Corn Growth & Development
What Goes On From Planting To Harvest?

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The corn plant is an a-maize-ing biological package that harvests sunlight as efficiently as any row crop grown in the US. From roughly 20 pounds of seed planted per acre in the spring, nearly 30 tons of stalks, leaves and grain are produced only 130 days in early fall.

A fundamental understanding of the growth and development processes of the corn plant is critical to growers and consultants alike in order to better diagnose crop problems when they occur in the field. As crop management becomes more fine-tuned (a.k.a. site-specific, precision farming), monitoring of the crop's developmental progress and accompanying stresses will need to become more finely tuned also.

Corn growth and development is divided in this publication by segments of the growing season. Early-season problems in corn are mostly stand establishment problems. Stand establishment problems are mostly growth and development problems.

Success during corn's pollination period goes a long way towards guaranteeing grain in the bin. Stress during pollen shed and silking can cause more yield loss than almost any other period in the crop's development. Conversely, optimum weather during pollination can set the stage for bumper yields in the fall.

The grain fill period in corn begins after pollination is complete and ends when the grain is physiologically mature. Much of the crop's yield potential was set prior to and during pollination (plant density, potential ear size and the degree of successful pollination), but the realization of the yield potential occurs during the grain fill period. The absence of stress (weather and pests) during grain fill will help ensure bumper yields in the fall at harvest time.

The information contained herein has been gleaned from the research and observations of many pupils of corn throughout the years, flavored with my own experience as a state Extension corn specialist in Indiana since 1982. Use it freely and generously. Corrections, comments, arguments and the like may be submitted to me at the addresses above.

Background Information

Determining Leaf (Vegetative) Stages in Corn

Troubleshooting problems in the corn field usually requires the investigator to determine the leaf stage of the plants that are damaged. Too often, definitions of corn leaf stages differ among the various players standing in the corn field. A farmer often looks at a corn plant differently than I do, I look at a corn plant differently than a hail insurance adjuster does, a hail insurance adjuster looks at a corn plant differently than a herbicide sales representative does. It's important that you understand the most commonly used staging systems and the differences between them.

DESCRIPTION OF A CORN LEAF

The **leaf blade** is the most visible component of the leaf. Casual observers of the corn plant often consider this single component to be the whole "leaf".

The **leaf collar** is a visible light-colored narrow 'band' at the base of the leaf blade. Before the leaf collar is visible, the leaf blade 'flows' from the whorl. When the leaf collar is visible, the leaf blade 'meets' the stem at a distinct angle.

The **leaf sheath** is the portion of the leaf that wraps around the stem of the plant. A leaf sheath attaches to the plant at a stalk node. Every leaf is attached to an individual stalk node. Consequently, there are as many stalk nodes as there are number of leaves.

LEAF COLLAR METHOD FOR CORN GROWTH STAGING

The leaf collar method, as described by Ritchie et al. (1992), is the one used by more university agronomists than all other methods of leaf staging. It is a simple and relatively fool-proof method for staging corn growth. Here's how it works…

Leaf stages are referred to as V (for vegetative) stages. The corn plant's first true leaf is shorter than the rest, has a rounded tip and is always counted as the #1 leaf when staging. A single plant is staged by counting the number of visible leaf collars. For example, if a plant has three visible leaf collars then it is defined as being at leaf stage V3 (3-leaf).

A field is defined as being at a specific leaf stage when at least 50% of the plants are in or beyond a given stage. For example, let's say you stage 100 plants in a field. If 70 plants are at growth stage V2 and 30 plants are at V3, then the field is defined as being at growth stage V2.

HORIZONTAL LEAF METHOD FOR CORN GROWTH STAGING

Crop insurance adjusters use a slightly different method for staging vegetative growth in corn for hail loss assessment. The National Crop Insurance Association's defoliation-yield loss chart (reproduced in ID-179, 1997, pp 13-14) is based on what I call the 'Horizontal Leaf Method'.

This staging method (described by Vorst, 1990) also begins counting with the rounded first leaf, but continues counting leaves beyond the last visible leaf collar to the uppermost leaf that is 40 to 50 percent exposed out of the whorl. This last leaf is called the "indicator" leaf.

The tip of the 'indicator' leaf is typically pointing downward. Identifying the 'indicator' leaf can be difficult depending on hybrid differences in leaf angle and your ability to estimate percent of exposed leaf.

U**seful Tip**: Typically, the 'Horizontal Leaf Method' will result in a leaf stage that is numerically one to two leaves greater than the 'Leaf Collar Method'. From growth stage V1 through about V5, there is typically one additional leaf (above that leaf with the last visible collar) whose leaf tip is pointing downward. Beyond growth stage V5, two additional leaves with 'droopy' leaf tips will usually be evident above the leaf with the last visible collar.

HERBICIDE LABEL DEFINITIONS FOR CORN LEAF STAGING[1]

First of all, few postemergence corn herbicides refer to leaf stage in their labels.

The staging method assumed with cyanazine, Buctril, Banvel and Marksman, ignores the first true leaf, but continues counting leaves beyond the last visible leaf collar to the uppermost leaf whose leaf tip is pointing downward.

The Accent label refers to leaves with visible leaf collars but begins counting with the 2nd true leaf, not the rounded 1st leaf. Therefore, a 10-leaf plant by Accent's definition is equivalent to an 11-leaf plant by the 'Leaf Collar Method'.

Some herbicide label examples...

Accent SP (Du Pont) labels state that the herbicide may be broadcast or applied with drop nozzles to field corn "up to 24 inches tall (free-standing) or that exhibits 6 or fewer leaf collars, whichever is most restrictive." The label also states that drop nozzle application of the herbicide not be used on "corn that is taller than 36 inches or that exhibits 10 collars, whichever is most restrictive."

Banvel & ***Marksman*** (Sandoz) state for early postemergence "Herbicide... may be applied during the period from corn emergence through the five leaf stage or 8 inches tall, whichever comes first."

Clarity (Sandoz), on the other hand, simply states that for early postemergence "may be applied during the period from corn emergence through 8 inch tall corn.", with no mention of growth stage.

Buctril (Rhone-Poulenc) states that, at the 1.5 pints/A rate, "Apply to corn between the 4 leaf stage and prior to tassel emergence."

Cyanazine for postemergence application in corn is sold alone or in combination with atrazine.

Bladex 90DF (Du Pont) states the herbicide can be applied "from crop emergence through the four-leaf stage of corn growth. Do not apply over the top of corn if the fifth

[1] Reproduced from *1996 Crop Protection Reference*, C&P Press Inc.

leaf is visible."

Extrazine II (Du Pont) states that "For best results, apply....from crop emergence through the two-leaf stage of corn. Postemergence application must be made before the fifth leaf is visible (typically 8 inches or less) ."

U<u>**seful Tip**</u>: My data suggest that the 'Leaf Collar Method' results in the same numerical growth stage as the herbicide label definition through the 5-leaf stage of development, but is faster and more accurate. Even though the #1 rounded leaf is ignored by herbicide labels, the additional 'droopy' leaf beyond that with the last visible collar is counted. Thus, similar stages will be defined by either method through about the 5-leaf stage.

STAGING CORN WHEN LOWER LEAVES ARE MISSING

The first few leaves of a corn plant usually remain intact through growth stage V5 or so. Lower leaves (including the #1 rounded leaf) will often 'disappear' once a plant develops beyond V5, due to natural death and/or physical ripping from the enlarging stalk. Staging knee-high corn or taller can be difficult if the lower leaves are absent. Luckily, an understanding of stalk nodes and internodes helps us stage older plants.

Stalk nodes are what most of us refer to as the horizontal 'woody' joints of the stalk. Roots, ear shoots, tillers and leaves arise from meristematic areas near the nodal tissue. **Stalk internodes** are the mostly white, pithy areas between the stalk nodes. Increases in stalk length result from cell elongation of these internodal areas.

Leaf staging of older corn begins by first splitting the stalk neatly down the middle and looking for the first (lowest) noticeable internode. This internode's length is typically ½ to ¾ inch long. Internodes above the first noticeable one are usually much longer. The internodes below the first noticeable one typically never elongate.

Carefully identify the leaf sheath that attaches to the node immediately above the first noticeable internode. This leaf is almost always Leaf #5. Once Leaf #5 is identified, then stage the plant by counting the remainder of the leaves up the plant, stopping at the uppermost true leaf as defined by either the 'Leaf Collar Method' or the 'Horizontal Leaf Method'.

U<u>**seful Tip**</u>: Unusual growing conditions can cause confusion by altering internode elongation. Once in a while, the first noticeable internode is the one below the #4 node or the #6 node. With popcorn, the node above the first noticeable internode is usually the #6 node.

Vegetative versus Reproductive Phases in Corn

Growth and development of the corn plant can be divided into distinct vegetative and reproductive phases. Visually, most of us usually consider the onset of pollen shed and silk emergence to be the onset of the reproductive phase. Technically, however, the vegetative phase occurs from germination through about growth stage V6 (six visible leaf collars), while the reproductive phase begins at about growth stage V6 and continues through grain maturation (growth stage R6).

VEGETATIVE & REPRODUCTIVE PHASES

The vegetative phase can be defined as that period in which leaf primordia are being formed by the apical meristem, otherwise known as the main 'growing point' of the corn plant. The apical meristem is located near the pyramid-shaped tip of the young stalk tissue, deep in the 'heart' of the corn plant.

The **vegetative phase** concludes after the final leaf primordia are formed, at about growth stage V6. Since a corn embryo contains about five leaves, a hybrid with 18 to 20 leaves must create the remaining 13 to 15 leaves 'on-the-fly' following germination. All of the leaf primordia for the 18 to 20 leaves of a corn plant are in place as early as growth stage V6.

The **reproductive phase** can be defined as that period beginning with the formation of tassel primordium at the apical meristem and the uppermost final ear primordium and ending at physiological maturity of the grain. The tassel and final ear primordia are formed after the final leaf primordium is formed.

'TURNING THE CORNER' (AKA THE GRAND GROWTH PHASE)

The beginning of the reproductive phase also signals the beginning of the 'grand growth phase', that period of rapid plant growth that continues until pollination. The corn plant 'factory' begins to produce dry matter at an increasing rate, fueling the increases in stalk and root weights.

Stalk elongation increases rapidly, resulting in rapid plant height increases. Root extension increases rapidly, resulting in rapid development of the root system and more substantial nutrient uptake by the plant.

Fields that have 'turned the corner' take on the characteristic dark green or blue green color. Leaves also take on the characteristic 'shine' of a rapidly growing plant. When conditions are favorable, this is the point in the growing season when the grower breathes a sigh of relief at the sight of a nicely established field of corn.

What Goes On Prior to Pollination?

Germination and Emergence

Many early-season problems in the corn field begin during germination and emergence. A thorough understanding of the germination and emergence processes is critical for successfully diagnosing stand establishment problems when they occur. Once you know what is supposed to happen, it is easier to recognize the problems.

IMPORTANCE OF UNIFORM SEEDLING EMERGENCE

Uneven seedling emergence can cause grain yield losses (Carter & Nafziger, 1989; Nafziger et al., 1990). When 25 % or more of a stand is made up of plants that emerged 7 to 10 days late, yield losses will approach seven percent. When 25 to 50 % of a stand is made up of plants that emerged 21 days late, yield losses will approach 10 percent. When more than 50 % of a stand is made up of plants that emerged 21 days late, yield losses will approach 20 percent.

Yield losses due to delayed emergence are caused by several factors. First of all, delayed emergers often silk and pollinate markedly later than the rest of the field. Late silking plants are very attractive to corn rootworm beetles which can cause extensive silk clipping as they feed on pollen. A small number of late tasseling plants scattered throughout the field may not provide adequate amounts of pollen for successful fertilization of the silks.

Secondly, delayed emergers are often at a competitive disadvantage for light, water and nutrients when surrounded by older, larger plants. The earlier emergers reach the grand growth phase (about V5 or V6) sooner than the delayed emergers. By the time the delayed emergers begin their rapid growth phase, the earlier emergers have 'leaped' ahead of them in terms of overall plant growth.

The critical difference in growth stages between early and delayed emergers is about two leaves (e.g., V4 versus V2). Beyond this difference in growth stage, the delayed emergers will invariably become barren plants (i.e., no ears). When delayed emergers compose a large percentage of the stand, yield loss is simply equivalent to that associated with late planting in general.

THREE REQUIREMENTS FOR UNIFORM GERMINATION AND EMERGENCE IN CORN

Adequate and uniform soil moisture at the seed zone. Adequate soil moisture is most simply defined as not too dry and not too wet. Uneven soil moisture in the seed zone can be caused by soil characteristics, tillage patterns, unusual weather conditions and uneven seeding depth control.

Adequate and uniform soil temperature at the seed zone. Adequate soil temperature is most simply defined as being greater than 50F at the 2-inch depth. Corn will not germinate or emerge quickly or uniformly when soil temperatures are less than 50F. When soils warm to the mid-50F or greater, emergence will occur in seven days or less if soil moisture is adequate.

Uneven soil temperature can be caused by soil characteristics, uneven residue cover in reduced tillage systems and uneven seeding depth control. Temperature variability is most critical when average soil temperatures are barely within the desired minimum 48 to 50F range for corn germination.

> **U**<u>**seful Tip**</u>: Dark-colored soils will typically warm more quickly than light-colored soils. If soils dry differently across the field, the drier areas will typically warm faster than the wet areas. Uneven residue cover in reduced tillage systems causes significantly lower soil temperatures under the heavier cover than under barer spots in the field. Uneven seeding depth exposes deeper planted seeds to slightly cooler seed zones than seeds placed shallower.

Adequate and uniform seed-to-soil contact. In order for the kernel to absorb moisture quickly and uniformly, soil must be firmed around the kernel completely.

Seed-to-trash contact results from 'hair-pinning' of surface trash into the seed furrow during no-till planting when soil and/or trash are too wet for adequate coulter cutting action. Seed-to-clod contact results from planting into cloddy fields created by working soil too wet. Seed-to-rock contact is, needless to say, not good for proper germination either. Seed-to-air contact results from open planter furrows when no-till planting into excessively wet soils. Germination of kernels lying in open planter furrows is dependent on rainfall keeping the open furrow environment moist.

SEED SIZE EFFECT ON GERMINATION & EMERGENCE

Small sized seed require less total water to germinate than larger sized seed, thus possibly offering an advantage in drier soil conditions. Larger sized seed (especially more dense seed) generally has greater seedling vigor, which can be advantageous in poor growing conditions.

Univ. of Wisconsin data (Graven & Carter, 1990) documented the stand establishment difficulty that small rounds could have under early plantings or no-till conditions. Vigor of large rounds, particularly from butt of ear, can also be low due to their relative age (butt kernels are older than tip kernels), rewetting occurrences of the ear and handling damage during seed processing.

The Germination Process

THE DETAILS

Germination is the renewal of enzymatic activity that results in cell division and elongation and, ultimately, embryo emergence through the seed coat. Germination is triggered by absorption of water through the seed coat. Corn kernels must absorb (imbibe) about 30 % of their weight in water before germination begins. Less than optimum absorption of water (perhaps due to a rapidly drying seed zone) may slow or stop germination. Repeated wetting/drying cycles can decrease seed viability.

By comparison, soybeans must imbibe about 50 % of their weight in water. But since soybeans are approximately 2/3 the weight of corn kernels, the total amount of absorbed water required for germination is relatively similar.

The visual indicators of germination occur in a distinct sequence. First of all, the **radicle root** emerges first, near the tip end of the kernel, within two to three days in warm soils with adequate moisture. In cooler or drier soils, the radicle root may not emerge until one to two weeks after planting.

The **coleoptile** emerges next, from the embryo side of the kernel, within one to many days of the appearance of the radicle, depending on soil temperature. The coleoptile (commonly called the 'spike') is a rigid piece of plant tissue and has a pointed tip with no visible openings. The coleoptile encloses four to five leaves (plumule) that were formed during grain maturation the previous year. These leaves begin to enlarge during the germination and emergence processes.

The **lateral seminal roots** emerge last, near the dent end of the kernel.

TROUBLESHOOTING CONSIDERATIONS

When temperatures are optimum, these three parts of the seedling may emerge from the kernel on nearly the same day. Excessively cool soils may delay the appearance of the coleoptile and lateral seminal roots for more than a week after the radicle root emerges. It is not uncommon in cold planting seasons to dig seed two weeks after planting and find only short radicle roots and no visible coleoptiles.

When excessively cold and/or wet soils delay germination and/or emergence, the kernel and young seedling are subjected to lengthier exposure to damaging factors such as soil-borne seed diseases, insect feeding and injury from preplant or pre-emergent herbicides and carryover herbicides from a previous crop

The Emergence Process

THE DETAILS

Growth stage VE refers to emergence of the coleoptile or first leaves through the soil surface. Successful germination does not guarantee successful emergence of the crop. The coleoptile must reach the soil surface before its internal leaves emerge from the protective tissue of the coleoptile. As with all of corn growth and development, germination and emergence are dependent on temperature, especially soil temperature. Corn typically requires from 100 to 150 MGDD (growing degree days) to emerge.

Elongation of the **mesocotyl** elevates the coleoptile towards the soil surface. The mesocotyl is the tubular, white, stemlike tissue connecting the seed and the base of the coleoptile. Technically, the mesocotyl is the first internode of the stem.

> **U**<u>seful Tip</u>: Physiologically, mesocotyls have the capability to lengthen from at least a 6-inch planting depth. Realistically, corn can be planted at least three inches deep if necessary to reach adequate moisture.

As the coleoptile nears the soil surface, exposure of the mesocotyl to the red light portion of the solar radiation spectrum halts mesocotyl elongation. Continued expansion of the leaves inside the coleoptile ruptures the coleoptile tip, allowing the first true leaf to emerge above the soil surface. Since the depth at which the mesocotyl senses red light is fairly constant, the resulting depth of the crown (base) of the coleoptile is nearly the same (½ to ¾ inch) at seeding depths of one-inch or greater.

U<u>**seful Tip**</u>: When corn is seeded very shallow (less than about ½ inch), the crown of the coleoptile will naturally be closer to the soil surface if not right at the surface. Subsequent development of the nodal root system can be restricted by exposure to high temperatures and dry surface soils.

TROUBLESHOOTING CONSIDERATIONS

Several factors can cause the coleoptile to split prematurely, allowing the leaves to emerge underground. Usually, more than one of the following factors are present when this problem occurs, making it difficult to place the blame on any one factor.

Exposure to light at deeper soil depths due to cloddy seedbeds, dry seedbeds, sandy soils, or open slots in no-till.

Injury from certain herbicides (e.g., acetochlor, alachlor, metolachlor), particularly under stressful environmental conditions. Symptoms include corkscrewed coleoptile, swollen mesocotyl and true leaves emerged from side of coleoptile.

Surface crusting, planter furrow compaction, or otherwise dense surface soil that physically restricts mesocotyl elongation and coleoptile penetration. The pressure of the expanding leaves within the coleoptile eventually ruptures the side of the coleoptile. Symptoms include corkscrewed coleoptile, swollen mesocotyl and true leaves emerged from side of coleoptile. Note the similarity to those symptoms from herbicide injury.

Cold temperature injury, either from exposure to long periods of soil temperatures around 50F or from exposure to wide daily swings (25 to 30F) in soil temperatures. Symptoms include absence of emerged coleoptile, corkscrewed mesocotyl or coleoptile and true leaves emerged from side of coleoptile. Note the similarity to those symptoms from herbicide injury.

U<u>**seful Tip**</u>: The mesocotyl should remain firm, white and healthy through at least the 6-leaf stage, if not longer. If it is mushy, discolored, or damaged prior to this stage, then it is likely part of the crop problem being investigated.

Leaf Development

LEAF INITIATION

Most corn hybrids grown in the central Corn Belt of the US produce from 17 to 22 leaves. Hybrids with fewer leaves are typically also shorter and mature earlier than hybrids with more leaves.

Remember that the first four or five leaves of a corn plant already exist in the young embryo of the corn kernel and were initiated before the kernel matured the previous growing season. The final 12 to 17 leaves begin developing shortly after germination at the growing point area of the young corn stalk. The main growing point (**apical meristem**) of a young corn plant is an area of active cell division located near the tip of the pyramid-shaped stalk tissue near the base of a split stalk.

All the leaves the young plant will ever have are in place by about V5 to V6 (i.e., leaf initiation is complete). Following completion of leaf initiation, the tassel is formed at the apical meristem. **Axillary meristems** located near the stalk nodes initiate ears and tillers.

Leaf Development Over Time

Corn development is closely related to heat. Measuring temperature is one way to measure heat. Warmer temperatures mean faster corn development, cooler temperatures mean slower corn development.

Another way of measuring heat is to use temperatures to calculate growing degree days (GDD), sometimes also called heat units. Several formulas exist to calculate these GDD, but the one used most frequently by those of us who work with corn is called the "Modified 86/50 Cutoff Method" and is abbreviated MGDD.

The number of MGDD for any given day are calculated by subtracting 50 from the average daily temperature. The average daily temperature is calculated by adding the daily high and the daily low temperatures, then dividing by two.

Two special rules exist, however. **Rule #1**: If the daily high was greater than 86F, then 86F is used to calculate the average. **Rule #2**: If the daily low was less than 50F, then 50F is used to calculate the average. These high and low temperature limits define the boundaries beyond which corn develops very slowly, if at all.

Over the years, researchers have investigated the relationships between MGDD accumulation and the occurrence of silking or grain maturation (black layer). Consequently, we often talk about hybrids that will mature in 2700 MGDD or maybe silk in 1400 MGDD.

However, MGDD accumulation can also be associated with the rate of leaf development prior to pollination. One of my former graduate students, Kirby Wuethrich, recently completed his M.S. thesis research that described this relationship for 14 corn hybrids. For more information on his research, contact Kirby by Email at wuethrichkl@phibred.com. In a nutshell, here's what he discovered:

From V1 to V10, new leaves (as defined by the appearance of leaf collars) emerge at a rate of about 85 MGDD per leaf. This is equivalent to about one leaf every five to six days in early May or about one leaf every three to four days in mid-June.

From V10 to the final leaf, leaves emerge at a rate of about 50 MGDD per leaf. During late June and early July, this rate would be equivalent to about one leaf every two to three days.

Armed with this knowledge, we can estimate how far along the corn crop should be for any given location if we know the planting date and the MGDD accumulations since that planting date. It especially helps if we also know the emergence date, but we can use an estimated 125 MGDD from planting to emergence in lieu of knowing the actual date.

An example: Corn should reach the V5 growth stage by the time 550 MGDD have accumulated since planting. This is calculated by figuring 125 MGDD from planting to emergence, then figuring 425 MGDD (5 x 85) from emergence to V5.

Another Example: Remember, warmer temperatures mean faster corn development, cooler temperatures mean slower corn development. Let's illustrate the effects of early season temperatures on corn development by comparing predicted leaf development for several planting dates using two different years' weather at the Purdue Agronomy Research Center in westcentral Indiana (Table 1). The values in the table represent actual accumulated MGDD from each respective planting date and the predicted leaf stage (Leaf Collar Method) as of June 25 each year.

By comparison, corn development occurred faster during the warmer early season of 1994. A mid-April planting in 1994 would have been three leaf stages farther along in its development by June 25 compared to the snail's pace of 1997.

Table 1. Estimates of leaf stage development for several planting dates in a 'normal' (1994) and cooler than 'normal' (1997) spring. Source of MGDD data: Purdue Agronomy Research Center, westcentral Indiana.

	June 25, 1994		June 25, 1997	
Planting Date	**Accum. MGDD**	**Est. leaf stage**	**Accum. MGDD**	**Est. leaf stage**
April 1	1104	13	911	9
April 15	1035	11	845	8
May 1	890	9	750	7
May 15	764	8	656	6
June 1	518	5	468	4

Remember that a shortage of MGDD resulting from early season cool temperatures can really never be recovered. Mid-summer days in the 90s don't necessarily accelerate MGDD accumulations (remember Rule #1). We normally toot along at 25 to 30 MGDD per day in mid-summer anyway. Warmer than normal temperatures in late summer to early fall don't seem to mean as much to the corn crop, probably because of increasingly shorter daylight hours and the corn crop's increasing senescence.

Useful Tip: Plant stress (soil compaction, excessive soil moisture, pest injury, hail damage) can interfere with this relationship and retard leaf development. Comparison of predicted leaf stages with actual leaf stages can therefore be used as an indicator of plant stress.

The following table provides estimates of leaf stage timing relative to planting and emergence, as well as approximate plant height at each leaf stage for corn grown in westcentral Indiana.

Table 2. Timing and plant height for early leaf stages in corn for medium- to full-season hybrids grown in westcentral Indiana.

	Approx. days after…			
Leaf stage	Planting	Emergence	Approx. MGDD after emergence	Approx. plant height (in.)
VE	6 to 10	-	-	-
V1	9 to 17	3 to 7	85	2 to 3
V2	13 to 21	7 to 11	170	3 to 5
V3	21 to 25	11 to 15	255	4 to 6
V4	25 to 29	15 to 19	340	6 to 10
V5	29 to 33	19 to 23	425	12 to 15
V6	33 to 37	23 to 27	510	14 to 24
V7	37 to 41	27 to 31	595	22 to 30
V8	41 to 45	31 to 35	680	30 to 36
V9	45 to 49	35 to 39	765	
V10	49 to 54	39 to 43	850	

Source for timing: Wuethrich, K.L., 1997 (M.S. Thesis), Vegetative and Reproductive Phenology of Fourteen Diverse Hybrids of Dent Corn (Zea mays L.), Purdue University, West Lafayette, IN

Root Development & Nutrient Uptake[2]

While most of us are quite familiar with the growth and development of the above ground parts of crops, few of us are as familiar with how the root system grows and develops and how this affects nutrient uptake. This is understandable since looking at plant roots requires a great deal of effort. In fact, very little research has been conducted to investigate the effects of production practices, compaction or weather on the root system.

Corn is a grass and has a fibrous type root system, as compared to soybeans or alfalfa which have tap root systems. Successful establishment of the corn plant's root system helps ensure successful establishment of the crop itself. Stunting or restriction of the root system, especially in young plants, will likely stunt the entire plant's development. To best understand rooting problems, it is important to understand that the corn plant actually establishes two distinct root systems, one more important than the other.

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[2] Portions of this section were adapted from Mengel, Dave. 1995. *Roots, Growth and Nutrient Uptake*. AGRY-95-08. Agronomy Dept., Purdue University, West Lafayette, IN.

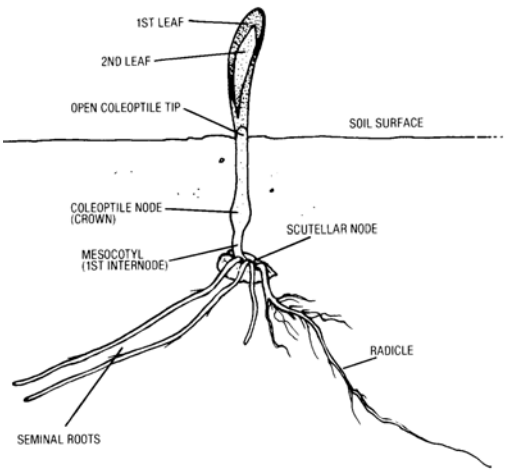

Figure 1. Growth stage VE

THE SEMINAL (OR SEED) ROOT SYSTEM

Seminal roots originate near the seed and are comprised of the radicle & lateral seminal roots (Figure 1). This initial seminal root system anchors the young plant and absorbs water and nutrients for the first two to three weeks. Seminal roots cease new growth shortly after the coleoptile emerges at the soil surface. A young corn seedling depends primarily on the energy reserves of the kernel until permanent (nodal) roots develop. Within a few days after emergence of the coleoptile and first leaves from the soil, a second root system, the nodal roots, begin to develop from the crown or growing point.

If damage occurs to seminal roots or the mesocotyl before nodal roots become established, stunting or death of the plant will occur. Such damage includes salt injury from excessive rates of starter fertilizer, seedling blight, herbicide injury and insect feeding damage

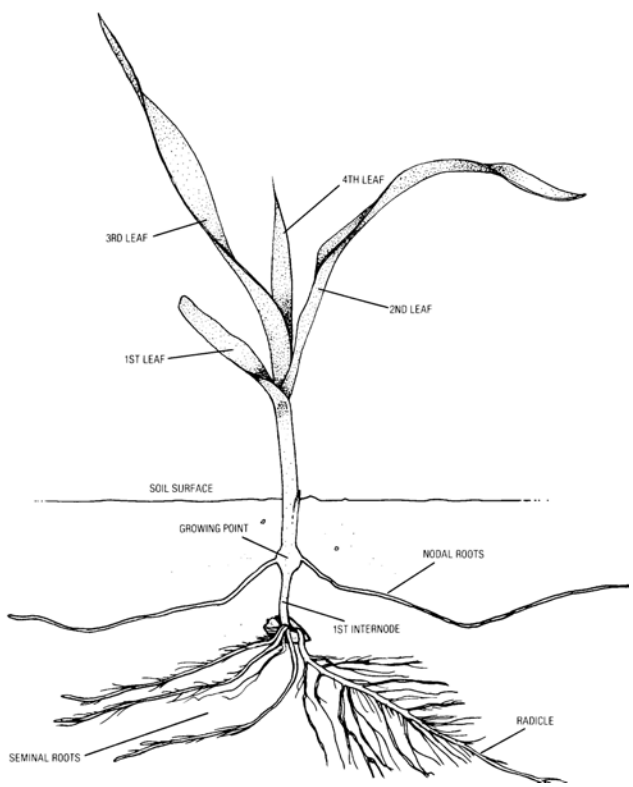

Figure 2. Growth stage late V1 (almost V2).

NODAL (OR PERMANENT) ROOT SYSTEM

Nodal roots begin to elongate from the coleoptile crown shortly after growth stage VE and are distinctly visible by growth stage V1 (Figure 2). An individual set of roots forms at each stalk node below-ground plus one or more above-ground nodes. By growth stage V6, the nodal roots are the main root system of the plant.

Four stalk nodes usually comprise the ‘woody’ triangle at the bottom of a corn stalk. The internode above the fourth node elongates about ½ inch, above which is found the fifth node (still below or just at the soil surface). Consequently, five sets of nodal roots will usually be detectable below ground (one set for each below ground stalk node). Elongation of the internode above the fifth node ‘pushes’ the sixth node above ground.

Continued elongation of subsequent stalk internodes will result in higher and higher placement of the remaining stalk nodes. Additional sets of nodal roots that form at above ground stalk nodes are usually assigned the ‘fancy’ name of brace roots, but are functionally identical to those nodal roots that form below ground. If surface soil conditions are suitable (moist and not excessively hot), brace roots can successfully enter the soil, proliferate and effectively scavenge the upper soil layer for water and nutrients.

Useful Tip: From growth stage V2 through about V6, there will be generally be one fewer set of nodal roots than number of visible leaf collars. For example, a plant at growth stage V3 will usually have 2 visible sets of nodal roots.

CAUSES OF ROOT GROWTH INHIBITION

Root growth can be hindered by factors such as cool soil temperatures, crop injury, soil compaction, drought stress, nutrient deficiencies, soil-borne diseases, root-feeding insects, current year's herbicides, or herbicide carryover. When faced with restricted root growth, growers should diagnose the cause of the rooting problem and decide whether it can be prevented next year. Ask yourself the following questions.

Is your fertilizer program based on recent soil tests and reliable fertility recommendations?

On soils testing low for phosphorus, use a starter fertilizer at planting. If phosphorus soil tests are adequate, temporary phosphorus deficiency symptoms can still occur if root development is restricted by other factors.

Did you till your fields a little on the wet side?

Soil compaction layers are easily created by wet tillage, sometimes only four to six inches below the surface. The combination of compaction and subsequent dry weather can greatly hinder root growth.

Similarly, did you plant your fields a little on the wet side?

The planter's double-disc openers can compact the sides of the seed furrow given the right (or wrong?) set of soil moisture conditions. The resulting furrow sidewall compaction can hinder and restrict initial root development very dramatically.

Have soil temperatures been stressfully cold?

Soil temperatures in the 40's and 50's are not conducive to rapid root development in corn. Slowly growing roots are more susceptible to soil-borne diseases, root-feeding insects and herbicide injury.

If the field was in soybeans last year, what is the possibility for carryover herbicide residues?

Root inhibiting herbicides often result in above-ground purpling of leaf tissue.

Was your corn no-till planted into heavy residue, such as corn stalks or winter cover crops?

Check for soil-borne insects such as wireworms or white grubs that damage seedling roots. Root injury by insect feeding often results in above-ground purpling of leaf tissue.

ROOTLESS CORN PHENOMENON & FLOPPY CORN SYNDROME

Warmer than normal temperatures, coupled with strong winds, can dry the upper inch or more of soil very quickly. Rapid drying of the upper soil surface during mid- to late May can stunt the growth and development of the corn plant's root system.

Root buds from any given node that begin to elongate in dry soil or in soil cracks will quickly cease growth due to lack of sufficient moisture. Eventually, the root tips may dessicate and die. If the soil remains dry long enough, the whole root bud may die. At this point, the plant's survival depends on improved soil moisture conditions and the development of the next set of nodal roots.

If dry surface soil and/or hot, dry weather prevail, several sets of nodal roots may fail to form, giving rise to the rootless corn phenomenon. Affected plants may be forced into depending on the seminal roots and mesocotyl for nourishment, when normally this lifeline has already taken a backseat to the nodal root system.

In addition to the nutrient stress imposed on the plants by not having an adequate nodal root system, the rootless phenomenon can eventually lead to the floppy corn syndrome, where plants simply ‘flop’ over at the soil surface at the slightest nudge from wind, tire traffic or even crop scouts walking down the row.

These plants are technically not root-lodged, they are simply broken over at the base of the stem near the crown area. The nodal roots will appear stubbed off but not eaten. The root tips will be dry and shriveled.

These symptoms are unlike any associated with herbicide injury or insect feeding. Because several sets of roots may not have formed below-ground, the crown may "appear" to be at or above the surface.

The important thing to remember is that roots will not develop in dry soil. They will not grow toward moisture. If roots are already in moist soil, however, they may proliferate rapidly enough to "follow" moisture down as the soil dries. Row cultivation may encourage root development if moist soil is thrown around the bases of the plants.

> **Useful Tip**: 'Rootless' corn can also be caused from extremely shallow seeding depths that result in nodal root initiation beginning at the soil surface rather than at the usual ¾ inch depth. Growers should avoid seed depths shallower than about 1 to 1½ inches.

DRY MATTER ACCUMULATION & NUTRIENT UPTAKE

Some data collected at Purdue illustrate the relationship between shoot growth, root growth and the nutrient content of the plant over the course of a growing season. The hybrid used was a full season hybrid requiring about 2800 MGDD to reach maturity. At seeding (21,700 plants per acre) 14 lbs of dry matter were planted. Twenty one days later, roughly the 4 leaf stage, dry weight had only increased to 29 lbs/acre (Figure 3). However, at that point there were 54 miles of roots per acre, located primarily in the top foot of soil. During the first three weeks after planting total nutrient uptake consisted of 0.7 lbs N, 0.12 lbs P and 0.77 lbs K per acre (Figure 4).

Over the next 50 days, from 21 to 71 days after planting, the plant completed its vegetative growth phase. Over 9,000 lbs of stover per acre were produced and the root system increased from 54 miles per acre located in the top foot 21 days after planting, to 32,000 miles of roots per acre growing down to 3 feet where dense glacial till provided a barrier to further growth.

At 71 days after planting, the plants began to tassel and started the process of shifting from vegetative to reproductive growth. At tasseling the crop had taken up 73 % of the N, 74 % of the P and 85 % of the K which would be accumulated.

Over the next three weeks, from 71 to 93 days after planting, growth and increased dry matter was concentrated in the developing ear. During these early stages of ear development nutrient uptake slowed down as the plant shifted gears from producing leaves to producing grain. Dry matter production also slowed as this shift occurred. This slowing of nutrient uptake and dry matter production has been noted in a number of growth analysis studies.

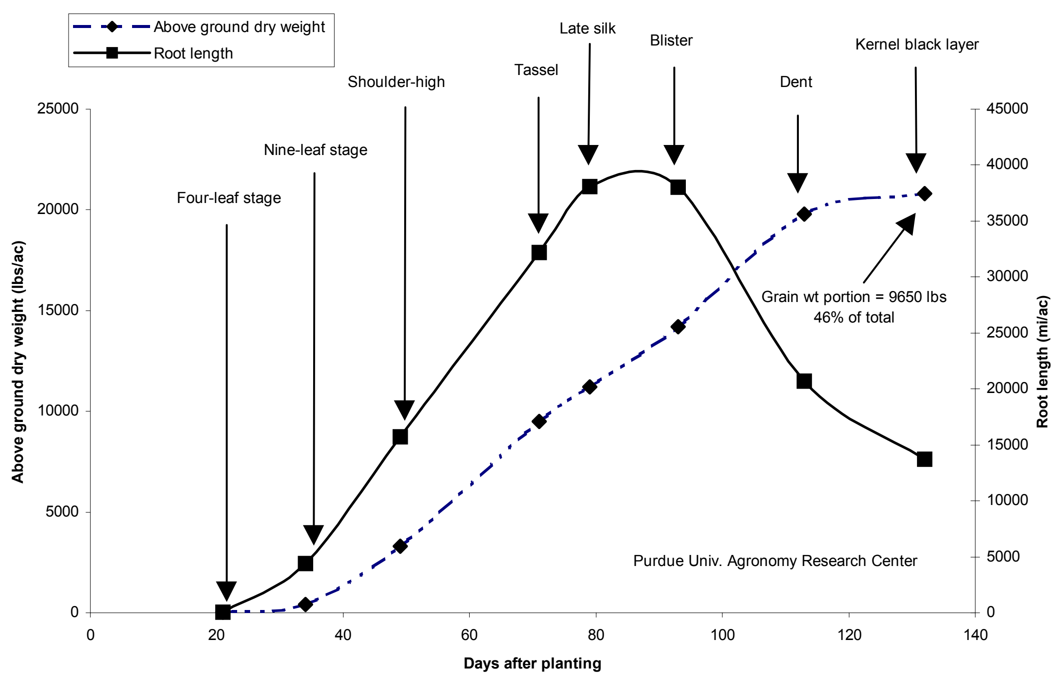

Figure 3. Seasonal changes in above ground dry weight and below ground root length of a full season corn hybrid grown in westcentral Indiana.

Between two and five weeks after pollination, roughly blister to full milk/dent, kernel fill proceeded rapidly and the balance of nutrient uptake occurred. At this time the root system began to senesce and die off. Actual decreases in total root length were seen after the late blister stage. By 113 days after planting root length had dropped from 38,000 miles per acre to 20,000 miles per acre. The lower leaves of the plant also began to die back as the plant got rid of "excess baggage" as it neared maturity.

During the last three weeks prior to black layer and maturity, the root system and lower leaves continued to senesce as the plant channeled photosynthate to the developing grain. Only about 5 % of the total dry matter was produced during these last few weeks prior to black layer. Essentially no nutrient uptake occurred. In fact K content of the plant decreased as leaf tissue died and the K leached out with fall rains.

At maturity, 132 days after planting, over 20,000 pounds of dry matter, roots, stover and grain had been produced. In this example 46 % of the dry matter was deposited in the grain, with a final yield of 204 bushels per acre.

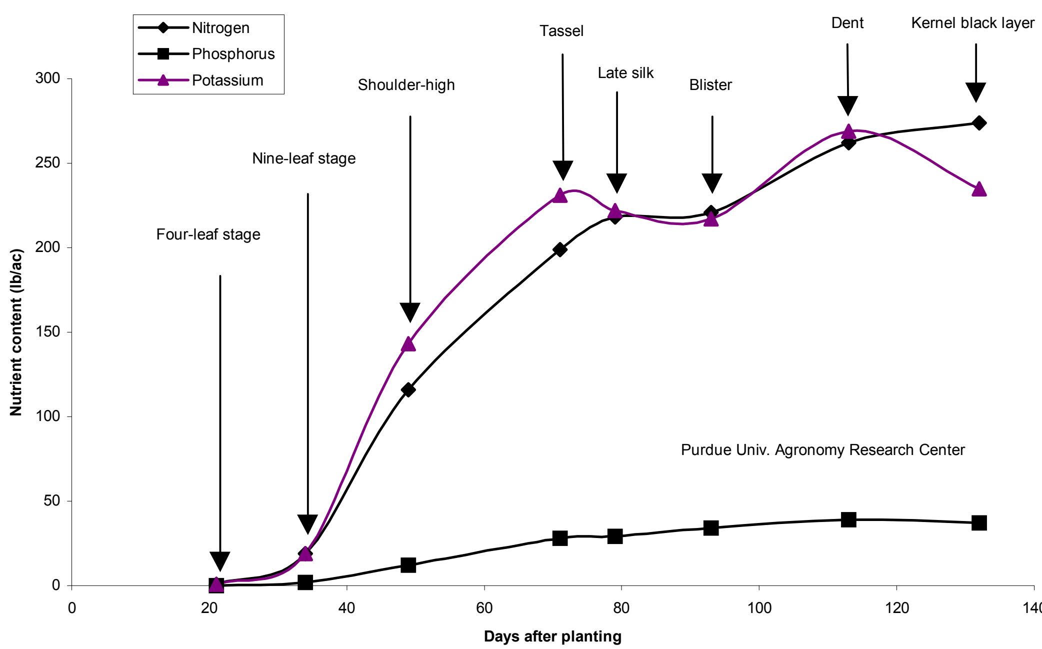

Figure 4. Total nutrient accumulation of a full season corn hybrid grown in westcentral Indiana.

This is just one example of how corn grows and develops. Root growth normally parallels stalk growth and will reach a maximum some time around silking. But a number of factors such as weather, compaction, fertilization practices, genetics and pests can alter the size of the root system, where it is located in the soil and the coordination of root and stalk growth.

Genetic Differences

An example of differences in root growth patterns between hybrids is found in a study by Mackay and Barber (1986). They found that the time required for the maximum root growth, growth stage at which senescence began and the maximum root length per plant were quite different between a full season hybrid, Mo17 × B73 and a short season hybrid, P3732.

The full season hybrid produced 4,670 feet of roots per plant and maximum root length occurred 91 days after planting.The short season hybrid produced a maximum of 2,550 feet of roots per plant with maximum root length found 75 days after planting at silking.

The two hybrids also responded differently to nitrogen fertility levels. With no nitrogen fertilizer applied, both hybrids had similar root length, N uptake and yield. However at 200 lbs of fertilizer N applied per acre, the full season hybrid produced more roots, took up more N and had a higher yield. Thus, corn hybrids can differ in how the below ground parts respond to management, just like they differ in yield potential and other characteristics.

THE NUTRIENT UPTAKE PROCESS

Movement of nutrients to roots

Roots do not intentionally grow towards a nutrient source. For nutrient uptake to occur, the individual nutrient ion must be in position adjacent to the root. Positioning of the nutrient ion can occur by one or more of three processes.

Root Interception. The root can "bump into" the ion as it grows through the soil. This mechanism is called root interception. Work by Barber estimates that perhaps one percent of the nutrients in a corn plant come from the root interception process.

Mass Flow. The soluble fraction of nutrients present in soil solution (water) and not held on the soil fractions flow to the root as water is taken up. This process is called mass flow. Nutrients such as nitrate-N, calcium and sulfur are normally supplied by mass flow.

Diffusion. Nutrients such as phosphorus and potassium are adsorbed strongly by soils and are only present in small quantities in the soil solution. These nutrients move to the root by diffusion. As uptake of these nutrients occurs at the root, the concentration in the soil solution in close proximity to the root decreases. This creates a gradient for the nutrient to diffuse through the soil solution from a zone of high concentration to the depleted solution adjacent to the root. Diffusion is responsible for the majority of the P, K and Zn moving to the root for uptake. Table 3 gives the relative importance of each mechanism in positioning nutrients adjacent to plant roots for uptake.

Table 3. Percent of nutrients taken up by a corn crop normally supplied by root interception, mass flow and diffusion.

Nutrient	Root interception	Mass flow	Diffusion
		Percent of uptake possible	
Nitrogen	< 1	80	19
Phosphorus	2	5	93
Potassium	2	18	80

Calcium	150	375	0
Magnesium	33	600	0
Sulfur	5	300	0

The nutrient uptake process

Uptake of nutrients by a plant root is an active process. As water is taken up to support transpiration, nutrients may be moved to the root surface through mass flow. But they are not taken directly into the root. The plasma membrane of the endoderm blocks the movement of ions into the root. At this point an active uptake process which requires energy is used to move the nutrients into the root and xylem for transport to the growing tissues. A specific protein carrier is used to bind with a nutrient ion and carry it across the membrane.

This active uptake process is a selective process. The root discriminates and only expends energy to take up nutrients it needs. Thus **nutrient uptake is not proportional to the ratios of nutrients in the soil solution**. Ions in large supply in the soil solution, such as calcium and sulfur, can accumulate near the root. In perennial plants this can actually result in visible quantities of calcium carbonate and calcium sulfate precipitating and coating old roots.

One important implication of the plants ability to pick and choose nutrients from the soil solution is the relative unimportance of the ratio of nutrients in the soil solution. As long as a given nutrient is supplied to the root surface at a concentration high enough to meet the demands of nutrient uptake, the demands of growth and development will normally be met. For example, the ratio of calcium and magnesium on the soil cation exchange sites and in soil solution has little effect on the ratio of these nutrients in the plant. The plant selects the ions it needs, allowing the others to accumulate in the soil solution at the root surface. Altering the soil to supply adequate amounts, the concept of critical concentrations, has generally proven more cost effective than altering soils to provide ratios of nutrients equivalent to the ratios at which the nutrients are found in the plants.

Normal patterns of uptake

Nutrient uptake parallels plant vegetative growth in many ways. Most crops take up the majority of the nutrients during the periods of vegetative growth and translocate stored nutrients to developing grain during reproductive growth. Nutrient uptake per acre increases rapidly from the 4-leaf stage to just prior to tasseling and then stays at high levels until after pollination (Figure 4). During this period the crop is growing very rapidly and the demand for nutrients to support that growth is high. After pollination nutrient uptake slows. Nutrients are actually lost from the plant after the dent stage.

Uptake per unit of root

The rate at which a given segment of root absorbs nutrients or the demand for nutrients placed on the root system also changes drastically over the growing season. Figure 5 illustrates seasonal rates of nitrogen uptake on a per acre basis and per mile of corn root. Similar patterns occur for phosphorus and potassium uptake.

Note that while the quantity of nitrogen taken up per day on an acre basis is quite small early in the season, the rate per mile of root is quite high. This is primarily due to a small number of roots trying to support the rapid growth occurring at the 2 to 5 leaf stage. This restriction in the size or extent of the root system coupled with high nutrient demand to support growth is why small plants may express nutrient deficiencies early but grow out of the deficiency later, even if no additional nutrient is applied.

As the root system expands during the second month of vegetative growth, the number of roots capable of nutrient uptake per pound of dry matter increases by about five fold (Figure 3). Thus the demand on a given segment of the root system drops. This is an important concept. If root growth is restricted by some factor such as compaction, cold temperatures, wet soils or rootworm feeding, increasing the availability of nutrients in the soil solution through starter fertilizer use or broadcast applications might have some impact on overcoming nutrient uptake restrictions. But at some point, the capacity of the active uptake system will become saturated and nutrient uptake will be limiting.

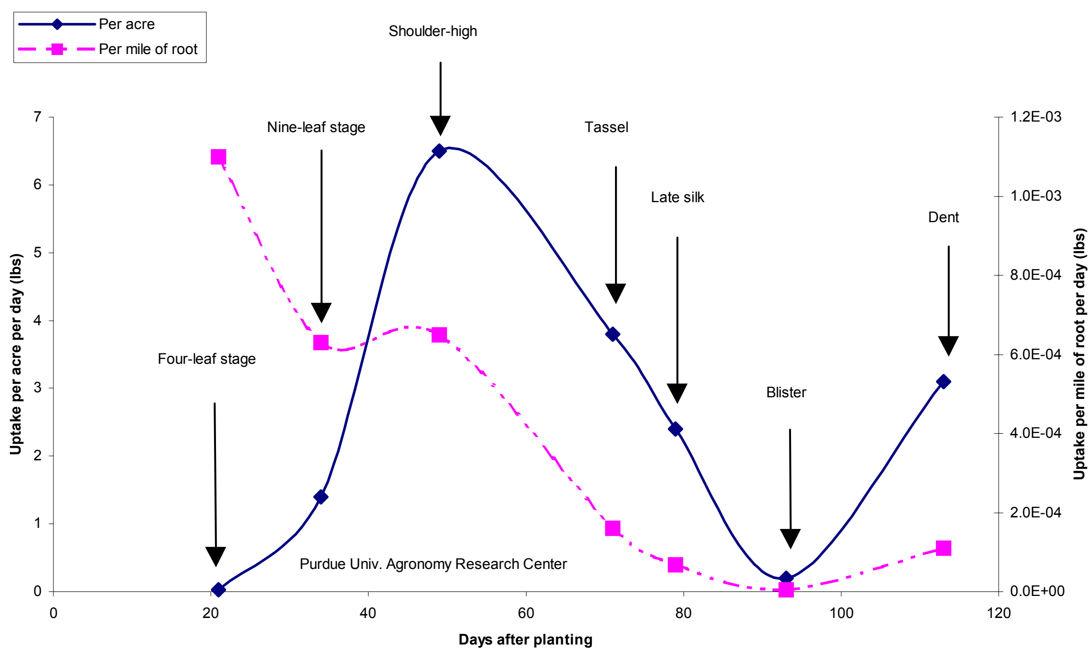

Figure 5. Seasonal nitrogen uptake per acre per day for a full season corn hybrid grown in westcentral Indiana.

This concept of saturating the roots capacity to take up nutrients also explains why placement techniques such as banding of P may increase nutrient availability but not nutrient uptake. If too small a portion of the root system comes in contact with the nutrient, uptake may be limited by the rate at which nutrients can be moved into the root. Having lower availability but a greater portion of the root system in contact with the nutrient can result in greater uptake.

This is why many states, including Indiana, recommend combinations of banding and broadcasting of nutrients such as P and K at low soil tests. A starter band will provide an area of high nutrient availability when root systems are small and demand per unit of root is high. But the broadcast materials provide an opportunity for a large portion of the root system to come in contact with the nutrient as the root system expands and demand per plant continues to increase.

EFFECTS OF WEATHER ON ROOTS AND NUTRIENT UPTAKE.

Soil temperature and moisture in May and June greatly influence root development. Roots develop in response to soil temperature, similar to the response of above ground plant development discussed earlier. As subsoils warm to acceptable temperatures, roots will develop down to deeper and deeper levels. If subsoils remain undesirably cool, root development will tend to remain nearer the soil surface where temperatures are warmer. Conversely, excessively warm surface soil will limit root development in the upper surface layers.

Wetter than normal conditions in April, May and June will slow the warming of soils because evaporation of soil moisture requires a lot of heat itself. Cold, wet soils encourage shallower rooting because subsoils remain undesirably cool to sustain root growth. Somewhat drier than normal conditions in April, May and June will hasten soil warming. Warm, dry soils encourage deeper rooting as subsoil temperatures warm to adequate levels.

In addition to affecting root growth and distribution in soils, weather can also impact nutrient uptake. Generally in dry years the nutrient content of crops is reduced, as compared to normal or wet years.

This reduction in the concentration of nutrients in stress years makes interpretation of plant analysis more difficult. For this reason we recommend that farmers not do routine monitoring under stress conditions or interpret the results very conservatively. Plant analysis is still a good diagnostic tool under stress years. But to use it successfully, comparison samples of problem and normal tissues is needed.

Tillers (a.k.a. Suckers) in Corn

'Suckers' in corn are more properly termed 'tillers' and are auxiliary corn plants that develop from one or more stalk nodes (joints) at the base of the main stalk, one tiller per node. Tillers become nearly independent plants as they develop, partly due to the fact that they will eventually develop their own root system. Tillers may compete somewhat with the main stalks, but given their late developmental start they usually lose out in the competition for water, nutrients and light.

TILLERING IN RESPONSE TO DAMAGE

One or more tillers commonly form if the main stalk is injured or killed by hail, frost, insects, wind, tractor tires, little kids' feet, deer hooves, etc. If the damage occurs early enough in the growing season, such tiller development may result in harvestable ears. Late tillering, however, usually doesn't allow enough time for tiller ears to develop and mature before a killing fall frost. An example of late tillering occurred in some Indiana fields damaged by the late June frost of 1992. The apparent 'regrowth' of these fields looked promising from windshield surveys, but little if any grain yield was obtained from these damaged fields.

TILLERS ON NORMAL PLANTS

Tillers may develop in undamaged fields, also. Most agronomists agree that such tiller development is a signal that growing conditions are very favorable, with few limitations on available nutrients, water, or light. Favorable growing conditions may exist simply due to favorable weather conditions or because the plant population is too low for the productivity level of the field. With favorable growing conditions, the corn plant has ample energy and nutrients to 'invest' in tiller development. Some hybrids are also genetically prone to developing tillers, even at adapted plant populations.

BOTTOM LINE ON EFFECTS OF TILLERS

As a rule, the end result of tiller development in an undamaged field is neutral. Usually, the main stalk will outcompete the tillers and the tillers eventually wither away. Tiller development in a field that was damaged or simply planted too thin MAY result in harvestable ears and thus contribute to grain yield.

Tassel and Ear Development Prior to Pollination

The corn plant has both male (tassel) and female (silks) flowers on the same plant. This flowering habit is called monoecious for you trivia fans. Both floral organs are initiated very early in the development of the corn plant.

TASSEL INITIATION

Following the initiation of the final leaf primordium by about leaf stage V6, the apical meristem completes its 'job' by initiating the tassel primordium. A small tassel can be visually detected as early as growth stage V7 by splitting a stalk and carefully shaving the leaf tissue near the pyramid-shaped tip of the stalk tissue.

Tassel size will increase rapidly over the course of a few weeks as the plant progresses through the 'grand growth phase'. The tassel's vertical position within the plant will move progressively higher as the stalk continues to elongate.

TASSEL DEVELOPMENTAL PROBLEMS

Tassel development can be arrested by sub-optimal temperatures, as evidenced by a late frost that occurred over the northwest third of Indiana on June 22, 1992. One month later, tassels dissected from plants in some frosted fields were no further developed than the day the frost damage occurred. These tassels were intact (i.e., were not rotted), indicating that frost per se (i.e., ice crystal formation) was not the cause of the arrested development. Critically low temperatures that accompanied the frost had apparently simply halted further cell division, elongation and differentiation.

Early infection (emergence to 10 inches high) of plant tissue by the widespread soil fungus *Sclerophthora macrospora* when fields are ponded or saturated for several days can subsequently cause the 'Crazy Top' phenomenon. The most visible result of the disease is that tassel development is altered to create a mass of leafy tissue rather than the usual tassel branches and anthers.

Early infestation (before tassel emergence from whorl) by corn leaf aphids can result in tassels plastered with aphid 'honeydew' secretions. Pollen shed from these tassels can be dramatically restricted. However, the percentage of affected plants in a field is usually low enough that overall pollination success is unaffected.

Drought stress prior to pollination will usually affect tassel development less than ear shoot development. Since the water content of silks is greater than that of tassels, drought stress that affects the overall water status of the plant will typically affect silk development more than tassel development.

EAR INITIATION

There are as many potential ears as there are leaves on the plant since every stalk node has an axillary meristematic bud associated with it. While axillary buds exist at the upper six to eight nodes of the stalk, they normally never become active.

Careful dissection of stalks at about growth stage V10 will reveal 8 to 10 ear shoots above ground. Each ear shoot is attached at a stalk node, behind its respective leaf sheath. A single groove is visible on the side of a stalk segment (internode) that contains an ear shoot. At growth stage V10, the identifiable ear shoots are composed primarily of husk leaf tissue. The developing ears themselves are only a fraction of an inch in length at this time.

Initially, the lower ear shoots are bigger than the upper ones because the lower ones form first. Later on, the upper one or two ear shoots take priority over the others and become the harvestable ears. Development of the upper ear is favored over the lower ones because of hormonal 'checks and balances', plus the proximity of the upper ear to the actively photosynthesizing leaves. Brace root development will rip off ear shoots at the lowest stalk nodes.

The uppermost, harvestable ear will normally be located at the 12th to 14th leaf. Damage to the upper ear prior to pollination will allow one or more of the lower ones to develop into the harvestable ear.

EAR SIZE DETERMINATION

Potential ear size (number of ovules) is an important factor that contributes to the grain yield potential of a corn plant. Severe plant stress may limit the potential ear size, and thus grain yield potential, before pollination has even occurred. Optimum growing conditions set the stage for maximum ear size potential and exceptional grain yields at harvest time. Ear size determination begins by the time a corn plant has reached knee-high and finishes 7 to 10 days prior to silk emergence.

Ear size is defined by the number of kernel rows per ear, the number of kernels per row and the weight per kernel. Total kernel number is determined by the number of kernel rows and the number of kernels per row.

Useful Tip: Every pair of rows is generally equal to 20 bushels per acre (for average populations and ear lengths). For a 16-row ear, 1 kernel per row is equal to about 5 bushels per acre (for average populations).

Kernel row number is determined shortly after growth stage V6 at the base of the developing ear. Subsequent development of the ear involves the 'lengthening' of each row by the initiation of additional ovules (potential kernels). Thus, ear development occurs from the base outward to the tip of the cob. The maximum **kernel number per row** is complete by about one to two weeks before silk emergence occurs. Typically, from 750 to 1000 ovules form per ear. Usual kernel number per harvested ear averages between 400 and 600.

Useful Tip: Kernel rows initiate as 'ridges' of cells that eventually differentiate into pairs of rows. Thus, row number on ears of corn is always even unless some sort of stress disrupts the developmental process. True row number is often difficult to visualize in tiny ears dissected from plants younger than about the 12-leaf stage.

Effects of Stress on Ear Size Determination

Row number per se is strongly determined by a hybrid's genetics rather than by environment. This means that row number is not easily influenced by external factors. Kernel number per row (ear length), however, is easily influenced by external factors and less so by the hybrid's genetics. It makes sense if you think about it: we talk about '18-row' hybrids but not '45 kernels per row' hybrids.

External factors that influence number of kernels per row can be positive or negative. Excellent growing conditions encourage high potential kernel numbers (long ears). Stressful conditions can terminate ovule initiation prematurely (short ears).

Examples of such stressful conditions prior to pollination include:

- Severe root pruning by deep row cultivation or corn rootworm damage.
- Extensive loss of photosynthetic leaf area by hail and frost.
- Injury by certain amino acid inhibitor herbicides.
- Severe drought stress.
- Severe nutrient deficiency (especially nitrogen).

What Goes On During Pollination?

Tassel Emergence & Pollen Shed: Growth Stage VT

Pollen shed and silk emergence represent the most critical period for corn growth and development in terms of fulfilling grain yield potential. Severe drought stress during the pollination period will cause more yield loss than at any other time of the growing season.

GROWTH STAGE VT

Technically, growth stage VT occurs when the last branch of the tassel emerges from the whorl. Portions of the tassel may be visible before the maximum leaf stage (final visible leaf collar) has occurred. Plant height is nearly at its maximum at growth stage VT. Pollen shed may begin before the tassel has completely emerged from the whorl.

The corn plant is most vulnerable to hail damage at growth stage VT since all of its leaves have emerged. Complete (100 %) leaf loss at growth stage VT will usually result in complete (100 %) yield loss by harvest. Even if pollination is successful, the ear shoots will usually die because few leaves remain to produce the necessary carbohydrates (by photosynthesis) to complete grain fill.

ANTHERS AND POLLEN

Pollen develops in and is dispersed from the anthers of the tassel. The anthers are those 'double-barrelled' structures that hang from the tassel during pollination. Anthers emerge from the glumes of each of the two flowers from each spikelet of the tassel. Anthers typically emerge from the upper flower first, while those from lower flower typically emerge later the same day or on following days. Spent anthers eventually drop from the tassel and are sometimes mistaken for the pollen itself when observed on the leaves or ground.

The yellow 'dust-like' pollen that falls from a tassel represents two to five million individual, nearly microscopic, spherical, yellowish-translucent pollen grains. Pollen grains contain the male genetic material that unites with the female genetic material of the ovule and produces an embryo.

The outer membrane of a pollen grain is very thin. Once dispersed into the atmosphere, pollen grains remain viable for only a few minutes before they dessicate. Yet, with only a 15 mph wind, pollen grains can travel as far as ½ mile within a couple of minutes.

POLLEN SHED

Pollen shed usually begins in the mid-portion of the central tassel spike, then progresses upward, downward and outward over time. Pollen is dispersed through pores at the anther tips which open when moisture and temperature conditions are suitable.

Weather conditions influence pollen shed. If the anthers are wet, the pores remain closed and pollen will not be released. Therefore, pollen shed typically begins after tassels dry from a heavy morning dew. Anther pores also do not open during rainy weather, therefore pollen does not wash off tassels. Cool, humid temperatures delay pollen shed, while hot, dry conditions hasten pollen shed.

Peak pollen shed usually occurs in mid-morning. Some research indicates that pollen shed decreases after temperatures surpass 86F. A second 'flush' of pollen often occurs in late afternoon or evening as temperatures cool. Pollen shed may occur throughout most of the day under relatively cool, cloudy conditions.

All of the pollen from a single anther may be released in as little as three minutes. Pollen shed for an individual tassel typically requires two to seven days to complete. Pollen shed for a field typically requires one to two weeks to complete due to field variability in development among plants. Approximately two to five thousand pollen grains are produced for each silk. Therefore, the amount of viable pollen available is almost never a limiting factor during pollination.

Silk Emergence: Growth Stage R1

The silks that emerge from the ear shoot are the functional stigmas of the female flowers. Every potential kernel (ovule) on an ear develops its own silk. Each silk must be pollinated in order for the ovule to be fertilized and develop into a kernel. Typically, up to 1000 ovules form per ear, even though we typically harvest only 400 to 600 actual kernels per ear.

Technically, growth stage R1 for a given ear is defined when even a single silk strand is visible from the tip of the husk. A field is defined as being at growth stage R1 when silks have emerged on at least 50 % of the plants.

SILK ELONGATION AND EMERGENCE

Silks begin to elongate from the ovules about 7 to 10 days prior to silk emergence from the husk. Dissection of young developing ears will reveal silk elongation beginning first from the basal ovules of the cob, then proceeding up the ear over time.

Similarly, silks from the basal (butt) portion of the ear typically emerge first from the husk, while the tip silks generally emerge last. Complete silk emergence from an ear generally occurs within four to eight days after the first silks appear.

As silks first emerge from husk, they lengthen as much as 1½ inches per day for the first day or two, but gradually slow over the next several days. Silk elongation occurs by expansion of existing cells, so elongation rate slows as more and more cells reach maximum size.

> **Useful Tip**: Silk elongation stops about 10 days after silk emergence, regardless of whether pollination occurs, due to senescence of the silk tissue. Unusually long silks can be a diagnostic symptom that the ear was not successfully pollinated.

Silks remain receptive to pollen grain germination up to 10 days after silk emergence. After 10 days without being pollinated, silk receptivity decreases rapidly. Natural senescence of silk over time results in collapsed tissue that restricts continued growth of the pollen tube. Silk emergence usually occurs in close synchrony with pollen shed, so that duration of silk receptivity is normally not a concern.

SILK EMERGENCE FAILURE

Severe Drought Stress

The most common cause of incomplete silk emergence is severe drought stress. Silks have the greatest water content of any corn plant tissue and thus are most sensitive to inadequate moisture levels in plant. Severe moisture deficits will slow silk elongation, causing a delay or failure of silks to emerge from ear shoot.

Silking in prolific hybrids (two-eared) is often not delayed as much as in strongly single-eared hybrids. Physiological preference for tassel development under stress is apparently less in prolific hybrids.

Silkballing

Silkballing is a type of silk emergence failure caused by the silks simply 'balling up' or 'knotting up' inside the husk leaves. Failure of silk emergence results in incomplete kernel set because some or most of the silks do not receive pollen. Initial diagnostic symptoms of silkballing when walking fields after pollination is complete include:

- Less than normal length of exposed, dried silks (which some may confuse with corn rootworm beetle silk clipping).
- Ear shoots that are not as 'solid' as they ought to be when squeezed.

> **Useful Tip**: The definitive diagnostic step is to make a single lengthwise cut, through the husk leaves, from the base of an ear shoot to the tip with a sharp knife and slowly unwrap the husk leaves, taking care not to disturb the arrangement of the silks. By doing this, you will easily observe the 'balled up' silks near the tip of the cob upward to the end of the husk leaves. In fact, a really good (or bad as it were) case of silkballing will look like a glob of spaghetti when you open up the ear shoot. Where silk emergence has been prevented almost entirely, the resistance of the 'balled up' silk mass at the end of the husk results in cobs with slight 'S' shapes and/or a 'shepherd's crook' tip as cob elongation continues after pollination.

The causes of 'silkballing' are neither well-understood nor well-documented. Cool nights at about the time of silk emergence appear to be the triggering event for 'silkballing'. Some interaction is also involved between the ear's husk coverage (length and tightness), cob length and silk elongation.

Hybrids with unusually tight husks may further worsen the problem. Conditions favoring unusually long husk leaves relative to cob length also likely contribute to the development of the problem. Hybrids themselves may vary in their genetic propensity for sensitivity of silk elongation to cool night temperatures.

Pollination and Fertilization

DEFINITIONS

Pollination is the act of transferring the pollen grain to the silks by wind or insects.

Fertilization is the union of the male gametes (genetic material) from the pollen with the female gametes in the ovule.

FERTILIZATION OF THE OVULE

Pollen grain germination occurs within minutes after a pollen grain lands on a receptive silk. Pollen grains are 'captured' by the 'hairs' of the silks. Some people mistakenly believe that the pollen must land at the very tip of the silk to be effective.

A pollen grain germinates on a receptive silk and develops a pollen tube, containing the male genetic material, that grows inside the length of the silk and fertilizes the ovule within 24 hours. While many pollen grains may land and germinate on an individual silk, only one will fertilize the ovule. A pollen grain can land and germinate anywhere along the length of an exposed, receptive silk.

Silk clipping by certain insects not only removes viable silk tissue, but also injures a certain length of the remaining silk. Generally, silk length on injured ear shoots must be at least ½ inch in order that a sufficient length of viable silk tissue be exposed for pollen germination.

THE 'EAR SHAKE' METHOD FOR DETERMINING FERTILIZATION SUCCESS

Within two to three days after an ovule has been successfully fertilized, the silk will collapse at its connection with the fertilized ovule and detach from the immature kernel. By carefully unwrapping the husk leaves from an ear and then gently shaking the ear, the detached silks from fertilized ovules will drop to the ground. The kernel itself will usually not be recognizable to the naked eye at this stage.

Such silk detachment can be used as a diagnostic tool to determine success of fertilization during periods of environmental or insect-caused stress (e.g., corn rootworm beetle silk clipping). Silks attached to unfertilized ovules eventually die, but remain attached.

Effects of Stress During Pollination

The appearance of ear shoots can be very misleading. Husks and cob will continue to lengthen even if kernel set is incomplete. A wonderfully long, robust-looking, healthy green ear shoot can completely mask even a 100 % failure of pollination. Unsuccessful pollination may be caused by several factors, sometimes working interactively.

SEVERE DROUGHT STRESS

Beginning about 10 to 12 days prior to silk emergence, severe moisture stress (i.e., near continual wilting of the leaves) begins to take its greatest toll on grain yield determination.

Table 4. Potential yield loss per day due to severe drought stress.

Drought stress occurring...	Potential yield loss per day
2 Weeks prior to silking	3 to 4 %
Silking (R1)	3 to 8 %
2 Weeks following silking	3 to 6%

As mentioned earlier, severe moisture deficits will slow silk elongation, causing a delay or failure of silks to emerge from ear shoot. Silks have the greatest water content of any corn plant tissue and thus are most sensitive to inadequate moisture levels in plant. Pollen shed, ironically, is often accelerated by drought stress and, when combined with slowed silk elongation, can result in incomplete 'nick' of pollen shed and silk emergence. The resulting symptom is uneven kernel set on the ears with many 'blanks'.

Other effects of severe drought during pollination include:

- Exposed silks may dessicate, becoming non-receptive to pollen germination, especially when stress occurs four to five days after silk emergence.
- Tassel firing (abortion of male flower) may occur. Pollen viability of unaborted flowers, however, is relatively unaffected by drought stress.
- Newly fertilized ovules easily abort when the plant is under severe moisture deficits. Aborted kernels will appear small and shriveled, often white.

HEAT STRESS

Pollen viability (ability to germinate) can decrease when exposed to stressful high temperatures, especially from the mid-90's upward. Exposed silks can dessicate due to high temperatures and low relative humidity, becoming non-receptive to pollen germination.

The effects of heat stress on silks is probably most important because it is unlikely that massive pollen death occurs from heat stress for two reasons. First of all, pollen shed usually occurs during mid-morning hours before temperatures reach their daily maximum. Pollen matures over time, so that 'fresh' pollen is available every morning. Secondly, pollen shed for a whole field usually takes one week or more to complete. It is unlikely that most central Corn Belt fields would experience so many successive days of stressful high temperatures.

INSECT STRESS

Corn leaf aphids can decrease pollen shed on individual tassels due to their 'honeydew' excretions on the tassel. However, rarely are enough tassels affected in a field to impact the success of pollination on a field basis.

Certain insects like corn rootworm beetles and Japanese beetles can interrupt pollination and fertilization by their silk clipping action. These insects feed on pollen and will subsequently clip silks as they feed on the pollen that has been captured.

Useful Tip: Entomologists generally consider a threshold for insecticide treatment to be a combination of less than 50 % completion of pollination plus silks continually clipped to less than ½ inch long. Use the 'ear shake' method described earlier (see page 29) to determine whether 50 % ovule fertilization has occurred.

UNUSUALLY LONG KERNEL ROWS

Unusually favorable conditions prior to pollination that favor ear size determination can result in ears with an unusually high number of potential kernels per row. Typical harvested ear size ranges from 30 to 40 kernels per row. Actual potential number of ovules per row may range as high as 60 to 70 per row.

Emergence of the silks from the tips of such long potential ears may occur a week or more after those from the butt of the ear. By the time the tip silks emerge, the source of pollen may be exhausted. The ovules connected with the tip silks are thus never fertilized, resulting in blank tips on the ears. Another side-effect of unusually long ears is that very late emerging silks are often restricted by the older (already pollinated) silks that have begun to dry up and turn brown.

Useful Tip: In this situation, while an inch or more of the cob tip may be blank, the rest of the ear may well contain a fairly normal (even satisfactory) complement of kernels. Before complaining about the barren tips, be sure to count the rest of the kernels. Remember that a typical harvested ear size is 16 to 18 rows around by 30 to 40 kernels long.

What Goes On After Pollination?

Kernel Development Stages

The grain fill period begins with the initiation of kernel development following pollination and ends approximately 60 days later when the kernels are physiologically mature. During grain fill, the primary sink for concurrent photosynthate produced by the corn plant will be the developing ear. A stress-free grain fill period can result in record yields, while severe stress during grain fill can cause kernel abortion or lightweight grain.

Kernel development proceeds through several relatively distinct stages, most recently described by Ritchie, et al., 1992.

KERNEL BLISTER STAGE (GROWTH STAGE R2)

About 10 to 14 days after silking, the developing kernels are whitish 'blisters' on the cob and contain abundant clear fluid. The ear silks are mostly brown and drying rapidly. Some starch is beginning to accumulate in the endosperm. The radicle root, coleoptile and first embryonic leaf have formed in the embryo by the blister stage.

Severe stress can easily abort kernels at pre-blister and blister stages. Kernel moisture content is approximately 85 percent.

KERNEL MILK STAGE (R3)

About 18 to 22 days after silking, the kernels are mostly yellow and contain 'milky' white fluid. The milk stage of development is the infamous 'roasting ear' stage, that stage where you will find die-hard corn specialists out standing in their field nibbling on these delectable morsels. Starch continues to accumulate in the endosperm. Endosperm cell division is nearly complete and continued growth is mostly due to cell expansion and starch accumulation.

Severe stress can still abort kernels, although not as easily as at the blister stage. Kernel moisture content is approximately 80 percent.

KERNEL DOUGH STAGE (R4)

About 24 to 28 days after silking, the kernel's milky inner fluid is changing to a 'doughy' consistency as starch accumulation continues in the endosperm. The shelled cob is now light red or pink. By dough stage, four embryonic leaves have formed and about ½ of the mature kernel dry weight is now in place.

Kernel abortion is much less likely once kernels have reached early dough stage, but severe stress can continue to affect eventual yield by reducing kernel weight. Kernel moisture content is approximately 70 percent.

KERNEL DENT STAGE (R5)

About 35 to 42 days after silking, all or nearly all of the kernels are denting near their crowns. The fifth (and last) embryonic leaf and lateral seminal roots form just prior to the dent stage.

A distinct horizontal line appears near the dent end of the kernel and slowly progresses to the tip end of the kernel over the next three weeks or so. This line is called the 'milk line' and marks the boundary between the liquid (milky) and solid (starchy) areas of the maturing kernels.

Severe stress can continue to limit kernel dry weight accumulation. Kernel moisture content at the beginning of the dent stage is approximately 55 percent.

Physiological Maturity (R6)

About 55 to 65 days after silking, kernel dry weight usually reaches its maximum and kernels are said to be physiologically mature and safe from frost. Physiological maturity (PM) occurs shortly after the kernel milk line disappears and just before the kernel black layer forms at the tip of the kernels.

Severe stress after PM occurs has little effect on grain yield, unless the integrity of the stalk or ear is compromised (e.g., ECB damage or stalk rots). Kernel moisture content at PM averages 30 percent, but can vary from 25 to 40 percent grain moisture.

Harvest Maturity

While not strictly a stage of grain development, harvest maturity is often defined as that grain moisture content where harvest can occur with minimal kernel damage and mechanical harvest loss. Harvest maturity is usually considered to be near 25 percent grain moisture.

Grain Maturation

Kernel Milk Line Development

Shortly after kernels are fully dented, break an ear of corn in half and look at the smooth or endosperm side of the kernels exposed on the tip half of the ear. A 'line' will usually be visible near the dented crown of the kernels.

> **Useful Tip**: Pricking the kernel with a pin or knife tip will aid in determining the position of the milky area if the milk line is difficult to see.

This milk line or starch layer marks the boundary between the liquid (milky) and solid (starchy) areas of the maturing kernel. As kernels continue to mature, the milk line 'moves' toward the tip (cob-end) of the kernels as more of the liquid sugary carbohydrates are converted to solid starches in the endosperm.

The position of the milk line on the kernel serves as a visual indicator of the progress of grain maturation prior to PM. When the milk line is halfway between the crown and tips of the kernels (half-milkline stage), grain moisture will be near 40 % and grain yield will be within 10 % of its maximum.

About 200 to 250 MGDD (about 14 days) are required to proceed from the half-milkline stage to black layer development (Afuakwa & Crookston, 1984). Optimum harvest moisture (25 % moisture) will typically occur two to three weeks after half-milkline stage, depending on temperatures and rainfall.

KERNEL BLACK LAYER DEVELOPMENT

Kernel dry weight accumulation ceases because a physical barrier develops at the tip (cob end) of the kernel that prevents further movement of dry matter into the kernel. The physical barrier is an abscission layer, commonly referred to as the kernel black layer. The abscission layer is actually several layers of placental cells at the tip of the kernel that die and collapse, then gradually thins and discolors and eventually turns brown and then black.

The kernel black layer (BL) is literally a thin black line at the tip of the kernel, most easily observed by splitting the kernel in half. In immature kernels, the layer of cells will be thicker and simply discolored, rather than thin and black.

Normally, the kernel BL will form shortly after the milk line disappears from the endosperm side of the kernel, about 60 days after pollination. Black layer development on an individual ear will normally proceed from the butt to the tip of the ear, following the same developmental sequence that the kernels were fertilized during pollination.

Grain moisture content at BL varies among years and hybrids, ranging from as dry as 25 % to as wet as 40 %, with most hybrids averaging about 30 % at black layer. Thus, grain will reach optimum harvest moisture (25 % moisture) about 5 to 10 days after BL occurs.

> **Useful Tip**: If pollination was erratic, kernel BL may form randomly throughout the kernels on the ear depending on when actual fertilization of the ovule occurred.

PREMATURE KERNEL BLACK LAYER DEVELOPMENT

Kernel BL can also form prematurely when ears or plants have been severely stressed during the grain fill period following pollination, or if a killing fall frost occurs prior to normal physiological maturity. Premature BL development will result in lower overall grain yield, as well as lower test weights.

Plants subjected to **severe drought and heat stress** during grain fill often abort substantial numbers of developing kernels shortly after pollination. Kernels that survive are often much smaller than normal and will often form BL prematurely.

Extensive **European corn borer** tunneling in the ear shanks, and even stalks, can greatly limit photosynthate movement into the developing ear and cause premature BL development.

Considerable **loss of green leaf area** by hail, insects, or disease early in the grain fill process can also cause premature BL development.

Finally, a **killing fall frost** prior to normal physiological maturity can result in premature BL development, even if the kernel milk line has not fully disappeared. About one week of average temperatures in the 50's late in the grain fill period can also trigger premature BL formation.

Effects of Stress During Grain Fill

While the pollination period is considered to be the most critical yield-determining interval in the corn plant's life cycle, severe stress on the corn plant during the grain fill period can also result in dramatic yield loss. Yield loss during grain fill can occur from 1) stand loss, 2) incomplete kernel set, 3) lightweight kernels and 4) premature plant death.

STAND LOSS DURING GRAIN FILL

Yield loss due to stand loss during grain fill is usually greater than that due to stand loss that occurs during the vegetative phase. When stand loss occurs prior to pollination, ear size (number of kernels) on surviving plants may compensate in response to the lesser competition of a thinner stand. Additional compensation may occur during grain fill in terms of greater kernel weight. When stand loss occurs during grain fill, ear size has already been set. Only kernel weight can compensate in response to the lesser competition of a thinner stand.

INCOMPLETE KERNEL SET IN CORN

Kernel set refers to the degree to which kernels have developed up and down the cob. Incomplete kernel set is not always apparent from 'windshield' surveys of a corn field. Husks and cob will continue to lengthen even if kernel set is incomplete. A wonderfully long, robust-looking, healthy green ear shoot can completely mask even a 100 percent failure of pollination or severe kernel abortion.

Yield loss due to incomplete kernel set can be estimated with the Yield Component Method (see page 43). For example, a field with 24,000 plants per ac. and average ear sizes of 16 rows per ear would sustain yield losses of approximately four bushels per acre for every one kernel decrease in row length.

Many factors can cause incomplete kernel set and distinguishing between them can be very difficult.

Unsuccessful pollination.

Unsuccessful pollination results in ovules that are never fertilized. Unsuccessful pollination results in ears with varying degrees and patterns of incomplete kernel set. See the earlier discussion (page 29) for more details.

Abortion of fertilized ovules.

Kernels are most susceptible to abortion during the first two weeks following pollination, particularly kernels near the tip of the ear. Once kernels have reached the dough stage of development, further yield losses will occur mainly from reductions in kernel dry weight accumulation.

Recently fertilized ovules (usually the tip kernels) are very sensitive to stress of all kinds, including sharply reduced rates of photosynthesis. Tip kernels are most sensitive to abortion by stress since they are the youngest (most recently pollinated) and farthest from the photosynthate supply.

<u>Causes of kernel abortion</u> include **severe drought stress** that continues into the early stages of kernel development (blister and milk stages) and can easily abort developing kernels. Apparent hybrid differences for level of kernel abortion may simply reflect different timing of blister and milk grain fill stages relative to the occurrence of severe heat or drought stress.

Severe nutrient deficiencies (especially nitrogen) can also abort kernels if enough of the photosynthetic 'factory' is damaged. Especially nitrogen deficiency that results in ½ or more of the lower leaves 'fired' at or shortly after pollination.

Extensive loss of green leaf tissue by certain leaf diseases by the time pollination occurs may limit photosynthate production enough to cause kernel abortion. Especially diseases like grey leaf spot in no-till continuous corn that destroys ½ or more of the photosynthetic leaf area at or shortly after pollination.

Consecutive days of heavily overcast, cloudy conditions may also reduce photosynthesis enough to cause abortion in recently fertilized ovules. Especially consecutive days of dense cloud cover immediately following pollination.

Useful Tip: Aborted kernels are distinguished from unfertilized ovules in that aborted kernels had actually begun development. Aborted kernels will be shrunken, mostly white, often with yellow embryo visible; compared to normal plump yellow kernels.

DECREASED KERNEL WEIGHT

Severe stress during dough and dent stages of grain fill decreases grain yield primarily by decreasing kernel weights. Decreased kernel weight results from the same stresses that cause premature black layer development (see page 34) and, in fact, is often caused by premature black layer formation itself.

Once grain has reached physiological maturity, stress will have no physiological effect on final yield, because final yield is already achieved. Stalk and ear rots, however, can continue to develop after corn has reached physiological maturity and indirectly reduce grain yield.

PREMATURE PLANT DEATH

Premature death of leaves greatly reduces the photosynthetic 'factory' output and can result in dramatic yield losses (Table 5). The plant may remobilize stored carbohydrates from the leaves or stalk tissue to the developing ears, but yield potential will still be lost.

Table 5. Effect of premature leaf death on grain yield of corn.[3]

Time of leaf death	Potential yield loss (%)
Soft dough	35
Full dent	27
Half-milkline[4]	6
Normal black layer	0

Premature death of whole plants results in greater yield losses (Table 6) than those resulting from death of leaves only. Death of all plant tissue prevents any further remobilization of stored carbohydrates to the developing ear. Whole plant death that occurs before normal black layer formation will cause premature black layer development, resulting in incomplete grain fill and lightweight, chaffy grain. Grain moisture of corn killed prior to normal black layer development will be greater than 35 %, requiring substantial field drydown before harvest.

Table 6. Effect of premature whole plant death on grain yield and whole plant moisture of corn.[5]

Time of whole plant death	Potential yield loss (%)	Whole plant moisture at time of death (%)
Soft dough	55	> 75
Full dent	41	75
Half-milkline	12	69
Normal black layer	0	60

Grain Moisture Loss In The Field

Grain moisture content (GMC) continually decreases as the kernel develops. Loss of grain moisture occurs partially through the plant (cob and ear shank), partially through the husk leaves and partially through the exposed end of the ear.

Hybrid variability for the rate of grain moisture loss during post-maturity drydown and the resulting grain moisture content at harvest are of great interest to grower and seed industry alike. Growers desire hybrids with superior yielding ability (maximum gross

[3] Adapted from Carter & Hesterman. 1990. Handling Corn Damaged by Autumn Frost. NCH-57. Purdue Univ. Cooperative Extension Service, W. Lafayette, IN 47907.

[4] Half-milkline refers to the position of the kernel milk line being halfway between the crown and tip of the kernel.

[5] Adapted from Carter & Hesterman. 1990. Handling Corn Damaged by Autumn Frost. NCH-57. Purdue Univ. Cooperative Extension Service, W. Lafayette, IN 47907.

income) that also dry very quickly in the fall (minimum drying or grain shrinkage[6] costs).

The seed industry also uses grain moisture loss data to rate hybrids for relative maturity. Many seed companies assign relative hybrid maturity ratings on the basis of relative harvest moisture differences among a group of hybrids. Two hybrids that differ in one 'day' of relative maturity will typically vary by about 0.5 % grain moisture if planted and harvested on the same days. Relative hybrid maturity ratings are most consistent within, not among, seed companies.

Desirable Hybrid Characteristics

Certain hybrid characteristics interact to influence grain moisture loss rates. The relative importance of each trait likely varies throughout the duration of the field drydown process.

- **Husk Leaf Number**. The fewer the number of husk leaves, the more rapid the grain moisture loss.
- **Husk Leaf Thickness**. The thinner the husk leaves, the more rapid the grain moisture loss.
- **Husk Leaf Senescence**. The sooner the husk leaves senesce (die), the more rapid the grain moisture loss.
- **Husk Coverage of the Ear**. The less the husk covers the tip of the ear, the more rapid the grain moisture loss.
- **Husk Tightness**. The looser the husk covers the ear, the more rapid the grain moisture loss.
- **Ear Declination**. The sooner the ears drop from an upright position to a downward position, the more rapid the grain moisture loss.
- **Cob Diameter**. The narrower the cob diameter, the more rapid the grain moisture loss.
- **Kernel Pericarp Thickness**. The thinner the pericarp, the more rapid the grain moisture loss.

Rates of Grain Moisture Loss in the Field

Grain moisture loss in the field occurs at a nearly linear rate within a range of grain moisture content beginning at about 40 percent and ending at 15 to 20 percent, then tapers off to little or no additional moisture loss after that. Figure 6 illustrates changes in grain moisture content over time for an early to mid-season maturity hybrid grown in Indiana in 1992 (unusually cool fall) and 1994 (more typical fall temperatures). Grain moisture loss was linear in both years until early to mid-October when loss rates leveled off to near zero

[6] For an excellent discussion on grain weight shrinkage, see Hicks and Cloud, 1991. Calculating Grain Weight Shrinkage in Corn Due to Mechanical Drying. NCH-61. Purdue Univ. Cooperative Extension Service, W. Lafayette, IN 47907.

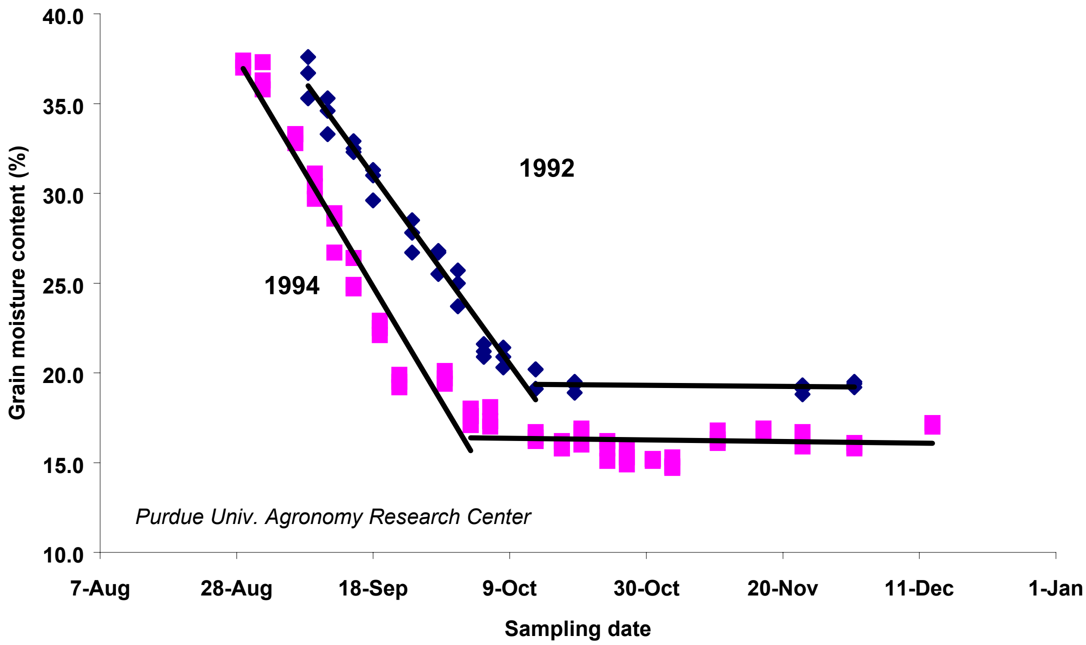

Figure 6. Grain moisture content changes over time for a 106-day corn hybrid grown in westcentral Indiana in 1992 (cool fall) and 1994 ('normal' fall).

The exact rates of grain moisture loss in the field are closely related to air temperature during the dry down period. The warmer it is, the faster the grain will dry per day. In fact, there is a close relationship between the rates of grain moisture loss per day and the average daily MGDD accumulation (Figure 7).

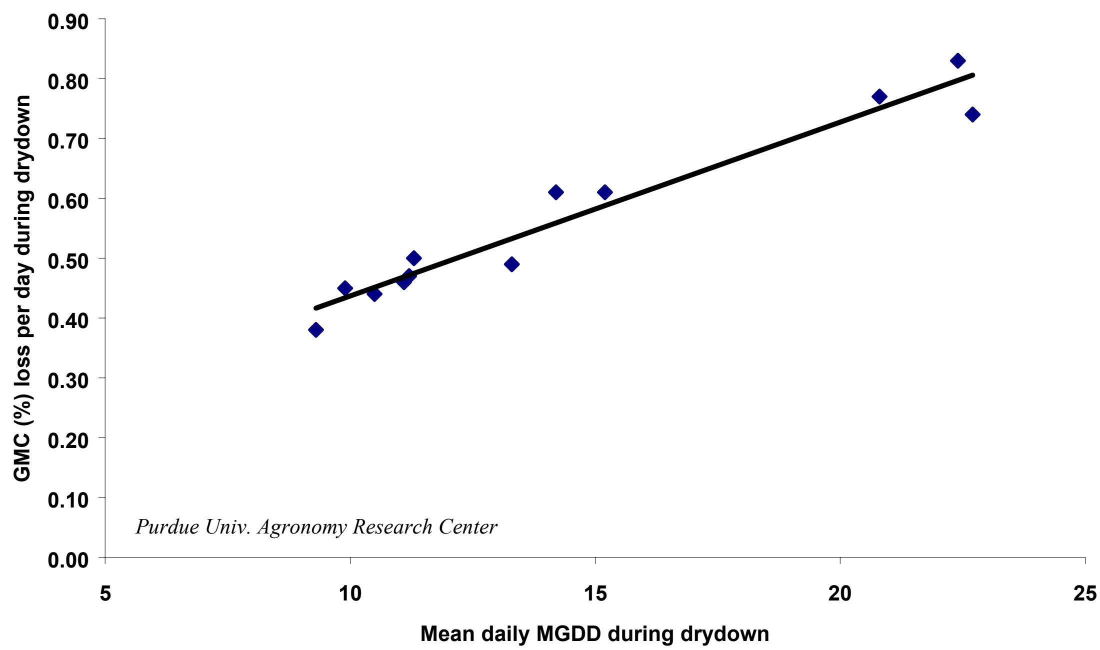

Figure 7. Relationship between GMC loss per day and mean daily MGDD during drydown for three corn hybrids planted late April to early May, 1991-94, in westcentral Indiana.

Since MGDD accumulations are closely related to calendar date, there is also a close relationship between the rates of grain moisture loss per day during the entire drydown period and the date when the grain nears maturity (approximately 38 % moisture content or about half-milkline). Dry down rates will range from about 0.8 percentage point per day for grain that nears maturity in late August to about 0.4 percentage point per day for grain that nears maturity in mid- to late September (Figure 8).

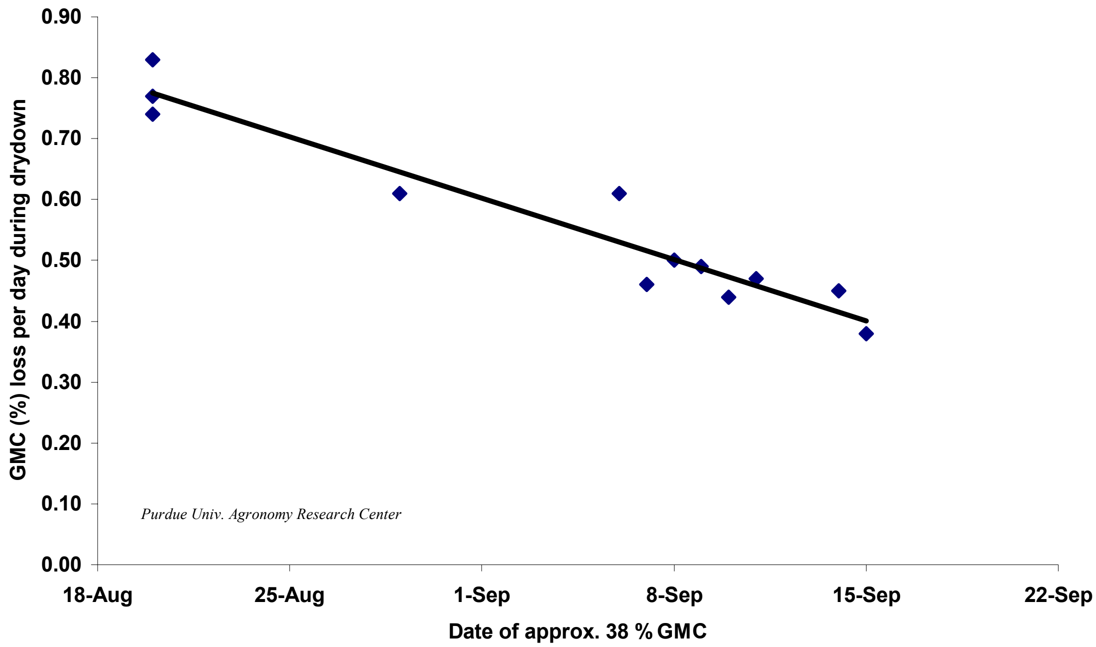

Figure 8. Relationship between GMC loss per day during drydown and date of approximate 38 % GMC for three corn hybrids planted late April to early May, 1991-94, in westcentral Indiana.

POTENTIAL FOR YIELD LOSS WITH FIELD DRYDOWN

Mechanical damage to the kernels can occur from harvesting mature corn grain that is too 'wet' due to the softness of the kernels. Mechanical harvest losses can occur from harvesting mature corn grain that is too 'dry' due to increased incidence of grain shattering from the ears or ear droppage. The grain moisture content at harvest that best minimizes the risks of mechanical kernel damage and harvest loss is near 25 percent (Aldrich et al., 1986).

Corn growers, however, often delay the harvest of mature corn grain to allow the grain to dry further in the field to grain moisture contents less than 25 % rather than incur the expense of mechanically drying wetter grain prior to storage. Such growers accept or ignore the risk of increased harvest losses in return for the decreased costs of mechanical grain drying.

Some researchers have suggested that additional yield loss with field drydown may occur, above and beyond mechanical harvest loss. Thorp Seed Co. in Illinois[7] reported a situation in 1992 wherein grain yield in the same field was reduced from 1.8 to 27 bu/ac by delaying harvest 3 weeks. Delayed harvest did not increase ear droppage, stalk breakage, or mechanical harvest loss. Average grain moisture content of 29 entries in a

[7] R.R. 3, Box 257, Clinton, IL 61727.

variety test plot declined 6 percentage points (from 30 % moisture to 24 % moisture) during the 3 weeks. Average yield loss for the 29 entries was 12 bu/ac. A similar study in 1983 with 14 entries resulted in 14 bu/ac yield loss as moisture content declined nine percentage points, from 24 % to 15 % moisture over a 3 ½ week period.

Similar yield losses were observed in field studies conducted at Purdue University[8] from 1991-94 during post-maturity drydown intervals from near 30 % to near 20 % grain moisture content. Kernel dry weight decreased significantly for all three hybrids evaluated during post-maturity drydown intervals in 1991, 1992, and 1994. The range of kernel dry weight loss was 1.7 to 6.5 grams per thousand kernels per percentage point loss in grain moisture content. This range of observed kernel dry weight losses translates to potential grain yield losses of 0.6 to 2.1 % per percentage point decrease in grain moisture content. Interestingly, none of the hybrids experienced kernel dry weight loss with field drydown in 1993.

Test Weight Tidbits for Corn

Test weight of shelled corn grain is an often used, although sometimes questionable, indicator of grain quality. Bragging rights down at the coffeshop during harvest season belong to those lucky few blessed with both high grain yields and 'high' test weights. Seed companies tout varieties with 'high' test weight potential. Grain buyers usually discount their purchase price for grain that is 'low' test weight, but don't necessarily reward sellers for 'high' test weight grain.

What Is Test Weight?

Test weight is a measure of the weight of a given volume of grain, namely a volume bushel (32 quarts). The standard test weight most often used for corn is 56 pounds per bushel. The minimum acceptable test weight for U.S. No. 2 yellow corn is 54 pounds per bushel.

As test weight decreases to 50 pounds or less, wet and dry millers often complain about lower than optimum yields of starch and grits. Feed value of low test weight corn is often thought to be questionable by farmers, but animal scientists don't always agree on this.

Relationship With Grain Yield and Moisture.

Test weight reflects the density of a sample of grain and is not necessarily related to grain yield (pounds of grain per acre). In 1992, low test weights and low yields occurred throughout northern Indiana, while low test weights and record high yields occurred in parts of southeast Indiana and southwest Ohio.

Test weight and grain moisture are related to the extent that wetter grain usually has lower test weight than drier grain. As wet grain dries (either in-field or artificially), its test weight typically increases several pounds per bushel.

Therefore, if a farmer harvests a field at unusually high grain moistures, test weight will

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8 R.L. Nielsen (unpublished data)

appear to be lower than expected. This is an 'optical illusion' of sorts because of the high grain moisture.

One of the reasons that test weight increases as grain dries is that dry kernels pack together more easily, thus more kernels fill a volume bushel and test weight increases. Another reason that test weight increases as grain dries is that kernels will shrink somewhat as moisture is removed, again allowing more kernels to fill a volume bushel.

Relationship With Conditions During Grain Fill

In general terms, test weight is a reflection of the level of stresses that occurred during the grain fill period following pollination. Any factor that decreases the rate or duration of grain fill can result in lower than desirable test weights at harvest.

Deficient soil moisture, excessive soil moisture, nutrient deficiencies, persistent cloudy weather, European corn borer infestations of the stalk and ear shank, too many hot days, too many cold days, frost that injures or kills immature corn, stalk rots and leaf diseases can all decrease test weight.

A Pre-Harvest Yield Estimation Technique for Corn

Growers often desire to predict grain yields four to six weeks prior to harvest in order to help develop grain marketing plans. A number of yield prediction methods exist, but the one most commonly used is probably the **Yield Component Method**.

Like any pre-harvest yield estimation, this method is indeed only an estimation. Yield estimates will probably be accurate to within plus or minus 20 bushels. Use the yield estimates for general planning purposes only.

This method is based on the fact that corn grain yield is a function of five yield components. The first four are easily measured prior to harvest. Since kernel weight is not finalized until physiological maturity, the Yield Component Method uses an assumed average kernel weight (a 'fudge' factor) to estimate yields.

1. Plants per acre
2. Ears per plant
3. Kernel rows per ear
4. Kernels per row
5. Weight per kernel

USING THE YIELD COMPONENT METHOD

1. Select several sites in the field.
2. At each site, measure off a length of row equal to 1/1000th acre (see Table 7)
3. Count the number of harvestable ears per 1/1000th acre.
4. Count the number of rows per ear on every fifth ear. Calculate the average.
5. Count the number of kernels per row on each of the same ears. Calculate the

average.

6. Calculate the estimated yield for each site by multiplying ear number by average row number by average kernel number, then dividing that result by 90.

The value 90 is a 'fudge' factor which accounts for the weight per kernel from a 90,000-kernel 56-pound bushel, the conversion from pounds to bushels and the conversion from 1/1000th acre to 1 acre.

Table 7. Length of a single row equal to 1/1000th acre for several row spacings.

Row spacing	Length of row
15-inch rows	34 feet, 10 inches
20-inch rows	26 feet, 1 inch
28-inch rows	18 feet, 8 inches
30-inch rows	17 feet, 5 inches
36-inch rows	14 feet, 6 inches
38-inch rows	18 feet, 9 inches

For example, let's say in Site #1 you counted 24 harvestable ears. Sampling every 5th ear resulted in an average row number of 16 and an average number of kernels per row of 30. The estimated yield for that site would equal 128 bu/ac, calculated by (24 × 16 × 30) divided by 90.

Since weight per kernel will vary depending on hybrid and environment, the Yield Component Method should only be used to estimate "ballpark" grain yields. For example, yield will be overestimated in a year with poor grain fill conditions, while it will be underestimated in a year with good grain fill conditions.

Useful Tip: Do not count butt or tip kernels that are less than half size (in other words, those that may be unharvestable), otherwise your yield estimate will likely be biased upward.

Miscellaneous Crop Problems

Puzzling Purple Plants

Young (V1 to V4) plants sometimes take on a distinct purpling in the leaves, seemingly overnight. A preponderance of purple plants always raises a lot of concerns among corn growers. What can cause leaf purpling in corn and what yield losses can be expected from leaf purpling (Crookston, 1983)?

The purpling results from the accumulation of a purple pigment called anthocyanin. Whether or not a corn plant produces anthocyanin is determined by the hybrid's genetics. A hybrid may have one or many genes that can trigger production of anthocyanin. Purpling can also appear in the silks, anthers and even coleoptile tip of a corn plant.

CAUSES OF PURPLING

Simple genetic response to low temperatures.

Bright sunny days with temperatures in the 60's or greater plus night-time temperatures in the 40's or lower. Hybrids with more anthocyanin-producing genes will purple more greatly. The purpling will slowly disappear as temperatures warm.

Excess photosynthetic sugars accumulated in the leaves.

Restricted root development (see page 15), coupled with an abundance of plant sugars produced by photosynthesis can result in an excess amount of sugars in the leaves. Similar excessive sugar amounts can be caused by leaf injury that restricts movement of sugars from the leaf. (e.g., the purple tip of a broken leaf or the reddish leaves severely damaged by European corn borer late in the season)

Nutrient deficiency, especially phosphorus.

Cold soils inhibit root development and aggravate a phosphorus deficiency situation, frequently causing even more intense leaf purpling (Cobbina & Miller, 1987).

DOES PURPLING CAUSE YIELD LOSS?

The cause of leaf purpling, not the purpling itself, will determine whether yield loss will occur by harvest time. If the cause of the root restriction is temporary (e.g., cool temperatures), then the purpling should disappear as the plants develop further and yield losses should be minimal, if any. If the cause of the root restriction continues to affect plant growth all season (e.g., soil compaction), then the purpling may continue for some time and some yield loss may result.

Twisted Whorls in Young Corn

Once in a while, whorls of corn plants become tightly twisted, often bent over severely, and do not unfurl on a timely basis. One's natural instincts would blame the twisted growth on herbicide injury. But, in most cases, the cause is something entirely different.

The problem often occurs when a period of poor growing conditions is followed by a sudden return to optimum growing conditions. An example would be corn that struggles through a cooler than normal and frequently cloudy May and early June. A return of sunshine and warmer temperatures encourages the previously struggling corn to grow rapidly.

Certain hybrids react to such a change in growing conditions by basically going 'bonkers'. The upper whorls of the plants don't unfurl properly. Younger leaves deeper in the whorl continue to grow rapidly, but are unable to emerge from the unfurled upper leaves. The now tightly twisted whorl then bends and kinks from the pressure exerted from the younger leaves' continued growth. The growth stage where this phenomenon seems to occur is around five to six visible leaf collars (about knee-high).

At the peak of the problem, the appearance of these plants is indeed unsettling and one would think that the whorls would never unroll properly. Given another week, though, the majority of the affected plants do unroll and continue to grow normally. Yield effects from the period of twisted growth will be minimal, if any.

If you didn't notice the twisted growth to begin with, you may notice the appearance of 'yellow tops' across the field after the whorls unroll. The younger leaves that had been trapped inside the twisted upper leaves emerge fairly yellow due to the fact that they had been shaded for quite some time. Another day or two will green these up and the problem will no longer be visible. In addition to being fairly yellow, the leaves will exhibit a crinkly surface caused by their restricted expansion inside the twisted whorl.

Recovery Following Early-Season Injury to Corn

When corn is damaged early in the growing season, growers are sometimes faced with the decision of whether or not to replant the field. One of the most important, and most difficult, steps in making a replant decision is estimating the surviving plant population in the field. Corn is remarkably resilient to above-ground damage early in the season, yet growers often underestimate the recovery potential of a damaged corn field. As a result, much replanting is unnecessarily performed each year. Use my replant publication (Nielsen, 1987) to estimate yield and dollar returns to corn replanting.

A damaged plant with a healthy, undamaged growing point (apical meristem) will survive. Damage to the growing point area will either kill the plant or severely stunt its recovery. Corn's growing point is initially located ¼ to ¾ inch below the soil surface, near the crown. The growing point remains below ground until about V6. The stalk internodes begin to elongate shortly before growth stage V6, elevating the growing point above soil surface. From this point on, the growing point becomes increasingly vulnerable to above-ground damage.

Prior to V6, a plant is relatively immune to above-ground damage from 'single event' damage by frost, hail, cutworm, sandblasting, anhydrous ammonia burn, 28% N solution burn, and paraquat drift. However, repeated injury to young plants may stunt a plant's development severely enough to eventually kill the plant even though the growing point was technically not injured.

While corn younger than V6 can tolerate a fair degree of above-ground damage to leaf tissue by frost, lethal cold temperatures (32F or less for several hours) can 'penetrate' the upper soil surface and damage or kill the growing point of a young corn plant. Corn younger than V6 is also susceptible to below-ground damage from soil insects, disease and flooding.

Damaged corn fields need to be left alone for several days after the damage occurs to give them some time to initiate recovery. Recovery from the whorl will appear within 3 to 10 days, depending on temperature and soil moisture. Warmer temperatures and adequate soil moisture encourage rapid recovery, while cooler temperatures and/or drought stress restrict the rate of recovery.

The stalk tissue near the growing point region should remain firm and yellowish-white. Injury occurring close to the growing point may alter normal hormonal activity and cause deformed regrowth. Given sufficient time, surviving corn plants should be showing new leaf tissue expanding from the whorls, while dead corn plants will still look dead.

Spring Frost Damage to Young Corn

Clear, calm nights with temperatures in the low to mid-30's may result in frost damage to young corn seedlings. Even though temperatures may not drop below 32 F, frost can still develop on exposed corn leaves due to heat loss to the atmosphere (radiational cooling) on clear, calm nights. Obviously when temperatures fall below 32 F, above-ground plant parts can freeze directly.

Spring frost damage to emerged corn plants often looks worse than it really is. As with most early-season injuries to corn, the recovery of frosted corn depends greatly on whether the internal growing point region was damaged.

Frosted leaves will turn greenish-black during the first 24 hours, then slowly bleach to a straw color as it dries out. Yield loss to frost damage in corn younger than V6 is related primarily to the degree of stand loss, not to the degree of leaf damage.

As the frosted leaf tissue in the whorl dries, the whorl will can develop a constricted 'knot' that restricts expansion of the undamaged whorl tissue later on. Knotted, dead leaves will usually cause only minor hindrance to recovery. Usually, knotted corn plants will successfully recover as the expanding whorl tissue breaks these knots.

Once in a great while, it may be necessary to mow a frosted corn field to cut off severely knotted leaf tissue. The key to deciding whether to mow or not is to allow the damaged field three to five days to show you how well it is recovering. Mowing such damaged plants just below the dead tissue may encourage recovery, but the growing point must be below the level of the cut or the mowed plant will die. Mowing almost always results in further removal of green leaf tissue, thus causing additional yield loss due to defoliation.

Silver Leaf Symptoms in Young Corn

Late spring frost damage may not be severe enough to kill leaves outright. Radiational cooling of leaves on clear, calm nights with temperatures in the mid- to upper 30's may simply result in damage to the outer leaf surface. The subsequent symptom of such minor damage is what many refer to as 'silver leaf' in corn. The 'silver leaf' symptom indeed appears as silvery or dull gray upper leaf surfaces. The effect of this type of minor leaf damage is negligible, if any. The leaves will not die abruptly as will severely frosted leaf tissue. Continued expansion of the whorl will not be restricted in any way. New leaves that expand from the whorl will be normal in appearance. This symptom is more of a curiosity than a nuisance.

Damage to Corn From Flooding or Ponding

Prior to the 6-leaf stage (measured by visible leaf collars) or when the growing point is near or below the soil surface, corn can survive only two to four days of flooded conditions. The oxygen supply in the soil is depleted after about 48 hours in a flooded soil. Without oxygen, the plant cannot perform critical life sustaining functions; e.g. nutrient and water uptake is impaired, root growth is inhibited, etc.

If temperatures are warm during flooding (greater than 77F) plants may not survive 24 hours. Cooler temperatures prolong survival. Once the growing point is above the water level the likelihood for survival improves greatly.

Even if flooding doesn't kill plants outright it may have a long term negative impact on crop performance. Excess moisture during the early vegetative stages retards corn root development. As a result, plants may be subject to greater injury during a dry summer because root systems are not sufficiently developed to access available subsoil water. Flooding and ponding can also result in losses of nitrogen through denitrification and leaching.

If flooding in corn is less than 48 hours, crop injury should be limited. To confirm plant survival, check the color of the growing point (it should be white and cream colored, while a darkening or softening usually precedes plant death) and look for new leaf growth three to five days after water drains from the field.

Certain disease problems which may become greater risks due to flooding and cool temperatures are corn smut and crazy top. The fungus that causes crazy top depends on saturated soil conditions to infect corn seedlings. There is limited hybrid resistance to these diseases and predicting damage is difficult until later in the growing season.

Tassels That Think They Are Ears

Ears where tassels should be or tassels that exhibit partial ears in addition to tassel branches always occur somewhere every year. While a tassel-ear is indeed an odd sight, its occurrence is simply a reminder that the flowers of the corn plant have the physiological capability to be perfect (male and female flowers in the same floral organ).

Most of the time, the plant's hormonal activity dictates that tassels develop male flowers exclusively. Certain situations alter the hormonal control such that female flowers (ovules or potential kernels) develop as well as male flowers (the pollen-containing anthers). Tassel-ears most often occur on tillers (suckers) and rarely on main stalks. The occurrence of tassel-ears, therefore, merely reflects the presence of tillers in a field.

The occurrence of tillers usually does not signal the presence of other problems in the field. On the contrary, tiller production is usually the result of favorable growing conditions during early vegetative growth and development.

Killing Fall Frost Prior to Physiological Maturity

Considerable whole plant damage will occur when temperatures fall below 32F for four to five hours or below 28F for even a few minutes. Less damaging frost can occur at temperatures greater than 32 F when conditions are optimum (clear skies, low humidity, no wind) for rapid radiational cooling of the leaves.

A frost incident that only damages the corn plants' leaves affects yield potential (Table 5, page 37) less than a true killing frost that obliterates the leaves, stalk and husks (Table 6).

Remember that even if a corn crop barely reaches black layer before a killing frost occurs, the grain moisture will still be 30 to 35 %. Some field drydown will need to occur before the corn can be safely harvested.

Frosted grain will dry fairly normally, after an initial delay in moisture loss. Drying rates in the field typically drop to ½ to ¾ percentage points per day in early October, so field-drying grain from 35 % to 25 % could require two to three additional weeks.

Premature Ear Declination

Ears of corn normally remain erect until sometime after physiological maturity has occurred (black layer development), after which the ear shanks eventually collapse and the ears decline (i.e., point toward the ground). Ear declination sometimes occurs earlier than expected. Causes of premature ear declination include:

Severe drought stress can reduce the water potential and turgor pressure in the plant tissue enough that the shank simply cannot support the weight of the developing ear. The ear shank simply collapses prematurely.

Severe European corn borer damage can cause the ear shanks to collapse under the weight of the developing ear. Eventually, such tunneling can cause extensive ear droppage from the plant.

Severe fall freeze damage to the ear shanks, especially of immature corn, can destroy the integrity of the cell tissue in the ear shank. The ear shank collapses under the weight of the ear.

Remember that the ear shank is the final "pipeline" for the flow of photosynthates into the developing ear. An ear shank that collapses prior to physiological maturity will greatly restrict, if not totally prevent, the completion of grain fill for that ear and will likely cause premature black layer development in the grain. If grain fill were totally shut down at late dough, early dent, or late dent stages of grain development; yield losses for individual ears would equal 50, 20 and 5 %, respectively.

Red Corn Plants

Late in the season, leaves and/or stalks of some corn plants take on a bright red color. Sometimes the reddening begins in the leaf midrib, later spreading throughout the whole leaf. Sometimes only certain leaves turn red, sometimes all do. Sometimes the stalk also turns red. Causes of leaf or stalk reddening include:

Barren Plants. Close inspection of some plants reveals that the ear is barren of kernels or perhaps is missing altogether. Without a full complement of kernels on the ears, the plants simply cannot translocate the sugars from the leaves as completely as usual. The reddening of the plants is caused by an oversupply of plant sugars relative to the demand for such carbohydrates. The accumulation of sugars in the leaves triggers the formation of red pigmentation.

Damaged Leaf Connection. Where single leaves turn red and the rest remain green, the cause is restricted to that single leaf. Close inspection of the point of attachment of the leaf sheath to the stalk node will usually reveal some sort of damage that doesn't quite kill the whole leaf. European corn borer larvae can feed at the stalk node and destroy most of the leaf sheath connection. The reddening of the leaf is caused by an oversupply of plant sugars because of the restricted pathway from the leaf. The accumulation of sugars in the leaves triggers the formation of red pigmentation.

Stunted Ear or Beer Can Ear Syndrome

A form of incomplete kernel set has been observed in recent years and has been labeled the Stunted Ear or Beer Can Syndrome. Symptoms include normal-looking plants and ear shoots (husk leaves), but cob-lengths of only about four inches, varying degrees of kernel set on the short cobs and a tasselbranch-like appendage on the tip of the cobs. Sometimes instead of a tasselbranch-like appendage on the tip of the cob, one finds the remainder of a tiny ear initial reminiscient of that visible at about the 9-leaf collar stage.

Because of the short cob and the normal length husk leaves, silkballing is evident on some portion of the upper ear. But, it's important to point out that the silkballing is only a result of the Beer Can Ear Syndrome and does not contribute to the problem itself, unlike other situations where silkballing is the major problem of interest (page 28).

Kernel row numbers at the base of these ears appear to be normal or at least acceptable. I've seen such ears with 16 to 18 rows of kernels. The problem is, compared to an acceptable 35 to 40 kernels per row, these ears only contain about half that in terms of ovules per row and often only 12 to 16 actual kernels per row. The problem can occur in well over 50 % of the plants in a field, thus resulting in a significant yield loss potential.

Causes of the Beer Can Ear Syndrome are unknown, but reflects a causal factor that affected early ear shoot development. I believe the problem occurs sometime after the 6-leaf collar stage, when the plants have completed development of leaf initials and begin development of tassel and ear initials, but not much beyond the 12-leaf collar stage, when potential kernel row numbers are finalized.

Few common factors exist among problem fields regarding soil fertility levels, herbicide programs, or corn diseases. My personal opinion is that severe cold snaps during the 6-leaf to 12-leaf stage contribute to its occurrence.

There are definite variety differences within individual fields, but the extent of the problem can also vary dramatically with the same variety planted from one field to another.

Kernel Sprouting on the Ear

On occasion, corn kernels will sprout while on the ear in the field. There are two causes of premature sprouting.

Rewetting of Dry Grain. Field observations suggest that grain that has dried in the field to moisture contents less than about 20 % can sprout if an extended rainy period rewets the grain. Rewetting of grain at moisture contents greater than 20 % does not seem to result in sprouting.

Ear Molds. The development of certain ear molds can trigger premature kernel sprouting.

Plant Stress & Stalk Rot Development

Almost any kind of plant stress, occurring almost any time during the growing season, can predispose the corn plant to invasion by root rot and stalk rot fungi.

Photosynthetic Stress - Translocation Balance Theory[9]

In response to either pre- or post-silk stresses, the corn plant will typically respond to insufficient concurrent photosynthate supplies during the grain fill period by remobilizing carbohydrates from the leaves and stalk to the developing ear. While this 'warehouse' of carbohydrates is nice insurance against the effects of photosynthetic stress, carbohydrate depletion of the lower stalk tends to reduce the plant's resistance to root rot and, subsequently, stalk rot fungi.

For many modern corn hybrids, the majority of the photosynthates required for kernel development are produced concurrently, that is during the grain fill period. Few of the carbohydrates stored in the 'warehouse' of the stalk are typically remobilized for grain fill. The ability to avoid remobilizing stalk carbohydrates to the developing ear helps maintain stalk health and integrity.

Such hybrids are often characterized as being 'stay-green' hybrids. Severe photosynthetic stress can 'force' even stay-green hybrids to remobilize more stalk carbohydrates than usual, resulting in increased stalk rot potential.

Photosynthetic Stress Prior To Silking

Prolonged photosynthetic stress prior to silking often results in a smaller photosynthetic 'factory' that subsequently produces less concurrent photosynthate during grain fill. Such stress includes:

- Above-ground damage to the plant
  - Hail injury
  - Sandblasting

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[9] Originally proposed by Dr. James Dodd, Professional Seed Research Inc., 411 Dugan Road, Sugar Grove, IL 60554.

  - Insect injury
  - Fertilizer injury
- Temperature stress
- Drought stress
- Excessive waterlogging of soils

PROLONGED PHOTOSYNTHETIC STRESS DURING GRAIN FILL

Prolonged photosynthetic stress during grain fill decreases the available concurrent photosynthates available for grain fill. Such stress includes:

- Hail damage
- Temperature stress
- Drought stress
- Severe insect injury
- Leaf diseases
- Cloudy weather
- Excessive waterlogging of soils
- Nutrient deficiencies

SCOUT FIELDS WHERE STALK ROT POTENTIAL IS HIGH

Growers should begin inspecting stressed fields for stalk rot development in late August to early September. Soft stalks resulting from stalk rot development can be detected by pinching the lower two or three stalk internodes with your fingers. Healthy stalks will not collapse, rotted stalks will collapse easily. If severe stalk rot development is detected, plan on harvesting the field soon after the grain is physiologically mature (development of black layer, about 30 % grain moisture).

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