A-834 (Revised)

Basics of CORN PRODUCTION in North Dakota

Compiled by:

Joel Ransom
Agronomist – Cereal Crops

Contributing authors:

Dave Franzen
Soil Science Specialist

Phillip Glogoza
Entomologist

Kenneth Hellevang
Agricultural Engineer

Vern Hofman
Agricultural Engineer

Marcia McMullen
Plant Pathologist

Richard Zollinger
Weed Specialist

NDSU EXTENSION SERVICE
North Dakota State University
Fargo, North Dakota 58105

JULY 2004

Corn Production in North Dakota

Corn is becoming an increasingly important crop in North Dakota, with the area planted for grain nearly doubling in the last three decades. Since 2002, more than 1 million acres are cultivated with corn each year. Grain yield of corn in the state has increased at a remarkable rate in the recent past, with yields now consistently averaging over 100 bushels per acre. The importance of corn silage in North Dakota has been on the decline, with the 180,000 acres planted in 2002 accounting for only about 60 percent of the area planted in the early 1970s.

Several factors have contributed to the increased interest by farmers in corn production for grain. First, the productivity of early maturing corn hybrids available to farmers has increased significantly. Gains in the genetic potential for yield of adapted hybrids have averaged 2 to 5 percent per year and there is no evidence that the genetic yield potential is approaching a plateau.

Second, the recent weather patterns have been more favorable for corn production relative to other cereal options. The current weather pattern of higher rainfall in the eastern third of the state, particularly in July and August during the period of high water use in corn, has been favorable to corn growth and at the same time been detrimental to small grain production, as these environmental conditions favor the development of fusarium head blight (scab), a pernicious disease of wheat and barley.

Environment and Corn Growth

Corn is currently grown in every county in the state, though the productivity and risk of production varies considerably from region to region. Temperature, rainfall and radiation are the major environmental factors that influence the growth and yield of corn.

Temperature and moisture are of particular concern in North Dakota. Temperature affects the rate of corn growth and the length of the growing season. Although corn is classified as a warm season crop, it still yields best when temperatures are moderate.

The potential productivity of corn is also directly related to the length of the growing season. The longer the growing season, the longer the corn plant has to photosynthesize and accumulate dry matter for grain yield.

Growing degree day (GDD) accumulations, also referred to as heat units, are the most common way of characterizing the length of the growing season. Unlike the number of days between killing frosts, GGD provides quantitative information about temperature during the growing season.
In calculating GDD for corn, temperatures from a lower limit of 50 degrees and an upper limit of 86 degrees are accumulated for the growing season by applying the formula below to each day's maximum and minimum temperatures.

$$\text{GDD} = \frac{(\text{Maximum Temperature} + \text{Minimum Temperature})}{2} - 50$$

Maximum temperatures higher than 86 degrees are entered as 86 and temperatures below 50 degrees are entered as 50 in the formula. GDDs are accumulated from seedling emergence until physiological maturity. Historical as well as current season GGD accumulations can be obtained from the North Dakota State University NDAWN weather site at *http://ndawn.ndsu.nodak.edu/application/corn degreedaysform.html* .

Kernel moisture content at physiological maturity generally averages about 33 to 35 percent. At physiological maturity a "black layer" will form under the outer layer of the kernel tip. When this forms, it signals that kernel dry matter accumulation has reached the maximum level. Corn will not be injured by frost after that point. Hybrids may vary up to 10 percent in kernel moisture at physiological maturity.

GDD accumulations vary considerably in the state, from up to 2,400 GDD in the southeast to less than 1,700 GDD in some seasons in the north. Matching the maturity length of a corn hybrid with the likely GDD accumulations at a given location is one of the basic management practices for successfully producing corn. Minimum soil temperatures of 46-50 degrees are required for corn germination and seedling growth.

Corn can tolerate some frost in the seedling stage and will recover from most early season frost damage because the growing point remains below or at the soil surface until the corn plant reaches the five-leaf stage (three to six weeks after planting, depending on soil and air temperature after planting). Beyond this stage, frost can kill corn.

Prolonged cold weather that reduces the soil temperatures two inches below the surface to below freezing can also kill corn seedlings regardless of their stage of development. Frost-kill in the fall after the kernels have reached maximum dry matter content hastens drying. However, freezing temperatures before physiological maturity (black layer) may slow dry-down, lower test weight and lower grain quality.

High ambient temperature or moisture stress can greatly affect corn silking and pollination. Pollen shed and silking often occur during the hottest period of the growing season. Total days of pollen production may be shortened, but the main effect of moisture stress is a delay in silk emergence.

Silk emergence and elongation are highly dependent on moisture. When soil moisture is in short supply, silks will grow little, if at all, during the day when water transpiration is high.

Under severe stress, some plants will not form any silks, or silks will emerge after pollen production has ceased, resulting in barren or poorly developed ears.

High plant populations in moisture-limiting environments add to moisture stress and will increase silking problems with reduced kernel set.

The lack of moisture frequently limits the productivity of corn in North Dakota, particularly in non-irrigated areas in the western two-thirds of the state. Corn is one of the most efficient crops for dry matter production relative to water used. However, given its higher yield potential, corn is a relatively heavy water user. As a general rule, 16 inches of water are required to produce 100 bushels of corn grain compared to 13 inches required for 32 bushels of wheat.

Some of the basic recommendations for growing corn, such as crop rotation, plant population and tillage, vary in the state depending on the moisture that will be available to the crop. Certainly, careful management is needed in the drier parts of the state to reduce the risk of crop failure.

Hybrid Selection

Literally hundreds of corn hybrids are available commercially in the United States. Although only a fraction of those hybrids are actually marketed in North Dakota, the number of hybrids that are adapted to any one area of North Dakota is substantial. Furthermore, because of rapid genetic improvement that seed companies are currently able to achieve, many hybrids remain in the market for less than five years.

The process of selecting hybrids should be a continual process. Important criteria to consider when selecting a hybrid are yield, maturity, specialty traits and stalk quality. Test new hybrids in a small area on your farm before growing them on large areas. Growing more than one hybrid introduces genetic diversity and helps reduce the risks associated with growing a single genotype. The same hybrid may be marketed by several different companies, as the inbreds used to make these hybrids can be purchased from foundation seed companies without proprietary restriction.

If you intend to diversify the genetics on your farm, purchase all your hybrids from one company or purchase only those hybrids that are known to have distinct differences in the field in order to avoid buying the same hybrid from different companies.

Seed costs have increased markedly in the last decade and vary substantially depending on the company and the traits included in the hybrid. Most hybrids that are currently sold are single-cross hybrids. They generally offer the highest yield potential but are also the most costly to produce.

Three-way and double-cross hybrids are available on a limited scale, and because of their lower seed price, might be considered for drier regions of the state where yield expectation are low due to water limitations.

Seed costs should be determined on a per acre basis and the expected income differences (grain yield x price) compared with seed cost differences.

Planting cheap seed may not lead to a lower cost per bushel grown if the hybrid is not high-yielding or well-adapted to the region. Don't spend money on technology traits that are not needed. Generally a hybrid without the specialty trait with similar genetics and yield potential is available from the same company.

Grain yield

Grain yield is obviously one of the most important factors to consider in selecting a hybrid. Given the large number of hybrids on the market, finding data that compares hybrids of interest may be difficult. Most published yield trials have only a limited set of hybrids that are adapted to a given region.

Data from yield trials conducted by North Dakota State University and University of Minnesota breeders and agronomists at various test locations throughout the states are updated and reported annually. Information is also available at regional research and extension centers. These trials are comprised of a limited number of hybrids submitted by the companies that are commercially active in the state. The North Dakota data can be viewed at *www.ag.ndsu.nodak.edu/aginfo/variety/corngrain.htm* and the Minnesota data at *www.maes.umn.edu/maespubs/vartrial/cropages/cornpage.html* .

Commercial seed corn companies also conduct testing programs. Company field tests results are usually of greatest value in comparing available hybrids within a given company. Data from county and company strip tests, though not as rigorous for comparison purposes as replicated trials, can be a good way to see how a new hybrid will look in the field.

When comparing hybrids, it is important to look at harvest moisture in addition to grain yield. High grain yields with high moisture does not necessarily equate to high profits!

Maturity

Select hybrids which have a maturity length adapted to the GDD accumulations for your region of the state. Most seed companies define the maturity of their hybrids using the Relative Maturity (RM) rating system. The term "relative maturity" does not define how many days a hybrid needs to mature, but is used to designate the length of time required for a hybrid to reach maturity compared to standard hybrids which have been grown in an area for a long time.

A few companies also indicate the number of growing degree days required for the hybrid to reach maturity. The relationship between relative maturity and GDD is summarized in Table 1. Later-maturing hybrids almost always have higher grain yield potential than earlier-maturing ones. Hybrids that are too late for a given environment, however, will have excessive grain moisture at harvest or may not reach physiological maturity in some seasons.

Table 1. Approximate relative maturity of hybrids that are adapted to environments with the indicated GDD accumulations from planting until killing frost.

Accumulated GDD (Heat Units)	Relative Maturity (Days)
1750-1850	70
1851-1950	75
1951-2050	80
2051-2150	85
2151-2250	90
2251-2350	95
2351-2450	100
2451-2500	105

Balance between lateness for yield and earliness for low grain moisture is key to obtaining the most profit from a crop. Grain drying costs can quickly negate any gains achieved with grain yield increases that may be associated with later maturity. General guidelines for hybrid maturities adapted to the various regions of North Dakota are summarized in Figure 1.

When comparing hybrids in yield trials, look at both the relative grain yield and the relative moisture at the time of harvest.

One way to compare hybrids that differ in moisture content at harvest is to convert them to a dried grain value. This is done by multiplying the grain yield of the hybrid by the price of corn and then subtracting the cost of drying the hybrid to 15.5 percent moisture.

For example, to compare hybrid A with a grain yield of 130 bushels/acre and a moisture content of 19 percent with hybrid B with a grain yield of 136 bushel and moisture content of 25 percent, convert both to their dried grain value. In this example, if we use a corn price of $2.25/bushel and a drying cost of 3 cents per percent moisture per bushel above 15.5 percent, hybrid A and hybrid B would have dried grain values of $274.95 and $267.24, respectively [(130 b./acre X $2.25) - (130 bu./acre X 4.5% X 0.03) = $274.95 and (136 bu./acre X $2.25) - (136 bu./acre X 9.5% X 0.03) = $267.24]. In this example, hybrid A, which produced the most dried grain value, should be selected to the higher-yielding hybrid B.

Another method that requires less mathematical calculation is the performance index (PI). The performance index is calculated using the following formula:

P.I. = [(Grain yield of a specific hybrid/grain yield of the mean of all hybrids in the trial)/(Grain moisture of a specific hybrid/grain moisture of the mean of all hybrids in the trial)] x 100.

Hybrids with the highest yield and the largest PIs are considered the most suitable as far as yield and grain moisture at harvest are concerned. Those with a PI greater than 100 are considered better than average for the environment where they were tested.

If you have a large number of corn acres, to spread the risk and workload at harvest, plant hybrids of differing maturities.

A good rule is to plant 25 percent of your acres with early hybrids (five to seven days earlier than the recommended RM), 50 percent of your acres with

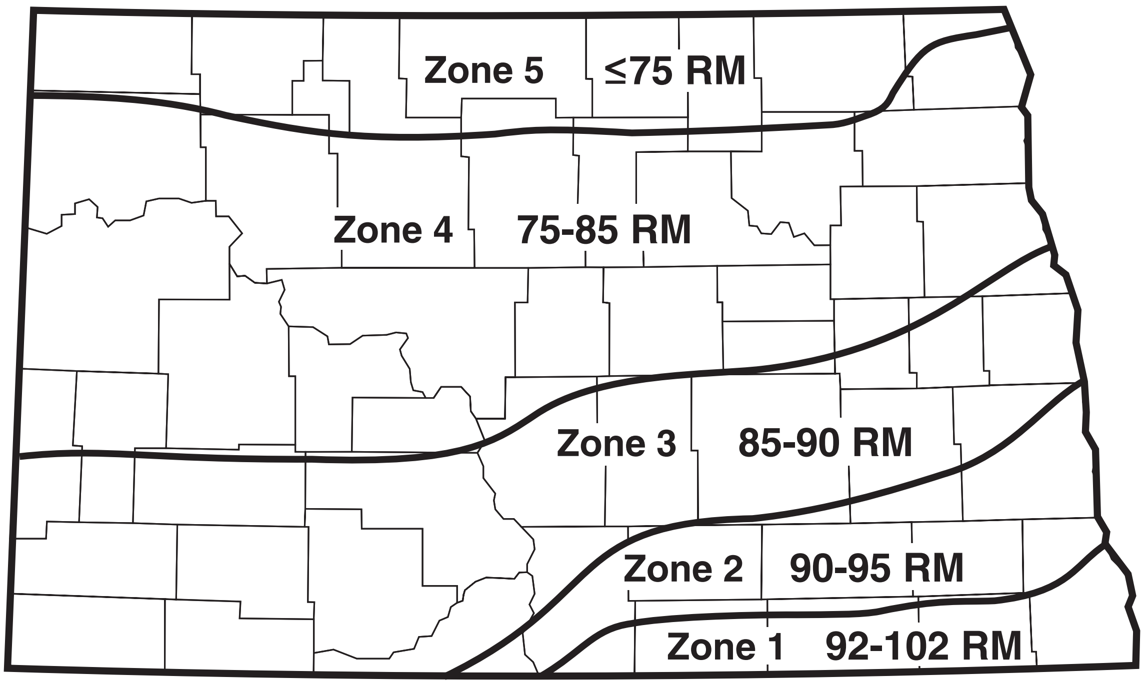

Figure 1. Corn Maturity Zones of North Dakota.
The maturity zones indicate where a corn variety of a given relative maturity has matured satisfactorily in an average season.

adapted maturity hybrids and 25 percent of your acres to full season hybrids (five to seven days later than recommended) for your area. This will not only reduce the risk associated with an unusually short season, but will also diversify the genetics of your hybrids across the farm, thus limiting the potential for other losses arising from diseases or insect problems that may be hybrid specific or plant stage specific.

The strategy of growing hybrids with differing maturities may also help spread out the harvest season. Moreover, early harvested corn in some seasons may fetch better market prices.

Technology traits

A number of proprietary technology traits are currently available in corn that should be considered when selecting a hybrid. The presence of these traits in a hybrid does not directly affect yield but protects the plant from insects or imparts herbicide resistance. Many corn hybrids are currently available with single or multiple technology traits. Most of the technology traits require the payment of a technology fee, which is added to the seed price. Carefully consider the cost-benefit as well as market restrictions associated with some traits (i.e. the European Union restricts the import of Roundup Ready corn) before paying the extra cost for the technology. The fructose processing facility in southeastern North Dakota currently does not buy Roundup Ready hybrids. As with any new technology, you should carefully consider the advantages and disadvantages of using a hybrid with a technology trait in your own farming operation.

Traits currently available include the following:

Herculex I® – This is a transgenic trait that provides resistance to European corn borer, southwestern corn borer, fall armyworm, black cutworm and western bean cutworm, and moderate resistance to corn earworm. This transgenic trait is generally linked with another transgenic trait (Liberty®) that imparts glufosinate herbicide tolerance. The Herculex I transgene that produces the protein that has insecticidal action was obtained from a bacterium, *Bacillus thuringiensis* (Bt) and is often referred to as a Bt hybrid.

YieldGard® Corn Borer – This transgenic trait (also of Bt origin) provides resistance to European corn borer, southwestern corn borer, southern cornstalk borer and fall armyworm and moderate resistance to corn earworm and common stalk borer.

LibertyLink® – Hybrids with this transgenic trait are resistant to Liberty® (glufosinate) herbicide. This trait is often combined (stacked) with one of the Bt traits. Liberty® controls small annual weeds.

Clearfield® – Corn hybrids with this non-transgenic trait are resistant to imidazolinone herbicides.

Roundup Ready® – This transgenic trait provides crop safety to over-the-top applications of Roundup® and other brands of glyphosate herbicide.

YieldGard® Rootworm – Hybids with this transgenic trait (Bt origin) have resistance to corn rootworm larvae. YieldGard Plus® hybrids contain both the YieldGard® Rootworm and the YieldGard® Corn Borer traits.

Grain produced from hybrids with the above traits can be used in the United States, Canada and Japan. However, YieldGard® Rootworm, Roundup Ready®, Herculex I® and YieldGard® Corn Borer and LibertyLink® stacked with another trait are currently (2004) not approved for use in the European Union.

References to commercial products or trade names in this publication are made with the understanding that no discrimination is intended and no endorsement by the NDSU Extension Service is implied.

The national Corn Growers Association maintains a current listing of traits and their export status, known as “Know Before You Grow,” on the Internet at: *www.ncga.com/index.shtml* .

Other factors

Other factors to consider when selecting a corn hybrid include: stalk strength and lodging resistance, resistance to stalk rots and other diseases, tolerance/resistance to insects, reaction to drought stress, harvestability, test weight and dry-down.

Some corn companies characterize hybrids they sell as “flex” or “fixed” ear hybrids. Flex-ear types are promoted as hybrids that are able to adjust yield components during the growing season to take better advantage of optimum growing conditions. All corn hybrids can compensate or flex yield components during the growing season by adjusting the number of ears per plant, number of kernels per row and kernel size, depending on environmental conditions. Nevertheless, using hybrids that are known to do well under low populations (these data are not always available) may be advantageous in the areas of the state where low plant populations are recommended due to moisture limitations.

Corn Production Practices

Date of planting

Optimizing corn yields starts with planting early. For most of the state, early means May 1. If you are growing a large area of corn, planting should start prior to May 1. Early planting is recommended because the risk of fall frost damage to crop yield and quality is greater with each day planting is delayed, and is more likely to be more harmful than early-season frost damage.

Even though corn seeds germinate optimally in soils that are warmer than 50 degrees, having the seed in the ground before these temperatures are reached often enables earlier emergence. If planting is delayed beyond May 20 in the northern part of the state, an alternate crop should be considered. For the southern part of the state, switching to a hybrid that is five to seven days earlier is recommended for plantings after May 20 up until the first week of June. Crop insurance coverage may not be available beyond certain dates and should be considered before planting too late in the season. Planting earlier than April 20 can also be risky as soil temperatures in most years are too low to allow germination until well into May.

Seedbed preparation

For rapid and uniform emergence, corn requires a soil that is warm, moist, well-aerated and fine enough for good soil-seed contact. In addition, an ideal seedbed should prevent wind and water erosion, conserve moisture, control weeds and improve or preserve soil tilth. Corn seed can be successfully sown using a wide range of pre-seeding tillage practices. Reduced- or zero-tillage practices, which help reduce wind and soil erosion and conserve soil moisture, are gaining in importance in the state.

Regardless of what pre-seeding tillage is employed, good soil-seed contact is critical to ensure uniform germination and emergence. Avoid tilling soils that are too wet and that will form clods, or making excessive trips across the field that may leave the seeding zone dry. Press wheels should be adjusted so the seed is in contact with soil on all sides.

In reduced-tillage systems, some residue removal over the seed row can increase soil temperatures. When planting into heavy residue, make sure the cutting coulter runs deeper than the disk openers and that it actually cuts the residue so residue is not simply pushed into the ground, causing "hair-pinning" which can negatively affect seed-to-soil contact and increase the rate of soil drying in the seed zone.

Row-width

Corn is most commonly grown in rows of 30 inches. There is a trend in the Corn Belt toward using narrower spacings. Recent data suggest that in the higher-yielding regions of the state, narrower rows do offer a slight advantage in yield (3-8 percent is most commonly reported in other states). This yield advantage is not always consistent and in areas of the state that are prone to drought, wider rows may offer an advantage. Before going to narrow rows, consider the cost of new equipment, the amount of area you plant to corn and the yield potential on your farm.

Plant population

Plant populations should be based on available moisture, potential rainfall during the growing season and soil type. The cost of seed should also be considered when determining the plant population. Populations of 14,000 to 20,000 plants per acre are recommended in low rainfall areas and on light sandy soils where yield expectations are below 100 bushels per acre. Populations of 24,000 to 32,000 plants per acre are recommended in higher rainfall areas and 28,000 to 32,000 plants per acre for corn grown under irrigation. The seeding rate should be 10-15 percent higher than the desired harvest populations. See Table 2 as a guide for estimating plant populations at various row-width spacings.

Table 2. Estimation of plant population on a per acre basis.

Row-width (inches)	Row Length (1/1000 acre)
15	34'8"
20	26'2"
22	23'9"
28	18'8"
30	17'5"
36	14'6"

Count the number of plants in the row length and multiply by 1,000 to determine the number of plants per acre.

> ***Example:***
> 20 plants counted in a 17.5-foot row length of 30-inch row spacing = 20,000 plants per acre.

Planting depth

In most circumstances, corn should be planted 1.5 to 2 inches deep. Planting too shallow can cause unevenness in emergence if the soil surface dries out before all seeds imbibe sufficient water to germinate. Planting too deep will delay emergence as soil temperature decreases with depth. Shallow planting also causes the early crown (or nodal) roots to be shallow and not properly located to supply the corn plant with nutrients and water. Make sure the packer wheels are adjusted so there is good soil-seed contact. When the soil surface is dry and rainfall is uncertain, consider planting to a depth where uniformly moist soil is found, even if it is deeper than two inches.

Fertilizer Requirements

Fertilization should be based on soil tests and yield goals. Corn nutrient uptake will be approximately 1.5 pounds of elemental nitrogen (N), 0.5 pounds of phosphate (P_2O_5) and 1.2 pounds of potash (K_2O) to produce one bushel of grain corn. A large proportion of this is normally supplied by organic matter and the mineral portion of soil. If the soil cannot supply enough, the supply has to be supplemented with nutrients from other sources.

Nitrogen is the nutrient that is most often lacking in corn production. Nitrogen may be applied before planting, at planting time, as a side-dressing after corn has emerged and through an irrigation sprinkler system. Fall applications of N are not recommended on sandy soils or soils subject to flooding. The formula for N recommendations is:

Yield Goal X 1.2 less soil test nitrate-N to 2 feet in depth, less any previous crop credit from legumes or other crops.

(See previous crop credit table in NDSU Extension Service publication SF-882, "North Dakota Fertilizer Recommendation Tables and Equations," revised 2003).

Site-specific farming methods, especially yield mapping, will aid in determining realistic yield goals between and within fields.

Phosphorous is the nutrient next most likely to be deficient. Phosphorous (P) soil test levels are optimized at 12 parts per million (ppm), and potassium (K) soil test levels are optimized at 150 ppm to maximize corn yields (see NDSU Extension Service publication SF-882 "North Dakota Fertilizer Recommendation Tables and Equations," revised 2003).

Starter fertilizer is defined as plant nutrients applied with the planter in a band with the seed or in a side band, which separates seed and fertilizer by at least an inch. The entire recommended fertilizer rate can be safely applied in a band two inches to the side and two inches below the seed. Under cool, wet conditions, no-till or ridge-till systems, starter fertilizer offers advantages over broadcast P and K. Fertilizer placed with the seed should not exceed 10 lb./acre N + K_2O in medium- or heavier-textured soils with normal soil moisture.

Potassium is most likely low in sandy soils with lower cation exchange capacity (CEC). However, recently K deficiencies have also been seen more regularly in South Dakota and Minnesota in heavier textured soils, especially in no-till systems.

Potassium deficiencies will be expressed as yellowing of the lower corn leaf margins, with the mid-rib being the last area of the leaf to lose greenness under severe K deficiency conditions.

Application of K with the seed is limited by potential salt injury. Higher levels of K can be applied as a side-band or in a broadcast application. Our most common K source is KCl (0-0-60), which also contains chloride. Responses to chloride in corn have been documented in New Jersey and Kansas. Work has not been conducted in the immediate region to date to confirm that attention to chloride levels would benefit North Dakota corn growers.

Zinc (Zn) is sometimes deficient for corn in this region. The DTPA soil test for Zn is most commonly used in North Dakota. However, composite soil sampling may miss deficient areas. Lower Zn levels are most common on uplands and slopes and higher levels are more likely in depressional areas. Deficient corn is stunted, with yellow to white stripes in upper leaves. Rescue applications of liquid Zn fertilizers are helpful. However, it may be a better plan to apply Zn prior to, or at, seeding. Zinc sulfate or other water soluble dry granular products can be applied in a broadcast application to increase soil test Zn levels.

These applications are effective for several years, compared to banded applications of chelates or ammoniated Zn products. Zinc chelates or an ammoniated Zn product can be mixed with liquid fertilizers, such as 10-34-0 and applied with the seed or in a side-band at planting. If applied with the seed, limit the application to 1 quart/acre on most soils, but reduce the rate of ammoniated Zn to a maximum of 1 pint/acre in dry, sandy soils. Application of starter P may magnify Zn deficiencies if Zn is not added to the starter.

Excessive fertilizer use, especially nitrogen and phosphorus, has potential to degrade ground and surface water quality. Establishing realistic yield goals and basing fertilizer applications on soil sample analysis will help preserve water quality.

Weed Control

A combination of cultural, mechanical and chemical methods may be necessary for consistently effective weed control in corn. In early spring, recently emerged weeds can be controlled before planting with secondary tillage. A rotary hoe or a light spring tooth harrow can be used to control weed seedlings when corn has emerged. Cultivation between the rows should be done soon after weeds emerge or on an as-needed basis.

In some cases, little if any cultivation is required if herbicide combinations are properly applied and activated. Corn producers have numerous herbicides for selective weed control in corn grown in conventional, minimum-till or no-till production systems.

Weed competition is a major source of corn yield loss. To prevent yield loss, weeds must be removed soon after corn emerges. Populations of grass weeds are usually high and if not removed within the first three weeks can stunt corn growth and reduced yield. Studies indicate that if weeds are removed two to three weeks after corn emergence, yield reductions are unlikely. Also, if fields are kept weed-free for four or five weeks after emergence, most weeds that emerge later will not significantly reduce yield.

Late-germinating weeds may produce many seeds, cause harvest problems and reduce crop quality, however. Weeds that germinate early and/or have large plant architecture, like common cocklebur, common ragweed, sunflower and marshelder, are very competitive. Wild oat, kochia and wild mustard can be very competitive, especially in dry conditions. Redroot pigweed and common lambsquarters are less competitive than the large-seeded weeds listed above but when present in high densities an infestation can severely reduce yields. On a plant-for-plant basis, small-seeded and small architecture plants like annual grasses, nightshade and wild buckwheat are the least competitive. Corn yield reduction based on different weeds and weed densities is listed in Table 3.

Herbicide or herbicide combinations used should be based on weed species present, crop rotation, herbicide-resistant corn technology available, soil type and cost. Consider the economics and weed species when selecting the most appropriate control system for each field. Refer to the current issue of the NDSU Extension Service publication W-253, "North Dakota Weed Control Guide" (located at *www.ag.ndsu.nodak.edu/weeds/w253/w253w.htm* on the Web) for more detailed information on corn herbicides, use of spray adjuvants and mixing recommendations.

Many corn herbicides are labeled for tank-mixing with other herbicides for broad-spectrum weed control. Several commercial corn herbicide mixtures are available. Consult the label for information on individual herbicides and a complete listing of all possible registered combinations. Herbicides suggested for specific weed control in North Dakota corn production are listed in Table 4 (pages 10 and 11).

Herbicide-resistant corn technologies are available. Lightning® herbicide controls most annual grass and broadleaf weeds and can be applied only to Clearfield® corn varieties. Lightning® is an ALS herbicide and will not control ALS-resistant kochia and other ALS-resistant weeds. Liberty® controls most small annual grass and broadleaf

Table 3. Weed interference and corn yield.

	Corn Yield Reduction (%)			
Weed Species	1	4	8	10
	——— number of weeds/100 ft of row ———			
Foxtail spp.	15	60	175	400
Velvetleaf	10	20	40	50
Lambquarters	12	50	125	150
Pigweed spp.	12	50	125	150
Cocklebur	4	16	34	40
Shattercane	6	25	75	100
Yellow nutsedge	400	–	–	–

Table 4. Herbicides for weed control in corn.

The following ratings give relative herbicide effectiveness. Under favorable conditions, control may be better than indicated and under unfavorable conditions, herbicides may give erratic results. Dry and cool weather increases herbicide persistence while wet and/or warm weather reduces herbicide persistence.

SOIL Applied Herbicides	Mode of Action	Barnyardgrass	Field Sandbur	Foxtail, Green	Foxtail, Yellow	Quackgrass	Volunteer Cereals	Wild Oat	Wild Proso Millet	Buckwheat, Wild	Cocklebur, Common	Flixweed	Kochia	Lambsquarters, C	Lanceleaf Sage	Mallow, Common	Mallow, Venice	Marshelder	Mustard, Wild	Nightshade, E/Black	Nightshade, Hairy	Pigweed, Redroot	Prickly Lettuce	Ragweed, Common	Smartweed, Annual	Sunflower	Thistle, Russian	Wormwood, Biennial	Thistle, Canada	Herb. Persistence
Atrazine (PPI)	5	G	F	F-G	G	P-F	E	E	P-F	E	G	E	E	E	E	-	G	E	E	E	E	E	E	E	E	G-E	E	-	N	O
Atrazine (PRE)	5	G	F	F-G	G	P	E	G-E	P	G-E	F-G	E	G-E	G-E	E	-	G	E	E	G-E	G-E	G-E	E	E	E	F-G	G-E	-	N	O
Axiom (PPI)	5,15	G-E	P	G-E	G-E	N	P	P	P	P	N	-	F	F	N	-	N	N	F	P	P	G-E	P	P	P	N	F	N	N	N
Axiom (PRE)	5,15	F-G	P	G-E	G-E	N	P	P	N	P	N	-	P-F	F-P	N	-	N	N	P	P	P	F-G	P	P	P	N	P-F	N	N	N
Balance Pro (PRE)	28	E	G	E	F-G	P	N	N	E	N	P	G-E	E	E	-	-	G-E	G	E	G-E	G-E	E	-	G-E	G	P	G	G-E	N	S
DoublePlay (PPI)	8,15	E	G-E	E	E	F-G	G-E	G-E	F-G	F	P	P	G-E	E	N	F-G	N	P	F	G-E	G-E	E	P	G-E	P	P	F	P	N	N
Eptam/Eradicane (PPI)	8	E	G-E	E	E	F-G	G-E	G-E	F-G	F	P	P	F	F	N	F-G	N	P	P	F	F	G	P	F	P	N	P	N	N	N
Dual Products (PPI)	15	G-E	P	G-E	G-E	N	F-G	P-F	P	P	N	-	P	F	N	-	N	N	P	P	P	G-E	P	P-F	P	N	F	P	N	N
Dual Products (PRE)	15	F-G	P	G	G	N	F	P	N	P	N	-	P	P-F	N	-	N	N	P	P	P	F-G	P	P-F	P	N	P-F	P	N	N
Harness/Surpass (PPI)	15	E	G-E	G-E	G-E	N	G	F	F-G	P	P	-	G-E	G-E	N	-	-	P	F	G-E	G-E	E	-	F-G	P	P	F	N	N	N
Harness/Surpass (PRE)	15	E	G	G-E	G-E	N	G	P	F-G	P	P	-	G	N	-	-	P	F	G	G	G-E	-	F	P	N	F	N	N	N	
Hornet (PPI)	2,4	N	N	N	N	N	N	N	N	E	G-E	E	E	E	G-E	-	E	E	E	E	E	E	E	E	E	E	E[1]	E	F-G	O
Hornet (PRE)	2,4	N	N	N	N	N	N	N	N	E	G	E	G-E	G-E	G-E	-	E	E	E	E	E	E	E	E	E	E	E	E	F	O
Lasso/generics (PPI)	15	G-E	F	G-E	G-E	N	F-G	P-F	P-F	P	N	-	P	F	N	-	N	N	P	P	P	G-E	P	P	P	N	F	N	N	N
Lasso/generics PRE	15	F-G	P	G	G	N	F-G	P	P	P	N	-	P	P-F	N	-	N	N	P	P	P	F-G	P	P	P	N	P-F	N	N	N
Outlook (PPI)	15	G-E	G	G-E	G-E	N	G	P	F	P	N	-	P	F	N	-	-	N	P-F	F-G	G	E	-	P	P	N	P-F	N	N	N
Outlook (PRE)	15	F-G	G	G-E	G-E	N	F	P	F	P	N	-	P	F	N	-	-	N	P-F	F-G	F-G	G-E	-	N	P	N	P	N	N	N
Prowl (PRE)	3	E	F	G-E[1]	G-E	N	F-G	P-F	P	P	N	P	F	G	N	-	F	N	N	N	N	G	N	P	P	N	F-G	P	N	S

PPI = Preplant Incorporated, PRE = Preemergence.
Mode of action = classification system developed by Weed Science Society of America. Weed Tech 11:384-385 or Section X1 in the North Dakota Weed Guide.
[1] Except where resistant populations have developed.

POST Applied Herbicides	Mode of Action	Barnyardgrass	Field Sandbur	Foxtail, Green	Foxtail, Yellow	Quackgrass	Volunteer Cereals	Wild Oat	Wild Proso Millet	Buckwheat, Wild	Cocklebur, Common	Flixweed	Kochia	Lambsquarters, C	Lanceleaf Sage	Mallow, Common	Mallow, Venice	Marshelder	Mustard, Wild	Nightshade, E/Black	Nightshade, Hairy	Pigweed, Redroot	Prickly Lettuce	Ragweed, Common	Smartweed, Annual	Sunflower	Thistle, Russian	Wormwood, Biennial	Thistle, Canada	Herb. Persistence
Accent	2	E	G-E	E	F-G	G-E	G-E	E	G-E	P	P	E	F[4]	P	P	-	P	P	E	N	N	E	-	P	G-E	P	P	P	N	O
Accent Gold	2,4	E	G	E	E	G-E	G	G-E	G-E	F	E	E	F[4]	G	E	-	E	E	E	G-E	G-E	E	-	E	E	E	F	E	G-E	O
Aim/Teamwork	14	N	N	N	N	N	N	N	N	P	P	E	F-E	F-E	-	-	N	P	P	G	G	G-E	N	N	N	N	F	-	N	N
Atrazine + oil	5	G	F	G	G-E	P-F	F-G	G-E	F	G	G	E	E	E	E	-	-	E	E	G	G	E	E	E	E	G	E	-	P	S
Basagran	6	N	N	N	N	N	N	N	N	P	G-E	E	P	F-G	P	P	E	G-E	E	N	F-G	F	E	F-G	E	E	G	G-E	F-G	N
Basis	2	G-E	F-G	G-E	G	F-G	F-G	F-G	F	P	P	-	F[4]	G	P	N	F	G	E	P	P	E	-	P	E	F-G	G[4]	P	P	S
Basis Gold	2,5	E	G	E	E	E	G	E	G-E	G-E	F-G	E	E[4]	E	E	-	E	E	E	F	F	E	E	G-E	E	G	E	-	N	O
Bromoxynil	6	N	N	N	N	N	N	N	N	E	E	F-G	G-E	G	E	P	G-E	E	F-G	E	E	F	E	E	G-E	G-E	E	F	P	N
Callisto + Atrazine	5,28	N	N	N	F	N	N	N	N	G-E	E	E	E	E	E	-	-	E	E	E	E	E	-	E	E	E	-	-	P	S
Celebrity Plus	2,4,19	E	G-E	E	G-E	G-E	G-E	E	G-E	E	E	E	E[4]	G	F	G	F	E	E	G-E	G-E	E	E	E	E	E	G	E	F-G	O
Dicamba	4	N	N	N	N	N	N	N	N	E	E	P-F	E	G	P-F	G	F-G	E	G	E	E	G	G-E	E	E	G-E	G	G-E	F-G	S
Distinct	2,19	P-F	P	P-F	P-F	N	P	P	P	E	E	G	E	E	G	G	E	E	E	G	G	E	E	E	E	E	E	E	G	S
Glyphosate[1]	9	E	E	E	E	E	E	G-E	E	P-F	E	G-E	F-E	P-E	E	F-G	E	G-E	G-E	F-G	F-G	E	E	E	E	G-E	G	G-E	G-E	N
Hornet	2,4	N	N	N	N	N	N	N	N	F-G	E	E	F-G[4]	P-F	E	-	E	E	E	G-E	G-E	P-F	-	E	F-G	E	F-G	E	G-E	O
Liberty[2]	10	E	G	E	G	P	F-G	G-E	E	E	E	G-E	E	F-G	E	E	E	E	E	E	E	E	G-E	E	E	E	G-E	E	P	N
Lightning[3]	2	E	E	E	E	F	G-E	G-E	G-E	E	G	E	E[4]	E	-	G	G	E	E	E	E	E	-	G	E	G	E	P	F	O
Lumax (3 pt)	5,15,28	E	E	E	E	F	G-E	G-E	G-E	E	G	E	E[4]	E	E	-	E	E	E	E	E	E	E	E	E	E	E	E	P	S
NorthStar	2,4	-	G-E	G-E	G-E	G-E	-	-	-	E	E	E	E	E	F	G	F	E	E	E	E	E	G-E	E	E	E	E	G-E	G	O
Option	2	E	G-E	E	F-E	G-E	-	E	G-E	N	G	E	E[4]	G	N	-	-	-	E	E	E	E	-	G	P	G	-	-	P	N
Permit	2	N	N	N	N	N	N	N	N	P	E	E	P[4]	N	P	-	E	G-E	E	P	P	F-G	-	G-E	F-G	E	-	P	N	O
Steadfast	2	E	G-E	E	G-E	G-E	E	E	E	P	P	E	P[2]	P	P	-	N	P	E	N	N	E	-	N	F	P	P	P	N	O
2,4-D	4	N	N	N	N	N	N	N	N	P-F	G-E	F-G	P-F	E	P-F	P	G-E	E	E	P-F	P-F	G	E	G-E	F-G	E	G	F-G	F	N

Mode of action = classification system developed by Weed Science Society of America. Weed Tech 11:384-385 also Section X1 in the North Dakota Weed Guide.

[1] Glyphosate can be applied anytime before corn emergence and only to Roundup Ready corn varieties.

[2] Liberty can be applied only to Liberty Link corn varieties.

[3] Lightning can be applied only to Clearfield corn varieties.

[4] Herbicides will not control resistant biotypes.

weeds and can be applied only to Liberty Link® corn varieties. Liberty® is a contact type, nonselective, nonresidual herbicide and should be applied to small weeds for the most effective weed control. Liberty® will control all ALS-resistant weeds.

Glyphosate controls most annual and perennial grass and broadleaf weeds and can be applied only to Roundup Ready® corn varieties.

Glyphosate is a systemic, nonselective, nonresidual herbicide and may require two sequential applications or use after a foundation soil-applied herbicide program. Other glyphosate resistant crops can be grown in North Dakota, such as Roundup Ready® soybean and canola.

Controlling volunteer Roundup Ready® corn in Roundup Ready® soybean maybe require use of a postemergence grass herbicide, such as Assure II® or Select® in addition to glyphosate. Public nonacceptance of Roundup Ready® technology may limit market potential. Plan ahead and secure an available selling market before growing a herbicide-resistant corn variety.

■ ■ ■

Consult the label for information on individual herbicides and a complete listing of all possible registered combinations.

Insect Control

Corn insects, if not adequately managed, may result in significant economic losses in corn grain and silage production fields. The major corn insect problems in North Dakota include: European corn borer (ECB), grasshoppers, wireworms, cutworms, white grubs, and northern and western corn rootworm.

Crop rotations and the use of properly labeled insecticides or insect-specific resistant hybrids are suggested as methods of control.

European corn borers (ECB) are the most common insect pest affecting corn yield in the region. They can be managed successfully with insecticides when applied correctly and timely, or through the use of transgenic Bt *(Bacillus thuringiensis)* corn (such as YieldGard® or Herculex I® hybrids).

Managing ECB in North Dakota is a challenge due to the lengthy emergence interval of the moths from overwintering. In North Dakota, borers have the potential for one or two generations during the season. Recent corn borer infestations in North Dakota have developed in mid- to late-July as a result of the later emergence cycle of the more numerous single-generation type borers. The two-generation borers are primarily present in the southeast quarter of the state. The two-generation type of ECB begins emerging in early- to late-June and represents the first flush of larval feeding in whorl-stage corn. The single-generation borer is present throughout North Dakota, and the moths emerge from mid-June through mid-July. ECB infestations from the single-generation type are occurring from mid-July to early-August.

The challenge of the crop manager is to distinguish when egg laying and larval populations can be tolerated or when they need to be controlled. Corn should be monitored from mid-June to early-August. Start in mid-June in areas where the two-generation type borers are present. Inspect plants for the presence of egg masses on the undersides of leaves, for whorl, leaf or tassel feeding and for active larvae. Observing ECB moth activity around field margins or within the field may be an early indication of potential infestations. In some years, the two-generation borers emerging first may contribute more to significant infestations, but generally this is restricted to the southeastern to south central counties of North Dakota only.

In a corn field, there is usually no more than 10 to 14 days during which borers are still feeding outside the stalk and when they can be contacted with an insecticide treatment. Once the borers tunnel into the stalk, it is too late to control them with an insecticide. Because of the long potential infestation window (mid-June to late-July) and difficult timing of insecticide treatments, many growers in the region have used Bt corn on their farm for ease of controlling corn borers.

Depending on the type of Bt corn, either the whole plant or the green portions of the plant contain a Bt toxin. When eaten by the corn borer larvae, the toxin stops their feeding and kills them. Acting as a stomach poison to the larvae, the Bt toxin is effective in minimizing damage to corn. Hybrids which produce the Bt protein in all plant tissues, including the grain, have overall protection. Other hybrids, which only produce the protein in green tissue, may not have protection against later corn borers feeding on the grain.

Chemical control of European corn borer in North Dakota during most years will be necessary only for first-generation borers, with second-generation populations being minimal and restricted to a limited geographic area.

For first-generation borers, field scouting should begin on non-Bt hybrids in late-June and continue through July. One general treatment threshold that can be used is when 40 to 50 percent of the plants in dryland corn or 25 to 35 percent of the plants in irrigated corn have shot-holing in the whorl leaves, egg masses on the undersides of leaves or live borers visible in the whorls.

Other scouting methods base treatment decisions on the number of larvae per plant and is based on field scouting to determine the percent infested plants, number of live larvae per infested plant, cost of insecticide treatment and expected value of the corn (Table 5).

For detailed information on the biology and control of corn insects with insecticides, see NDSU Extension Service publications E-631, "Corn Insects in North Dakota," and E-1143, "North Dakota Field Crop Insect Management Guide."

Table 5. Economic threshold (corn borer/plant) when factoring crop value and control costs.

Control Costs[2]	Value of Corn Crop[1] ($/acre)								
	200	250	300	350	400	450	500	550	600
($/acre)									
6	0.75	0.60	0.50	0.43	0.38	0.34	0.30	0.27	0.25
7	0.88	0.70	0.58	0.50	0.44	0.39	0.35	0.32	0.29
8	1.00	0.80	0.67	0.57	0.50	0.45	0.40	0.37	0.34
9	1.12	0.90	0.75	0.64	0.56	0.50	0.45	0.41	0.38
10	1.25	1.00	0.83	0.71	0.63	0.56	0.50	0.46	0.42
11	1.38	1.10	0.92	0.79	0.69	0.61	0.55	0.50	0.46
12	1.50	1.20	1.00	0.86	0.75	0.67	0.60	0.55	0.50
13	1.63	1.30	1.08	0.93	0.81	0.72	0.65	0.59	0.54
14	1.75	1.40	1.17	1.00	0.88	0.78	0.70	0.64	0.59
15	1.88	1.50	1.25	1.07	0.94	0.84	0.75	0.68	0.63
16	2.00	1.60	1.33	1.14	1.00	0.89	0.80	0.73	0.68

[1] Crop value = expected yield (bu/acre) X projected price ($/bu)

[2] Control costs = insecticide price ($/acre) + application costs ($/acre)

Diseases in Corn

Corn diseases have not had large economic impacts on corn production in North Dakota, but as corn acreage increases and shorter rotations between corn crops occur, an increase of disease problems is possible. Corn diseases currently observed to some degree in commercial corn fields each year include seed and seedling diseases, corn stalk rot, fungal and bacterial leaf diseases, corn smut and ear rots. Virus diseases are observed infrequently.

Seed rots and seedling blights (various fungi)

Seed may rot before germination or shortly after, resulting in no seedling emergence, or seedlings may emerge and turn yellow and die. Seed rots generally are caused by fungi, and infection is enhanced under conditions of poorly drained soils, cold and wet soils, compacted soils, deep and early planting and poor-quality seed. Risk of these problems can be reduced by planting injury-free seed of high quality and germination percentage. Seed treatments can reduce the risk of seedling blight and seed rot. Most corn seed is sold pre-treated, but further information on corn seed treatments registered in North Dakota may be found in the NDSU Extension publication PP-622, "Field Crop Fungicide Guide." Some fungicide seed treatments contain multiple products to control a variety of fungal pathogens.

Corn stalk rot

Stalk rots are the most common and important diseases of corn, both in the United States and in North Dakota. Stalk rots are generally caused by fungi, although bacterial stalk rot also occurs. The causal organisms infect through roots or through insect wounds. The interior of the stalk becomes rotted, the pith often is shredded and discolored and lodging frequently occurs. Yield losses occur due to poor filling of ears, early ear drop and stalk breakage. Stalk rots are favored by crop stress, so management is aimed at reducing crop stress: selection of hybrids with good standability or stalk strength; use of appropriate plant nutrition for the corn hybrid; use of recommended plant populations; control of insects; and use of sound agronomic rotations.

Common leaf diseases

Fungi and bacteria may cause leaf diseases in corn. The common leaf diseases observed in North Dakota include common rust *(Puccinia sorghi)*, eye spot *(Kabatiella zeae)*, Bipolaris zeicola leaf spot *(= Helminthosporium carbonum)*, Northern corn leaf blight *(Exserohilum turcium = Helminthosporium turcicum)* and Holcus spot *(Pseudomonas syringae)*. Another fungal leaf spot, gray leaf spot *(Cercospora zeae-maydis)*, has not been observed in North Dakota, but has become an economic disease in corn fields in Corn Belt states in recent years. Hybrids may vary in their resistance to these fungal and bacterial diseases. In addition to choosing hybrids with leaf disease resistance, crop rotation and tillage will reduce carryover and overwintering of the disease organisms.

Although these leaf diseases are seldom of economic importance to North Dakota commercial corn production, seed production fields may occasionally warrant fungicide treatment. Information on fungicide treatments available for leaf diseases in corn is available in the NDSU Extension Service publication PP-622, "Field Crop Fungicide Guide."

Corn smut

Common smut

This fungus (*Ustilago maydis*) disease is caused by smut spores that overwinter in the soil and subsequently infect the growing plant through wounds or injuries due to hail, blowing soil, cultivation and insects. The leaves, stalks, ear or tassels may be replaced by a black spore mass which is covered by a persistent grayish membrane. Hail damage or various stresses increase the risk of smut. Hybrids vary in susceptibility, and more resistant hybrids should be chosen.

Head smut

The spores of the causal fungus (*Spahcelotheca reiliana*) infect plants systemically while they are in the seedling stage. Only tassels and ears are smutted and black spore masses covered with only a thin membrane are present. Most hybrids are resistant, but crop rotation reduces the risk of infection.

Ear rots

Ear rots are caused by various fungi. The kernels of the ears turn pink, white, black to green, depending on the fungus which is causing the infection. Wet weather late in the season and insect injuries increase the risk of ear rots. Management is through use of hybrids with more resistance, crop rotation and reduction of insect injury.

Corn rotations and disease management

For purposes of disease management, corn should follow a broadleaf crop whenever possible. Corn does not have any diseases in common with broadleaf crops such as drybean, soybean, sunflower or canola, so alternation of corn with these crops helps break the disease cycle of organisms.

Corn has some important and damaging diseases in common with other cereal crops, such as wheat, barley, oats, millet or sorghum. The Gibberella (*Fusarium graminearum*) stalk rot of corn is caused by the same fungus that causes head scab in wheat and barley. This fungus survives very well in corn root and stalk residue. Infected corn residue is a source of very high populations of the spores of the head scab fungus. Thus, planting wheat or barley back into corn ground results in a high risk of head scab in the small grain crops if wet weather should occur during the heading stage of the wheat or barley. Wheat, barley and oats also have some root disease fungi in common with corn.

Leaf diseases, such as the northern corn leaf blight and grey leaf spot, are caused by fungi that survive in corn residue. Sorghum and sudangrass also are hosts of several corn leaf diseases. Crop rotation to broadleaf crops reduces the potential for corn leaf diseases that survive in corn debris.

Corn for Silage

Many management practices that are recommended for corn grown for grain also apply to corn silage production. For example, early planting favors corn grown for grain as well as silage, though the risks associated with late planting may be less for corn grown for silage. Usually, high-yielding grain corn hybrids produce high-quality silage. Select a hybrid that is five days later in maturity than one you would grow for grain in your area. Several corn seed companies have developed special silage corn hybrids and silage blends. Research has shown that Bt traits have no detrimental impact on intact and digestibility of silage. Stalk strength is not as important since the crop is harvested before breakage normally occurs.

For areas of the state where moisture is not severely limiting, consider establishing a plant population 2,000-3,000 plants higher than you would if you were growing the crop for grain.

The advantage of narrower rows is greater (up to 9 percent reported in Wisconsin) for corn grown for silage than for grain.

The best quality corn silage is made when the grain is in the late dough stage. At this stage, the kernels are well-dented. Moisture in the entire plant at silage-making time should be between 63 and 70 percent. High-quality silage contains a relatively large percentage of grain or dry matter. Quality silage is palatable to livestock. This occurs when proper harvesting, storage and ensiling techniques are used. Top-quality silage has good keeping characteristics with little mold. The growth of mold and other organisms depends on the presence of air. Good packing and even distribution of cut material within the silo is necessary for air elimination and rapid ensiling to occur.

Corn that is too mature, too dry or that packs poorly will result in poor silage. If corn is too dry, add water to bring moisture to the proper level. The amount of water required to increase forage moisture content 1 percent is approximately five to six gallons per ton of ensiled material. Knives on the forage harvester should be kept sharp. Bruised and ragged silage is difficult to pack. Silage should be fine chopped (⅜- to ¾-inch pieces) for best packing.

Frosted immature grain corn can be salvaged for silage. If the immature corn has a majority of leaves destroyed and the stalk is frozen to the ground at the time of frost, the best choice is to chop it for silage. Silage can be made from frozen corn stalks with little reduction in quality except for a small loss in dry matter. The best quality silage comes from stalks that are 63 to 68 percent moisture when chopped. Immature corn may need to stand several days in the field following a killing frost for drying stalks to reach the optimum moisture range.

When corn is drought-stressed and is to be salvaged as livestock feed, cutting for silage is preferred over grazing or green-chop feeding. This also helps to avoid nitrate poisoning which can be a problem when feeding drought-stressed corn. Over one-third to one-half of the nitrate accumulated in the plant material can be dissipated during fermentation. Since fermentation takes two to three weeks for completion, drought-stressed corn silage should not be fed for at least three weeks following ensiling. Testing for nitrate content of drought-stressed corn should be done before green chopping or grazing. Contact your county Extension agent for information on the nitrate analysis.

Estimating Corn Grain yield

There are several techniques for estimating corn grain yield prior to harvest. Perhaps the most widely known and used is called the Yield Component Method which was developed at the University of Illinois Depart The steps of this method are:

Step 1.
Count the number of harvestable ears in a row length equivalent of 1/1000 acre (see Table 2).

Step 2.
Count the number of kernel rows per ear on every fifth ear. Calculate the average.

Step 3.
Count the number of kernels per row on each of the same ears, but do not count kernels on either the butt or tip that are less than half-size. Calculate the average.

Step 4.
Yield (bushels per acre) =

$$\frac{\text{(number of ears) x (average number of rows) x (average number of kernels/row)}}{90}$$

A numerical constant for kernel weight is figured into the equation in order to calculate grain yield. Since weight per kernel will vary depending on hybrid and environment, the yield equation should only be used to estimate relative grain yield. For example, grain yield will be over-estimated for a hybrid with small kernel size or in a year with poor grain-fill conditions, while it will be underestimated in a year with good grain-fill conditions.

Harvesting Grain Corn

Methods of harvesting corn include combining with a corn head, all-row crop headers, mechanical pickers for ear corn and field picker-shellers. The best time to harvest corn varies with the harvest and storage system. Harvesting early reduces field losses.

For high-moisture corn stored in a silo, the ideal moisture is 25 to 30 percent with no drying required. Corn grain will spoil and there is a potential of a silo fire if corn is stored in a silo at moisture contents below 25 percent. Grain corn can be stored at moisture contents up to about 23 percent if kept near or below freezing.

The recommended moisture content for long-term storage during summer temperatures is 13.5 percent and for storage during cooler temperatures is 15.5 percent. Corn is commonly marketed at 13.5 to 15.5 percent moisture.

The optimum moisture content for limiting mechanical damage during harvest is about 22 percent. Increased damage occurs both below and above this moisture content. Harvesting at moisture contents of 30 percent and above results in poor kernel separation from the cob. Combining at moisture contents of 15 percent or lower results in high levels of cracked and broken kernels. Combine cylinder speed and cylinder-concave clearance are also important factors determining mechanical damage at harvest. Damage increases significantly with increasing cylinder speed.

It is usually best to follow the recommendations in the operator's manual for initial combine settings and recommended harvesting procedures. Then, after harvesting a small area, make changes based upon field conditions. Make only one adjustment at a time, checking the results before making another adjustment. Results can be determined by measuring grain loss on the ground. Loss measurements should be done by counting corn kernels or ears in a measured area. The following is a general guideline to use in estimating corn loss:

> A field average of two kernels per square foot is 1 bushel per acre loss,
>
> ***-or-***
>
> One, three-quarter-pound ear in a 100-square-foot area is 1 bushel per acre loss.

All of the crop cannot be saved. A reasonable total field loss should not exceed about 3 percent. If harvest conditions are excellent, a good operator should be able to keep losses well below 3 percent. This includes the loss of ears dropping off the stalk, kernels shelled off at the snapping rollers and the threshing and separation loss in the combine. For example, a 3 percent loss for a corn crop of 100 bushels per acre would be about three bushels per acre. All combines used on farms are capable of keeping harvest losses low if the crop is collected by the machine. Usually the largest losses occur at the header. Check for grain losses and damage frequently, particularly as harvest conditions change.

A simple and easy way to determine loss is with the use of a square foot frame dropped on the ground. Do several counts in various parts of the field to determine an average. Then, divide the average seeds per square foot by two to determine the bushels per acre left in the field.

Ear loss can be determined by counting the number of three-quarter-pound ears in a 10- by 10-foot area or 100 square feet. The number of ears counted is the bushels lost per acre. Most ear loss will occur before the combine enters the field except when stalks are severely lodged so some ears are lost as the header points lift the stalks.

Loss of ears can only be reduced by harvesting earlier if crop conditions permit. If partial ears with kernels attached are coming from the rear of the combine, check and readjust the cylinder or rotor to concave spacing and narrow it, or as a last resort, speed up the cylinder slightly.

Storage Management

Corn needs to be dried to a safe storage moisture and then cooled by aeration during storage to prevent mold growth and limit insect activity. Molds consume corn dry matter, produce odors and sometimes produce toxins. Corn should be dried to 15.5 percent for short-term storage over winter and to 13.5 percent for long-term storage. Grain stores best if kept cool and dry.

Optimum temperatures for insects and mold are between 70 and 90 degrees. At grain temperatures below 40 degrees, insect and mold activity is limited. Corn should be cooled, using aeration, to about 25 degrees for winter storage to minimize moisture migration and to enhance storability.

Stored grain should be checked at least monthly. Check the corn temperature and moisture content at several locations and record the information. Cover fans and air ducts when not in use to prevent rodents and moisture from entering and to prevent excessive warming in the spring.

Measuring moisture content

A representative sample must be used to determine the moisture content of a load of grain. Also, the moisture content should be uniform in the kernel. Most meters are affected by the moisture content of the outside surface of the kernel, so if the outside is drier than the inside of the kernel, such as when corn comes directly from a dryer, the meter will give an erroneously low reading. A temperature adjustment must be used if the sample is not at the standard temperature, which is usually about 75 degrees. A moisture meter should be periodically checked against a reference, such as where the grain is marketed or other meters, to assure that accurate readings are being provided.

It is difficult to accurately measure the moisture content of hot grain. It is best to cool the samples slowly in a sealed moisture-proof container before checking the moisture content. By comparing the difference between the moisture content of a cooled sample and a sample immediately out of the dryer, an adjustment factor can be developed and used as an estimate for managing the dryer. It is only an estimate, since the adjustment factor will vary depending on initial moisture content, drying rate and other factors. Remember to add or subtract the temperature correction factor for your moisture meter, if your meter doesn't have automatic temperature compensation.

Holding wet corn

To avoid mold damage while holding wet corn, it is necessary to keep the corn cool. An aeration system delivering a uniform airflow of about 0.25 to 0.5 cfm/bu. with cool outdoor temperatures is needed to carry away heat generated by corn and mold respiration. The approximate allowable storage time for corn is shown in Table 6 (page 18). The allowable storage time is approximately doubled by reducing the corn temperature by 10 degrees.

Table 6. Approximate allowable storage time for shelled corn based on 0.5% maximum dry matter loss.
(Transactions ASAE 333-337, 1972.)

	Corn Moisture (%)						
Grain Temp.	18	20	22	24	26	28	30
(F)	(Days)						
30	648	321	190	127	94	74	61
40	288	142	84	56	41	32	27
50	128	63	37	25	18	14	12
60	56	28	17	11	8	7	5
70	31	16	9	6	5	4	3
80	17	9	5	4	3	2	2

Selecting and managing dryers

Column Dryers

A cross-flow dryer is the most common type of dryer used. It is referred to as a cross-flow dryer because the heated air moves across the grain column perpendicular to the flow of the grain. The grain moisture content and temperature varies across the column of a cross-flow batch dryer. The temperature of corn in a dryer increases as the corn dries.

A recirculating batch dryer is one way to mix the grain to create more uniform drying. Some continuous cross-flow dryers use a grain turner that moves corn from the inside of the column to the outside, and corn from the outside of the column to the inside. This minimizes the amount of time the corn is adjacent to the inside of the column where it may get too hot and over-dried.

Another feature that can minimize variation across the drying column is having the drying columns tapered, so the grain on the plenum side of the column moves faster than grain near the outside of the column. In multi-stage, continuous-flow, cross-flow dryers, the top stage, which contains the wettest corn, can be operated at higher temperatures, and the bottom stages, which contain drier corn, can be operated at lower temperatures.

The drying airflow rate selected is a compromise between energy efficiency, dryer capacity, average grain temperature and moisture variation across the column. Generally, the best drying energy efficiency is obtained by using the highest drying temperature that does not damage the corn. Some cross-flow dryers recirculate air to increase energy efficiency.

In a concurrent-flow dryer, airflow enters the wet grain and travels in the same direction as the grain. This results in a much lower grain temperature.

In the mixed-flow or rack type dryer, the grain flows over alternating rows of air supply ducts and air exhaust ducts. This action provides mixing of the grain and alternate exposure to hot drying air and air which has been cooled by previous contact with the grain. This promotes moisture uniformity and limits grain temperature.

Bin Dryers

High-temperature batch-in-bin drying involves drying a three- to four-foot-deep layer of corn in the bin using typical drying air temperatures of 120 to 160 degrees with airflow rates of 8 to 15 cubic feet of air per minute per bushel of grain (cfm/bu.). Grain at the floor of the bin becomes excessively dry while the top layer of the batch remains fairly wet. As the grain is moved from the bin, the grain is mixed so the average moisture content going into storage is acceptable. There are variations, however, in grain temperature and moisture content in the dried corn.

A stirring device can be added to batch-in-bin dryers to provide a more uniform moisture content and corn temperature. Stirring will also increase the airflow, which increases the drying speed. Stirring allows grain depths of up to six to eight feet. Grain stirrers tend to sift fine materials to the bin floor, so it is important to clean the bin floor between batches.

A recirculating bin dryer incorporates a tapered sweep auger that removes grain from the bottom of the bin and places it on the top of the corn in the bin to create more uniform drying. A continuous-flow bin dryer also incorporates a sweep auger that removes the corn from the bottom of the bin when it is dry. The airflow moves from the driest grain on the bottom to the wettest grain on the top. Because all kernels approach the drying air temperature in this type of dryer, the drying temperature needs to be reduced to prevent damaging the grain. Cooling occurs in a separate bin.

Be aware that increasing the grain depth reduces the airflow rate (cfm) and therefore the drying rate of in-bin dryers.

Cooling corn from high-temperature dryers

Dryeration involves tempering, then cooling the grain slowly in a bin, rather than in the dryer to achieve a large reduction in breakage susceptibility. Other advantages of dryeration include about two percentage points of moisture removal, a 20 to 40 percent energy savings and a 50 to 75 percent increase in dryer capacity. The dryer capacity increases because the corn is only dried to about 17.5 percent moisture and cooling time is eliminated. The amount of moisture removal is related to the amount of cooling that occurs. About a 0.25 percentage point of moisture is removed for each 10 degrees of cooling.

With dryeration, the corn is moved directly to a cooling bin, is allowed to temper without airflow for four to six hours and then is cooled over a 12- to 24-hour period. Condensation forms along the bin wall, which rewets some corn during the tempering period. The corn must be moved from the cooling bin to prevent this wet grain from spoiling. The wet corn is mixed with dry corn as it is moved into storage.

With in-storage cooling, the grain is moved directly to the storage bin without cooling in the dryer, but unlike dryeration, the grain is cooled without delay. Size the fan to provide an airflow rate of 12 cfm per bushel per hour of dryer capacity or fill rate to cool the corn at the filling rate. For example, if hot corn is being added to the bin at the rate of 500 bushels per hour, size the fan to provide 6,000 cfm of airflow. The air should flow upward through the corn, so additional hot corn can be added to the top to be cooled without reheating the corn below.

Natural-air and low-temperature drying

Natural-air and low-temperature (NA/LT) crop drying maintains the high quality of the corn, does not require constant supervision, is energy efficient and does not limit harvest capacity. A drying fan is required for each bin, and the initial moisture content that can be dried in a full bin is limited to about 21 percent. An airflow rate of 1.25 cfm/bu will dry 21 percent moisture content corn to about 15 percent in about 36 days under average Upper Midwest October conditions.

NA/LT drying works very well during October but is not efficient with typical mid- to late-November weather conditions. It will take about 70 days to natural air dry 21 percent moisture content corn to 18 percent under November conditions with an airflow rate of 1.25 cfm/bu. Heating the November air by 5 degrees reduces the EMC to 14.6 percent moisture and reduces the drying time to 52 days. However, since November has only 30 days, 43 percent of the corn still is not dried after running the fan and heater the entire month of November. Adding more heat will over dry the corn without substantially increasing the drying speed.

A stirring device in the bin is required if more than a five-degree temperature rise is used. The drying fan will warm the air three to five degrees, depending on fan type and operating conditions. This needs to be considered in designing a system.

Corn can be held over winter and dried in the spring. Based on average April conditions, 21 percent moisture corn can be dried to about 15 percent in 41 days using an airflow rate of 1.25 cfm/bu. Based on average May conditions, the corn can be dried to about 13 percent moisture in 35 days using the same airflow rate. This is a good option instead of drying during late November, if the corn does not need to be delivered before spring. Cool the corn to about 25 degrees for winter storage.

NDSU Extension Service Corn Related Publications

(with Web site address when available)

- Fertilizing Corn Grain and Silage (SF-722)
  www.ext.nodak.edu/extpubs/plantsci/soilfert/sf722w.htm
- North Dakota Weed Control Guide (current year W-253)
  www.ag.ndsu.nodak.edu/weeds/w253/w253w.htm
- North Dakota Field Crop Insect Management Guide (current year E-1143)
  www.ext.nodak.edu/extpubs/plantsci/pests/e1143w1.htm
- Field Crop Fungicide Guide (current year PP-622)
  www.ext.nodak.edu/extpubs/plantsci/pests/pp622w.htm
- North Dakota Hybrid Corn Performance Testing (current year A-793)
  www.ag.ndsu.nodak.edu/aginfo/variety/corngrain.htm
- Corn Insects in North Dakota (E-631)
- Grain Drying (AE-701)
  www.ext.nodak.edu/extpubs/plantsci/smgrains/ae701-1.htm
- Crop Storage Management (AE-791)
- Crop Dryeration and In-Storage Cooling (AE-808)
- Corn Production Pocket Guide (A-1130)
  www.ext.nodak.edu/extpubs/plantsci/rowcrops/a1130-2.htm#Index
- Maintaining Corn Quality for Wet Milling (AE-1119)
  www.ext.nodak.edu/extpubs/plantsci/rowcrops/ae1119
- Corn Silage Management (AS-1253)
- Silage Fermentation and Preservation (AS-1254)

Useful Corn Web Sites

- North Dakota Corn Growers Association
  www.ndcorn.com/
- Minnesota Corn Growers Association
  www.mncorn.org/
- National Corn Growers Association
  www.ncga.com/
- NDSU Row Crop and Oilseeds Page
  www.ag.ndsu.nodak.edu/plantsci/rowcrops/main.htm
- University of Minnesota Extension Service
  www.extension.umn.edu/
- King Corn (Purdue University)
  www.agry.purdue.edu/ext/corn
- Ohio State University Extension
  http://ohioline.osu.edu/lines/acrop.html#FCORN
- The Maize Page
  http://maize.agron.iastate.edu/
- Wisconsin Corn Agronomy
  http://corn.agronomy.wisc.edu/

For more information on this and other topics, see: www.ag.ndsu.nodak.edu

A-834

NDSU Extension Service, North Dakota State University of Agriculture and Applied Science, and U.S. Department of Agriculture cooperating. Duane Hauck, Director, Fargo, North Dakota. Distributed in furtherance of the Acts of Congress of May 8 and June 30, 1914. We offer our programs and facilities to all persons regardless of race, color, national origin, religion, sex, disability, age, Vietnam era veterans status, or sexual orientation; and are an equal opportunity employer. This publication will be made available in alternative formats for people with disabilities upon request, 701/231-7881.

3M-7-04