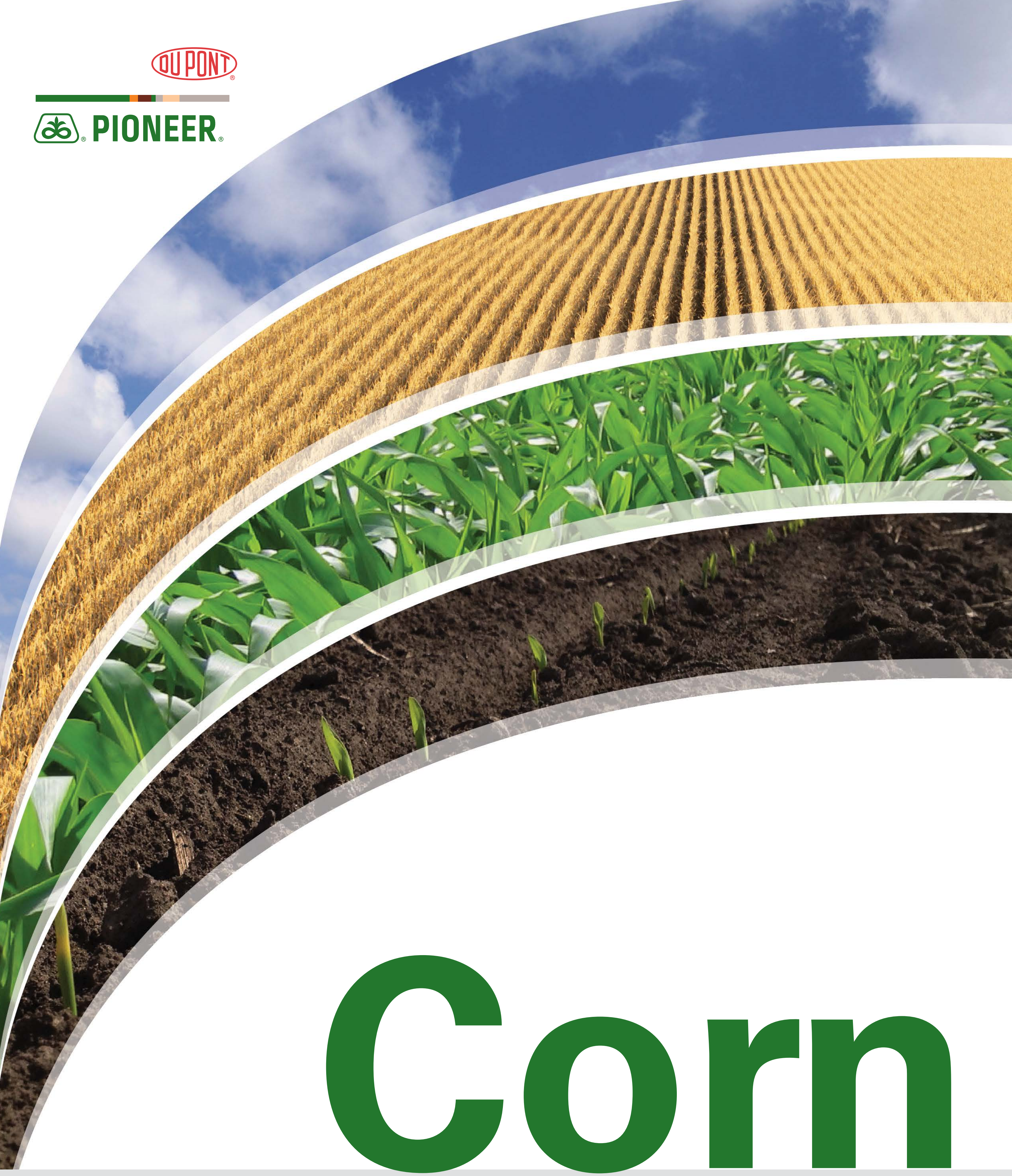

Corn

Growth and Development

Introduction

Corn Growth and Development by DuPont Pioneer is a reference to assist with the understanding of the various vegetative and reproductive stages of corn. This document is intended to be concise, educational, and informative for those individuals that work with and produce corn. All DuPont Pioneer employees have exclusive rights to use this document and quote information directly without restriction. Photographic images contained within the Corn Growth and Development reference guide are subject to copyright protection.

For this document, we have chosen to discuss only the physiological stages of corn development without giving recommendations on tillage, nutrients, and other variable corn management decisions as they vary from country to country, and within countries. There are abundant other DuPont Pioneer and local resources to assist with corn management decisions.

Visit www.pioneer.com for more agronomic information or contact your local Pioneer sales representative, Dealer, or DuPont Pioneer agronomist.

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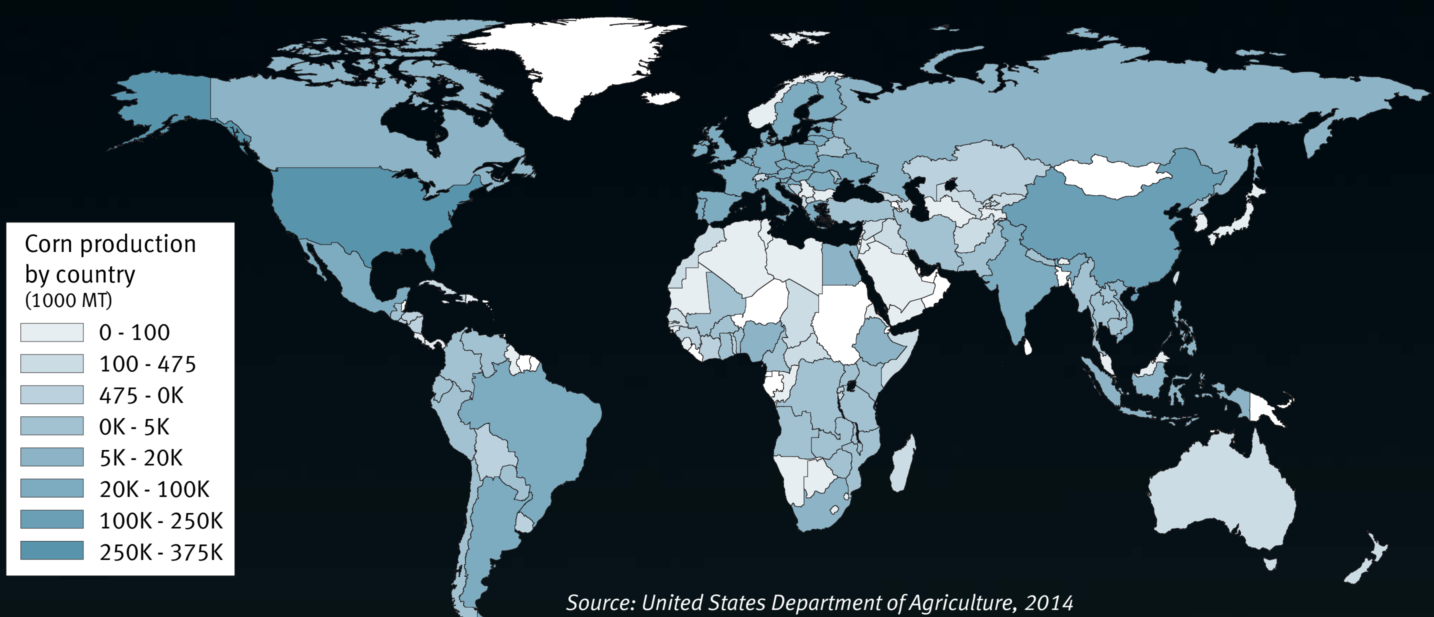
Corn: The King of Crops

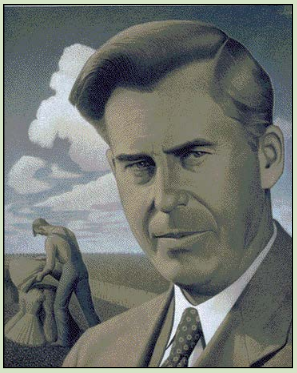
Corn (*Zea mays*, L.), or maize, as it is known in many areas outside the United States, is grown for grain or silage on nearly 464 million acres (188 million hectares) worldwide. In the past decade, total corn area has increased more than 20 percent, with most of that growth occurring outside the United States.

The United States alone produces more than 35 percent of the world's total corn grain. Although global wheat area exceeds corn, and rice area is nearly as large as corn, global corn production (tons) far exceeds either. Thus, corn production plays a significant role in world agriculture, both economically and agronomically.



Source: United States Department of Agriculture, 2014

Henry Agard Wallace



learned about agriculture from his father, a farmer, university professor, and former Secretary of Agriculture. Wallace became acutely interested in corn in 1903, at age 15, when he watched Iowa State professor Perry G. Holden, judge a corn show. He wondered how the prize-winning ears of corn would do in the field. The next spring, Wallace's father (Henry Cantwell Wallace) encouraged him to plant kernels from the "best" and "worst" samples side-by-side. When the fall harvest came, Holden and the Wallaces were surprised to find the highest yield came from the samples that Holden had judged among the worst. From then on, Wallace campaigned against "pretty ear" corn shows until they lost their significance in the 1930s.

Wallace graduated from Iowa State in 1910 as top man in the College of Agriculture. During his college years, he had taken an interest in Dr. George Shull's pure-line corn breeding, a practice which stimulated his own ideas for corn variety improvement. In 1913 he produced his first hybrid in his own backyard garden in Des Moines. In 1926, Wallace formed what was then called the "Hi-Bred Corn Company" with a small group of Des Moines businessmen.

"Pioneer" was added to the title in the mid-1930s to distinguish it from other hybrid companies that had sprung up elsewhere. Looking beyond the common practice of saving the seed from one year's crop to plant the next, Wallace perceived the possibility of improving corn production through the selected inbreeding of varieties. He was convinced that growing corn from hybrid seed was the wave of the future and that there was a vast marketplace for the product once farmers could be convinced of its benefits.

By the end of the 1930s, Pioneer had expanded its corn selling activities into Minnesota and South Dakota and eastward into Illinois, Indiana, and Ohio. By World War II, Pioneer was one of the leading suppliers of hybrid seed corn planted in the country, providing 90 percent of the hybrid corn raised by farmers in the United States Corn Belt states (Iowa, Illinois, Indiana, Ohio, Minnesota, Nebraska, Kansas, Missouri, and South Dakota).

Wallace left Pioneer in 1933 to be the United States Secretary of Agriculture, and eventually became the Vice President of the United States (1941-1945) during the administration of Franklin D. Roosevelt.

In the 1960s, members of Pioneer shared a deep interest in improving world food supplies, and believed the company should apply its genetic expertise at every opportunity, which led Pioneer to greatly expand its foreign operations.

Corn Hybrids

Modern corn hybrids have little resemblance to corn's most distant ancestor, teosinte.

A corn hybrid is produced when the pollen from one inbred line is used to pollinate the silks of another inbred line. Once this takes place, heterosis, or hybrid vigor, results and the plants produced from hybrid seed tend to be more robust with improved characteristics, including increased grain yield. The more unrelated the two inbreds are, the more heterosis created.

Hybrid seed production relies on the use of inbred lines, which are developed by the self-pollination of silks by pollen produced on the same plant. This process is repeated through several generations, until the inbred line is considered genetically pure and as homozygous as possible.

Prior to the 1930s, "races" or "varieties" of corn were open-pollinated. At harvest, farmers would visually select the largest, best-looking ears and save the kernels to plant the next season. This method resulted in "unintentional" selection for certain traits, either favorable or unfavorable. As this process continued, certain races or varieties, were selected with definite characteristics in different regions and were even given local names, like Bloody Butcher, etc. Various versions of this process are still used in some corn producing areas of the world.

The United States began using hybrid corn seed in the early 1920s. Hybrid corn performance was proven in the adverse years of the 1930s, when farmer demand for hybrid seed increased dramatically (Troyer, 2009). In the early years of hybrid use, most were the result of double-crossing the parent stock, which used four parent inbred lines. From the 1950s on, single-cross hybrids, using only two parent inbred lines, predominated and now nearly all hybrid corn seed in the United States is comprised of single crosses. Many corn producing areas outside of the United States still use double and three-way cross hybrids.

Modern hybrids in the United States are often the result of the crossing of the Southeastern Dent selections with the Northwestern Flint selections (Galinat, 1988). (Figure 1)

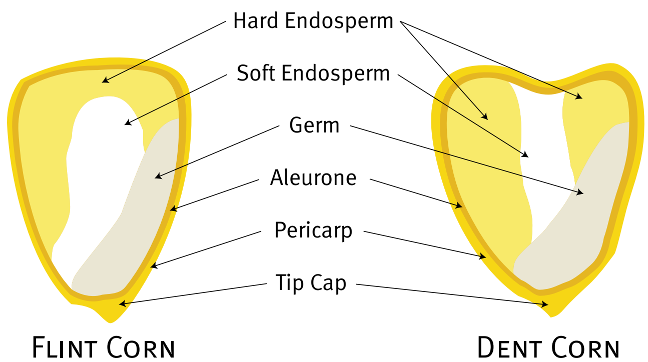


Figure 1. Comparison of the components of typical flint and dent kernels.

Teosinte: *The Ancestor of Modern Corn*

Teosinte is an annual grass native to Mexico and Central America. Approximately 9,000 years ago, farmers began selecting for plants with certain mutations and, through a series of selections consisting of only about five genetic mutations, modern *Zea mays* was developed. The images at right show a teosinte plant, tassel, and ear from left to right, respectively.

Teosinte images courtesy of Tom Schultz, DuPont Pioneer

The Corn Plant

Corn is a monoecious plant, which means it produces separate male and female flowers on the same plant. The tassel (male flower) produces pollen (Figure 2), while the ear (female flower) produces ovules that become the seed (Figure 3).

As shown in Figure 4, there is a vertical separation of about three to four feet (1 meter) between the flowers, which can add to the challenge of successful pollination.

In terms of production, the tassel can produce more than 1,000,000 pollen grains, and the ear can produce more than 1,000 silks. Consequently, there are approximately 1,000 to 1,500 times as many pollen grains as silks produced. In theory, 20 to 30 plants could fertilize all the silks in one acre (0.405 hectares), but not all the pollen shed by a plant lands on a silk.

Figure 2. Fully emerged corn tassel (male flower).

Figure 3. Immature corn ear (female flower) showing emerging silks.

Figure 4. Vertical separation between the male and female flowers on a corn plant.

Figure 5. Corn tassel during pollen shed.

Pollen shed occurs discontinuously for a period of approximately five to eight days, and only sheds when temperature and moisture conditions are favorable (Figure 5). The peak time for pollen to shed is mid to late morning. The average life span of a pollen grain is approximately 20 minutes after it is shed, and most of the pollen that is shed by a plant falls within 20 to 50 feet (6 to 15 meters) of that plant. However, pollen can be transported much greater distances by the wind. It has been estimated that roughly 97 percent of kernels produced are fertilized with pollen from another plant.

Silks emerge from the husk over a period of three to five days, starting with those silks attached at the lower middle portion of the ear and progressing toward the ear tip. Depending on the environment, an individual silk continues to grow for about seven days or until the silk intercepts pollen grains (Figure 6). Research studies have shown that typically, a minimum of five pollen grains must land on each silk and start pollen tube growth (Figure 7) to ensure that genetic material from one of these pollen grains successfully fertilizes the ovule. Immediately after fertilization, the ovule creates an abscission layer at the base of the silk that restricts entry of genetic material from other pollen grains. The silk then detaches from the developing kernel, begins to desicate, and turns brown. If the ovule is not successfully fertilized within this seven day window, the silk dies, the unfertilized ovule eventually disappears, and the portion of the cob to which this ovule is attached becomes barren.

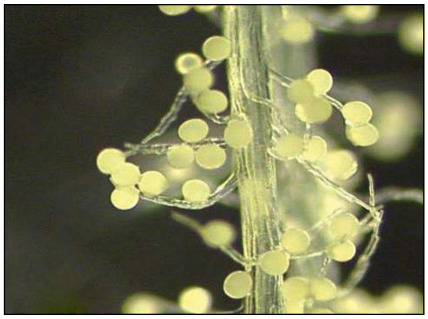


Figure 6. Pollen attached to silk trichomes.
Courtesy of Dr. Don Aylor, University of Connecticut.

Kernel set (actively growing kernels after pollination) can be checked two or three days after pollen shed stops by carefully removing the husks from an ear and then gently shaking the ear to see if the silks are detached. Silks drop off ovules that have been successfully fertilized (kernels), but any ovule that retains a silk has not been fertilized and no kernel will develop (Figure 8).

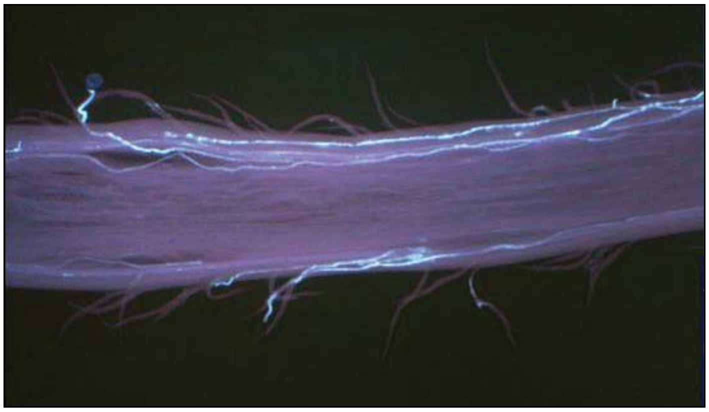


Figure 7. Pollen tubes growing along silk vascular tissue.
Courtesy of Dr. Antonio Perdomo, DuPont Pioneer.

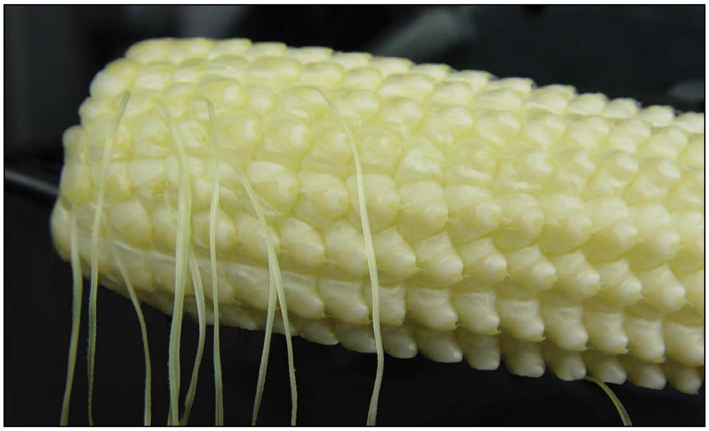


Figure 8. Corn ear at R1 with husks removed, showing attached silks where ovules were not pollinated. (R = Reproductive developmental stages, R1 = Silking).
Courtesy of Sandy Endicott, DuPont Pioneer.

It is important that pollen shed and silk emergence happen concurrently to ensure successful pollination, which is called “nick.” However, with today’s modern hybrids, it is not unusual to see silks emerging from the husks one or two days before full tassel emergence occurs. This is a large change from hybrids of a few decades ago, and has resulted in a greatly improved pollination process and higher yields.

Figure 9. Ears showing results of pollen exposure from one to seven days before having a bag placed over the ear to stop pollination.
Courtesy of Jason DeBruin, DuPont Pioneer.

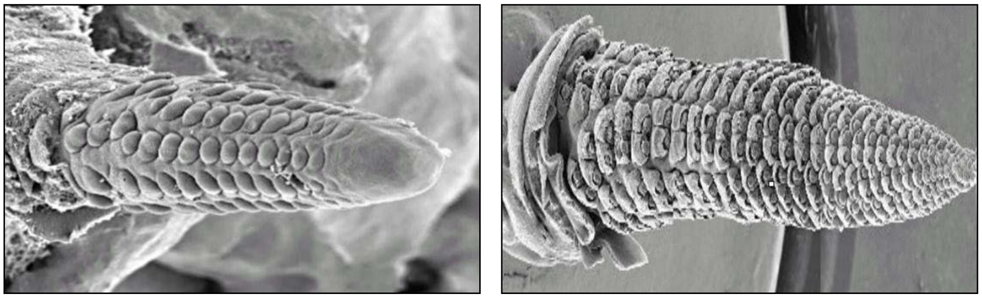


Figure 10. Development of the primary ear at V9 (left) and V12 (right). V9 ear showing node 14 (dome ~ 400µm). (V = Vegetative developmental stages).

Courtesy of Dr. Antonio Perdomo, DuPont Pioneer.

Growth and Development

In the corn producer's vocabulary, there are perhaps no two terms used more frequently than "growth" and "development." The two terms are often used interchangeably when, in fact, they have different meanings. Growth is simply an increase in size and is enhanced by favorable growing conditions (adequate moisture, nutrients, temperature, etc.), and decreased by stressful growing conditions (abnormal temperatures, deficiencies in nutrients, moisture, etc.). Development is the progression from one plant stage to a more advanced or mature stage.

Solar radiation is an essential input for plant growth and development. Plant leaves absorb sunlight and use it as an energy source for photosynthesis. A crop's ability to collect sunlight is proportional to its leaf surface area per unit of land area occupied, or its leaf area index (LAI). At full canopy, a crop's LAI and ability to collect available sunlight are maximized. From full canopy through the reproductive period, any shortage of sunlight is potentially limiting to corn yield. When stresses such as low light limit photosynthesis during ear fill, corn plants remobilize stalk carbohydrates to the ear. This may result in stalk quality issues and lodging at harvest. Sensitive periods of crop development, such as flowering and early grain fill, are when plants are most susceptible to stresses, including insufficient light, water, and/or nutrients.

Growing Degree Days

It has been demonstrated that the amount of time required for corn to pass from one developmental stage to another is contingent on the amount of heat accumulated (Gilmore & Rogers, 1958).

There are several known methods for estimating accumulated heat, with the most common method being that of Growing Degree Days (GDDs), also known as Growing Degree Units (GDUs) or Heat Units (HUs). This method is based on the use of minimum and maximum Farenheit temperatures for growth and development. For corn, these temperatures are:

Minimum = 50° F (10° C)

Maximum = 86° F (30° C)

There will be little, if any, growth below the minimum temperature of 50° F (10° C) or above the maximum temperature of 86° F (30° C). The concept of Growing Degree Days uses the following calculation:

$$GDD = (T_{min} + T_{max})/2 - 50\ (°\ F)$$

T_{min} = the minimum daily temperature, or 50° F (10° C) if temperature is less than 50° F (10° C)

T_{max} = the maximum daily temperature, or 86° F (30° C) if temperature is greater than 86° F (30° C).

The minimum number of GDDs that accumulate in one day would be 0 GDDs if the temperature stayed at or below 50° F (10° C) for the entire day, or maximum 36 GDDs, if the temperature remained at or above 86° F (30° C) for the entire day. By totaling accumulated Growing Degree Days for a specific time period, they can be used to predict crop development.

One difficulty with this method, however, is in the calculation of an "average" daily temperature based on the minimum and maximum temperatures for the day. No consideration is given for the duration or length of time the corn plant is exposed to any specific temperature during either the warming or cooling parts of the day. Over time these have a tendency to randomly balance and may not affect the resulting growth stage estimates.

Approximately 90-120 GDDs are required for a corn seedling to emerge following planting, but the exact number required may be affected by planting depth, solar radiation, moisture, tillage, or other factors. Although air temperature is monitored and reported, the speed of germination, seedling emergence, and subsequent growth while the growing point is below the soil surface is goverened by soil temperature (soil GDDs) at the seed zone. Soil GDDs employ a dominant role as the corn seed germinates and play a progressively diminishing role as the seedling grows through V stages until about V6. Air temperature inserts its dominant influence on the rate of corn growth after the growing point rises above the soil surface.

Determining Corn Developmental Stages

In determining the developmental stages of corn, it is important to know there is more than one system used to describe development.

The leaf collar system described in this publication, developed at Iowa State University, separates corn development into vegetative (V) and reproductive (R) stages. Use of this system marks defined physiological stages in plant development. This makes it easier to distinguish between stages, rather than using other indicator systems, such as plant height or exposed leaves. These other systems include the leaf tip number and the plant height systems (used by herbicide labels). The number of leaves exposed or plant height systems are not as accurate as the leaf collar system. Plants will respond to different environments/stresses and may be older than they appear if looking only at plant height. The leaf number system does not require collar formation to count, so it is open to interpretation, and may lead to less consistent staging.

In continuously warm parts of the world (tropical and subtropical regions), many farmers refer to "days to maturity." This is a measurement of the time from planting to "ready to harvest," and is a good tool to use in these parts of the world because daily high and low temperatures are very consistent.

In Canada, a system of Crop Heat Units (CHUs) is used that gives credit for time as well as temperature. Crop Heat Units accumulate even though all temperatures are below the minimum.

Table 1. Vegetative and reproductive stages.

Vegetative Stages		Reproductive Stages	
VE	Emergence	R1	Silking
V1	First leaf	R2	Blister
V2	Second leaf	R3	Milk
V3	Third leaf	R4	Dough
V(n)	nth leaf	R5	Dent
VT	Tasseling	R6	Mature

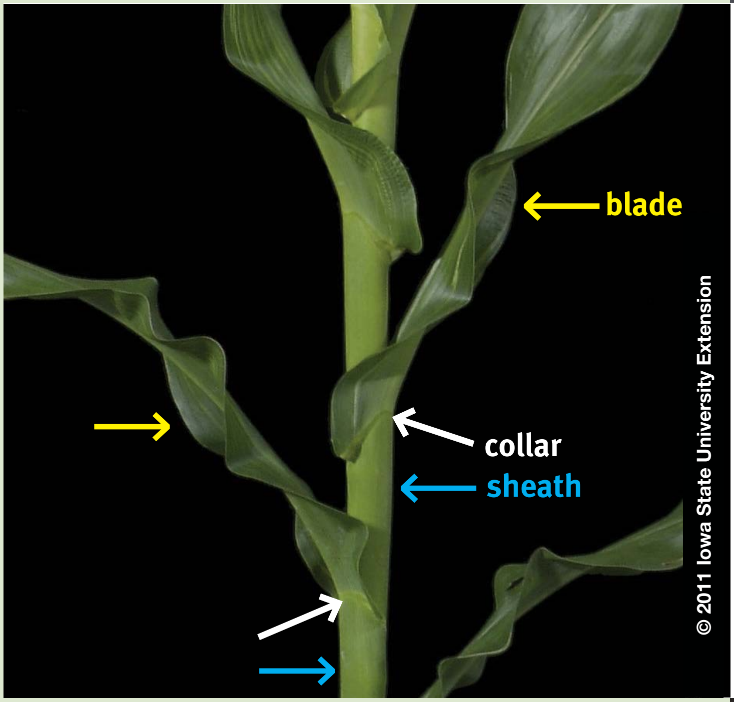


Figure 11. Corn plant showing fully emerged leaves with visible leaf collars.

Vegetative Stages

The vegetative stages (V) are characterized by the presence of a leaf collar on emerged leaves. The corn leaf has three main parts: the blade, sheath, and collar. The blade is the flat portion of the leaf that intercepts the sunlight, the sheath is the portion that wraps around the stalk, and the collar is the line of demarcation between the blade and sheath, usually with a distinct bend (Figure 11). As the corn plant grows, each succeeding leaf is pushed into view by the elongating stalk and by leaf expansion in sequence from the seed up to the tassel. The leaf tip is the first part visible, followed by the leaf blade, and finally by the leaf collar and sheath.

When a collar is visible, the leaf is considered fully emerged and is counted in the staging scheme. The vegetative stages (Table 1) of development begin with emergence (VE), and continue numerically with each successive leaf until the tassel emerges (VT).

Relative Maturity

Corn plants develop leaves based on their relative maturity and growing environment. Locally adapted hybrids in the United States Central Corn Belt (Iowa, Illinois, Indiana, and Ohio) typically develop 20-21 leaves. Early maturing hybrids may have as few as 11-12 leaves at full maturity, and the latest maturing hybrids in tropical environments may develop 30 or more leaves. Between VE and V14, each new collared leaf will appear after the accumulation of approximately 66 to 84 GDDs, depending on the hybrid (Figure 12).

Between V15 and VT, leaf development happens faster with each new collared leaf appearing after the accumulation of approximately 48 to 56 GDDs, depending on the hybrid.

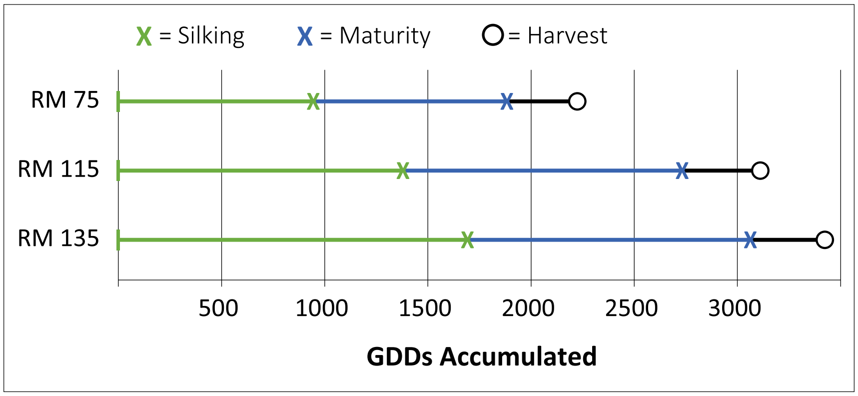


Figure 12. Comparison of 75, 115, and 135 relative maturity (RM) hybrids showing GDDs accumulated at silking and maturity.

Reproductive Stages

Reproductive stages are characterized by the appearance of developing kernels on the ear, except for the first reproductive stage (R1), which is identified solely by the emergence of silks from the husks (Figure 13). There are six reproductive stages (Table 1).

The average United States Corn Belt hybrid will silk (R1) approximately 60-65 calendar days (1,400 GDDs) after VE and will reach maturity (R6) approximately 125-130 calendar days (2,800 GDDs) after VE. Corn hybrids vary in the time required to reach physiological maturity when they are estimated using either calendar days or GDDs.

Figure 13. Corn silks emerge from the husk marking the first reproductive stage (R1).

Seven Key Components Of a Corn Seedling

Table 2. Corn seedling parts.

Seed coat (pericarp)	Comprises 5-6 percent of seed total weight
Endosperm (starch)	Comprises 83 percent of seed total weight and is composed of a hard starch outer layer surrounding a softer inner starch core
Embryo (germ)	Comprises 11 percent of seed total weight and consists of a plumule (embryonic plant) and the scutellum (cotyledon or seed leaf)
Coleoptile	Protective sheath that surrounds the emerging shoot
Mesocotyl	First internode or portion of the stem between the cotyledon and the first node
Radicle	Seed root or primary root
Coleorhiza	Protective sheath that surrounds the radicle

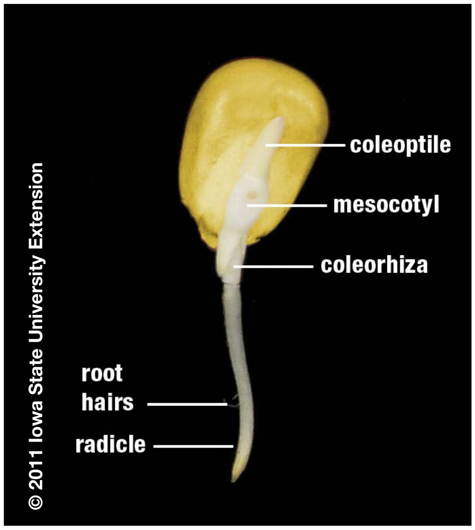


Figure 14. Germinated corn seedling.

Germination and Emergence (VE)

After a corn seed has been planted, it will imbibe water and absorb approximately 30-35 percent of its weight in water. It has been shown that soil temperatures have little effect on this process.

For the radicle to begin elongation, soil temperatures must be conducive to the germination process; a commonly accepted minimum soil temperature is 50° F (10° C). Shortly after the radicle emerges, three to four additional roots emerge from the seed. These roots and the radicle form the seminal root system which functions in the uptake of water and some nutrients for the seedling. Most nutrients for the seedling are supplied by hydrolyzed starches and proteins from the endosperm. Crown and nodal (permanent) root development is initiated at VE.

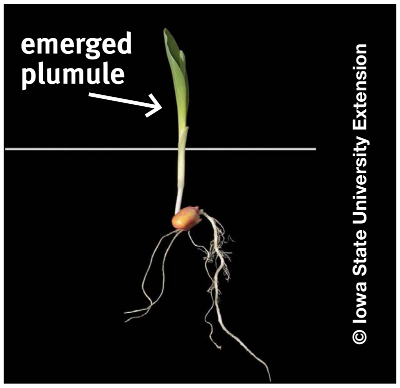


Figure 15. Emerged corn seedling (VE).

The corn plant demonstrates "hypogeal" emergence, where the cotyledon remains below the surface. The mesocotyl, or first internode, elongates and pushes the coleoptile tip to the soil surface. When the coleoptile breaks the soil surface, emergence (VE) has occurred. Sunlight disrupts coleoptile and mesocotyl elongation, which fixes the position of the crown and first nodal root at approximately 0.75 inches (2 cm) below the soil surface. This is a fairly constant measurement, unless seeding depth is exceptionally shallow (less than 1.5 inches or 3.8 cm). The apical meristem (growing point) and leaf initiates continue to elongate upward from this position (Figure 16).

Following emergence of the coleoptile, the seminal root system growth slows and then ceases at approximately V3. As the nodal root system grows, the seminal root system remains active, but progressively supplies a lower percent of the total water and soil nutrients for plant growth. The emerged coleoptile, with the enclosed plumule (embryonic plant), then elongates (Figure 15).

Embryonic leaves grow through the coleoptile and the first true leaf (rounded tip) emerges and is counted as the V1 leaf during early staging (Figure 16). The subsequent leaves all have pointed tips. Some scales do not count the rounded leaf and instead name this stage VC, between VE and V1.

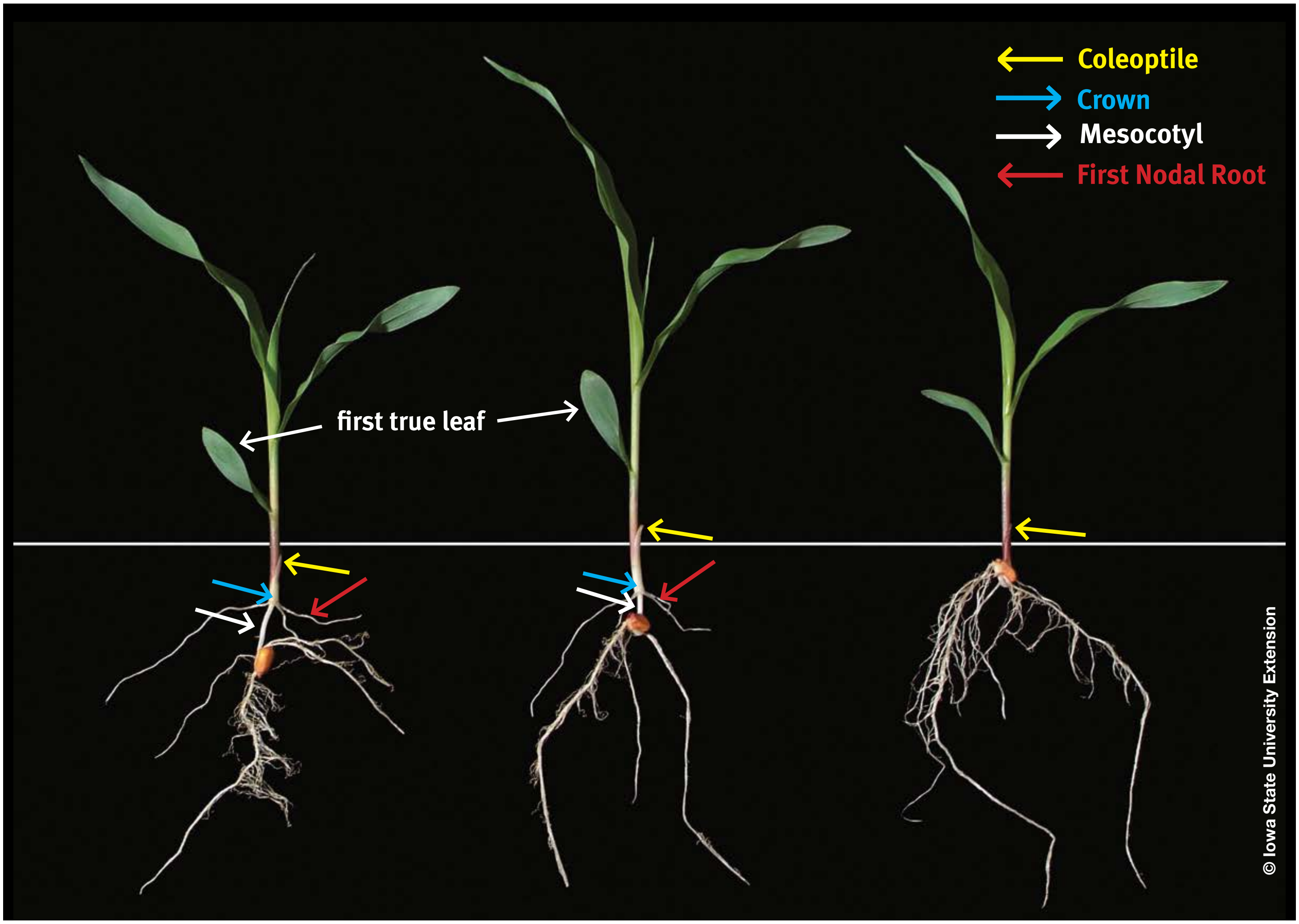


Figure 16. Three different variations in seeding depth showing coleoptile, crown, length of mesocotyl, and first nodal root placement. Note absence of mesocotyl, crown and first nodal root development on the shallow planted (less than 1.0 inches or 2.5 cm) corn seedling on the right.

Early Vegetative Stages (V1 to V5)

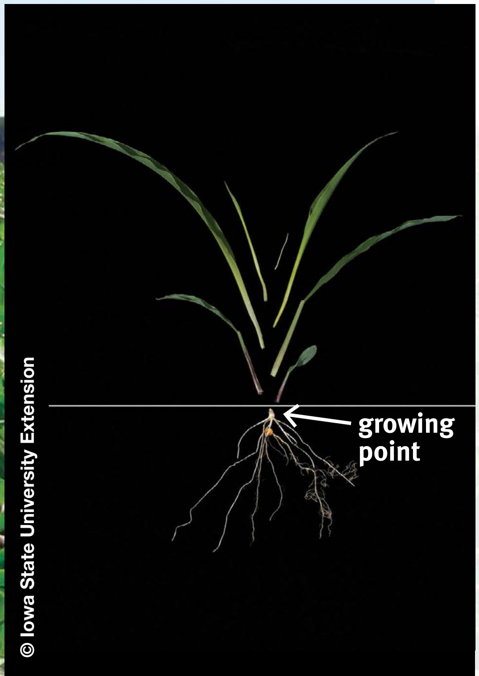


Figure 17. Dissected view of a V3 plant.

During this period, there is minimal stalk (internode) elongation, which is somewhat dependent on soil temperature. Prior to V5, the growing point is below the soil surface and all leaves and ear shoots are initiated (Figure 17).

A shoot initiates at each node (axil of each leaf) from the first leaf (below ground) to approximately the 13th leaf (above ground). Shoots that develop at above ground nodes may differentiate into reproductive tissue (ears or cobs), and shoots that develop below ground may differentiate into vegetative tissue (tillers or suckers).

Permanent roots develop at five nodes below the surface, one at the soil surface, and potentially one or more nodes above the soil surface. Roots above the soil surface are commonly referred to as “brace” or “anchor” roots and may support the stalk and take up water and nutrients if they penetrate the soil (Figure 18).

The uppermost roots may not reach the soil because the plant stops growing when it switches from vegetative to reproductive development. The development of this stage is dependent on genetics and the environment.

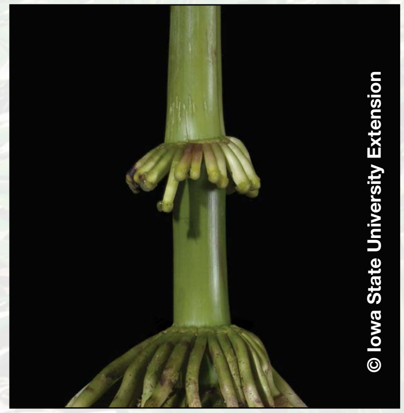


Figure 18. Brace or anchor root development.

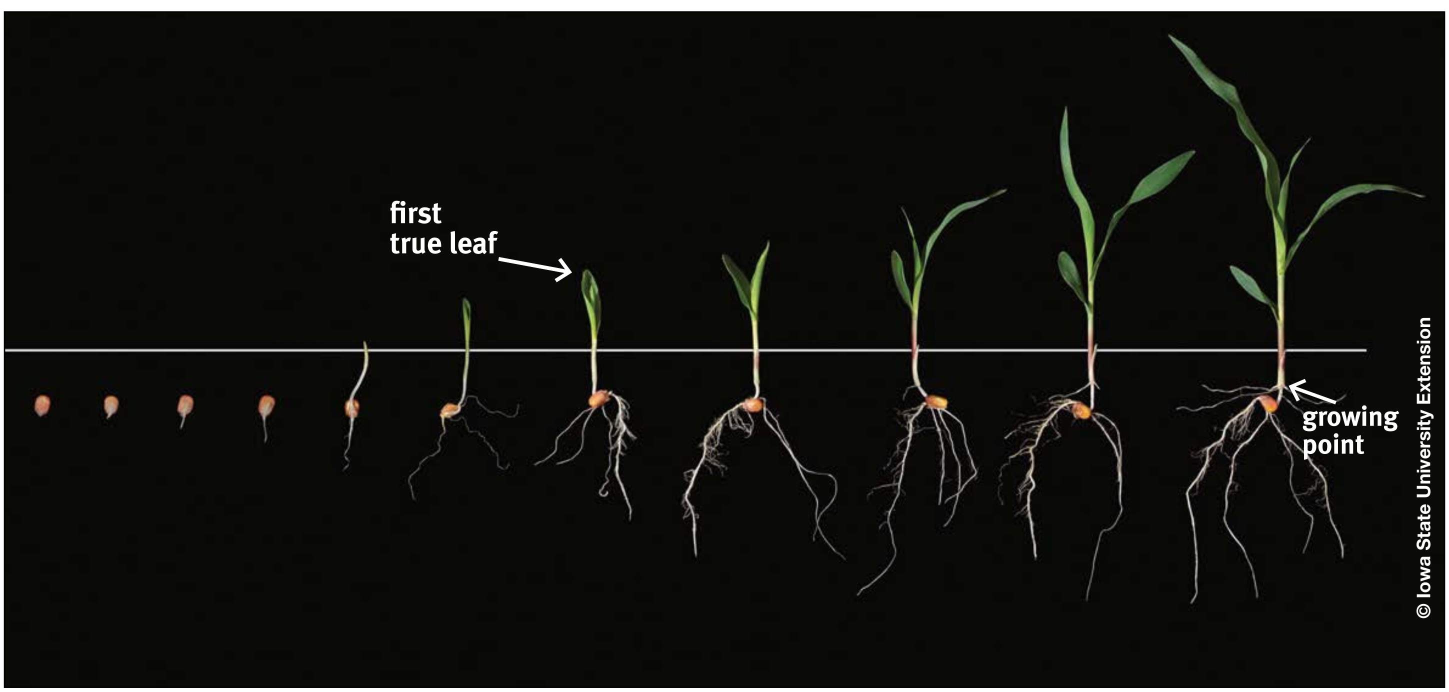


Figure 19. Corn seedling development from germination through V2.

Mid-Vegetative Stages (V6 to V11)

During these stages corn plants begin a period of very rapid internode elongation. The growing point moves above the soil surface around V6, and the plant is now susceptible to environmental or mechanical injuries that may damage the growing point (Figure 20).

As a result of this rapid growth, the lower three or four leaves, including the first true leaf, may become detached from the stalk and decompose. When this occurs, other techniques for determining the vegetative stage of development are used.

One way to identify the developmental stage is to dig the corn plant and split the stalk lengthwise. Elongation is minimal during early growth; nodes one through four are tightly compressed with no visible internodes. Typically, the first noticeable internode will be between nodes four and five and will be approximately 0.25 inch (0.6 cm) in length. Identify the leaf attached at the fifth node and count successive collared leaves above that to determine the vegetative stage (Figure 21).

Another way to determine the plant stage is to identify the sixth leaf. Find the node at the soil surface, and if the soil has not been disturbed (no cultivation), this will typically be the sixth node. Identify the leaf attached at the sixth node (leaf 6) and count successive collared leaves above that to determine the vegetative stage.

In the Central Corn Belt of the United States, the number of rows of kernels around the cob is established at about V7 at which time the ear shoots (Figure 20) and/or tillers are visible, as well as the tassel (Figure 22). For Northern latitude hybrids this happens earlier, and for tropical hybrids it happens later. There will always be an even number of rows, as a result of cellular division. Most mid-maturity hybrids average 14, 16 or 18 rows of kernels, but it may be fewer or more. Lower row numbers are highly correlated to early maturity hybrids. The absolute number is strongly controlled by hybrid genetics and often consistent within a hybrid at a given location. Severe metabolic stresses during these stages, such as timing of some herbicide applications, may reduce the number of kernel rows produced.

Figure 20. Dissected view of a V6 plant showing relationship of growing point with soil surface and developing ear shoots.

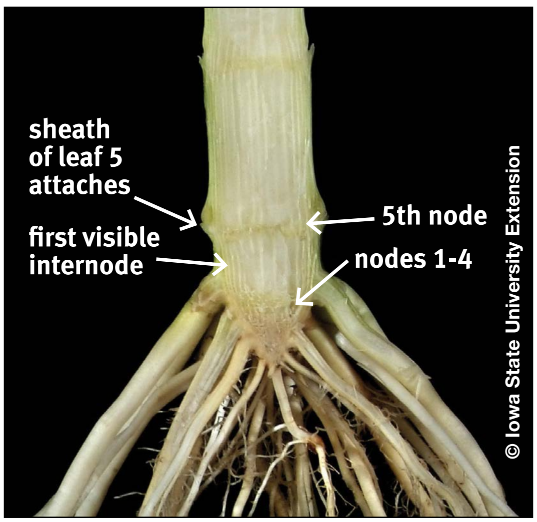


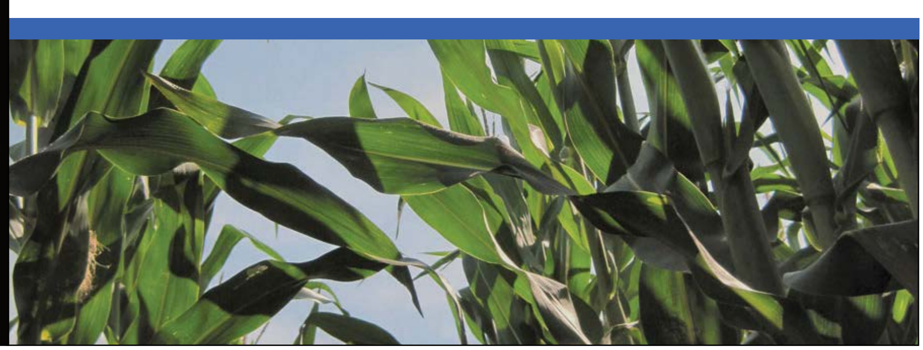
Figure 21. Lower corn stalk split lengthwise showing nodal development, internodal elongation, and nodal root positioning.

Figure 22. Upper portion of stalk with tassel visible, V7 plant.

Late Vegetative Stages (V12 to VT)

The length of the ear (number of kernels per row) is determined the last few weeks prior to tasseling. Stress at this time may reduce the number of kernels produced in each row, however, the ultimate kernel number is determined during and after pollination.

Figure 23. Dissected view of a V12 plant.



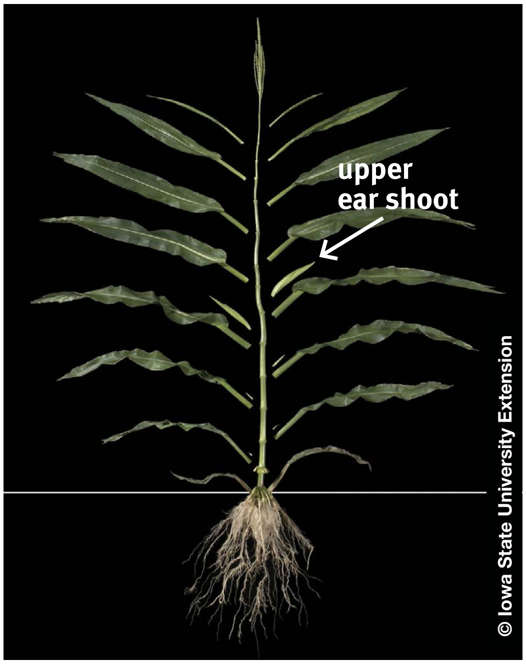


Figure 24. Dissected view of a V18 plant. Tassel may be visible outside of whorl at this stage.

Transition Stage (VT to R1)

The transition from vegetative development to reproductive development (VT to R1) is a crucial period for grain yield determination. At this point, the upper ear shoot becomes dominant (Figure 24).

VT occurs when the last tassel branch has emerged and is extended outward (Figure 26). VT overlaps with R1 when visible silks appear before the tassel is fully emerged.

Vegetative development is now complete: maximum plant height is nearly achieved, stalk cells continue to lignify which improves stalk strength, and the plant transitions to reproductive development (R1).

Figure 25. Three uppermost ears with silks. Primary ear is on right.

Figure 26. Tassel growth from V7 through VT.

Silking Stage (R1)

R1 occurs when silks are visible outside the husks. Once a pollen grain lands on a silk (pollination), a pollen tube forms and takes about 24 hours to grow down the silk to the ovule. Once it reaches the ovule, fertilization occurs and the ovule becomes a kernel. Kernels at this stage are almost entirely enclosed in glumes (sepals), and are white with a clear, watery inner content.

This period is important for kernel development, and ultimately, yield. Stress at this time, and during the next two weeks, can significantly reduce the number of kernels per ear.

Figure 27. Primary ear at R1, with and without husks and silks.

Figure 28. Three uppermost ears from a R1 plant. Note pointed kernels. This point is where the silk was attached.

Figure 29. Dissected view of a R1 plant. Note silk emergence prior to tassel branches being fully extended.

Blister Stage (R2)

R2 occurs 10 to 14 days after silking and is referred to as the "blister" stage. Developing kernels are about 85 percent moisture, resemble a blister, and the endosperm and the inner fluid are clear. As the kernels expand, the surrounding glumes become less visible (Figure 31).

Stress-related kernel abortion may occur during this time. Kernels fertilized last (near the tip) are often aborted first. Kernel abortion risk is highest within the first 10-14 days after pollination or until the kernels reach R3.

At this stage, maximum ear length is achieved. Silks from fertilized kernels dry and turn brown. Unfertilized silks may be visible among the brown silks (Figure 32).

Figure 30. Primary ear at R2, with and without husks and silks.

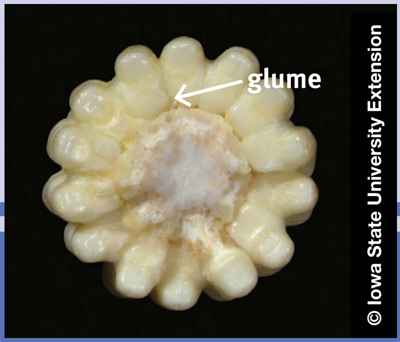


Figure 31. Cross-section of an ear from a R2 plant showing kernels and glumes.

Figure 32. Two uppermost ears from a R2 plant. Note kernel development at base of plant with silks detached, while silks remain attached to ovules at tip waiting to be pollinated.

Milk Stage (R3)

R3 occurs 18 to 22 days after silking when the kernels begin to display final coloring, which is yellow or white for most dent hybrids, or variations of yellowish orange or white for flint hybrids.

Kernels are about 80 percent moisture, inner fluid is milky white from accumulated starch (endosperm), and they completely fill the space between kernel rows. The embryo and the endosperm are visually distinguishable upon dissection (Figure 33). Stress-related kernel abortion is still possible at this time.

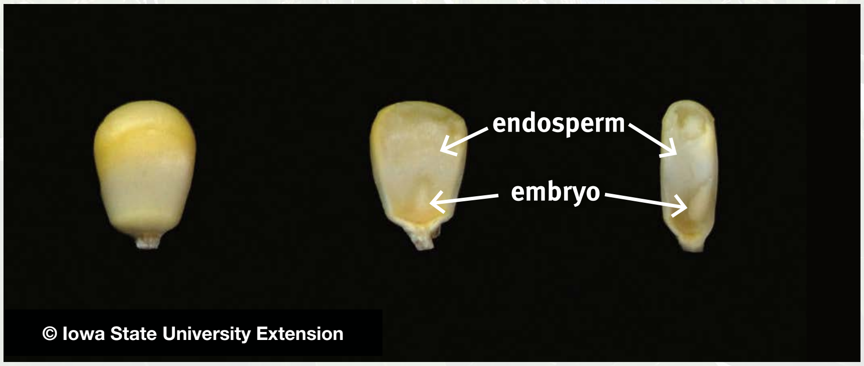


Figure 33. Kernels from a R3 plant.

Figure 34. Primary ear from a R3 plant, with and without husks and silks.

Dough Stage (R4)

R4 occurs 24 to 28 days after silking. Kernels are about 70 percent moisture and the inner fluid thickens to a pasty, dough-like consistency. Kernels attain their final color and around one-half of their mature dry weight.

Cob color (white, pink, light red, or dark red) begins to develop and is hybrid specific. Husks begin to turn brown on the outer edges (Figure 36).

Stress during this stage does not generally cause kernels to abort, but it can reduce the starch accumulation rate and average kernel weight.

Figure 35. Kernels from a R4 plant.

Figure 36. Primary ear from a R4 plant, with and without husks and silks.

Figure 37. Primary ear from a R5 plant, with and without husks and silks. Note kernels are dented.

Dent Stage (R5)

R5 occurs 35 to 42 days after silking and accounts for nearly one half of the reproductive development time. Kernels are comprised of a hard starch outer layer surrounding a soft starch core. When the softer starch core begins to lose moisture and shrinks, an indentation (dent) forms at the top of the kernel (Figure 38).

The amount of denting that occurs is dependent on genetics and growing conditions. Flint hybrids generally produce very little to no dent because the kernels contain hard starch and do not collapse.

Figure 38. Kernels from a R5 plant.

Milk line

A "milk" line forms, creating a separation between hard starch and soft starch. It forms at the crown of the kernel and progresses toward the base, or kernel tip, which usually takes around three to four weeks. The total time for this movement is related to temperature, moisture availability, and hybrid genetics. The milk line generally is referred to as ¼ milk line, ½ milk line, or ¾ milk line as it moves toward the cob (Figure 39).

In the early dent stage, kernels are about 55 percent moisture and have accumulated about 45 percent of their total dry matter, and about 90 percent of total dry matter by R5.5 (½ milk line). (Mahanna et al., 2014)

The husk will start to senesce and lose color (Figure 37). Stress during this stage will result in reduced starch accumulation and kernel weight.

Figure 39. Corn ears showing milk line stages. Milk line begins at the crown of the kernel and progresses toward the kernel tip.
Courtesy of Steve Butzen, DuPont Pioneer.

Physiological Maturity (R6)

R6 occurs about 60 to 65 days after silking. Kernel moisture is approximately 35 percent, kernels are considered physiologically mature, and have reached their maximum dry weight.

The milk line, or hard starch layer, has advanced to the kernel tip. Cells at the tip of the kernel lose their integrity and collapse causing a brown to black abscission layer to form, commonly referred to as “black layer” (Figure 41). Once the black layer forms, starch and moisture can no longer move in or out of the kernel, with the exception of moisture loss through evaporation.

Black layer formation progresses from the tip of the ear to the base. If the corn plant dies prematurely (prior to physiological maturity) the black layer still forms, but may take longer, and yield may be reduced.

Stress at this stage has no impact on yield.

Figure 41. Progression of black abscission layer formation. *Courtesy of Steve Butzen, DuPont Pioneer.*

Figure 42. Kernels from a R6 plant showing embryo (germ), endosperm (starch), and black layer.

Figure 40. Primary ear from a R6 plant, with and without husks and silks.

Standard Measurements

A typical ear of corn has 500 to 800 kernels, based on favorable environment and production practices.

Average kernel weight at 15.5 percent moisture is approximately 0.012 ounces (350 mg), with a range of 0.007 to 0.015 ounces (200 to 430 mg).

A standard bushel weighs 56 pounds (25.5 kg) and contains approximately 90,000 kernels, with a range of 59,000 to 127,000 kernels per bushel (2.3 to 5.0 million kernels per metric ton).

Figure 43. Primary ears from R1 through R6 plant. Both embryo and non-embryo sides are shown once they become distinguishable.

Grain Drydown

The rate of corn grain moisture loss is highly dependent on air temperature (Table 3), air movement, relative humidity, and grain moisture content. Drydown is highly related to hybrid characteristics, such as ear orientation, plant density, tightness and length of husks, and kernel hardness. As a general rule, it requires 30 GDDs to remove one point of moisture from the grain early in the drying process (30 to 25 percent), and 45 GDDs to remove one point of moisture late in the drying process (25 to 20 percent). Grain drying rates will vary between hybrids and environments. For example, corn dries better on a 50° F (10° C) sunny day than on a 50° F (10° C) rainy or cloudy day. Both days have the same number of heat units, but the additional energy provided by the radiant energy on a sunny day dramatically improves the drying process.

Table 3. Drydown potential by date at Ames, Iowa, United States.

Date	Maximum Temperature	Minimum Temperature	GDDs/ Day
September 20	75° F (24° C)	51° F (11° C)	13
October 10	65° F (18° C)	42° F (6° C)	7
November 1	55° F (13° C)	33° F (1° C)	2

Source: Iowa State University Extension

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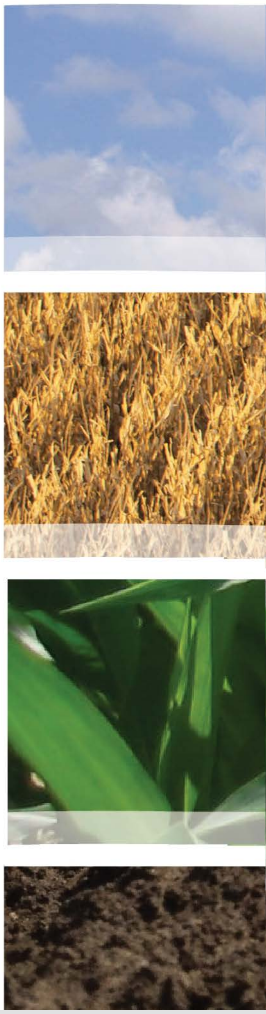

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