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Corn

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Corn was an important crop for people who lived in the area that became Illinois before the Europeans first set foot here; it was the staple food crop of the people who lived in the Cahokia area some 1,000 years ago. It was a crop of choice when Europeans settled and started to farm in Illinois, and acreage in the state first reached 10 million acres in 1895. Acreage over the past 100 years has ranged from about 7 to 13 million acres and is now about 50% of the row-cropped acres in the state.

The major reason that so much corn is grown in Illinois is that the soils and weather are very well suited to the crop, and as a result yields are high. **Figure 2.1** shows yield trends for corn and other major Illinois field crops over the period 1990 through 2008. Corn yields have increased by 2.6 bushels per year over that period, or a total of more than 45 bushels, or some 30%. There are few places in the world, and none without extensive irrigation, that can point to such high productivity for any crop. In 2007, the average U.S. yield was nearly twice the world average yield, and the average Illinois yield was about 15% higher than the U.S. average yield. Illinois produces about 17% to 18% of the U.S. corn crop, and more than 7% of the corn produced in the world.

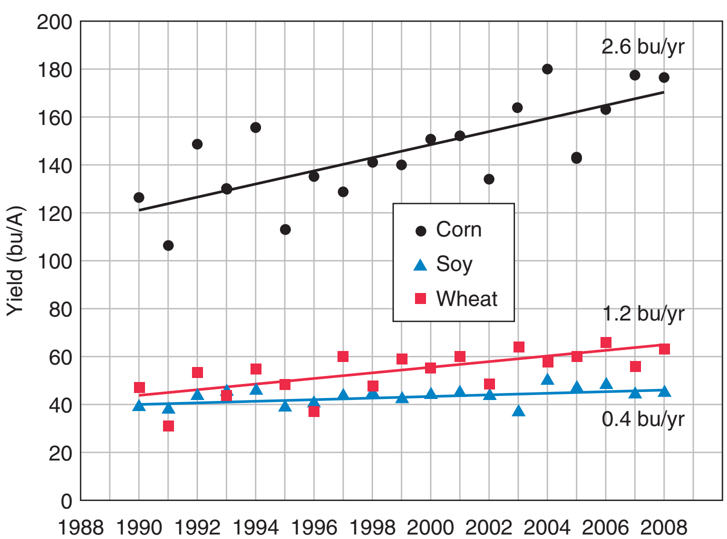

Figure 2.1. Yield trends of corn, soybean, and wheat in Illinois from 1990 through 2008. The "trend line" yields for each crop are shown, with average per-year yield change.

Though corn is by far the highest-yielding grain crop in Illinois, differences in soils and weather mean that yields are not consistently high in all locations and all years. Some find it useful to develop yield goals for individual fields, though the fact that yields are often higher than expected when the weather and management are ideal means that most producers have had yields higher than their realistic expectations (goals) at least once in recent years. That means that management should be done in ways that don't greatly restrict yield potential, even in above-average yields. As an average, though, it can be a useful exercise to look up yield potential for individual soil types, as listed in University of Illinois publications *Soils of Illinois* (B778), *Average Crop, Pasture and Forestry Productivity Ratings for Illinois Soils* (B810), and *Optimum Crop Productivity Ratings for Illinois Soils* (B811).

Corn Plant Development

Understanding the development of the corn plant, including when during its life cycle it is most vulnerable to stress, is a great help in managing this crop. **Figure 2.2** outlines plant development. Another very useful reference is *How a Corn Plant Develops* (Special Publication No. 48), from Iowa State University. The basics of this system are as follows:

- Ve refers to "vegetative" emergence.
- Vn, where n is the number of leaves with collar visible **(Figure 2.3).** Plants typically develop about 20 leaves, but the lowermost leaves are damaged by expansion of the stalk and often disintegrate. So by the time of pollination there may be only 14 to 16 intact leaves.

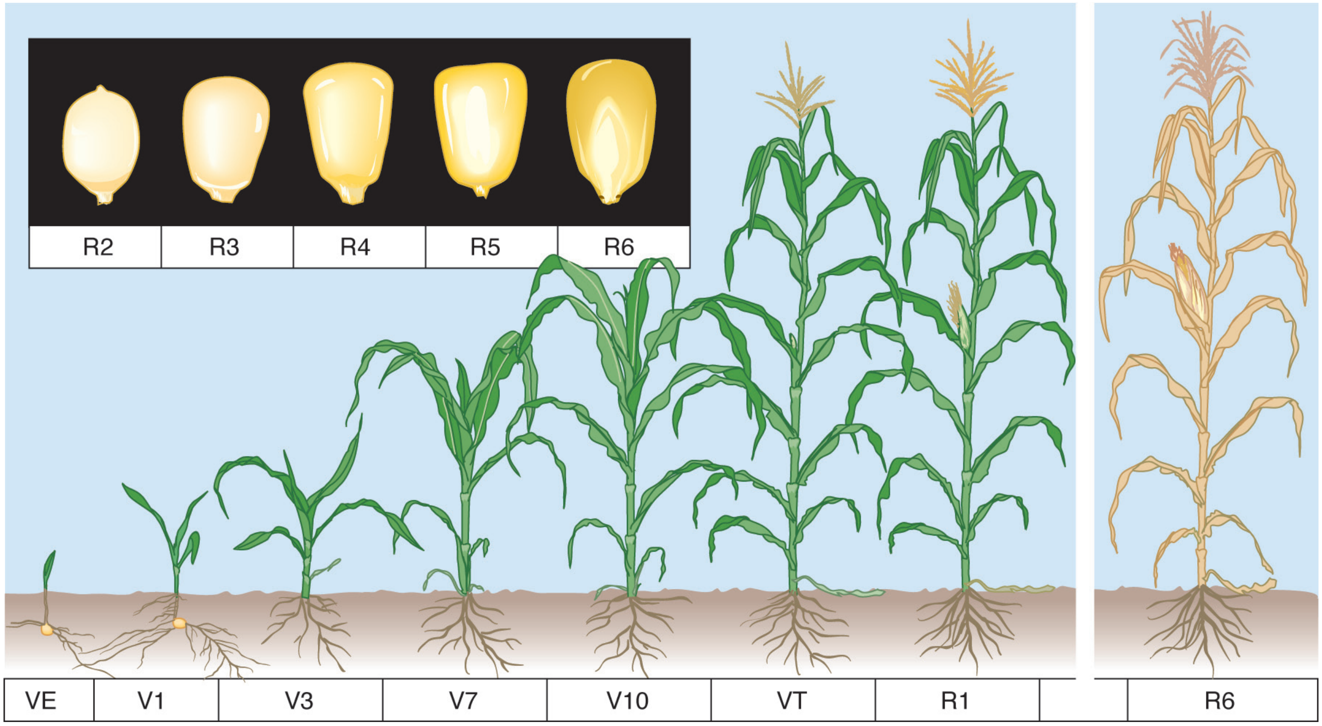

Figure 2.2. Corn plant development.

● Rn, or "reproductive" stage n, where n goes from 1 (silking, which coincides with pollen shed) to R6, which is physiological maturity.

This staging system is almost universally used, though other methods in use count leaves when they have most of their area exposed, which occurs several days before the collar appears.

Many years ago scientists observed that corn plant development follows very closely the accumulation of average daily temperatures during the plant's life. This accumulation is calculated as "growing degree days" (GDD). The GDD concept has been very useful in knowing how the crop will respond to temperatures and in helping fit hybrids into situations where expected GDD accumulations are known from weather records.

The GDD accumulation for a day is the average of the low and high temperature, minus 50 °F. The subtraction of 50 degrees is done because corn plants don't grow much at or below 50 °F. If the low temperature for the day is below 50 °F, then use 50 instead of the actual low temperature; otherwise, the GDD could be negative. Another modification made in the case of corn is a high temperature cutoff, done because growth rates don't continue to increase as temperature increases above a certain point. This cutoff point for corn is 86 °F; if the high temperature for the day is above 86, then use 86 instead of the actual high temperature.

If the low temperature for a day is 50 or higher and the high is 86 or lower, then average the high and low temperatures and subtract 50. So a day with low and high temperatures of 60 and 80 would produce (60 + 80) ÷ 2 – 50 = 70 – 50 = 20 GDD. For a day with temperatures of 44 and 66, substitute 50 for the actual low: (50 + 66) ÷ 2 – 50 = 58 – 50 = 8 GDD. And for a warm day with temperatures of 74 and 93, substitute 86 for the actual high: (74 + 86) ÷ 2 – 50 = 80 – 50 = 30 GDD. Note that the maximum GDD possible for a day is 86 – 50 = 36, but this would require a low temperature of 86 or higher, which is very unusual in Illinois. If the daytime high temperature is 50 or less, the GDD for that day is 0.

Figure 2.3. A V4 corn plant. Notice that the collar of the 4th leaf from the base is visible, but the 5th leaf collar has not yet emerged from the whorl of leaves.

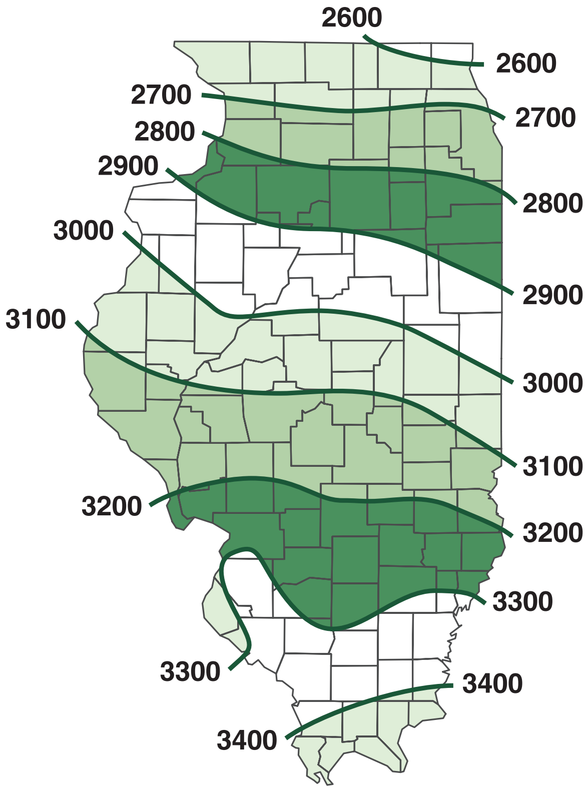

Figure 2.4. Average number of growing degree-days in Illinois, May 1 to September 30, based on 1971–2000 data. Map provided by the Illinois State Climatologist Office, Illinois State Water Survey.

Corn hybrids grown in Illinois have planting-to-harvest GDD requirements ranging from 2,200 to 2,400 for early hybrids grown in the northern part of the state to 2,800 to 2,900 for late hybrids grown in the southernmost part of the state. A full-season hybrid for a particular area generally matures in several hundred fewer GDD than the number given in **Figure 2.4.** Thus, a full-season hybrid for northern Illinois would be one that matures in about 2,600 GDD, while for southern Illinois a hybrid that matures in 2,900 GDD or more would be considered full-season. Medium-maturity hybrids require 100 to 200 fewer GDD than full-season hybrids. This GDD "cushion" reduces the risk of frost damage and also allows some flexibility in planting time; it is usually not necessary to replace a medium-maturity hybrid with one maturing in fewer GDD unless planting is delayed into June.

Research has shown that the number of GDD required for the corn crop to reach particular stages of development tends to be fairly consistent. **Table 2.1** shows the predicted GDD required to reach each vegetative (V) and reproductive (R) stage for a hybrid that requires a total of 2,700 GDD from planting to physiological maturity. These numbers are approximate, especially for R stages, which are not particularly exact. But they should work reasonably well to help predict when, under average temperatures, a crop will reach certain stages.

Table 2.1. Approximate GDD needed to reach different growth stages of a corn crop (planted at the normal time, using a hybrid that requires 2,700 GDD to reach maturity).

Stage	GDD from planting	Stage	GDD from planting
VE	115	V13	995
V1	155	V14	1,045
V2	235	V15	1,095
V3	315	V16	1,140
V4	395	V17	1,180
V5	475	V18	1,220
V6	555	VT (tassel)	1,350
V7	635	R1 (silk)	1,400
V8	715	R2 (blister)	1,660
V9	795	R3 (milk)	1,925
V10	845	R4 (dough)	2,190
V11	895	R5 (dent)	2,450
V12	945	R6 (mature)	2,700

In some recent work in Indiana and Ohio, researchers found that the GDD requirement for corn hybrids decreased when planting was later than May 1. For each day that planting was delayed after May 1, the reduction in GDD requirement was about 6.5 GDD; thus, a 2,700 GDD corn hybrid planted on May 20 would require only 2,700 – (20 x 6.5) = 2,570 GDD. While the actual decrease in GDD varied somewhat among years, the fact that there is an expected decrease indicates that changing to a shorter-season hybrid when planting is delayed should rarely be done. This decrease in GDD requirement, however, usually comes at the cost of decreased yield; planting on time is still an important goal.

Hybrid Selection

When tested under uniform conditions, the range in yields among available hybrids is often 50 or more bushels per acre. Thus it pays to spend some time choosing the best hybrids. Maturity, yield for that maturity, standability, and disease resistance are the most important factors to consider when making this choice.

Yield

Corn yields have risen steadily and dramatically over the past two decades (**Figure 2.1**), due partly to improved management, but mostly to genetic improvements in hybrids. While several genetically modified (GM) "traits" now exist in commercial hybrids, these traits by themselves have not likely contributed much of the improvement in yield potential of hybrids. Traits available to date help protect against insects or provide resistance to herbicides; both of these trait types help improve protection against yield loss from pests, but they may not directly increase genetic yield potential. Still, most of today's better hybrids are sold in versions that include GM traits, and many hybrids contain multiple GM traits, combinations of which are called "stacks."

Concern exists with what many consider to be a lack of genetic diversity among commercially available hybrids. Although it is true that a limited number of genetic pools, or populations, were used to produce today's hybrids, these pools contain a large amount of genetic diversity, and there is no evidence that this diversity is "running out." In fact, a number of studies have shown that breeding progress for most traits is not slowed even after a large number of cycles of selection. Many of today's hybrids are substantially better than those only a few years old, and there is no evidence that the rate of improvement is decreasing.

Despite considerable genetic diversity, it is still possible to buy the same hybrid or very similar hybrids from several different companies. This happens when different companies buy the same inbreds from a foundation seed company that breeds or markets inbreds, or when hybrid seed is purchased on the wholesale market, then resold under a company label. In either case, hybrids are being sold on a nonexclusive basis, and more than one company can end up selling the same hybrid.

Many producers would like to avoid planting all or most of their acres to the same or very similar hybrids. One way to do this is to buy from only one company, though this may not be the best strategy because it discourages looking at the whole range of available hybrids. Another way of ensuring genetic diversity is to use hybrids with several different maturities. Finally, many dealers have at least some idea of what hybrids are very similar or identical and can provide such information if asked. Even when the genetics are similar, the way by which hybrid seed is produced—the care in detasseling, harvesting, drying, grading, testing, and handling—can and does have a substantial effect on its performance.

Maturity

Maturity is one of the important characteristics used in choosing a hybrid. Hybrids that use most of the growing season to mature generally should produce higher yields than those that mature much earlier. The latest-maturing hybrid should reach maturity at least 2 weeks before the average date of the first killing freeze (32 °F), which occurs about October 8 in northern Illinois, October 15 in central Illinois, and October 25 in southern Illinois. Physiological maturity is reached when kernel moisture is 30% to 35%. It is easily identified by the appearance of a black layer on the base of the kernel where it attaches to the cob. The approach to maturity also can be monitored by checking the "milk line," which moves from the crown to the base of the kernel as starch is deposited. The kernel is mature soon after the milk line reaches the base of the kernel.

Full-season hybrids are often considered to have higher yield potential due to the fact that they use more of the growing season. There is evidence, though, that this relationship may not consistently hold true with modern hybrids. **Figure 2.5** shows the data from the regional hybrid trial in northern Illinois in 2007, where there was almost no relationship between harvest moisture (as a measure of maturity) and yield. This pattern has been very common in recent years; it is rare to find trials in which later hybrids yield more. One reason is that late-season weather is not always favorable for filling the grain of later-maturing hybrids. It may also be that corn breeding efforts have concentrated on early and mid-maturity hybrids. Earlier hybrids can be harvested earlier, and they have drier grain at harvest and so require less drying cost. As a result of the good performance of earlier hybrids, the range in maturity between "early" and "full-season" hybrids is smaller than it was a few decades ago.

Most seed companies describe the maturity of a particular hybrid in terms of "days." This designation does not predict how many days the hybrid will actually take to produce a crop. Rather it refers to a "relative maturity" (RM)

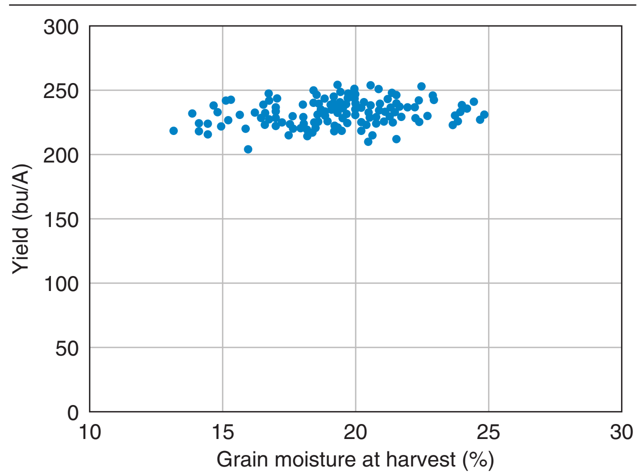

Figure 2.5. Relationship of grain moisture at harvest and grain yield among hybrids in the northern Illinois regional hybrid trial, 2007. Data are averaged over three locations, and each point represents a different hybrid. Relative maturity (RM) ratings ranged from 100 days (very early) to 115 days (late), and grain moisture was well correlated with RM. Source: University of Illinois Crop Sciences Variety Testing Program.

rating based on comparison with hybrids of known maturity. This rating is useful as a comparative measurement—comparing relative maturity ratings tells us whether one hybrid will mature earlier or later than another hybrid. RM ratings tend to change slightly as hybrids are moved north or south, reflecting comparative differences with other hybrids adapted to different regions. The number of growing degree days required to reach maturity is also available from some companies. It is more consistent from place to place than is RM, but RM is more commonly used. As a guideline, 100-day RM hybrids require about 2,400 GDD from planting to maturity, and each additional RM day later adds about 25 GDD to the total GDD requirement. So a 110-day RM hybrid may require about 2,650 GDD and a 115-day hybrid about 2,800 GDD.

After yield and maturity, resistance to lodging is usually the next most important factor in choosing a hybrid. Because large ears tend to draw nutrients from the stalk, some of the highest-yielding hybrids also have a tendency to lodge. Such hybrids may be profitable due to their high yields, but they should be watched closely as they reach maturity. If lodging begins or if stalks become soft and weak (as determined by pinching or pushing on stalks), then harvesting these fields should begin early. Stalk disease organisms are always present in the soil, but if stalks are able to retain some sugars up to maturity they usually can fend off invasion by these organisms. It also helps to have good growing conditions early in the season so that stalks get larger and "woody" enough to stand well at the end of the season. But maintaining stalk quality means that the stalk has to compete with the ear for sugars, and if there is not enough sugar to meet the demand, especially if stress reduces photosynthesis (sugar production) during grain fill, then the stalk often loses out.

Resistance to diseases and resistance to insects are important characteristics in a corn hybrid. Leaf diseases are easiest to spot, but stalks and ears also should be checked for disease. Resistance to insects such as the European corn borer and corn rootworm are incorporated into most modern hybrids using Bt genes. Another useful trait is the ability of the hybrid to emerge under cool soil conditions, which is especially important in reduced-till or no-till planting.

More than 10 years ago, seed companies began to release hybrids containing "genetically engineered" or "genetically modified" (GM) traits. These were initially single-gene traits, genetically transferred into the corn plant from another organism; for example, the Bt gene came from a bacterium. This technology holds great potential since it means that genes found in almost any living organism or even genes produced in the laboratory can be put into a crop or animal. Most of the genes released in this way so far have been for resistance to insects or herbicides, and they have been incorporated into commercial hybrids using backcrossing. Backcrossing takes time, and except for the inserted gene, the resulting hybrid is usually little or no better than the parent into which the gene was crossed. Complex traits such as yield are usually controlled by many genes that interact with one another. Such groups of interacting genes are very difficult to isolate and transfer, so progress for traits such as yield will probably continue to depend largely on traditional methods of breeding. Genetic techniques developed in recent years that can help show what genes are present in high- versus low-yielding lines are, however, proving useful as a way to increase the rate of genetic improvement.

With the many hybrids being sold, choosing the best one can be challenging. The fact that individual hybrids often are sold for only two or three years adds to this challenge; by the time we know what to expect from having grown a hybrid, it is often no longer sold. An important source of information on hybrid performance is the annual report *Performance of Commercial Corn Hybrids in Illinois*, published soon after harvest on the Web at vt.cropsci.illinois.edu. The report summarizes hybrid tests run each year at 12 Illinois locations and includes yield information from the previous 2 years. The report gives data on yields, grain moisture, and standability of hybrids. Other sources of information include your own tests and tests conducted by seed companies, neighboring producers, and extension staff. Producers should see the results of as many tests as possible before choosing a hybrid.

Planting Date

Long-term studies show that the best time to plant corn in much of Illinois is in mid- to late April, with little or no yield loss when planting is within a week on either side of this period. Weather and soil conditions permitting, planting should begin sometime before the optimal date to allow for delays related to weather. Corn that is planted 10 days or 2 weeks before may not yield quite as much as that planted on or near the optimal period, but it will often yield more than that planted 2 weeks or more after.

Figure 2.6 shows yield changes over planting dates from a recent study in different regions of Illinois. The planting time that produced the highest yield was about April 6 in southern Illinois, and April 16 and 17 in central and northern Illinois. Yields declined by only about 1/2 bushel per day as planting was delayed to early May. Yield loss then accelerated with later planting, with average losses of about 1 bushel (0.5%) per day for the first third of May, 1.5 bushels for the second third, and 2 bushels for the last

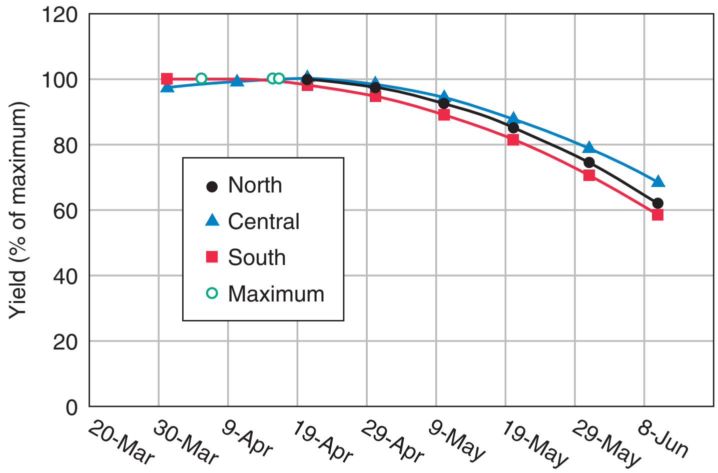

Figure 2.6. Changes in corn yield by planting date in three Illinois regions, two locations per region. Data are averaged over three years (2005 to 2007). The green circles indicate the dates when maximum yield occurred.

third. Yield losses continue to accelerate as planting is delayed into June, and expected yields reach 50% of early-planted yields by about June 20 to 25.

Early planting results in drier corn in the fall, allows for more control over the planting date, and allows for a greater choice of maturity in hybrids. In addition, if the first crop is damaged, the decision to replant often can be made early enough to allow use of the first-choice hybrid. Disadvantages of early planting include cold, wet soil that may produce a poor stand, more difficult weed and insect control, and increased likelihood of frost damage after emergence. Improved seed vigor, seed treatments, and GM traits that greatly improve insect and weed management options have substantially reduced the first two hazards, and the fact that the growing point of the corn plant remains below the soil surface for 2 to 3 weeks after emergence minimizes the danger of frost damage. In general, the advantages of early planting outweigh the disadvantages.

The lowest temperature at which corn germinates is about 50 °F, and some people like to measure soil temperature at the planting depth before starting to plant. Soil temperature, however, is not the major consideration in deciding when to start planting. A more important consideration is the condition of the soil: It generally is a mistake to till and plant early when soils are still wet, and the advantages of early planting may well be lost to soil compaction and other problems associated with "mudding in" corn, whether using conventional tillage or no-till techniques. If the weather conditions have been warm and dry enough to result in workable soils by early April, then planting can begin in early April in southern and central Illinois and in or before mid-April in northern Illinois, with little danger of loss. The weather may change after planting, however, and a return to average temperatures means slow growth for corn planted this early. Rainfall after planting can also lead to emergence problems. It may be desirable to increase seeding rates by a few thousand seeds per acre for April planting, mainly to allow for greater losses and to take advantage of the more favorable growing conditions that the crop is likely to encounter.

When planting begins in April, it is generally best to plant fuller-season hybrids first, but planting midseason and then early hybrids in sequence tends to "stack" the times of pollination and harvest of the different maturities. It is probably better to alternate between early and midseason hybrids after the fuller-season hybrids are planted. This practice helps to spread both pollination risks and the time of harvest.

Planting Depth

Ideal planting depth varies with soil and weather conditions. Emergence is more rapid from relatively shallow-planted corn, so early planting should not normally be as deep as later planting. For most conditions, corn should be planted 1-1/2 to 1-3/4 inches deep. Early-planted corn should be in the shallower end of this range, keeping in mind that variation in depth means that some seeds will end up shallower than average and may not establish plants as easily. Later in the season, when soil temperatures are higher and evaporation is greater, planting as much as 2-1/2 inches deep to reach moist soil may be advantageous, especially if the forecast is for continued dry weather.

Planting depth studies show not only that fewer plants emerge when seeds are planted deep but also that those emerging may take longer to reach the pollination stage and may have higher moisture in the fall. Deeper planting also brings more danger of reduced stand due to crusting or wet soils and an increased chance of uneven emergence, which can cause yield loss.

Plant Population

The goal at planting time is to establish the highest population per acre that can be supported with normal rainfall without excessive lodging, barren plants, or pollination problems. Plant populations used by corn producers in Illinois have been rising steadily, with most fields now having

28,000 to 32,000 plants at harvest. The data in **Figure 2.7** illustrate why populations are increasing. The results from northern Illinois are mostly from high-yielding fields under good weather conditions, while those from southern Illinois are from less-productive soils, with weather conditions ranging from stressed (dry weather) to very good. Yields respond to populations as high as 35,000 to 40,000 under good conditions in northern Illinois, while under less-ideal conditions in southern Illinois, yields leveled off between 25,000 and 30,000 plants per acre. The fact that yields leveled off but did not drop off as population increased above that needed for maximum yield is an important feature of how modern hybrids respond to population. Today, the loss from having populations too high for the conditions is typically only the cost of the extra seed that was not needed—there is no large increase in barrenness and drop in yield, as was often the case with older hybrids. This finding shifts the best risk management approach from making sure population is not too high to making sure population is high enough to take advantage of conditions when they are good.

Our research shows little change in plant population response when planting time changes from April to mid-May **(Figure 2.7).** In all of these studies, plant population is the population established by thinning to exact stands, so it is very close to the population at harvest time. Most people plant 5% to 10% more seeds than the target population at harvest. Under good conditions, it is not uncommon for more than 95% of seeds to establish plants.

While **Figure 2.7** shows that plant population producing the highest yield did not change much with the planting date, other factors are important in setting plant population:

- **Hybrid**. Though hybrids differ in their ability to tolerate the stress of high populations, such differences can be difficult to predict, and they have been decreasing over time. In recent years, most hybrid types with problems of barrenness or standability at high populations have been replaced by hybrids selected under higher populations. Most modern hybrids can tolerate populations of 25,000 to 28,000 per acre even when weather conditions are stressful. Under good soil conditions, most need populations above 30,000 per acre to produce the best yields. One characteristic commonly defined by seed companies is ear "flex," which refers to the ability of the hybrid to change its size in response to population or conditions. Thus "flex-ear" hybrids might be planted at lower populations on less-productive soils and increase their ear size if conditions are better than normal. The opposite is "fixed-ear" hybrids, which tend to maintain ear size better as populations increase but to increase ear size less if populations are low for any reason. In practice, most producers have had high yields when plant populations have been relatively high, and most modern hybrids are of the fixed-ear type. On productive soils, populations should be kept high, and how a hybrid might flex its ear size under low population is of little interest.

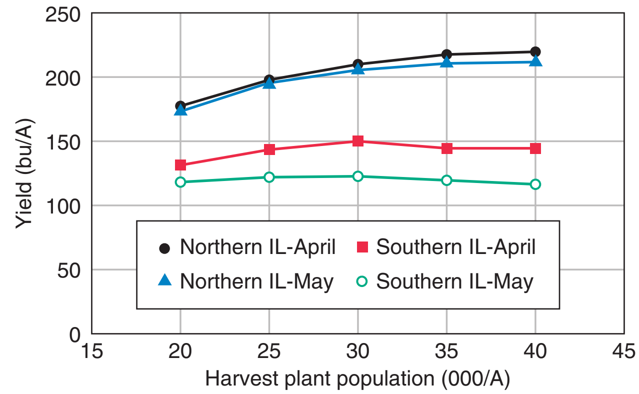

Figure 2.7. Plant population responses for corn planted early (April) and moderately delayed (mid-May) in northern and southern Illinois. Data are averaged over three years.

- **Planting date.** Early planting enables the plant to produce more of its vegetative growth before and during the long days of summer and to finish pollinating before the hot, dry weather that is normal for late July and early August. Early planting usually produces larger root systems as well. So to the extent that early planting produces conditions for higher yields, early-planted corn might respond slightly more to increases in population, even though results averaged over years (**Figure 2.7**) do not show this clearly.
- **Row spacing.** While many people believe that corn grown in narrower rows should be grown at higher plant population, our research results do not support this; for a given hybrid and field, the same population should be established regardless of row spacing.
- **Yield level: variable-rate planting?** Many newer planters can vary seed-drop rates across the field, and to many this seems a very logical approach. A number of studies have shown that, at least across trials, high yields usually require higher plant populations. **Figure 2.8** has some recent data from Illinois trials. Notice that there are some points well off the line, but according to the line on the graph, each 5-bushel increase in yield required about 1,000 more plants per acre. Compared to using the same population at all sites, having the optimum population at each site returned about $15 more per acre. These trials were conducted at sites ranging from northern to southern Illinois, and they included some stress environments in southern Illinois, where the optimum population was 20,000 plants per acre, the lowest population used in the studies. While these data suggest that higher-yielding parts of fields do need more plants, it

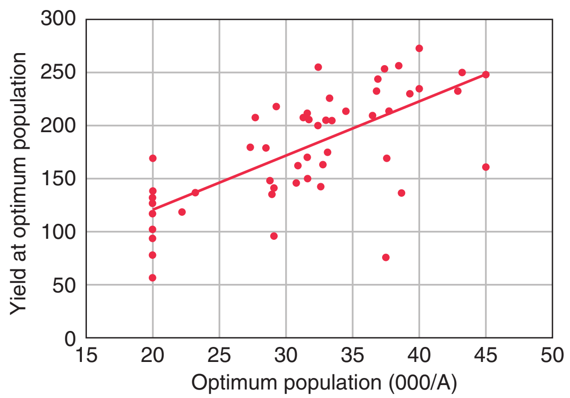

Figure 2.8. Relationship between optimum plant population and corn yield at that population over 53 recent trials in Illinois.

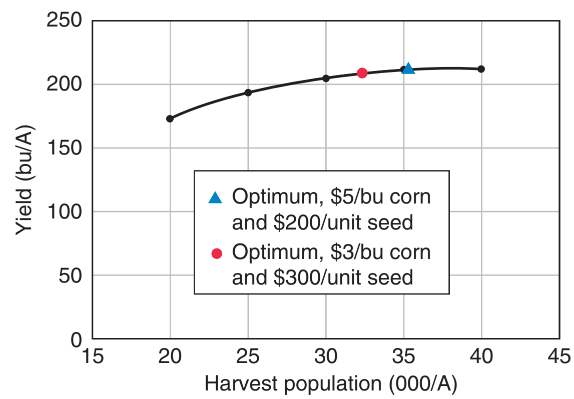

Figure 2.9. A plant population response averaged over nine Illinois trials. Optimum plant populations for two seed cost–corn price situations are shown.

is not easy to know in advance what the higher-yielding parts of a field will be. Previous yield maps might help, but if the weather is especially good during the season, dropping the population in the "low-yielding" areas might be counterproductive. In general, having population too low for conditions is more costly than having population too high. So vary seeding rates according to productivity, but make sure that populations are high enough to take advantage of above-average conditions in all parts of the field. Except in areas with very light, drought-prone soils, dropping less than 28,000 is probably not warranted. In fields without such soils, varying seed drop rates by 2,000 to 3,000 around an average of 32,000 to 35,000 might result in some economic benefit in some years. It might be instructive to vary planting rate by strip, using the normal rate and one higher and one lower rate on either side, then use a yield monitor to see how much benefit is provided. Remember that one year's results, while useful, are unlikely to repeat a second year.

- **Seed and corn prices?** Corn seed prices and corn prices have risen in recent years, and because plant populations should be close to the point where the last plants added yield just enough to pay for the seed to establish them, it may make sense to take seed costs and corn prices into account when setting seed drop rates. **Figure 2.9** uses some population response data to illustrate how this works. When the ratio of the seed cost to the corn price increases—that is, seed cost goes up more than corn price—then the optimal population decreases. In the example shown in the figure, increasing this ratio by 2.5 times decreased the optimum plant population by about 2,800 plants per acre and decreased the yield by 2.5 bushels. Most changes would not be this large, and the fact remains that decreasing the population can, if the year turns out to be very good, cause some lost yield and income opportunity.

It can be helpful to set seed drop rates according to conditions at the time of planting, in addition to such factors as soil productivity and hybrid characteristics. See the corn seed drop calculator at iah.ipm.illinois.edu/corn_seed_drop to determine seeding rates and to help calibrate planters.

Row Spacing

Recent survey data from the National Agricultural Statistics Service show that about 80% of the corn acres in Illinois are planted in rows from 20.6 to 30.5 inches apart, which would be mostly 30-inch rows, with perhaps some 22- or 24-inch rows. Some 10% of acres are listed as having row widths between 30.6 and 34.5 inches apart, which would be mostly 32-inch rows, but may include some 30-inch rows where there is some variability in spacing on the planter or between passes. Another 5% are in 36-inch rows, and the rest are in rows less than 20 inches or more than 36 inches apart. There has been some recent interest in rows narrower than 30 inches apart, and in twin-row configurations, which are usually paired rows spaced 6 to 8 inches apart, with 30 inches between pairs of rows. But 30-inch rows remain the norm, and indications are that this is changing slowly, if at all.

Interest in narrowing rows to less than 30 inches has grown for a number of reasons: Reports of narrow-row performance in the northern part of the Corn Belt (Minnesota and Michigan) have been positive; newer hybrids can, unlike those used in 20-inch-row experiments in the 1960s, stand and yield well at the higher populations that normally accompany narrow rows; and the required equipment is more widely available. Drawbacks to row spacing of 20 inches or less include the requirement for a new cornhead, which tends to be heavy for its width. Fitting equipment tires between narrow rows is difficult or impossible, which may rule out side-dress applications of nitrogen or require driving over plants in order to apply herbicides. Narrow rows are also difficult to walk through to scout, and reports are that harvest of narrow rows is tiring.

Although some of our work in Illinois in the 1980s had shown yield increases of 5% to 8% when row spacing was reduced from 30 to 20 inches, more recent results have not shown as much increase. **Figure 2.10** shows the response to narrowing rows from 30 to 15 inches, with plant population thinned carefully to 30,000 plants per acre, at 15 sites in Illinois. Only one site (No. 9) showed a significant yield difference (in favor of 15-inch rows); averaged over all sites, yields from the two row spacings were virtually identical. There was also no trend for higher- or lower-yielding sites to show more response to narrowing the row spacing. Earlier work had shown that narrow rows produced higher yields at low plant populations but not at high ones. These results indicate that most hybrids can form a complete canopy, and produce high yields, in 30-inch rows if plant populations are maintained high enough.

Despite some questions about the yield response expected from narrowing the rows to less than 30 inches, some producers are investing in the equipment needed to make this change. Other benefits to narrower rows may include slightly more yield stability over a range of weather conditions, better suppression of early-emerging weeds, and the fact that moving to narrower rows usually means a move to somewhat higher plant populations. For those who need to be convinced that narrow rows will produce enough extra yield to pay the cost of conversion, it might be prudent to first increase population at existing row spacing, to see if that's a constraint on yield. If we believe that complete canopy formation is the goal, then getting a complete canopy by using higher populations instead is usually more cost-effective than doing so through narrow rows. It is certainly not necessary to convert to narrower rows in order to get "permission" to raise plant populations.

It is common for those who do change to narrower rows to wonder if a change in hybrid might be necessary to better take advantage of the narrower rows and the (often) higher populations. It is likely that shorter, earlier-maturing hybrids with fewer leaves or narrower leaves will tend to respond more to both narrow rows and higher plant populations than will later, taller hybrids with more leaf area. However, such hybrids should be chosen for narrower rows only if they are in fact superior in their ability to produce yield and stay standing. In most cases, the best hybrids for 30-inch rows are likely to also be the best ones for 15- or 20-inch rows if they are managed well. Until breeders start to select hybrids in narrower rows, we expect most hybrids to do very well in 30-inch rows and to show limited response to narrower rows.

There has recently been an increase in the marketing of twin-row planters. Twin rows have the advantage of not requiring a new cornhead; rather, the two paired rows are gathered into the same row unit at harvest. Twin-row configurations also allow the use of conventional equipment for spraying, without having to drive down corn.

The main advantage suggested for twin rows is that the plants are spaced farther apart; plants that are 6 inches apart in 30-inch rows (34,848 plants per acre) are, if planted in a "diamond pattern," 9.6 inches away from their nearest neighbor across a 7.5-inch twin row. Some who advocate twin rows emphasize the importance of maintaining such a diamond pattern for maximum benefit. In practice, it can be difficult to maintain such a pattern with most commercial planters, especially if dropped population changes. We do not yet have enough research results to estimate how much yield advantage there might be when switching to twin rows. Limited data and some anecdotal evidence indicate that yield increases will be small, especially for those who manage 30-inch rows well.

Results we have seen so far indicate that, while some modest responses may result from narrowing rows from 30 inches, these differences may not be very large or very consistent. There are few serious problems with narrower rows, however, and some producers may find moving to narrower rows beneficial. Producers who are doing a very good job in 30-inch rows might calculate

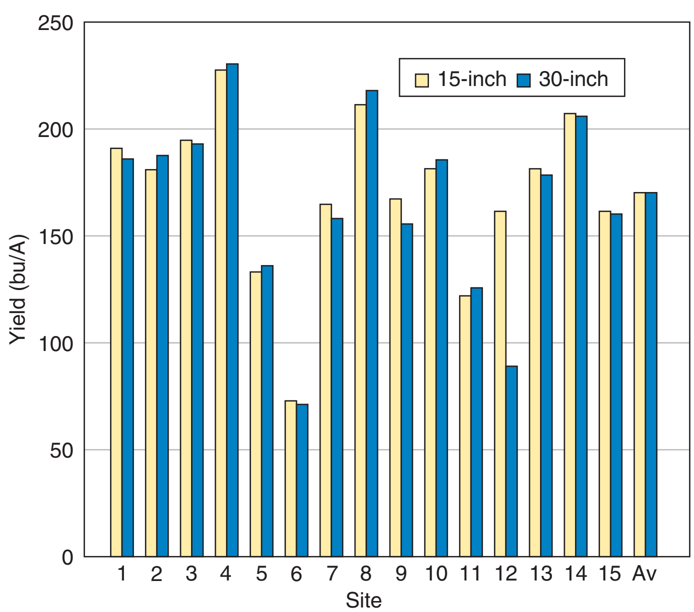

Figure 2.10. A comparison of yields from 15-inch and 30-inch rows at 15 Illinois sites. Plots were larger than normal, and all were thinned to 30,000 plants per acre.

the potential return to moving to narrower rows by assuming a yield increase over fields and years of no more than 2% to 3%, and perhaps less if plant populations and yields have been high in 30-inch rows. If possible, try to observe narrow rows in the field and speak with producers who have experience with narrow rows before making the change. Some might want to borrow narrow-row equipment and put side-by-side strips in a few fields to see what response they could expect. If you do this, be sure the narrow rows that are harvested are bordered by narrow rows; otherwise, there might be an edge effect that makes the narrow rows appear to do better than they actually do.

Uniformity of In-Row Plant Spacing and Plant Size

In recent years a number of researchers have reported that uneven distribution of corn plants down the row can decrease yield. The evenness of distribution of plants in the row can be measured using a statistic called the standard deviation, which is calculated from measurements of individual plant-to-plant distances and which ranges from zero with perfect spacing to 6 inches or more in cases where plants are very unevenly distributed. Standard deviation tends to increase with lower plant populations because missing plants (skips) leave large gaps in the row. Doubles—two plants in the space usually occupied by one plant—also increase standard deviation. Because skips and doubles usually have very different effects on yield, it is clear that standard deviation is not a perfect measure.

Table 2.2 gives the results of a series of planter speed studies that were conducted by farmers in east-central Illinois. These results showed that, even though planting faster tended to increase the standard deviation of plant spacing, it had little effect on plant population or yield. In only 1 of the 11 trials that were averaged to produce the data in the table did faster planting decrease yield, and in that trial faster planting also decreased the plant population. If a planter can drop the intended number of seeds when run at a faster speed, there appears to be little reason to slow it down unless faster planting causes a lot of variation in the depth of planting. Our general conclusion on the effect of plant distribution in the row may be summed up as follows: Within reason, plant spacing uniformity within the row has little effect on yield if plant population is adequate for high yields.

Table 2.2. Effect of planter speed on corn plant spacing variability (standard deviation), plant population, and yield.

Planting speed (mph)	Std deviation (in.)	Plants/A	Yield (bu/A)
3	2.87	27,231	152.5
5	2.99	27,373	152.2
7	3.22	26,996	153.1
LSD 0.05	0.33	NS	NS

While plant spacing uniformity generally has little effect on yield, the same cannot be said about plant size uniformity. Results of a number of studies show that uniformity of emergence is important, especially at high populations where plants must compete with neighboring plants for light, water, and nutrients. When a plant emerges more than a few days later than its neighbors, or is injured while its neighbors are not, chances are that it will never regain its competitiveness with its neighbors, and as a result it will usually yield less than other plants. We have also found that the plants next to a late-emerging or injured plant, while they often yield more as a result of gaining competitively against their weak neighbor, do not make enough extra yield to make up for the loss of yield by the plant that falls behind. The net result is that any unevenness that develops early in the season often results in some yield loss. In extreme cases, where we have injured plants between healthy neighbors early in the season, injured plants produce no yield at all, even though they might complete their growth cycle. Normally, such plants are not "weeds"—they don't hurt the yield compared to their being absent altogether—because they are so small.

Crop Canopy

All of a crop's growth and yield results from the ability of its green leaves to absorb sunlight and to turn sunlight energy into usable energy in the form of sugar, which the plant uses to make all other plant material, including grain. How soon in the season the leaf area appears, how fast it develops, and how long it stays healthy, well nourished, and green are thus critical to production success. The crop canopy refers to the leaf cover that a crop maintains; it includes both the leaf area of the plants and how the leaves are arranged to intercept sunlight. The total leaf area in an acre of corn is usually 3 to 4 times the ground area; we refer to this proportion as the leaf area index (LAI). An LAI of 3.5 to 4.0 is very efficient, in that it's close to the minimum amount it takes to absorb nearly all of the sunlight.

Figure 2.11 illustrates the importance of canopy cover during grain fill. These data were taken from a plant population trial at Urbana. They help explain some of the responses to such things as row spacing, plant population, and nitrogen supply. Though there may be exceptions, such as when pollination fails or pests are severe, it is clear that forming and maintaining a canopy that intercepts at least 95% to 98% of the sunlight after pollination is essential for high corn yields. In a real sense, managing row spacing and plant population for a particular corn hybrid should be seen as managing to produce and maintain this canopy.

The success of an attempt to "manage for canopy" can best be measured by looking down the rows at about noon on a clear day in early August. **Figure 2.12** shows how an ideal canopy intercepts nearly all of the sunlight. Although you probably can't tell whether light interception is 95% or 98% or slightly less than that, streaks or patches of sunlight on the soil beneath the canopy indicate that you probably have not optimized the management of that particular hybrid for the soil and conditions in that field.

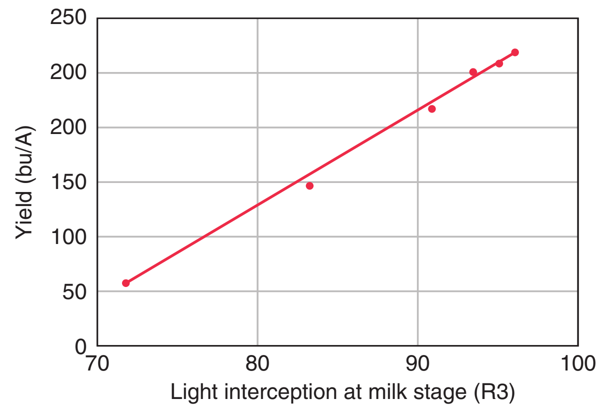

Figure 2.11. Relationship between light interception during grain fill and corn yield. Plant populations ranged from 10,000 to 35,000 per acre, corresponding to interception levels ranging from low to high.

Figure 2.12. Low amounts of light reaching the soil beneath a good corn canopy indicate very high percentages of light interception.

Dealing with Crop Difficulties

Stand Counting

The most common method of taking plant populations is to count the number of plants in 1/1,000 of an acre, which is 17.424 feet, or 17 feet 5 inches, for 30-inch rows. For other row spacings, divide the number 522.72 (17.424 x 30) by actual row spacing to give the number of feet of row in 1/1000 of an acre. This length of row is small enough that it's easy to bias the count by consciously or unconsciously selecting better-than-average places to count.

Taking plant counts in longer sections of row usually provides less opportunity for bias and can give more accurate counts. That means that fewer counts per field might be needed, if stands are relatively uniform. Using a measuring wheel instead of a tape can make such counting more efficient. Simply push the measuring wheel down a row while counting plants; it's much faster to count plants in groups of three. When you reach 150 plants, record how many feet the measuring wheel has traveled for the count. For 30-inch rows, divide this distance into the number 2,613.6 to give plant population in thousands. For other row spacings, divide the number 78,408 by the actual row spacing to give the number into which the distance traveled should be divided.

Replanting

Although it is normal that 5% to 10% of planted seeds fail to establish healthy plants, additional stand losses due to insects, frost, hail, flooding, or poor seedbed conditions may call for a decision on whether to replant a field. The first rule in such a case is not to make a decision in haste. Corn plants often outgrow leaf damage, especially when the growing point, or tip of the stem, is protected beneath the soil surface, or up to about the six-leaf stage. If new leaf growth appears within a few days after the injury, the plant is likely to survive and produce near-normal yields, providing its neighbors are affected the same way.

When deciding whether to replant a field, assemble the following information: original planting date; likely replanting date and expected number of plants per acre in the replanted stand; and costs of seed, planting operation including tillage if needed, and pest control for replanting.

When the necessary information on stands and planting and replanting dates has been assembled, use **Table 2.3** to determine both the loss in yield to be expected from the stand reduction and the yield expected if the field is replanted. To do this, locate the expected yield of the reduced plant stand by reading across from the original planting date to the plant stand after injury. If the damaged plant stand or planting date is between two of the lines or columns listed, estimate the percentage between the two numbers on either side. Then locate the expected replant yield by reading across from the expected replanting date to the stand expected after replanting. Subtract the expected yield from the damaged stand from that expected from the replanted stand. The difference between these

Table 2.3. Percent of maximum corn yield expected from different planting dates and plant populations in northern Illinois.

Planting date	% of maximum yield for final plant population (000/acre)						
	10	15	20	25	30	35	40
April 1	54	68	78	88	95	99	99
April 10	57	70	81	91	97	100	100
April 20	58	71	81	91	97	100	99
April 30	58	70	80	89	95	97	96
May 9	55	68	77	86	91	93	91
May 19	50	63	72	80	85	86	84
May 29	44	56	65	73	77	78	75
June 8	35	47	56	63	67	67	64

numbers is the percentage of yield increase (or decrease) to be expected from replanting.

For example, corn planted at 35,000 per acre on April 25 with its plant stand reduced to 15,000 by cutworm injury would be expected to yield 71% of a normal stand. If such a field were replanted on May 19 to establish 35,000 plants per acre, the expected yield would be 86% of normal. Whether it would pay to replant such a field depends on whether the yield increase of 15 percentage points would repay the costs to replant. In this example, if replanting is delayed until early June, the yield increase to be gained from replanting disappears. For a calculator to help make replanting decisions, see iah.ipm.illinois.edu/corn_replant.

Weather-Related Problems

Corn frequently encounters weather-related problems during the growing season. The effects of such problems differ with the severity and duration of the stress and the stage of crop development at the time of the stress. Descriptions of some stress conditions and their effects on corn growth and yield follow:

- **Flooding.** The major stress caused by flooding is lack of oxygen needed for the root system to function properly. If water covers the leaves, photosynthesis also stops, and mud deposited on the leaves and in the whorl can cause ongoing problems. Plants at V2 or smaller are generally killed after about 3 or 4 days of being submerged. Death occurs more quickly in warm, sunny weather because high temperatures speed up the processes that use oxygen, warm water has less dissolved oxygen, and bright sunshine can damage submerged leaves. In contrast, plants may live for more than a week under flooded conditions if the weather is cool and cloudy. When plants reach the six- to eight-leaf stage, they can tolerate a week or more of standing water, though total submergence may increase disease incidence. Plants that have been submerged usually suffer from reduced root growth and function for some time after the water recedes, and in some cases roots never fully recover. Tolerance to flooding generally increases with age, but reduced root function from lack of oxygen is often more detrimental to yield before and during pollination than during rapid vegetative growth or grain fill.
- **Hail.** The most common damage from hail is loss of leaf area, though stalk breakage and bruising of the stalk and ear can be severe. Loss charts based on leaf removal studies generally confirm that defoliation at the time of tasseling causes the greatest yield loss (often 100%), while loss of leaf area during the first 3 to 4 weeks after planting or when the crop is near maturity generally causes little yield loss. Loss of leaf area in small plants usually delays their development, and plants that experience severe hail damage may not always grow normally afterward, even if they stay alive and grow back.
- **Cold injury.** Corn is of tropical origin and is not especially tolerant of cold weather. Although the death of leaves from frost is the most obvious type of cold injury, leaves are often damaged by temperatures in the low 40s or upper 30s, and photosynthesis can be reduced even if the only symptom is a slight loss of leaf color. The loss of leaves from frost is generally not serious when it happens to small plants, though such loss delays plant development and can delay pollination to a less favorable (or, less frequently, a more favorable) time. There have been cases, however, where temperatures are low enough to cool the soil to near the depth of the growing point and to either kill or seriously damage small plants. Frost injury symptoms may appear on leaves even when nighttime temperatures do not fall below the mid-30s; radiative heat loss can lower leaf temperatures to several degrees below air temperatures on a clear, calm night. If frost kills leaves before physiological maturity (black layer) in the fall, sugars usually can continue to move from the stalk into the ear for some time, although yields generally are lowered and harvest moisture may be high due to high grain moisture at the time of frost and to the slow drying rates that usually follow premature death.
- **Drought.** Through the late vegetative stage (the end of June in normal years), corn is fairly tolerant of dry soils, and mild drought during June can be beneficial because roots generally grow downward more strongly as surface soils dry. The crop also benefits from the greater amount of sunlight that accompanies dry weather. In the 2 weeks before, during, and in the 2 weeks following pollination, corn is very sensitive to drought, and lack of adequate water can cause serious yield losses. Most of these losses

are due to failure of pollination, and the most common cause of this is the failure of silks to emerge on time. When this happens, the silks do not receive pollen, so kernels are not fertilized and do not develop. Developing kernels can also abort for several weeks after pollination. Drought later in grain fill has a less serious effect on yield, though root function may decrease and kernels may not fill completely. But any time soils are dry enough to reduce the amount of water available for transpiration (water loss through the leaves), photosynthesis decreases and the chance of yield loss increases.

- **Heat.** Because drought and heat usually occur together, many people assume that high temperatures are a serious problem for corn. In fact, corn is a crop of warm regions, and temperatures up to 100 °F usually do not cause injury if soil moisture is adequate. Extended periods of hot, dry winds can cause some tassel "blasting" and loss of pollen, but pollen shed usually takes place in the cooler hours of the morning, and conditions severe enough to cause this problem are unusual in Illinois. Corn hybrids vary in their sensitivity to both heat and drought, and there is currently some effort to develop GM corn with drought tolerance. Because drought is not the normal condition in Illinois, hybrids should be chosen based on their ability to yield well over a range of conditions, including drought stress, but not solely on their tolerance to drought.

Estimating Yields

Making plans to harvest, store, and market the crop often calls for estimating yields before corn is harvested. Such estimates are easier to make for corn than for most other crops because the number of ears per acre and number of kernels per ear can be counted fairly easily and accurately. These numbers are used to estimate the number of kernels per acre, which is then divided by the expected number of kernels per bushel to estimate yield in bushels per acre.

Corn yields can be estimated after the kernel number is fixed, or about 2 to 3 weeks after the end of pollination. Walk to a predetermined spot in the field (to avoid bias), and count the number of ears with more than 50 kernels in 1/1,000 of an acre (17.424 feet or 15 feet, 5 inches in 30-inch rows; divide the number 522.72 by the actual row spacing to get this distance for other row spacings). Take three ears from the row section that was counted. To avoid using only good ears, take the third, sixth, and 10th ears in the length of row. Do not take ears with so few kernels that they were not included in the ear count. Count the number of rows of kernels and the number of kernels per row on each ear. Multiply these two numbers together for each ear, then average this kernel count for the three ears. Take this average kernel number times the number of plants to give the estimated number of kernels in the 1/1000 of an acre.

Divide the number of kernels in 1/1000 of an acre by the number (in thousands) of kernels that you expect a bushel to have. This number was 90 (thousand) in older hybrids, but kernel weights have increased in recent years, and it's usually more accurate to use a number between 75 and 85, especially in more productive fields, where good yields are likely. Hybrids differ some in kernel weight, and this can be factored in if it's known. But the final weight of kernels is always a best guess, although this guess usually improves as grain filling progresses. A helpful calculator to assist in estimating yield is located at iah.ipm.illinois.edu/corn_yield_estimate.

Special-Use Corn

There remains considerable interest in producing corn with characteristics that give the grain higher value. Most such types are more or less normal corn in terms of how the plant grows and develops, and most do not require special management, though there are some exceptions. Care during harvesting, drying, and storage usually is critical to maintaining quality and preventing mixtures with other types of corn. Some types also require isolation from other types of corn to prevent or minimize cross-pollination, which can compromise grain quality. This is usually done by maintaining a certain distance from other corn, but in some cases it may be done in time as well, by requiring the specialty corn to be planted later so pollen from normal corn is not present when the specialty corn pollinates.

Many specialty types are grown under contract. The contract buyers often specify what hybrids may or may not be used, and they may specify other production practices to be used or avoided. Some contracts also may include pricing information and quality specifications. Risks associated with growing specialty types of corn vary considerably. Milling companies may buy corn with "food-grade endosperm," requiring only that the grower choose hybrids from a relatively long list of popularly grown hybrids; the risk in this case is small. By contrast, some types of specialty corn may not yield or stand well and so may entail considerable risk. Production contracts in such cases may shift some of the risk to the buyer. In any case, every grower of specialty types of corn should be aware of risks associated with each type.

Food-grade corn, either white or yellow, is one of the most common specialty types grown in Illinois. Many normal hybrids produce good quality for use as food, and so the largest difference in growing food-grade corn is the care needed in drying the crop in the field or with low temperatures and the storage, handling, and delivery needed to keep kernels intact. **Waxy** corn contains 100% amylopectin starch, compared to 75% in normal corn. Amylopectin starch has certain characteristics that are useful in food and industrial products. In contrast, **high-amylose** corn has lower amylopectin and more than 50% amylose, which has different properties than amylopectin and so has use in a different group of food and industrial products. Waxy corn yields much like normal corn, so it carries little risk even if there's not much premium for it. High-amylose corn usually yields much less than normal corn and is normally grown only under contract.

Nutritionally enhanced corn, with higher-than-normal oil or protein, may have more value as livestock feed than normal corn, and some hybrids are available with these characteristics. Many who choose to grow these hybrids feed the grain themselves; the market for nutritionally enhanced hybrids like these remains small, in part because there are alternative sources of extra protein and oil to add to livestock feed.

Popcorn is a specialty type with very hard endosperm that expands rapidly when water in the endosperm is turned to steam by rapid heating. Most popcorn is produced under contract to a processor. Popping volume is an important characteristic of popcorn hybrids, and premiums may be paid for hybrids that have high popping volume, especially if they produce less yield. There are yellow- and white-hulled popcorn hybrids, as well as types with purple or black seedcoat colors. Most popcorn hybrids are less vigorous than normal corn hybrids and so are less tolerant of adverse weather. Increasingly popcorn is grown under irrigation.

A recent opportunity has developed to produce **non-GMO** corn. There are no known health or nutritional issues with GM corn, but many consumers remain uncomfortable with what they consider "unnatural" corn that contains genes from other organisms, and they are willing to pay extra for grain without any such traits. There are usually strict limits on the amount of GM corn that can be present. Special tests exist for most commercialized GM traits, and loads may be rejected if the amount of GM grain found exceeds the maximum allowed.

With a substantial percentage of corn now being used to produce **ethanol**, there has been some work to develop hybrids that will produce more ethanol per bushel than normal corn. This trait refers to the amount of "highly fermentable starch," or HFS, in the grain. While genetic research has shown that there is some range among hybrids in HFS, most processing plants are able to pay little if any premium for high-HFS grain, in part because of the cost to isolate it from normal grain and because getting more ethanol from such grain might require adjustments in processing that may remove the profitability.

Though commercial development has been slow due mostly to concerns about pollen escape and outcrossing, pharma corn—genetically modified to produce proteins or other products with medicinal properties—has the potential to dramatically lower costs of some very expensive vaccines and other pharmaceuticals. **Nutriceuticals**, which are products with special nutritional value, including higher levels of things like vitamins, might also be produced in GM corn in the future. Production of nutriceutical and pharma corn will require the strictest of isolation, including in some cases isolation by miles of deserts or oceans, to prevent pollen spread to other corn.

Organic corn acreage has been increasing in recent years as the market demand increases. The main difference between normal corn and organic corn is the complex set of rules under which organic corn must be produced. These rules prohibit the use of chemical fertilizer, GM hybrids, or "artificial" pesticides. Major challenges typically include weed control, which is generally restricted to mechanical means, and getting enough nutrients, especially nitrogen, in fields where using manure is not practical. Controlling insects such as corn rootworm without chemicals or the use of GM traits is also difficult. Rules may specify crop rotations and other practices that may make production more expensive. Organic corn generally commands a much higher price than normal corn, so it can be profitable, even if yields are somewhat lower.