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Basics of Corn Production in North Dakota

EXTENDING KNOWLEDGE ❯❯ CHANGING LIVES

NDSU | EXTENSION

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Corn Production in North Dakota

In terms of area planted, corn is the third most important crop in North Dakota, following soybean and wheat, and is the second (following soybean) or third most important crop in terms of gross value, depending on the marketing year. The area planted to corn increased by more than 3.5 times between 2001 and 2012, with recent production predicted to be on more than 4 million acres.

Of the major crops, corn is the highest yielding on a per-acre basis and produces the highest total bushels. Furthermore, since 2000, corn yields in North Dakota have increased by an impressive 1.6 bushels per acre per year. These yield gains have been achieved through a combination of growers using improved genetics and crop management practices. The average yield of corn in North Dakota has been near 140 bushels per acre.

Current corn hybrids are responsive to favorable environmental conditions and good management, with many growers consistently obtaining yields in excess of 250 bushels per acre. The intent of this publication is to provide recommendations that help corn producers sustainably improve corn productivity and profitability.

Environment, Corn Growth and Production

Corn can be grown in every county in the state, although 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.

Low temperatures and inadequate moisture frequently can limit corn productivity 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 also is 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, rather than calendar days, more precisely characterize the length of the growing season. Unlike the number of days between killing frosts, GGDs provide quantitative information about temperature during the growing season. In calculating GDDs 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:

$$\text{Corn GDD} = \frac{(\text{Maximum temperature} + \text{minimum temperature})}{2} - 50$$

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 and current season GGD accumulations can be obtained from the North Dakota State University NDAWN weather site at https://ndawn.ndsu.nodak.edu/corn-growing-degree-days.html.

GDD accumulations (normal values) for May 1 to Oct. 1 vary considerably in the state, from more than 2,400 GDD in the southeast to fewer than 1,700 GDD in the north (Figure 1). 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 producing corn successfully.

A corn growing degree day decision support tool (https://hprcc.unl.edu/gdd.php#) also is available. It allows the user to obtain growing degree day data for any location that is selected on the map that is part of the interface. It allows the user to enter planting dates and hybrid maturity grown to generate up-to-date information on GDD accumulations, and using past weather data, predicts various growth stages and the probability that the crop will reach maturity prior to a freeze.

For additional details on corn growth and development, including descriptions of various growth stages and important developmental processes that occur at these stage, refer to the NDSU Extension publication "Corn Growth and Management – Quick Guide" (www.ag.ndsu.edu/pubs/plantsci/rowcrops/a1173.pdf).

Minimum soil temperatures of 46 to 50 F are required for corn germination and seedling growth. Cold soil temperatures soon after planting can cause imbibitional chilling injury to the seed (discussed in more detail below). Cold rain or snow soon after planting often is associated with this type of injury.

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 it 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.

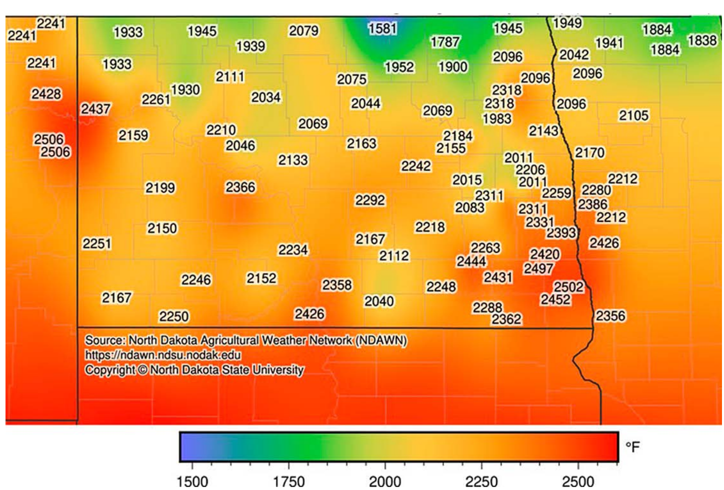

Figure 1. Normal (average of the period 1981 to 2010) growing degree day accumulations in North Dakota from May 1 to Oct. 1.

Prolonged cold weather that reduces the soil temperatures 2 inches below the surface to below freezing also can kill corn seedlings regardless of their stage of development. A killing frost 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 decrease grain quality.

Corn tolerates high temperatures, although the rate of corn growth reaches a maximum at 86 degrees. Pollen can be desiccated and killed when temperatures are above 100 degrees, but given the large quantity of pollen produced relative to the number of silks available for fertilization and that pollination usually occurs for many days, pollen mortality due to high temperatures very likely will not be the limiting factor in kernel fertilization in North Dakota.

Air temperature after physiological maturity determines the rate of grain drying in the field. Air temperatures drop rapidly in October, so choosing hybrids that mature prior to the beginning of October reduces the risk of having corn with excessive moisture in November. Little field drying occurs after the first part of November due cold temperatures.

Corn is one of the most water use-efficient crops (inches of water to bushel of grain) grown in North Dakota, but because of its heavy biomass and high yield potential, it is a heavy water user. Daily water use can exceed 0.3 inch per day once canopy closure has occurred (Figure 2). Corn tolerates moderate water stress during early vegetative growth and again during the latter part of grain filling (Table 1).

However, yield losses due to water stress can be significant when water stress occurs between silking and the early dent stage. When corn plants are water stressed during silking, silks grow little, if at all, during the days 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 partially fertilized ears. Drought stress during grain filling also can weaken stalks and predispose plants to stalk rots and lodging.

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. Careful management is needed in the drier parts of the state to reduce the risk of crop failure.

Table 1. Range in corn grain yield loss when stress occurs for four or more consecutive days at the following growth stages (Adapted from Licht and Archontoulis, 2017).

Growth Stage	Estimated loss (%) in grain yield per day of stress
Early vegetative (VE-V12)	1-3
Late vegetative (V12-VT)	2-5
Pollination to blister (R1-R2)	3-9
Milk (R3)	3-6
Dough (R4)	3-5
Dent (R5)	2-4
Maturity (R6)	0

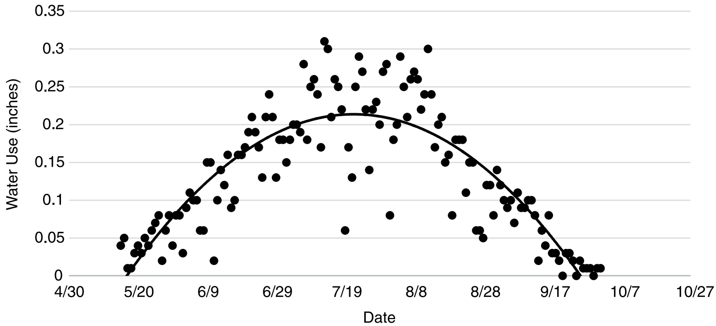

Figure 2. Estimated daily water use (inches per day) by corn in 2018, Prosper, N.D. Data are from the NDAWN Corn Water Use application.

Agronomic Practices

Hybrid Selection

Selecting the right hybrid is a critical step for achieving high yields and sustainable production. The selection process can be challenging because many commercially available corn hybrids are adapted for use in North Dakota. Moreover, because of rapid genetic improvement achieved by corn breeders, most hybrids remain in the market for less than five years; selecting new hybrids will be required regularly, if not every season.

Important criteria to consider when selecting a hybrid are yield, yield stability, maturity, specialty traits, disease resistance and stalk quality. To the extent possible, use impartial information based on local research about the hybrids under consideration.

Furthermore, growing more than one hybrid is recommended because it introduces genetic diversity and helps reduce the risks associated with weaknesses that might be associated with a single genotype. Identical hybrids may be marketed by more than one company because some 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 to avoid buying the same hybrid from different companies. Trying a small amount of one or more new hybrids to see how they performs on your farm is another way to check out new options.

Seed costs have increased markedly in the last two decades and vary substantially, depending on the company and the traits included in the hybrid. Planting inexpensive seed may not lead to a lower seed cost relative to the bushels grown if the inexpensive hybrid is not high yielding or well-adapted to the region. Conversely, expensive seed does not guarantee that it will be higher yielding than a less expensive hybrid.

Don't pay for technology traits you don't need. For most situations, hybrids without traits that perform as well as those with traits in environments where those traits offer no yield advantage likely are available.

Grain Yield

Grain yield is obviously one of the most important factors to consider in selecting a hybrid. The yield spread between the highest and lowest yielding hybrids in trials conducted by NDSU are frequently as large as 30 to 40 bushels/acre. Given the large number of hybrids on the market, finding data that compare 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 the University of Minnesota at various test locations throughout the states are updated and reported annually. These trials consist of a limited number of hybrids submitted by the companies that are commercially active in these states.

The North Dakota data can be viewed at www.ag.ndsu.edu/varietytrials/corn and the Minnesota data are at www.maes.umn.edu/publications/field-crop-trials. Additionally, the results of the corn hybrid testing program in eastern North Dakota, with adapted entries for the three major maturity zones of this region replicated in three or more locations, are available at www.ag.ndsu.edu/cornhybridtesting. These results usually are available on the web within a few days of harvest and prior to the end of the early order discounts offered by many companies.

Because the environment plays a significant role in the performance of a hybrid, using data that compare hybrids in multiple locations and years will provide the best estimate of how a hybrid might perform in future years. A hybrid that is high yielding, relative to other hybrids being tested, in good and poor yielding environments, has a good chance of being higher yielding in subsequent seasons than a hybrid that does extremely well in a high-yielding environment but relatively poorly in a poor-yielding environment.

Commercial seed corn companies also conduct testing programs. Company field test results usually are of greatest value in comparing hybrids within a given company. County and company strip tests, are not as useful for comparing many hybrids as are small plot replicated trials, but they can be a good way to demonstrate how a new hybrid will look when planted to an entire field.

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

Maturity Length

Select hybrids that have a maturity length adapted to the GDD accumulations for your region of the state. 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 it is used to designate the length of time required for a hybrid to reach maturity, compared with standard hybrids that have been grown in an area for a long time.

Some companies also indicate the number of GDD degree days required for the hybrid to reach maturity. You can match these values with the GDD accumulations for your area using NDAWN. General guidelines for hybrid maturities adapted to the various regions of North Dakota are summarized in Figure 3.

When not constrained by moisture stress, later-maturing hybrids usually have higher grain yield potential than earlier-maturing ones. However, hybrids that are too late for a given environment will have excessive grain moisture at harvest or may not reach physiological maturity in some seasons.

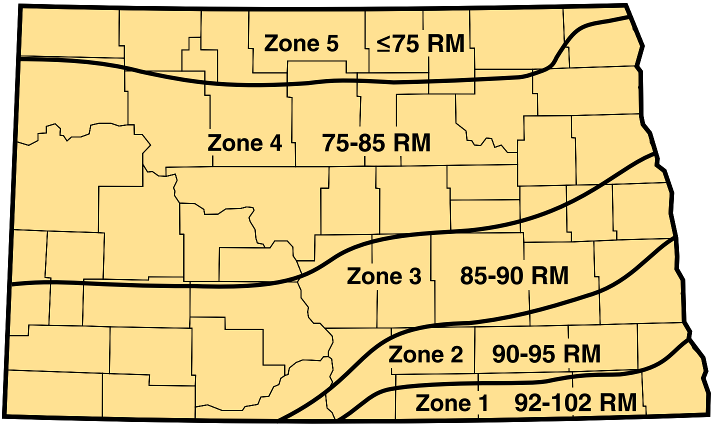

Figure 3. Corn Maturity Zones of North Dakota.

Balancing 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.

When comparing hybrids in yield trials, look at 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. To do this, multiply the grain yield of the hybrid by the price of corn and then subtract the cost of drying the hybrid to 15.5% moisture.

For example, to compare hybrid A with a grain yield of 130 bushels/acre and a moisture content of 19% with hybrid B with a grain yield of 136 bushel and moisture content of 25%, convert both to their dried grain value.

In this example, if we use a corn price of $3/bushel and a drying cost of 4 cents per percent of moisture per bushel above 15.5%, hybrid A and hybrid B would have dried grain values of $366.60 and $356.32, respectively [(130 bushels/acre X $3) – (130 bushels/ acre X 4.5% X $0.04) = $366.60 and (136 bushels/acre X $3) – (136 bushels/ acre X 9.5% X $0.04) = $356.32].

In this example, hybrid A, which produced the most dried grain value, should be selected versus the higher-yielding hybrid B.

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% of your acres with early hybrids (five to seven days earlier than the recommended RM), 50% of your acres with adapted maturity hybrids and 25% of your acres to full-season hybrids (five to seven days later than the maturity of your main hybrid).

This will not only reduce the risk associated with an unusually short season, but it also will 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 also may help spread out the harvest season. For areas where drought stress is common, relatively earlier maturing hybrids usually are higher yielding than full-season types.

Technology Traits

A number of proprietary technology traits are available in corn hybrids. The presence of these traits in a hybrid does not directly affect yield potential of the hybrid but protects the crop from insects or imparts herbicide resistance. Many corn hybrids are available with single or multiple technology traits.

Seed of hybrids with technology traits will be more expensive than "conventional" hybrid because each trait has a technology fee associated with it, which is added to the seed price. Carefully consider the cost benefit, as well as market restrictions associated with some traits, before paying the extra cost for the technology. Certain markets may require conventional hybrids and some of the newer traits may not be accepted in all external markets.

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. Available traits impart resistance to insects (cutworms, earworms, rootworms and stalk borers) and others impart resistance or tolerance to herbicides (glyphosate, glufosinate and 2,4-D).

The national Corn Growers Association maintains a current listing of traits and their export status, known as "Know Before You Grow," on the web at www.ncga.com/for-farmers/know-before-you-grow/trait-table. The Handy Bt Trait Table (www.texasinsects.org/bt-corn-trait-table.html) compiled by university entomologists also lists the status of insect resistance to Bt proteins in the trait package. Check this table to see if resistance to any of the traits you are considering has been reported in North Dakota.

Obviously, using a trait for which insect resistance has developed within North Dakota is not recommended. If resistance to a trait has developed in insect populations in other states, this suggests that if that trait is used, the crop should be scouted regularly to check for trait failure.

Predicting the value of traits that control above-ground insects (European corn borer, cutworms, earworms, etc.) is difficult because these insects can fly in from some distance and build up to damaging levels. Based on a recent survey (2018), populations of these insects in North Dakota are quite low, largely due to the effectiveness of hybrids containing these Bt traits in controlling them and their widespread use in current hybrids.

Nevertheless, many farmers find that the extra cost of using this trait serves as a relatively cheap insurance against damage from this group of insects because chemical control practices are not nearly as effective.

Bt traits that target corn rootworms, on the other hand, are effective only against the corn rootworm larvae, which feeds on corn roots. These larvae arise from eggs laid the season before.

The biotypes of corn rootworms we have in North Dakota (as far as we know) only lay their eggs in cornfields. Because these larvae are unable to move except short distance, corn rootworm larvae are damaging only in corn that was planted in a field grown to corn the previous year (see comments later for exceptions). Therefore, if you grow corn following a crop other than corn, you run little risk of having damaging levels of corn rootworms in that field, so paying any extra fee for the rootworm trait is not recommended.

However, biotypes of northern corn rootworms that have an extended diapause resulting in some of the eggs hatching two or more season after being laid have been found in Minnesota, so this recommendation would not apply if these biotypes move into or develop in North Dakota.

Other Factors

Other factors to consider when selecting a corn hybrid include stalk strength and lodging, green snap resistance, resistance to stalk rots and Goss's wilt, 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, the number of kernel rows, the 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 because these types may be better able to respond when conditions are favorable.

Planting Date

Building high yield potential in a corn crop starts with planting early. For most of the state, planting early means during the first part of May. If you are growing a large area of corn, planting should start on or just 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. Delayed planting likely will 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 when planting after May 20 and up until the first week of June.

Crop insurance coverage may not be available beyond certain dates and should be considered when planting is delayed beyond the normal planting window. Planting earlier than April 20 also can be risky because soil temperatures in most years are too low to allow germination until well into May and you run an increased risk of imbibitional chilling injury when planting into cold soils.

Seedbed Preparation

For rapid and uniform emergence, corn requires soil to be warm, moist, well aerated and fine enough for good soil-seed contact. In addition, an ideal seedbed should conserve moisture, control weeds, improve or preserve soil tilth and not be susceptible to wind and water erosion.

Corn seed can be sown successfully after a wide range of pre-seeding tillage practices. Conventional, strip and zero-tillage practices all are used in the state. In western regions of the state, no-till is a critical practice if the corn crop is to have enough moisture to be productive.

Regardless of what pre-seeding tillage is employed, good soil-seed contact is essential to uniform germination and emergence. Avoid tilling soils that are too wet and that will form clods and be prone to compaction. Also avoid 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 the rate of soil warming.

When planting into heavy residue, make sure the cutting coulter runs deeper than the disk openers and that it actually cuts the residue so the residue is not simply pushed into the ground, causing "hair pinning." Hair pinning can reduce seed-to-soil contact and increases the rate of soil drying in the seed zone.

Row Width

Corn in North Dakota is grown most commonly in rows of 30 inches. However, one trend is to use narrower row spacing. Recent data conducted in the northern Corn Belt suggest that in regions not prone to drought stress, narrower rows do offer a slight advantage in yield (2% to 5% increase is reported commonly). For example, eight site-years of trials conducted at Carrington and Oakes indicated a 1.5% yield increase with 15- versus 30-inch rows.

This yield advantage is not always consistent, and in areas of the state that are prone to drought, wider rows usually offer an advantage. Twin rows also have been proposed as a means of reducing the row spacing while allowing for the use of 30-inch headers at harvest. Research from a range of studies (many in the central Corn Belt) found no consistent advantage to twin rows versus a normal 30-inch spacing.

Before going to a narrower row spacing, consider the return to the purchase cost of the new equipment (planters and headers). If you are new to corn production, purchasing a narrower row system may make sense.

Plant Populations

Corn plant populations have been increasing in the U.S. during the past decade. In the major corn-producing states, average plant populations are between 30,000 and 32,000 plants per acre. Higher plant populations, combined with hybrids that tolerate the stress of higher plant density, have been the major driver of recent yield increases.

The yield of corn to increasing plant populations in a given environment usually follows a quadratic relationship in which yields increase up to an optimum and then decline with increasing plant density. Sometimes this relationship is described as a quadratic plateau; the yield does not decline after reaching the optimum point but remains level, at least within the range of the plant populations tested. In either case, the curve around the optimum point is usually fairly flat, meaning that yields will be similar within a range of a few thousand plants around the optimum population. For most regions of the state and for most hybrids, 29,000 to 35,000 seeds per acre is a reasonable range to consider when establishing a seeding rate.

The optimum seeding rate for a field will depend on its productivity and characteristics of the hybrid grown. The optimum seeding rate for higher yielding environments, for example, will be greater than that for lower yielding ones. Earlier maturing hybrids may require a higher seeding rate than later ones, for a given yield level because they are shorter and have less leaf area, and the higher population allows them to exploit more of the incoming radiation. Some companies have seeding rate recommendations for each hybrid they sell that may be a guide for the seeding rate for a field with a given yield potential.

In the regions of the state where the crop will experience drought stress during the season, lower plant populations allow for more effective utilization of the available moisture by reducing the amount of water used during vegetative development so that more is available during silking and early grain filling, when corn is most sensitive to water stress.

For these regions, adjust the plant population based on the amount of available moisture the crop likely will have, taking into account the amount of moisture in the soil at the time of planting. Research in Nebraska found optimum populations as low as 7,000 plants per acre in the driest research sites. For most drought prone areas in North Dakota the recommended population is between 16,000 and 25,000.

The economic optimum seeding rate, the rate at which the greatest financial returns to the cost of the seed planted is achieved, takes into account not only yield but seed cost and the value of the crop produced. The economic optimum seeding rate is usually several thousand seeds lower than the agronomic optimum.

Adapt seeding rates based on the price of seed (more expensive seed pushes the recommendation to the lower end of the range), the market value of the grain (higher prices push the recommendation to the higher rate of the range) and your own experience on your farm. As an example of how price of seed and grain affects the recommended plant population see Table 2, which summarizes data from seeding rate experiments in the Carrington REC in 2012-2014.

Available technology allows for planting different rates in different areas of the same field. In fields with variable yield potential, varying plant populations (variable-rate seeding, or VRS) may help maximize the returns to the cost of seed planted.

For example, reducing the seeding rate in a low-yielding area of the field associated with a sand ridge might not only increase the agronomic yield of that area, it also would reduce the cost of seed planted. VRS will provide the greatest returns when substantial, well-defined differences occur in productivity within the field.

Table 2. Plant population giving the maximum economic return based on seed cost per unit (80,000 kernels) and grain price, for hybrids ranging from RM83 to RM85, with an average yield of 150 bushel per acre, Carrington REC. 2012-2014.

Seed Cost ($ per unit)	Price of grain ($ per bushel)							
	$2.50	$3.00	$3.50	$4.00	$4.50	$5.00	$5.50	$6.00
	Seeds per acre							
150	32,230	33,070	33,660	34,100	34,440	34,710	34,930	35,120
175	31,390	32,370	33,070	33,580	33,980	34,300	34,560	34,780
200	30,530	31,670	32,470	33,070	33,530	33,870	34,190	34,440
225	29,650	30,860	31,870	32,550	33,070	33,480	33,820	34,100
250	28,760	30,240	31,270	32,020	32,600	33,070	33,440	33,750
275	27,840	29,500	30,650	31,490	32,140	32,650	33,070	33,410
300	26,900	28,760	30,030	30,960	31,670	32,230	32,700	33,070
325	25,920	28,000	29,400	30,420	31,200	31,810	32,310	32,730

The basic concept is to optimize the seeding rate for each defined area of the field. In other words, areas that are more productive are seeded at higher rates and areas of lower productivity are seeded at lower rates.

The most common method of establishing seeding rate zones is to use multiple years of yield monitor data. The value of VRS can be verified by planting strips of different seeding rates across the length of the field that include all of the variable zones and by comparing the returns to seed cost for each of the strips after measuring the yield of each strip at harvest.

Planting Depth

In most circumstances, corn should be planted 1.5 to 2 inches deep. Seedlings emerge more quickly when planted more shallowly early in the season when soils are still cold. However, planting too shallowly can cause unevenness in emergence if the soil surface dries out before all seeds imbibe sufficient water to germinate.

Planting too shallowly (less than an inch) can result in the early nodal roots to be shallow and not properly located to supply the corn plant with nutrients and water. Planting too deeply, on the other hand, will delay emergence because the soil temperature decreases with depth and may increase the variability in the timing of emergence.

Make sure packer wheels are adjusted to provide good soil-seed contact. When the soil surface is dry and rainfall is uncertain, consider planting to a depth at which uniformly moist soil is found, even if it is deeper than 2 inches.

When planting later in the spring, planting deeper (within the recommended range) may result in better stands because the soil will be warmer by then and will be less likely to dry out before the seed has germinated fully.

Managing for Stand Uniformity

Uniformity in emergence timing and plant-to-plant spacing is desirable because it establishes a foundation for high yield potential. Uniformity in emergence is important because corn seedlings do not compete well with other plants, including other corn plants.

Corn seedlings that emerge more than a week later than neighboring seedlings will not "catch up" and will yield much less than if they emerged at the same time as their neighboring plant. In extreme cases, they will not produce a cob and will act as an expensive weed.

Additionally, corn does not compensate as well as many other crops when the row has gaps. The optimum scenario for corn is that every seed planted emerges within 48 to 72 hours of each other, with no skips and doubles, and that the plant-to-plant spacing is uniform. However, even with the best of conditions and equipment, achieving perfect uniformity of emergence is unlikely.

Cold soils, or soils that are too dry or too wet, common conditions in the spring in North Dakota, increase the challenge of achieving optimum stand uniformity. Surveys of farmers' fields in North Dakota by county Extension agents and agronomists found the most commonly observed factor contributing to stand variability was variability in the emergence date, and not skips and doubles. In fact, doubles were observed rarely.

When measuring the yield loss on a plant basis, skips were the most impactful, followed by plants emerging 11 to 17 days after the early emerging seedlings. Plants next to a skip could add 10% to their yield, when compared with normal spaced plants, but this was much less than the 50% needed to totally compensate for the lost plant. Plants next to late emergers were able to add 5% greater yield, but again, they could not completely compensate for the loss of production by plants emerging later.

When evaluating stand uniformity, expect a few skips that are caused by nonviable seeds (the range in germination for most commercial seeds lots is 90% to 95%). Doubles can be traced back to a planter problem. Although doubles generally do not result in a yield reduction, they are not an efficient use of seed.

Determining the causes of poor uniformity in emergence timing may not be easy, but the following are some known causes that should be considered:

- **Differences in access to soil moisture by the seeds –** Cloddy soils (tilled when too wet), dried or compacted soils (from too much tillage), non-optimal seeding depth, improper press-wheel tension, hair pinning of residues that results in the seed being placed next to crop residue rather than soil, and sidewall compaction are a few reasons why seeds have access to differing amounts of moisture during germination. Excessive speed while planting can impact the uniformity in planting depth, especially with larger planters that will have greater bounce toward the end of the wings.
- **Soil crusting –** Crusting most often results from tilled soils high in silt that received a heavy rain event after planting.
- **Differences in soil temperature –** Small difference in the temperature that the seed encounters can be caused by difference in depth of seeding and the amount of residue that is retained directly above the seed. Differences in soil texture, color and drainage also can result in differences in soil temperature.
- **Seed lot vigor –** Although being overly concerned about the quality of the corn seed that is planted is not common, seed lots with poor vigor could cause variability in emergence timing. This is likely to be a concern only when additional stress has occurred during germination, such as cold or excessively wet or dry soils.

Although uneven emergence often is caused by factors beyond the grower's control, the following are factors to consider that can help improve the likelihood of stand uniformity:

- Avoid excessive tillage trips that dry or compact the seedbed prior to planting.
- Avoid tillage when soils are wet because it may produce large clods that will impact seeding depth and soil-seed contact.

- Plant at an optimum depth for conditions. Soil temperature and soil moisture are two factors to consider when deciding on an optimum seeding depth.
- Avoid planting when the soil is too wet; this may cause sidewall compaction resulting in the seed furrow remaining partially open.

Figure 4. Variability in emergence timing and plant-to-plant spacing observed in 2018. (J. Ransom, NDSU)

Figure 5. Impact of emergence date and spacing (next to a skip) on cob development. (Lindsey Novak, NDSU)

- Adjust seed openers and/or press-wheel pressure to improve soil-seed contact.
- Do not plant too fast. Even with today's planters, planting too fast for the conditions will result in uneven seeding depth and possibly poor soil-seed contact.
- Adjust residue managers properly so that surface residue is removed and the soil directly above the seed row is free from residues that may inhibit soil warming.

Evaluating Corn Stands for Replanting Decisions

Given the small optimum window for planting corn and the challenges of colder than optimum temperatures and moisture for corn planting, stand establishment problems can occur, requiring a decision on whether to replant or plant another crop. The following information can be used in helping determine if these options will be beneficial.

First, estimate the plant population by counting the number of emerged plants in a thousandth of an acre (17-foot 5-inch and 23-foot 10-inch row lengths for 30-inch and 22-inch row spacing, respectively) in about 20 places in your field and then multiply the average of those counts by 1,000. Use Table 3 to estimate the likely yield of your current crop and your likely yield if you replant and obtain a more optimum stand.

These data indicate that even a half stand planted early likely will be more productive than a full stand planted after June 1. Of course, uniformity of the field and uniformity of emergence also can be factors to consider when looking at the potential productivity of your field and the need for replanting.

If you determine that replanting is required, chose a hybrid that is earlier than the "full-season" hybrids recommended for your area of the state (Table 4). You may give up some yield potential, but an earlier hybrid will help minimize the risks associated with the crop being damaged by frost before maturity in the fall and the challenges and expenses of dealing with corn that is too wet to harvest and profitably dry to safe levels before snow begins to fall.

Also, take into account the final planting date for full insurance coverage for corn in your area. When replanting, the original stand of corn should be destroyed before you replant. Late planted plants that grow next to an early planted plant will be at a competitive disadvantage and very likely will not produce an ear.

Table 3. Expected relative corn grain yield from various planting dates and harvest populations†.

Plant Population	May 1	May 20	June 1	June 10	June 20
	----------------	% of expected yield	----------		
32,000	98	80	64	45	18
28,000	95	78	62	44	18
24,000	91	75	59	42	17
20,000	86	70	56	40	16
16,000	80	65	52	37	15
12,000	72	59	47	33	13

†Information in this table is adapted from data obtained for the northern zone (70 to 95 RM hybrids) of Wisconsin. See http://corn.agronomy.wisc.edu/Pubs/UWEX/A3353.pdf by J. Lauer for the full report. The May 1 column in this table assumes that a full-season hybrid is used. All other columns assume that an earlier maturing hybrid is grown.

Table 4. Recommended relative maturity of corn hybrids for various regions and planting dates in North Dakota.

Full-season relative maturity zone	After May 20	After June 1	After June 10
75 or less	For silage only	Not recommended	Not recommended
75-85	<75-80	75-80 (silage)	Not recommended
85-90	80-85	75-80 (silage)	Not recommended
90-95	85-90	75-80	75-80 (silage)
92-102	87-92	80-85	75-80

Terminating Existing Corn Stand in Replant Situations

If the decision to replant a field is made, you have a few chemical options to terminate the existing corn stand successfully. Six ounces of Select Max®, or the equivalent of a generic clethodim, will be the best option for termination. This method requires a seven-day waiting period between application and replant.

Paraquat (Gramoxone®, others) plus metribuzin (Sencor®, others) is another viable option. Both of those programs will work on any traited corn hybrid. Glyphosate is an option for corn that is not Roundup Ready® or has another glyphosate-tolerant trait.

If the corn does not have the Liberty Link® trait, then two applications of glufosinate (Liberty®) will provide acceptable control. This option works best if the replanted corn crop is Liberty Link®, so the second application can occur once the replanted corn has emerged.

Residue Management

Corn produces a large amount of residues relative to other crops. Roughly speaking, a pound of stover is produced for every pound of grain. Because yields have increased dramatically during the past decades, so has the amount of corn stover that growers must manage after harvest. A 200 bushel corn grain crop will produce nearly 5 tons of stover on a dry weight basis.

Corn residues are valuable because they contain plant-essential nutrients that can be recycled for subsequent crops and protect the soil from wind and water erosion, and are an important source of organic carbon that is key to maintaining soil organic matter and promoting soil health. Soils covered by residues will warm more slowly and be wetter in the spring than soils that have little or no residues.

Furthermore, large amounts of surface residues make planting at a uniform depth more challenging and can cause hair pinning, resulting in poor soil-seed contact and potentially uneven emergence.

Proper management of corn residues is needed to realize their benefits and mitigate their negative effects, from excessive cover, on soil temperature and planting the subsequent spring. Corn stover can be managed during harvest, after harvest and before planting the following spring.

Residue Removal

Removing some or all of the residues after harvest can reduce or eliminate the challenges of excessive residue amounts. Bailed corn stover can be used for animal feed and bedding.

Corn stover also has been proposed as the major feedstock for cellulosic ethanol production. A few cellulosic ethanol plants are in operation, but few new projects of this type are being proposed.

The amount of residue that can be removed safely so as not to impact soil productivity depends on the yield of the crop and the type of tillage used. For continuous corn in high-yield environments, about half the residues can be removed.

In a corn and soybean rotation, removing less than 1,300 pounds of stover per acre is the recommended limit. For environments that produce less than 150 bushels per acre of grain, no residues should be removed in a corn/soybean rotation, and removals should be limited to 1.5 tons per acre in continuous corn (see https://extension.umn.edu/corn-harvest/crop-residue-management#sources-1213310 for additional information).

If all the residues are removed, this should be done only once in three years and not from soil that is prone to wind and water erosion. Grazing also can be used to reduce the amount of residues. To calculate the value of the nutrients in stover, use 17 pounds of nitrogen (N), 4 pounds of phosphorus (P) and 20 pounds of potassium (K) per ton of residue.

Residue Management During Harvest

Stalk and chaff should be distributed evenly behind the combine while combining. Ideally, residues should be spread the width of the header so you have no areas of residue concentration. Check the spread of residues at the start of harvest and adjust choppers and/or spreaders as needed.

Corn headers can be adapted to process corn stalks during harvest. The standard snap rollers can be replaced with knife rollers that cut, lacerate and crush the stalks as they are pulled though the header. The suggested advantage of this processing is that it exposes more surface area to decomposition, which hastens breakdown, and the smaller pieces make tilling the field easier.

Another option is to add rotary blades that chop the stalk after it moves through the rollers. Rotary choppers produces many small pieces with increased exposed surface area to aid in more rapid decomposition.

However, these smaller pieces are more prone to blowing and leave a thick layer of residue that is difficult to manage in no-till systems. Also, these add-on stalk choppers require extra horsepower to operate and regular maintenance, which adds cost to the harvest operation.

Cutting stalks close to the ground can be hard on tires. For no-till, leaving corn stalks 12 to 18 inches high with no additional stalk processing is recommended. This limits the depth of residue on the soil's surface at the time of planting in the spring.

Adding extra nitrogen in the fall to speed up residue degradation often has been recommended. However, research in other states indicates that adding extra nitrogen does not hasten residue decomposition consistently. This practice not only adds cost with marginal benefit, but because you have no growing crop, the applied nitrogen is at risk of being lost in the environment.

Fall Residue Management After Harvest

Stalks can be chopped after harvest with flail or rotary blade-type choppers. These choppers are very effective in reducing the size of the stalk and in distributing residues uniformly.

These smaller pieces may break down more quickly than solid stalks and may make tilling and incorporating easier. However, the small pieces of stalk can blow and may form a thick mat that will be difficult to plant through if the field is not tilled.

Tillage probably is the most common way to manage residues in North Dakota. Primary tillage is most effective if done in the fall during somewhat dry soil conditions before soil freezing. Soils with heavy and thick residue cover rarely will be in an ideal condition for primary tillage in the spring because the residue will slow soil warming and drying.

Disking in the fall can be effective in cutting stalks and anchoring them in the soil. Chisel plowing is more effective in burying residues and reducing surface compaction within the tilled depth, but it does not cut up stalks. Combination tools with discs and chisels that allow for the discs to cut and the chisel plow to cover the residue are quite popular.

When tilling, retaining some level of residue cover to reduce the risk of wind and water erosion during the winter and early spring is important. Tillage that results in at least 30% of the soil's surface being covered by residues often is referred to as conservation tillage. However, with current equipment that allows for more effective handling of residues at planting, seek to leave more than 30% cover to better protect the topsoil from losses.

Typically, chisel plows (with or without discs) will leave 20% to 40% residue cover when you use twisted chisels. Strait points will leave a somewhat higher amount of residue cover (between 30% and 50%).

Strip tillage offers the benefit of darkening the soil and removing the residue cover over the strip that will be planted in the spring. The strip-till berms warm and dry in the spring equally well as or slightly better than with chisel plowing. The no-till strips, on the other hand, retain all of the residue, providing significant protection against erosion losses.

However, strip-till berms facing down slope on steep areas may be prone to concentrated runoff flows and water erosion during heavy rain events. Strip tillage (shanks or coulters) typically will leave 50% to 70% residue cover, depending on the row width and retain higher amounts of soil moisture. These residue-covered strips can provide much needed moisture to crops during the drier portions of the growing season when water demand is high; this is done without any consequence to the springtime warming and drying of the tilled berms.

Strip tillage should not be performed in wet conditions because this can smear the berm sidewalls and create compacted slabs of soil in the berm, which will impact seedling growth. If such conditions occur and are not alleviated during the winter freeze/thaw cycles, then a second pass in the spring may be needed to prepare a proper seedbed.

Typically, farmers in North Dakota use shanks during fall strip tillage and coulters during wetter spring strip tillage. Corn yields typically are similar among fall and spring strip tillage as long as good soil moisture conditions are present at the time of tillage. Strip tillage has the convenience of eliminating a separate field pass for fertilizer application because fertilizers are applied in the tilled berm at the time tillage.

Vertical tillage is the name given to tillage performed by equipment that causes limited horizontal shearing of the soil. Although we know of some controversy about what constitutes a vertical tillage implement, generally vertical tillage implements consist of large discs that have no or a limited gang angle. These are followed by some type of harrow/roller (tines, basket, chopper) that evens out the soil and residue.

Vertical tillage implements can be effective in cutting corn stocks and thinning accumulated residue from previous crops, and it leaves most of the residue on the surface of the soil (60% to 80% cover). They usually are operated at high speeds and can be used in a wide range of soil moisture conditions because the depth of tillage is very limited. If residues are too wet, they may bunch up in the harrow/roller and form piles in the field.

Although vertical tillage leaves a high residue cover on the soil, two passes with this implement to thin the residue layer typically will allow soils to warm and dry 50% more efficiently than no-till, when compared with chisel plowing or strip-till berms.

A few vertical tillage passes to thin thick residue layers may be a good option for no-till farmers after four or five years of continuous no-till corn. Vertical tillage does a poor job of leveling ruts and does not break up deep to moderately deep compaction layers.

Spring Residue Management

If primary tillage is done in the spring, it should be done as soon as possible to hasten soil warming and drying. However, avoid tilling soils when they are too wet because this will result in greater compaction and produce large clods.

Because soils dry from the surface first, you safely can assume that the soil below the tillage depth likely will be even wetter than the surface. Therefore, the down pressure of tillage implements can cause the soil immediately below the tillage shanks, coulters or discs to form a plow pan. Secondary tillage in the spring may be needed to smooth the soil to facilitate optimum planting, particularly when chisel plowing was performed in the fall.

Field cultivators bury less residue than discs and usually prepare a better seedbed. Field cultivators with straight points will bury less residue than those with sweeps. Secondary tillage should be shallow and planting should take place soon thereafter to retain moisture for germination. In strip-tilled fields, you should have no need for spring tillage.

At the time of planting, residue managers are recommended if residue remains on the soil's surface. Their purpose is to remove any residue in a 6- to 12-inch strip directly over the seed row to allow for more even soil warming and, therefore, more uniform seedling emergence. Residue managers should be adjusted carefully so that they remove residues but are not so aggressive that they move much soil.

Benefits to corn yields from tillage are observed less often when diverse crop rotations are implemented. The frequency and degree of yield benefits in rotated systems have lessened in recent decades due to other improvements in planter technology, crop genetics and weed control practices. However, continuous corn systems will benefit more frequently from tillage due to the large quantity of crop residue produced.

When yield benefits are observed, the yields typically can increase between 5 and 15 bushels per acre. However, tillage during wet conditions should be avoided because this can induce a similar range of yield losses. If wet harvest conditions cause ruts, fill and level the ruts using a secondary tillage implement if the ruts are less than 4 inches deep and a primary tillage implement if ruts are more than 4 inches deep.

Avoid soil smearing and further subsoil compaction by tilling no deeper than the depth of the ruts. Two to three passes typically will be needed to fill and level ruts before planting of the next crop.

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, although 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 for silage 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 intake and digestibility of silage. Stalk strength is not as important because the crop is harvested before breakage normally occurs.

For areas of the state where moisture is not severely limiting, consider establishing a plant population of 2,000 to 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% 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%.

High-quality silage contains a relatively large percentage of grain or dry matter. High-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 or too dry or packs poorly will result in poor silage. If corn is too dry, add water to bring the moisture to the proper level. The amount of water required to increase forage moisture content 1% is approximately 5 to 6 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 finely 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% 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 to grazing or green-chop feeding. This also helps avoid nitrate poisoning, which can be a problem when feeding drought-stressed corn. More than one-third to one-half of the nitrate accumulated in the plant material can be dissipated during fermentation.

Because fermentation takes two to three weeks for completion, drought-stressed corn silage should not be fed for at least three weeks following ensiling. Test drought-stressed corn for nitrate content before green chopping or grazing. Contact your county Extension agent for information on the nitrate analysis.

Abiotic Stresses

Water Logging

Due to the flat topography of soils in the Red River Valley, intermittent flooding or saturated soils can be common in the spring when plant water use is low (Figure 6). Waterlogging (flooded/ponded/saturated soils) affects a number of biological and chemical processes in plants and soils that can impact crop growth in the short and long term.

The primary cause of waterlogging in crop plants is oxygen deprivation, or anoxia, because excess water itself does not react chemically with the plant. Oxygen diffuses through undisturbed water much more slowly than a well-drained soil, so the plant's oxygen requirements rapidly exceed what's available when soils are saturated.

The rate of oxygen depletion in a saturated soil is impacted by temperature and the rate of biological activity in the soil. Faster oxygen depletion occurs when temperatures are higher and when soils are actively metabolizing organic matter.

Cooler temperatures reduce the adverse effects of waterlogging on emerged corn. Generally, the oxygen level in a saturated soil reaches the point that is harmful to plant growth after about 48 to 96 hours. In an effort to survive, tissues growing under reduced oxygen levels use alternate metabolic pathways that produce byproducts, some of which are toxic at elevated levels.

Germinating seeds/emerging seedlings are very sensitive to waterlogging because their level of metabolism is high. As a crop, corn is quite sensitive to waterlogging when the growing point is still below the surface of the soil (before the five- to six-leaf stage).

Waterlogged conditions also reduce root growth and can predispose the plant to root rots, so the ultimate effect of excess moisture may not be known until late in the season. Plants that have experienced waterlogging commonly are especially sensitive to hot temperatures, and they display nitrogen and phosphorus deficiencies later in the season due to restricted root development. Yield losses can occur even if these obvious visible symptoms are not observed.

Waterlogging also can impact corn growth indirectly by affecting the availability of nitrogen in the soil. Excessive water can leach nitrate nitrogen beyond the rooting zone of the developing plant,

Figure 6. Yellowing in corn associated with waterlogged conditions early in the growing season. (J. Ransom, NDSU)

particularly in well-drained lighter-textured soils. In heavier soils, nitrate nitrogen can be lost through denitrification.

The amount of loss depends on the amount of nitrate in the soil, soil temperature and the length of time that the soil is saturated. Research conducted in other states found losses from denitrification between 1% and 5% for each day that the soil remains saturated. Soils that have experienced nitrogen loss may require extra in-season nitrogen to ensure that nitrogen deficiency does not limit yield.

Imbibitional Chilling Injury

Corn requires soil temperatures at or near 50 degrees before it will begin to grow and an accumulation of about 120 growing degree days (GDDs) before it emerges. Cold soils not only delay germination, but at planting, they may injure the seed during germination.

When a newly planted corn seed imbibes cold water (some refer to this as it first drink of water), imbibitional injury may result. This injury can occur when soil temperatures are below 50 degrees, with colder soils (and therefore colder water that the seed imbibes) being more likely to be problematic.

Cold water damages cell membranes in the seed, damaging developing tissue that ultimately results in deformed shoot and root growth. In some cases, the coleoptile will not emerge. Often the injured seedling's mesocotyl will be twisted and corkscrew or the true leaves will emerge from side of coleoptile before emerging from the soil (Figure 7).

Plants that developed from these seedlings may be stunted and have distorted leaves and also may develop more slowly than normal plants. This can result in unevenness in the growth stages of plants within the field.

Anything that impacts plant stands and evenness of emergence and/or plant size has the potential to impact yields negatively. A heavy, cold rain or snow soon after planting seems to increase the chances of imbibitional injury probably because, as this cold water enters the soil, it overwhelms the ability of the soil to warm it before it reaches the seed.

Figure 7. Corkscrewing of coleoptiles, seeds without shoot development and leaves emerging from the side of coleoptiles before emergence due to chilling injury soon after planting.
(G. Mehring, Bayer CropScience)

Floppy or Rootless Corn Syndrome

Corn plants that are planted into dry or compacted soils or planted too shallowly may fail to develop nodal roots. When these seedlings get larger, they will flop over because they have no lateral roots to support them (Figure 8). This malady generally is referred to as the floppy or rootless corn syndrome and occurs when the surface layer of the soil is too dry for nodal roots to develop during the V1-V6 stages.

Nodal roots arise from the crown, which, with normal planting depths, will establish about ¾ inch below the surface of the soil. When the soil around the crown is too dry, emerging nodal roots become desiccated and will not grow. The stubby and darkened stumps of nodal roots that try to develop will have the appearance of having been injured by an herbicide or infected by some disease (Figure 8).

Nevertheless, the cause of this problem is inadequate soil moisture at the crown for nodal root development. Shallow

Figure 8. Corn with normal nodal root development on the left and corn with limited nodal root development due to dry soil conditions around the crown at the time of normal nodal root development on the right. (J. Ransom, NDSU)

seeding (less than an inch deep) can increase the likelihood of this problem because the crown, where the first nodal roots arise, cannot become established deeper than the depth of the seed.

Leaves on plants that do not develop nodal roots also may appear purple (see right plant in Figure 8) due to the lack of root development and the accumulation of anthocyanin in the leaves.

Rootless corn plants have the potential to develop nodal roots when conditions around the crown of the plant become sufficiently moist to support nodal root development. A good rainfall is the best remedy for this problem. A light cultivation to throw some soil around the base of the plant may be helpful in some situations, but if the soil is dry, it will not induce nodal roots until after a rain event.

Green or Brittle Snap

Stem breakage, usually at a node, caused by high winds is referred to as green or brittle snap (Figure 9). Green snap occurs most commonly during the V5-V8 stages and from two weeks prior to tasseling until silking. During these developmental stages, particularly when conditions for plant growth are favorable, tissues comprising the stalk are not fully lignified and, therefore, are prone to breakage in strong winds.

Once stems have completed elongation and have lignified, they are quite resistant to snapping. From that point forward, root lodging will be more likely than “snapping.” Plants that snap below the normal ear node likely will not produce an ear.

Figure 9. Green snap in corn approaching the tassling stage.
(J. Ransom, NDSU)

Hybrids vary in their resistance to green snap. Given the frequency of high-wind events in North Dakota, green snap "resistance" should be an important criterion when selecting a hybrid.

The plant stage of development when a strong wind occurs also can affect whether a specific field is damaged. Therefore, the same hybrid may suffer damage in one field and little in another simply due to differences in the stage of plant development.

Buggy Whipping/Twisted Whorls/ Yellow Flagging

During vegetative development, leaves may become twisted as they emerge from the whorl, in some cases forming a tight tip that resembles a buggy whip. This phenomenon is not that uncommon in North Dakota and has been referred to as buggy whipping or the twisted whorl syndrome (Figure 10).

As leaves in the twisted whorls unfurl, they are bright yellow until a few days after they are fully exposed to sunlight (Figure 11). This display has been referred to as "yellow flagging." These yellow plants usually will green up in a couple of days.

Twisted whorls can be caused by a misapplication of growth regulator-type of herbicide, but most frequently they are caused by a physiological response induced by significant changes in temperature during certain vegetative growth stages. A warm period followed by a cool period (length not defined) or a cool period followed by a warm period (a rapid growth spurt followed by slow development) seems to disrupt the way that leaves develop, causing leaf deformations that eventually result in twisted whorls because the crinkled leaves have difficulty moving vertically.

Why some plants are impacted and others nearby are not is a bit of a mystery. In almost all cases, including those that are very severely twisted, the tightly twisted leaves will unfurl and the plants will resume normal development with no adverse effect on yield.

Figure 10. Young corn plants with twisted whorls caused by alternating cool and warm periods during early plant development. (J. Ransom, NDSU)

Figure 11. Leaves emerging from twisted whorls are bright yellow until a few days after being exposed to sunlight. This has been referred to as yellow flagging. Also note the crinkled leaves that impeded normal leaf extension, resulting in twisted whorls. (J. Ransom, NDSU)

Fallow Syndrome

Corn plants that are stunted with a purple leaf/stem (severe and widespread phosphorus deficiency symptoms), especially early in the growing season, may be affected by what is referred to as the fallow syndrome (Figure 12). This name is used because historically these types of symptoms were seen after black fallow.

Mycorrhiza is a symbiotic fungi that extends the effective root system of a supportive plant by means of its rootlike hyphae strands that can be 100 times longer than roots. Mycorrhiza is

Figure 12. Significant phosphorus deficiency symptoms expressed in young corn plants that were grown following sugarbeets. This phenomenon is referred to as the fallow syndrome. (J. Ransom, NDSU)

important for corn to gather the phosphorus (P) it requires most efficiently, even in soils that have high levels of phosphorus or that recently have been fertilized with phosphorus.

Black fallow, flooding and the cultivation of nonmycorrhizal crops in the Cruciferae (mustard) and Chenopodiaceae (lambsquarter) plant families result in low mycorrhiza survival into the next crop year. Cruciferae crops in North Dakota include canola, mustard and cover crops include mustard, radish, rapeseed and turnip.

The only commonly grown crop in the Chenopodiaceae family is sugarbeet. Corn is one of the most susceptible crops to fallow syndrome, but flax also can be affected.

Mycorrhiza populations will build up during the growing season. Usually severe symptoms will disappear without any intervention after several weeks. Yield losses can be substantial, however. In a corn hybrid trial established after sugarbeets in the field pictured (Figure 12), the average yield was 171 bushels per acre, while the other three locations of the same trial yielded more than 215 bushels per acre.

When growing corn after canola or sugarbeets or in a field that was flooded the previously season, consider growing a crop other than corn. If corn is to be grown, apply 150 pounds per acre of 11-52-0 (MAP) or equivalent P rates of other fertilizers in a 2- by 2-inch band.

Any safe rate of fertilizer in-furrow likely will not be enough to overcome the lack of mycorrhiza and provide early season P nutrition to corn. VAM in inoculum are available, but at current prices are not deemed economical to use.

Soil Fertility Management

Nitrogen

A fall soil test to 2 feet in depth is a very important component in the establishment of the nitrogen (N) recommendation. The relationship between N applied and relative yield is very poor if soil test nitrate-N is not considered. Include the soil test nitrate-N results in a "law of diminishing returns" relationship of total known available N and yield.

A change from previous recommendations is that N recommendations are not linked directly to expected yield. N recommendation categories within high-clay soils and medium-texture soils are divided into those soils with a historic capability to produce more or less than 160 bushels per acre.

However, within the higher-productivity categories, N rates have supported more than 240 bushels per acre in experiments conducted in North Dakota. Yields less than this were caused by too much water or not enough, but not by a deficiency of N.

Nitrogen recommendations are based on an economic production function that takes into account the yield response of corn to added N, less the cost of the N. This recommendation system is called the "return to N" approach, as defined by Sawyer and Nafziger (2005).

In our work, we determined the formula that related the total available N to yield for each recommendation category. As available N increases, yield increases until the cost of another pound of N equals the income benefit for the fraction of a bushel of corn the N will produce.

At some rate of N, yield can decrease with added N. The yield decrease often is related to greater lodging; "green snap," which is caused by unusually rapid stalk elongation; and poor stalk structure that results in stalk breakage during a high wind event, or other physiological factors.

The response of corn to N is different between west-river soils and soils east of the Missouri River. Part of this difference may be due to the tendency for productive corn acres west of the Missouri River to be in long-term no-till, but some is due to the soils and generally warmer and drier climate of the west-river region (Table 5). In eastern North Dakota, long-term no-till, defined as continuous no-till six years or longer, is segregated from conventional-tillage sites (Table 6).

This phenomenon also was seen in North Dakota spring wheat and durum research between 2005 and 2010, where a 50-pound-per-acre N credit was recommended in fields in long-term no-till. In the corn N rate studies, the difference in N recommendation between long-term no-till and conventional-till soils was between 40 and 50 pounds less N per acre for long-term no-till soils. However, rather than incorporate a credit, a separate return to N analysis was prepared.

Within the conventional-till soils in eastern North Dakota, soils are divided into high-clay and medium textures. High clays include the textures of clay, clay loam and silty clay loam. Bearden, Fargo, Hegne and Viking soils are some of many soils in eastern North Dakota that would fall into this category.

These soils have a high susceptibility for denitrification, which is a soil bacteria-led process in which nitrate is converted to nitrous oxide and nitrogen gas and is lost from the soil into the atmosphere. Denitrification proceeds when soil pores are filled with water and soil oxygen levels are low. Denitrification can be found anytime that the soil is flooded, but in high-clay soils, significant denitrification occurs, even when the soil is muddy or saturated but not flooded.

Tiling or no tiling made little difference in our N rate plots on N efficiency in high-clay soils. Water takes a long time to percolate through high-clay soils. Some estimates of downward water movement are 0.015 inch per hour, or about ⅓ inch per day, in a Fargo soil.

High-clay soils are divided into those with historic yields exceeding 160 bushels per acre and those with historic yields of less than 160 bushels per acre. In the higher-productivity, high-clay soils, side-dress N is encouraged due to denitrification susceptibility. However, these soils have better internal drainage than those with lower yield capability, and growers might be able

Table 5. Corn N recommendation table for west-river soils, considering maximum return to N using corn N price and N cost.

Corn Price, $/bushel	N cost, $/ pound N								
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
2	150	120	37	0	0	0	0	0	0
3	150	150	149	94	38	0	0	0	0
4	150	150	150	150	121	79	38	0	0
5	150	150	150	150	150	138	105	71	38
6	150	150	150	150	150	150	149	121	94
7	150	150	150	150	150	150	150	150	133
8	150	150	150	150	150	150	150	150	150
9	150	150	150	150	150	150	150	150	150
10	150	150	150	150	150	150	150	150	150

Table 6. Corn N recommendation table for eastern long-term no-till soils, considering maximum return to N using corn N price and N cost.

Corn Price, $/bushel	N cost, $/ pound N								
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
2	200	168	137	106	75	43	12	0	0
3	220	200	179	158	137	116	95	75	55
4	232	216	199	185	169	154	137	119	107
5	239	226	213	200	187	176	163	150	137
6	243	232	220	211	201	190	179	169	158
7	246	237	226	217	209	200	191	183	173
8	247	241	232	223	215	207	200	192	184
9	249	243	235	228	220	213	207	200	194
10	252	244	239	232	225	218	212	206	200

to achieve maximum economic yield with a greater portion of their total N applied preplant (Table 7). The high-clay soils with lower productivity (Table 8) are likely to benefit from a side-dress N application.

The N rate from the recommendation table at a certain N cost and corn price is the maximum to apply preplant to these soils. To apply enough preplant N to these soils to support yields

Table 7. Corn N recommendation table for eastern high-clay soils with historic yields greater than 160 bushels per acre, considering maximum return to N using corn N price and N cost.

Corn Price, $/bushel	N cost, $/ pound N								
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
2	242	214	186	159	131	103	75	47	19
3	260	242	222	205	186	169	149	131	113
4	270	257	243	229	213	200	186	172	158
5	276	265	254	243	232	220	208	196	184
6	280	270	260	250	240	230	220	210	200
7	285	274	263	252	243	235	226	218	212
8	285	277	270	264	257	251	243	236	229
9	286	280	274	267	261	255	249	243	237
10	287	283	276	270	266	260	254	248	242

Table Table 8. Corn N recommendation table for eastern high-clay soils with historic yields less than 160 bushels per acre, considering maximum return to N using corn N price and N cost.

Corn Price, $/bushel	N cost, $/ pound N								
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
2	150	150	150	117	67	17	0	0	0
3	150	150	150	150	150	133	100	67	34
4	150	150	150	150	150	150	150	143	118
5	150	150	150	150	150	150	150	150	150
6	150	150	150	150	150	150	150	150	150
7	150	150	150	150	150	150	150	150	150
8	150	150	150	150	150	150	150	150	150
9	150	150	150	150	150	150	150	150	150
10	150	150	150	150	150	150	150	150	150

similar to those soils with higher historic yields would result in impractical N rates of more than 400 pounds per acre.

The answer to higher yield in these soils is not rate but timing. Application of half or more of the recommended N at V6 to V8 would increase yield and N efficiency greatly in wetter years. Considering the tendency for high-clay soil to have sticky, mucky characteristics in wet conditions, the use of a coulter UAN (solution of urea and ammonium nitrate in water) side-dress applicator is recommended.

Medium-textured soils would include fine sandy loams, silt loams, loams, sandy loams, loamy sands and sands. The medium-textured soils with historic yield greater than 160 bushels per acre (Table 9) were the most productive and N-efficient soils in the conventional tillage category. These soils do not require N to be side-dressed to be N efficient.

However, the medium-textured soils with less than 160 bushels per acre were the most N-inefficient soils in our studies (Table 10). These soils are highly susceptibility to leaching and would benefit greatly from side-dressing part of the N. Soils in this category usually are side-dressed using an anhydrous ammonia applicator, although a coulter UAN side-dress applicator also would work well.

Table 9. Corn N recommendation table for eastern medium-textured soils with historic yield greater than 160 bushels per acre, considering maximum return to N using corn N price and N cost.

Corn Price, $/bushel	N cost, $/ pound N								
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
2	222	201	180	160	139	118	97	76	55
3	235	222	208	194	180	166	152	138	124
4	236	234	223	213	202	192	181	171	161
5	249	241	243	223	215	206	198	190	182
6	252	245	238	231	223	216	209	202	195
7	254	248	242	236	230	222	217	211	205
8	255	250	245	240	234	229	223	218	213
9	256	252	247	243	238	233	229	223	218
10	257	253	248	244	239	234	230	224	219

For any subsurface-applied side-dress applicator, application may be made in every other row, rather than every row. An alternative side-dress application would be UAN streamed between each row.

The efficiency of this alternative is high except in drier years, where surface dryness leads to greater N inefficiency. A more risky application method would be to apply up to 100 pounds of urea (46 pounds of N per acre) broadcast over the whorl using a granular ground applicator or by air. The urea used in an over-the-top application should include a NBPT coating (Agrotain or similar product).

The N recommendations for irrigated corn are included in Table 11. These are the total N rates recommended through a return to N model based on data collected in the Oakes area by Knighton, Derby and Albus in the 1990s. The total N recommended should be divided into preplant, side-dress and the remaining N, which should be provided through the irrigation pivot up to tassel initiation.

An additional 20 to 30 pounds of N could be applied if yield conditions are exceptional after pollination. No N is recommended through the pivot during pollination.

Table 10. Corn N recommendation table for eastern medium-textured soils with historic yields less than 160 bushels per acre, considering maximum return to N using corn N price and N cost.

Corn Price, $/bushel	N cost, $/ pound N								
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
2	150	150	124	0	0	0	0	0	0
3	150	150	150	150	124	41	0	0	0
4	150	150	150	150	150	150	124	62	0
5	150	150	150	150	150	150	150	150	124
6	150	150	150	150	150	150	150	150	150
7	150	150	150	150	150	150	150	150	150
8	150	150	150	150	150	150	150	150	150
9	150	150	150	150	150	150	150	150	150
10	150	150	150	150	150	150	150	150	150

For the interactive North Dakota Corn Nitrogen Calculator, go to www.ndsu.edu/pubweb/soils/corn. Also available is a cellphone app for Android and iPhones. The app is free to download. Go to the app store on your phone and search for NDSU N calculator. Follow the download instructions.

The values in Table 8 are the maximum to include in a preplant N application, followed by a side-dress N application, based on the difference between the value in this table, compared with the corresponding N cost/corn price value in Table 7. The use of an active-optical sensor to direct the side-dress N rate instead of the difference between the Table 7 rate and preplant rate from this table is encouraged.

The values in Table 10 are the maximum to include in a preplant N application, followed by a side-dress N application, based on the difference between the value in this table, compared with the corresponding N cost/corn price value in Table 9. The use of an active-optical sensor to direct the side-dress N rate instead of the difference between the Table 9 rate and preplant rate from this table is encouraged.

Table 11. Corn N recommendation table for irrigated soils, considering maximum return to N using corn N price and N cost. This is the total amount for the season, which includes several split-N applications.

Corn Price, $/bushel	N cost, $/ pound N								
	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
2	255	241	228	215	201	188	175	162	149
3	263	254	245	237	228	219	210	201	194
4	268	262	256	250	244	238	232	226	220
5	272	267	262	257	252	247	242	237	232
6	273	268	263	258	253	248	243	238	233
7	274	269	264	259	254	249	244	239	234
8	275	270	265	260	255	250	245	240	235
9	276	271	266	261	256	251	246	241	236
10	277	272	267	262	257	252	247	242	237

Phosphorus

In states to the south and east of North Dakota, distinctions are made within states where banded phosphorus (P) would be expected to have a consistent positive yield response and areas where it might not. These distinctions are usually a point north or south of some line within the state.

In North Dakota, we are north of all of these lines; so in North Dakota, every corn acre would benefit in most years from an in-furrow or side-band P application. An example of the dramatic difference possible through banding P in some North Dakota soils is provided in Table 12 from the Carrington Research Extension Center. A summary of a decade of NDSU research with starter P can be found in the NDSU Extension publication A1851 "Corn response to P starter fertilizer in North Dakota".

The two most adopted at-seeding P banding strategies are in-furrow, also called "pop-up," and the 2 by 2 band, which is the starter band being placed 2 inches to the side and 2 inches from the depth of seed placement. The in-furrow band, as seen in Table 12, is effective at placing fertilizer near the initial small rootlets. However, placing fertilizer in the 2 by 2 band eliminates the risk of seed damage from salt or ammonium concentration near the seed, which always results in a lower stand with an in-furrow fertilizer placement.

The configuration of a 2 by 2 band in modern planters is not easy, but many growers use this configuration. They are able to apply

Table 12. Corn yield with in-furrow application of 10-34-0, Hendrickson, 2007.

Rate of 10-34-0, gallons per acre	Corn yield, bushels per acre
0	101
2	121
4	125
6	150
8	156
10	153

N, P, potassium (K), sulfur (S) and zinc (Zn) easily with their starter with no reduction in stand.

In a 2 by 2 starter band, the N rate should be 50 pounds per acre or less to achieve a starter effect with any P in the band. Nitrogen rates higher than 50 pounds per acre in the starter band produce levels of free ammonia that are not penetrated by roots until later in the season, when the time for helpful early season effects of concentrated P are past.

Most of the P applied to corn is applied as broadcast P. Starter P sometimes can produce most of the yield benefit from a P application; however, corn grain contains about 0.4 pound P_2O_5 per bushel, so more P should be available to the crop than from starter alone.

The P soil test used in the state should be the Olsen sodium bicarbonate extractant because it is diagnostic of relative soil P availability in acidic and basic soils. In one fertilization strategy utilized by most of the central U.S. Corn Belt states for buildup and maintenance, P anticipated to be removed is applied (maintenance) along with enough P to increase soil test levels through time (buildup).

A typical P application in Illinois, for example, that is necessary to increase soil test levels is about 9 pounds of P_2O_5 to increase the soil test 1 pound in the Bray P1 test. Experiments in Minnesota have indicated a range of P_2O_5 rates from 9 pounds to more than 40 pounds to achieve a similar soil test increase.

Most inorganic soil P is held by some soil mineral. No P fertilizer amendment effectively reduces the binding of P to soil minerals. In acid soils from below pH 5 to 6.8, the dominant P-binding element is iron. In alkaline soils with a pH above 7, the dominant P-binding ion is calcium.

In some experiments, yields approaching 200 bushels per acre were achieved in soils with P levels in the low range (less than 8 parts per million [ppm]). The corn obviously was taking up large quantities of P, even in soil test levels that were not optimum.

Some of the soil P available to crops is in organic form, which neither the Olsen nor the Bray test is very good at estimating. Recent studies in Minnesota have indicated that the current critical level for P should be closer to 20 ppm Olsen rather than 15 ppm.

North Dakota corn growers with very high yield potential might strive to achieve this higher soil test level if soil conservation methods and terrain were consistent with low wind and water erosion from their fields. General P recommendations for corn can be found in Tables 13-1 to 13-3.

Many states' best management practices to reduce P pollution of surface waters are based on soil P particulate movement. However, studies in Manitoba indicate that the greatest source of P in surface water bodies in our relatively flat-terrain region is not from particulates but from soluble P in residues and other rotting organic sources, mostly released in early spring.

Table 13-1. Corn recommendations, west river, nonirrigated, pounds P_2O_5.

Olsen Soil Test Phosphorus, ppm				
VL 0-3	L 4-7	M 8-11	H 12-15	VH 16+
78	52	39	26	10

Table 13-2. Corn P recommendations, east river, nonirrigated, pounds P_2O_5 per acre.

Olsen Soil Test Phosphorus, ppm				
VL 0-3	L 4-7	M 8-11	H 12-15	VH 16+
104	78	52	39	10

Table 13-3. Corn P recommendations, irrigated, pounds P_2O_5 per acre.

Olsen Soil Test Phosphorus, ppm				
VL 0-3	L 4-7	M 8-11	H 12-15	VH 16+
156	104	78	52	26

Corn is susceptible to a condition known as "fallow syndrome." Fallow syndrome is a stunting of corn, and often purpling leaves, and general P deficiency following a bare fallow, or following crops that do not support mycorrhizae. Mycorrhizae are a group of soil fungi that have a symbiotic relationship with many plant families, except for the Chenopodiaceae (lambsquarter family) and the Cruciferae (mustard family).

When corn follows canola (mustard family) or sugarbeet (lambsquarter family), the likely result is fallow syndrome. Prevent plant acres generally have not resulted in fallow syndrome the following year, probably because in most cases, these acres are seeded to a cover crop (highly recommended) or weeds grow for a significant portion of the summer, which also promotes mycchorizal populations.

Work in South Dakota indicates that high rates of P fertilizer banded near the seed are necessary to offset the effects of fallow syndrome. A minimum P fertilizer rate in one study was 150 pounds of 0-46-0 per acre in a 2 by 2 band. Simply increasing an in-furrow 10-34-0 rate from 3 gallons per acre to 6 gallons per acre does not eliminate fallow syndrome.

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Potassium

Soil test potassium (K) values have been high for most soils in North Dakota until recently. With greater K removal with soybean and corn grain, soil test K levels have decreased in eastern North Dakota. Recent K-rate research in North Dakota has shown that consideration of the clay chemistry in the soil is very important in predicting whether corn yield will increase with K if the soil test is lower than the critical level.

Three major clay chemistries in the clay-fraction of North Dakota soils influence K availability: smectite, illite, and kaolinite and other related clays. Smectite and illite are referred to as "2:1" clays; in addition to their small size, clay particles also have a specific crystalline structure. The 2:1 clays have two sheets of silicon oxide: one above one sheet of aluminum hydroxide and one below the sheet of aluminum hydroxide, like a sandwich.

In illites, the three sheets are rather tightly held together with K+ ions. The edges of the illite can expand and contract with soil moisture differences, but most of the sheets are held together relatively tightly. Whether the soil is moist or dry, K+ ions are free to escape into the soil solution to maintain an equilibrium.

Smectite clays are also 2:1 clays, but the sheets are not held tightly by K+ ions; K+ ions are free to move in and out of the clay inter-layers. In moist soil conditions, K+ moves freely into the soil solution to maintain equilibrium, but when the soil dries, the clay layers collapse and draw K+ ions into the inter-layers, rendering them temporarily unavailable to plants.

Without using consideration of smectite and illite clays, the presently used dry K soil test only predicted corn yield response to K half of the time. If a smectite/illite ratio of 3:5 was used to separate sites, the dry K soil test predicted the K response in nearly all sites.

The new critical K soil test level for soils with a smectite-to-illite ratio greater than 3:5 is 200 ppm. The critical K soil test for soils with a smectite-to-illite ratio of less than 3:5 is 150 ppm. Figure 13 is a map showing regions in North Dakota where the smectite-to-illite ratio of the clay fraction of soil is less than or greater than 3:5.

The general recommendations for K fertilizer based on soil test for corn can be found in Tables 14, 15, 16 and 17. Our studies also found that rates of K_2O greater than 120 pounds per acre resulted in lower yield than rates of 90 and 120 pounds per acre K_2O; therefore, rates of K_2O recommended are capped at 120 pounds K_2O per acre. As an alternative to these tables, a North Dakota Corn K app is available for Android and iPhone smartphones. The app is free to download and it is interactive for the user.

Soybean harvest usually removes more K each year than corn, but corn is much more susceptible to K deficiency than soybean. Lower rates of K than those recommended in the tables will not result in the most economically achievable corn yield. Banding K in subsurface bands, such as those possible in strip-till shank applications, have been found beneficial in highly smectitic soils but not in soils with nonsmectitic chemistry.

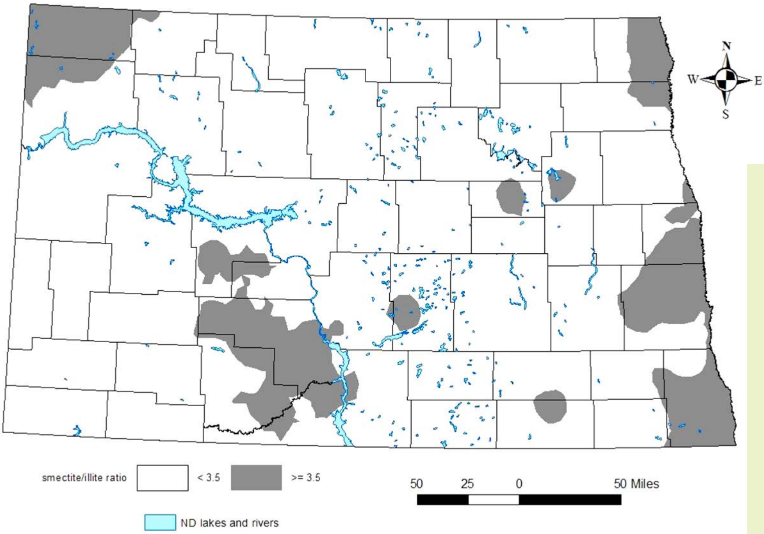

Figure 13. Smectite-to-illite ratio of surface soils in North Dakota from a soil sampling conducted in spring 2017. Dark gray regions are greater than 3:5. White areas are less than 3:5.

Potassium recommendations sometimes are given by sources other than NDSU based on the ratio of calcium and magnesium to potassium. These recommendations are based on poor soil fertility research and interpretation in Missouri and New Jersey in the late 1940s and early 1950s.

Table 14. Potassium recommendations for corn in soils with clay chemistry having a smectite-to-illite ratio greater than 3:5 and soil test K levels 150 ppm or less.

Corn Price, $/bushel	Price per pound K_2O, $ per pound									
	0.125	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
	------------ Recommended pounds K_2O per acre ------------									
2	90	90	90	90	60	60	0	0	0	0
3	90	90	90	90	60	60	60	60	60	0
4	90	90	90	90	90	90	90	90	90	60
5	90	90	90	90	90	90	90	90	90	90
6	120	120	120	120	90	90	90	90	90	90
7	120	120	120	120	120	120	120	120	120	90
8	120	120	120	120	120	120	120	120	120	120
9	120	120	120	120	120	120	120	120	120	120
10	120	120	120	120	120	120	120	120	120	120

Table 15. Potassium recommendations for corn in soils with clay chemistry having a smectite-to-illite ratio greater than 3:5 and soil test K levels from 151 to 199 ppm.

Corn Price, $/bushel	Price per pound K_2O, $ per pound									
	0.125	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
	------------ Recommended pounds K_2O per acre ------------									
2	90	90	60	60	60	0	0	0	0	0
3	90	90	90	90	60	60	60	0	0	0
4	90	90	90	90	90	90	90	60	60	0
5	90	90	90	90	90	90	90	90	90	60
6	120	120	120	120	90	90	90	90	90	90
7	120	120	120	120	120	120	120	120	120	90
8	120	120	120	120	120	120	120	120	120	120
9	120	120	120	120	120	120	120	120	120	120
10	120	120	120	120	120	120	120	120	120	120

Despite the general soil fertility scientific community discarding these results, the concept of a "balanced soil" persists. Studies in several states indicate that the K extraction method, although not flawless, is a much better predictor of the K requirement, compared with the balanced cation approach.

Table 16. Potassium recommendations for corn in soils with clay chemistry having a smectite-to-illite ratio less than 3:5 and soil test K levels 100 ppm or less.

Corn Price, $/bushel	Price per pound K_2O, $ per pound									
	0.125	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
	------------ Recommended pounds K_2O per acre ------------									
2	90	90	90	90	60	60	0	0	0	0
3	90	90	90	90	60	60	60	60	60	0
4	90	90	90	90	90	90	90	90	90	60
5	90	90	90	90	90	90	90	90	90	90
6	120	120	120	120	90	90	90	90	90	90
7	120	120	120	120	120	120	120	120	120	90
8	120	120	120	120	120	120	120	120	120	120
9	120	120	120	120	120	120	120	120	120	120
10	120	120	120	120	120	120	120	120	120	120

Table 17. Potassium recommendations for corn in soils with clay chemistry having a smectite-to-illite ratio less than 3:5 and soil test K levels from 101 to 149 ppm.

Corn Price, $/bushel	Price per pound K_2O, $ per pound									
	0.125	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
	------------ Recommended pounds K_2O per acre ------------									
2	90	90	60	60	60	0	0	0	0	0
3	90	90	90	90	60	60	60	0	0	0
4	90	90	90	90	90	90	90	60	60	0
5	90	90	90	90	90	90	90	90	90	60
6	120	120	120	120	90	90	90	90	90	90
7	120	120	120	120	120	120	120	120	120	90
8	120	120	120	120	120	120	120	120	120	120
9	120	120	120	120	120	120	120	120	120	120
10	120	120	120	120	120	120	120	120	120	120

Growers should be aware that extraction of K in our soils often extracts calcium (Ca) and magnesium (Mg) from soluble salts and free lime in our soils, unrelated to Ca and Mg on the clay and organic matter particles. This will result in unreasonable cation-exchange capacity (CEC) values.

For example, a CEC test for a loam soil may be 30 millimhos per centimeter (mmhos/cm), where a true CEC value would be about 15 mmhos/cm. A very good review of the poor basis for the use of base exchange ratios for fertilization is available in Kopittke and Menzies (2007).

Sulfur

Sulfur deficiency has become an increasing problem for all North Dakota crops due to increased yield demand, increased rainfall compared with previous records, and decreased S in rainwater and erodible conventional till fields, decreasing organic matter levels and the thickness of the A horizon through time.

The S soil test is nondiagnostic and is available only because soil testing laboratory clients demand it, not because it is a reliable test. A better predictor of the need for S in a particular spring is to understand the soils and pay attention to rainfall and snow pack between the fall and spring planting season.

In soils with higher clay content and high organic matter levels, S hardly ever is a problem except in the most extraordinarily wet springs. In medium-textured or coarser soils (loams, sandy loams, loamy sands, sands) with lower organic matter levels (3% or less), particularly on hill/ridge tops and slopes, if rainfall/snowfall is normal or higher in the fall, winter or early spring, application of at least 10 pounds per acre of S as sulfate or thiosulfate is recommended.

These are spring fertilizers and should be applied in the spring. In coarser-textured soils, high rainfall after planting may require a second application.

Application of S as elemental S is not nearly as effective as sulfate or thiosulfate forms. Application of S as elemental S the fall before planting most often is not effective because any sulfate produced by very slow oxidation may be leached away by early spring rains, leaving only immediately unavailable elemental S near the soil surface.

Ammonium thiosulfate should not be applied as a row starter. Any ammonium sulfate applied is subject to similar rate restrictions of $N+K_2O$ as other row-placed fertilizers.

Sulfur deficiency appears in the spring as yellow upper leaves, with lower leaves remaining greener. The pattern of deficiency usually is related to landscape, with eroded areas, hilltops and slopes being particularly vulnerable, especially in medium- and coarser-textured soils. Rescue with sulfate or thiosulfate sources such as ammonium sulfate, gypsum or ammonium thiosulfate. These are effective in correcting deficiencies, although a preplant application would result in the greatest yield improvement.

Liquid solutions should be stream-applied between the rows or applied through an irrigation pivot to avoid serious leaf injury. Dry application on corn up to V4 is possible with little injury. Injury will increase as corn advances in maturity.

Zinc

Corn is one of four crops regularly grown in North Dakota that has shown yield increases from zinc application when soil levels are low. The critical level of soil test zinc, using the DTPA (diethylenetriaminepentaacetic acid) extraction method is 1 ppm.

Potential zinc deficiency may be avoided by a broadcast application of at least 30 pounds per acre of zinc sulfate 36% granules, or by adding a compatible zinc chelate of ammoniated zinc product to the starter fertilizer at planting. The broadcast zinc sulfate application will increase soil test zinc levels for more than 10 years, while the starter chelate application will be necessary each year that the field is planted to corn.

Zinc deficiency is expressed as yellow-striped newer leaves and stunting. The deficiency can be corrected by a zinc chelate application, although when detected, some yield decrease already has occurred.

Additional nutrient deficiencies in North Dakota have not been documented.

Corn Nutrient Deficiency Symptoms

A deficiency symptom is an indication that the crop is not well, but it is not a nutrient diagnosis by itself. For example, corn may show purpling of leaves early in the season, which can be a P deficiency symptom, but the purpling also can be caused by any soil or environmental condition that reduces the rate of root growth, such as spring compaction, cold soils, very wet soil conditions and a tendency of purpling in certain hybrids. Therefore, a plant analysis, most often accompanied by a soil sample, except in the case of sulfur, from a "good" area and the "not-as-good" area most often will result in a diagnostic analysis.

Nitrogen Deficiency

Nitrogen deficiency symptoms can occur at any growth stage through ear development. Symptoms are yellowing lower leaves, starting at the leaf tip and following the midvein in a "V" pattern (Figure 14).

Figure 14. Nitrogen deficiency in corn. Note how the deficiency starts at the tip and moves down the midvein. The outer leaf edges are the last to turn yellow.
(D. Franzen, NDSU)

Phosphorus Deficiency

Phosphorus deficiency symptoms are purpling of leaves, with the lowest leaves most affected (Figure 15).

Potassium Deficiency Symptoms

Potassium deficiency symptoms are the result of low soil K, and they are intensified by dry soil conditions. The symptoms are yellowing of the leaf margins on older leaves. As the deficiency intensifies, the yellowing moves toward the leaf midvein, with the midvein the last leaf part to be affected (Figure 16).

Sulfur Deficiency

Sulfur deficiency symptoms are yellowing of upper leaves, often with a striped appearance (Figure 17).

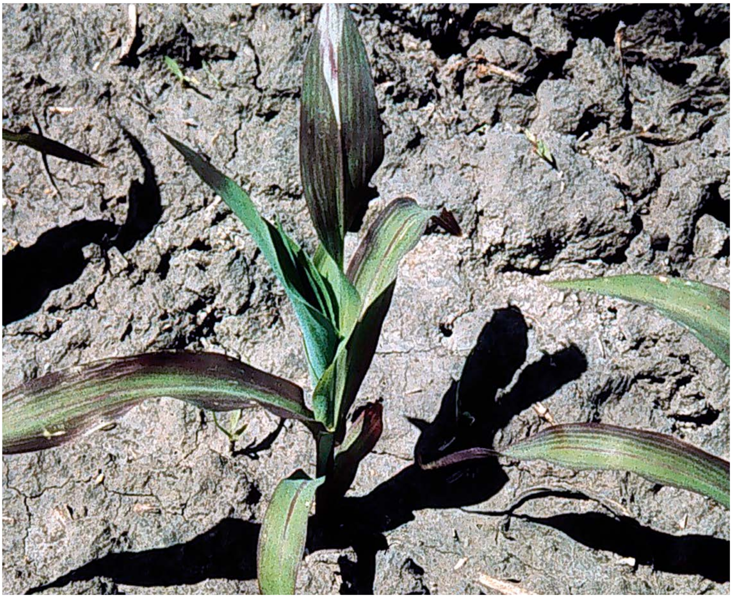

Figure 15. Phosphorus deficiency symptoms. These symptoms also can be caused by soil or environmental factors that limit root growth, such as compaction, cold soils and excessive soil wetness. (NDSU photo)

Zinc Deficiency Symptoms

Zinc deficiency symptoms are stunted plants with broad striping on upper leaves (Figure 18).

Figure 16. Potassium deficiency symptoms in corn. Note the yellowing of lower leaf margins. (G. Endres, NDSU)

Figure 17. Sulfur deficiency symptoms on corn. Note upper leaves are most affected, with yellowing and striped appearance. (NDSU photo)

Figure 18. Zinc deficiency symptoms in corn. (NDSU photo)

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 applied and activated properly. 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 reduce 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 reduce yield significantly.

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, such as 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 reduce yields severely. On a plant-for-plant basis, small-seeded and small-architecture plants such as annual grasses, nightshade and wild buckwheat are the least competitive. Corn yield reduction based on different weeds and weed densities is listed in Table 18.

Waterhemp is a pigweed species that is more competitive and has more resistance to herbicide mode of actions than redroot pigweed. Waterhemp has been spreading in the eastern half of North Dakota during the last decade.

Another pigweed, Palmer amaranth, recently was found in North Dakota. Palmer amaranth and waterhemp can be far more difficult to control in crops than redroot pigweed. Both of these weeds have extended germination windows, so using enough residual herbicide to provide weed control until the corn crop canopies is important. Overall control of these weeds is best achieved by following a zero-tolerance policy for seed production.

Corn has more herbicide control options for these weeds than any other crop in North Dakota, so proper planning can help control populations of these two weeds when corn is introduced into rotation. Corn-on-corn crop rotation can help drive down populations of these weeds in a field due to the abundance of

Table 18. Weed interference and corn yield.

Weed Species	Corn Yield Reduction (%)			
	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	258	75	100
Yellownutsedge	400	—	—	—

herbicide options and the overall competitive nature of corn, compared with other crops grown in North Dakota. However, due to the propensity of these two weeds to evolve herbicide-resistance, careful planning is needed to rotate herbicides, even in corn crops, to maximize the effective modes of action applied for control of waterhemp and Palmer amaranth.

Herbicide or herbicide combinations used should be based on the weed species present, crop rotation, herbicide-resistant corn technology available, soil type and cost. Consider weed species when selecting the most appropriate control system for each field.

Many corn herbicides are labeled for tank-mixing with other herbicides for broad-spectrum weed control. Several commercial corn herbicide mixtures are available.

Several herbicides registered in corn may have a residue and injure susceptible crops planted the year following corn. Atrazine can leave a residue if high rates are used. Atrazine applied at 0.38 pound of active ingredient per acre (ai/A) with other corn herbicides will increase control of weeds and will allow most all crops to be planted the following year.

Growth Stage Restrictions With Postemergence Herbicides

Many of the corn herbicides that can be used postemergence have specific growth stage or corn height cutoff restrictions. For example, any product that contains atrazine must be applied before corn exceeds 12 inches tall. While a few products allow applications on corn up to 36 or 48 inches tall, we encourage you to make applications on smaller corn.

Once corn enters the rapid-growth phase, you will have some challenges with making a herbicide application. The corn canopy will intercept a large amount of the spray solution, and some products become more injurious when the spray solution gets into the whorl of the plant.

Several product labels encourage the use of drop nozzles on larger corn to maximize the amount of product that is applied to weeds, and not the corn plants themselves. As always, refer to product labels for corn height and growth stage restrictions. Table 19 from the Ohio, Indiana and Illinois Weed Control Guide provides a nice summary of cutoff heights and growth stages for corn herbicides.

Table 19. Rainfast intervals, spray additives and crop size for postemergence corn herbicides (adapted from table developed by Mark Loux, The Ohio State University).†

Herbicide	Rainfast Interval (hours)	Spray Additives/Maximum Crop Size (field corn)
2,4-D Amine	6-8	No additives. Broadcast up to 8-inch corn; directed spray before tassel stage.
2,4-D Ester	2-3	No additives. Broadcast up to 8-inch corn; directed spray before tassel stage.
Accent Q	4	MSO, COC or NIS (Addition of UAN or AMS is recommended). Broadcast up to six collars or 20-inch corn; directed spray up to 10 collars or 36-inch field corn.
Aim	1	SURF. AMS or NIS may be added if required by tank-mix partner. Do not use COC or tan-mix with EC formulations of other crop protection chemicals except as specifically directed by label. Apply up to eight-collar corn.
Armezon PRO	1	MSO or COC plus UAN or AMS applied alone. NIS plus UAN or AMS in mixtures. Up to the V8 stage or 30-inch corn.
Atrazine	2	MSO or COC. Apply before corn is 12 inches tall.
Basagran	8	COC + UAN or AMS, depending on weed species present.
Bromoxynil	1	No additives. Apply before tassel emergence.
Bromoxynil + atrazine	2	No additives. Apply before corn is 12 inches tall.
Cadet	4	NIS, COC or MSO. UAN or AMS can be added. Preplant up to 48 inches tall, and before tassel emergence.
Callisto GT	-	NIS, AMS. COC can be used instead of NIS but increases risk of crop injury. Broadcast up to 30-inch or V8 corn.
Callisto Xtra	-	COC or NIS + UAN or AMS. Apply up to 12-inch corn.
Capreno	1	COC, UAN or AMS. Apply broadcast from one-leaf up to 20-inch corn, and prior to V7 stage.

Herbicide	Rainfast Interval (hours)	Spray Additives/Maximum Crop Size (field corn)
Coyote	1	NIS or COC. UAN or AMS may be added. Apply up to eight-leaf or 30-inch corn.
Dicamba	6-8	Add UAN if velvetleaf is present. NIS, COC or UAN may be added under dry conditions. Do not apply with COC when corn height exceeds 5 inches. Broadcast up to five-leaf stage or 8-inch corn; directed spray up to 36-inch corn.
Dicamba/ atrazine	6-8	Add UAN if velvetleaf is present. NIS, COC or UAN may be added under dry conditions. Do not apply with COC when corn height exceeds 5 inches. Apply broadcast up to five-leaf stage or 8-inch corn.
DiFlexx	6-8	Can add NIS, COC or MSO + UAN or AMS. Broadcast spray from spike through V10 stage and corn less than 36 inches tall.
DiFlexx DUO	4	COC or MSO is recommended, plus UAN or AMs. HSOC also can be used. Broadcast up to but not including V7 stage, and less than 30 inches tall; directed spray up to V10 or 36 inches tall, or 15 days prior to tassel, whichever occurs first.
Enlist One/ Duo	24	See Enlist website for adjuvant information. Broadcast up to V8 or 30 inches, whichever occurs first, directed spray up to 48 inches.
Glufosinate	4	AMS. Broadcast or directed up V6 (Liberty) or up to 24-inch or V7 corn (Cheetah/Interline). Directed spray up to 36-inch corn.
Halex GT	2	NIS + AMS. Broadcast up to 30-inch or eight-leaf corn.
Halosulfuron	4	NIS, MSO or COC. UAN or AMS may be added. Apply through layby stage of corn.
Harness Max	1	NIS or COC. UAN or AMS can be added. Popcorn – SURF only. Up to 11-inch corn.
Impact/ Armezon	1	MSO or COC. UAN or AMS. NIS can be used in mix with other herbicides. Broadcast or directed up to 45 days before harvest (impact) or up to V8 stage (Armezon).
ImpactZ	4	MSO + UAN or AMS. NIS can be used in mix with other herbicides. Broadcast up to 12-inch corn.
Laddok	8	MSO, COC, UAN, AMS, DASH or combinations of these. Apply before corn is 12 inches tall.
Laudis	1	MSO + UAN or AMS. Broadcast up to V8 corn.

Herbicide	Rainfast Interval (hours)	Spray Additives/Maximum Crop Size (field corn)
Laudis + atrazine	2	COC + UAN or AMS. Broadcast up to 12-inch corn.
Mesotrione	1	COC + UAN or AMS. Apply up to 30-inch or eight-leaf corn.
Northstar	4	NIS, COC or MSO up to 12-inch corn. Only SURF between 12- and 36-inch corn. UAN or AMS may be added. Broadcast 4- to 20-inch corn; directed spray up to 36-inch corn.
Realm Q	4	NIS or COC + UAN or AMS. Broadcast or directed up to 20 inches and prior to the seven-collar stage.
Revulin Q	4	COC or HSOC + UAN or AMS. Broadcast up to V8 stage or 30 inches tall, whichever occurs first.
Resolve Q	4	NIS + UAN or AMS unless mixed with a glyphosate product or Ignite. Broadcast up to 20-inch or six-collar corn.
Resource	1	COC, UAN or AMS may be added to improve control of certain species. Apply up to the 10-leaf stage.
Shieldex	1	MSO (preferred) + UAN or AMS. COC is preferred adjuvant. Do not use MSO. Up to V8 or 30-inch corn.
Shotgun	6	No additives. Apply before 12-inch corn.
Solstice	1	COC or NIS + UAN or AMS. COC is preferred adjuvant. Do not use MSO. Up to V8 or 30-inch corn.
Starane	1	An adjuvant can be used if required by tank-mix partner. Broadcast up to the V5 stage; directed spray after the V5 stage.
Status	4	NIS, COC or MSO + UAN or AMS. Broadcast from 4- to 36-inch corn (rates up to 5 oz/A) or V2 to V8 stage.
Steadfast Q	4	COC, MSO or NIS + UAN or AMS. COC or MSO is preferred vs. NIS. Broadcast up to and including six collars or 20-inch corn.
Stinger	6-8	No additives. Up to 24-inch corn.
WideMatch	6	No additives. Broadcast up to the V5 stage; directed spray after the V5 stage.
Yukon	4	NIS or COC. UAN or AMS maybe added. Apply broadcast or directed up to 36-inch corn.

† This table shows the required time interval between herbicide application and rainfall and summarizes label recommendations for spray additives and maximum crop stage. Check herbicide labels for additive rates. Information in this table applies to field corn only.

Grass Weed Control

Grass weed control is more difficult in corn than many of our broadleaf crops. This is due to the difficulty in developing herbicides that can control grass weeds selectively in a grass crop. Grass weed control is easier to achieve with pre-emergence herbicides in conventional corn hybrids.

Many premix herbicides that can be applied pre-emergence on corn provide excellent grass control in corn. Postemergence grass control is more difficult in conventional hybrids than those that contain glyphosate-tolerance traits. Products available for postemergence grass weed control include products containing nicosulfuron (Accent Q, others), and many of the HPPD-inhibiting (WSSA Herbicide Group 27) containing products.

What is important to note is that the Group 27 products, with active ingredients containing topramezone (Impact/Armezon), tolpyralate (ShieldX), tembotrione (Laudis) and mesotrione (Callisto) will provide increased weed control when tank-mixed with atrazine. Any of these combinations work better when applied on grasses that are less than 6 inches tall. These programs become marginal once grasses exceed 6 inches tall.

Grass weed control also can be challenging in Liberty Link® corn hybrids. Glufosinate (Liberty, others) will control grasses that are less than 3 inches tall, but control becomes marginal at larger weed heights. The Roundup Ready® and Enlist™ herbicide-resistant traits will offer the best postemergence grass weed control.

Glyphosate resistance is increasing in many broadleaf weeds across North Dakota, but as of April 2019, we do not have any confirmed cases of glyphosate resistance in grass weeds. Glyphosate remains one of the best grass herbicides in glyphosate-tolerant crops, including corn.

Enlist™ corn is the newest trait to come to market and has tolerance to aryloxyphenoxypropionate (FOP) herbicides. Assure II (quizalofop) has a label for postemergence use in Enlist™ corn. If this product is used in corn, we encourage you to use a different mode of action in rotational crops for grass weed control to delay the onset of weed resistance.

Herbicide-resistant Corn Technologies

Herbicide-resistant corn technologies are available, with more in development by private industry. Roundup Ready® and other glyphosate-tolerant hybrids are the most popular herbicide-resistant technology in corn.

Many modern hybrids also are stacked with Liberty Link® traits, which confer resistance to glufosinate (Liberty herbicide and generics). Liberty® controls most small annual grass and broadleaf weeds and can be applied only to Liberty Link® corn hybrids.

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. Liberty® efficacy is increased with carrier volumes of at least 15 gallons per acre, and under hot, sunny weather conditions.

Glyphosate controls most annual and perennial grass and broadleaf weeds and can be applied only to Roundup Ready® and other glyphosate-tolerant corn hybrids. Glyphosate is a systemic, nonselective, nonresidual herbicide and may require two sequential applications or use after a foundation soil-applied herbicide program.

Enlist™ corn is one of the newest traits to be commercialized. Enlist corn is resistant to glyphosate, glufosinate, 2,4-D and FOP herbicides. While 2,4-D can be applied to any corn hybrid, the Enlist™ trait offers increased tolerance and protection against typical injury such as leaning or green-snap that can occur with 2,4-D applications in corn. What is important to note is that not all 2,4-D or Group 1 herbicides may be labeled for use in Enlist™ corn, so as always, consult herbicide labels before making an application.

Several weed species have developed resistance to glyphosate in North Dakota. Some include common ragweed, waterhemp, horseweed and kochia. Effective weed management programs should be used in corn and other crops used in rotation to delay other weed species from developing resistance. Applying residual pre-emergence herbicides provides a foundation for weed management, and many have a different mode of action than postemergence herbicide used in corn.

Newer herbicide-resistance traits in corn offer an increasing portfolio of herbicides to use for postemergence weed control in corn. Many of these traits also are being bred into soybean, so not only rotating crops, but rotating chemicals used from year to year, is important to delay the development of herbicide resistance. Effective management options may require using other tools, such as cultural and mechanical control methods.

Control of Volunteer Corn

Record-keeping is becoming increasingly important to remember which fields were planted to different herbicide-resistance traits. The herbicide-resistance traits will drive the potential herbicide options available for control of volunteer corn in subsequent crops.

Conventional corn hybrids can be controlled in a soybean crop with glyphosate, two applications of glufosinate or any of the Group 1 herbicides. In terms of herbicide options, the Enlist™ corn hybrids will be the most difficult to control because the only viable options will be the cyclohexanedione (DIM) herbicides, clethodim (Select, others) and sethoxydim (Poast).

Refer to the current free issue of the NDSU Extension publication W253, "North Dakota Weed Control Guide" (www.ndsu.edu/weeds) for more detailed information on corn herbicides, mixing directions, weed control, crop rotation restrictions, herbicide-resistant weeds and the use of spray adjuvants. Consult the label for information on individual herbicides and a complete listing of all possible registered combinations.

Insect Control

Insect Pest Management

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 cutworms, corn rootworms, European corn borer, grasshoppers and wireworms.

For insecticides registered in corn, producers should consult the most recent version of E1143, "North Dakota Field Crop Insect Management Guide," (published annually) at www.ag.ndsu.edu/publications/landing-pages/crops/field-crop-insect-management-guide-e-1143.

NDSU Extension publications are available from the Extension office in your county or the NDSU Distribution Center.

For guidance in selecting a suitable Bt corn hybrid, consult the Handy Bt Trait Table for U.S. Corn Production or the corn section of E1143, "North Dakota Field Crop Insect Management," at www.canr.msu.edu/news/handy_bt_trait_table.

Scouting for insects is a critical component of an integrated management program. In Table 20, the scouting times for the various insects of economic importance in North Dakota corn are summarized.

Table 20. Insect pest scouting calendar for field corn by crop stages.

Seedling to V3 stage	V4 to V12 stages	Tasseling to early reproductive stages	Reproductive stages to harvest
May	**June**	**July**	**August**
Cutworms Grasshoppers Wireworms	Cutworms European corn borers Grasshoppers Wireworms	Corn rootworms European corn borers Grasshoppers	Corn rootworms European corn borers Grasshoppers

Corn Rootworms

Coleoptera: Chrysomelidae

The northern corn rootworm (*Diabrotica barberi*, Smith and Lawrence) and the western corn rootworm (*D. virgifera virgifera*, LeConte) are major economic pests of corn in North Dakota. For more information, consult the NDSU Extension publication E1852, "Integrated Pest Management of Corn Rootworms in North Dakota," at www.ag.ndsu.edu/publications/crops/integrated-pest-management-of-corn-rootworms-in-north-dakota.

Life Cycle

Northern and western corn rootworms have one generation per year. Corn is their preferred host; however, weeds such as volunteer corn and foxtail grasses also are attractive for these pests in other crop fields. Corn rootworm adults (Figures 19 and 20) begin emerging in mid-July in North Dakota. The northern corn rootworm usually emerges first; the western corn rootworm emerges one to two weeks later. In North Dakota, adult emergence is 50% completed by late-August to early September.

Adult corn rootworm beetles can be identified easily in the field. Northern corn rootworm adults (Figure 19) are tan to pale green beetles and about ¼ inch long. Western corn rootworm adults (Figure 20ab) are yellow-green and black beetles.

Most female western corn rootworm beetles (Figure 20a) have three longitudinal stripes on their backs. In contrast, most male western corn rootworm beetles (Figure 20b) have a more solid black marking. Western corn rootworm adults vary from ³⁄₁₆

Figure 19. Northern corn rootworm adult. (V. Calles-Torrez, NDSU)

Figure 20a. Female western corn rootworm adult. (J. Knodel, NDSU)

Figure 20b. Male western corn rootworm adult. (P. Beauzay, NDSU)

inch to 5⁄16 inch long. Female beetles of both species are usually slightly larger than males, and often have enlarged abdomens when carrying eggs inside of their abdomen.

Male beetles emerge first, and female beetles emerge about five to seven days later. Female northern corn rootworm beetles mate within two days after emerging; whereas western corn rootworm females are rarely mated beyond one day after emergence.

Two weeks after mating, females are ready to lay eggs. Most egg laying occurs from late July through September. A single northern corn rootworm female can lay more than 1,000 eggs in a season; western corn rootworm females are capable of producing more than 1,800 eggs in a season.

However, not all laid eggs survive due to several mortality factors, including predation, soil factors, extreme temperatures and excessive rainfall. Females lay eggs within the upper 8 inches of the soil surface.

Before eggs will hatch, eggs must undergo a long period in a slowed physiological state referred to as diapause. Eggs overwinter in the soil from September to June of the following year. After overwintering, most eggs hatch into small larvae from late May through June in North Dakota.

As soon as they hatch, the tiny first-instar larvae orient to volatiles emitted from growing corn roots to find their host plants and begin feeding. Larvae pass through three instars. Larvae reach maturity in the third instar (Figure 21) and are ready to enter the pupal stage.

Full-grown larvae (third instar) first begin pupating in an earthen cell in the soil during early July. The transformation from pupa to adults takes about one week, and adults begin emerging from the soil in mid-July. Because of variation in the timing of egg hatch and developmental rates, different corn rootworm life stages may overlap in the field.

Damage

The most significant corn rootworm injury to corn occurs when larvae feed on the root system (Figure 21). First-instar larvae usually feed on root hairs and outer root tissue. Second-instar larvae feed on lateral roots and sometimes tunnel into the roots. Mature third instars cause the most damage by feeding on lateral roots and sometimes tunneling into the roots.

Tunneling injury can sever individual roots completely. Injured root systems, especially those in which brace roots are heavily injured and/or severed (Figure 22), have reduced the capacity to uptake water and nutrients from the soil. Severe larval root feeding injury can cause yield losses that approach 50%.

Corn plant lodging (Figure 23) or goose-necking symptoms (base of stalk is bent in a curved shape) may be observed in fields with severe root feeding injury from corn rootworm larvae. The presence of lodged plants makes harvesting difficult, resulting in additional harvest losses.

Adults of both species also feed on corn leaves, silks, pollen and kernels. If populations are high, adult clipping to corn silks can interfere with pollination.

Pest Management

Crop rotation and use of *Bacillus thuringiensis* (Bt) corn hybrids are the two most common pest management strategies for control of corn rootworms in North Dakota.

Figure 21. Corn rootworm larvae and tunneling into root. (P. Beauzay, NDSU)

Crop Rotation

Crop rotation is the No. 1 strategy for managing corn rootworm populations. Corn rootworms are dependent on corn as a food plant. Larvae usually will starve to death on other noncorn plants. As such, crop rotation can break the weak link of the corn rootworm's life cycle.

Figure 22. Root injury by corn rootworm. (V. Calles-Torrez, NDSU)

Figure 23. Corn plant lodging near Page, N.D. (J. Ransom, NDSU)

NDSU Extension encourages crop rotation to nonhost crops, such as soybean, flax, canola, sunflower or wheat. Crop rotation also can help slow the development of resistance to other control strategies, such as Bt corn hybrids.

Bt Corn Hybrids

Corn rootworm management can be achieved using transgenic (genetically modified) Bt corn, which has been modified to express a variety of crystal (Cry) protein(s) derived from the bacterium *Bacillus thuringiensis*. Proteins were selected because of their ability to specifically kill corn rootworm larvae as they feed on roots of Bt hybrids.

A Bt corn hybrid may express a single Cry protein or combination of multiple proteins, and can be engineered to target a single insect pest group (rootworm species) or multiple insect pest groups (corn rootworms and caterpillar pests, such as European corn borer).

Bt corn hybrids expressing a single protein, such as Cry3Bb1, mCry3A or Cry34/35Ab1, are specific and kill only corn rootworms. A Bt hybrid with two or more proteins targeting the same insect group, such as those expressing Cry3Bb1 plus Cry34/35Ab1 or mCry3A plus eCry3.1Ab, is called a "pyramid" because all of these proteins are specifically toxic to corn rootworms.

When a Bt corn hybrid contains two different protein types targeting separate insect pest groups, the hybrid is referred to as "stacked." A Bt corn hybrid containing multiple Bt proteins for controlling corn rootworm and other above-ground pests is called a "stacked pyramid." Bt corn hybrids also can be stacked with a herbicide-tolerant trait.

When a Bt corn hybrid is planted, always follow the instructions for planting the refuge in the correct location and follow the percentage of area requirements. The refuge seed will lack expression of the Bt protein that is used to control the target pest(s).

Some Bt corn hybrids are packaged as "refuge in the bag" (RIB) products, meaning the bag contains a mixture of non-Bt and Bt corn seeds in the proper ratio. If refuge seeds are not included in the bag, usually refuge seeds must be planted adjacent to or within the Bt corn field. Planting non-Bt refuge is extremely important because it will help delay corn rootworm resistance to Bt proteins, thus extending the durability of this technology as a corn rootworm management tool.

How to Prevent Bt Resistance Development in Corn Rootworms

Western corn rootworm populations already have become resistant to several Bt proteins, including Cry3Bb1, mCry3A, eCry3.1Ab and Cry34/35Ab1 in Iowa and Minnesota. Resistant of western corn rootworm to some of these proteins also has been reported in Illinois, Nebraska and South Dakota. **In southeastern North Dakota, recent research found that some populations of northern corn rootworms have developed resistance to Cry3Bb1 and Cry34/35Ab1, and western corn rootworm to Cry3Bb1.**

The following strategies are recommended to reduce the risk of rootworm populations developing resistance to Bt proteins:

- Crop rotation: Rotate fields annually between corn and nonhost crops as mentioned above. If practical, rotate corn from the field for two to four years. In addition, remember to control volunteer corn and grassy weeds that could serve as hosts for local Bt-resistant rootworm populations.
- Plant a conventional (non-Bt) corn hybrid plus soil insecticide instead of a Bt hybrid, especially when the local rootworm pressure is expected to be low. A Bt corn hybrid plus soil insecticide is not recommended because the soil insecticide does not provide any additional yield protection due to the Bt protein killing rootworms. This practice also prevents detection of Bt-resistant insect populations.
- Plant the non-Bt corn refuge according to guidelines on the Bt corn seed bag tag.
- Rotate fields with Bt corn hybrids that have different modes of action each year. For example, use one Bt corn hybrid with Cry 3 protein (for example, Cry3Bb1, mCry3A or eCry3.1ab) the

first year, then switch to a Bt corn hybrid expressing a different mode of action (for example, Cry34/35Ab1) in the subsequent year.

- Plant Bt corn hybrids expressing multiple Cry proteins (pyramid hybrids) targeting both corn rootworms.
- Be vigilant in scouting fields for corn rootworm adults, and assess larval root-feeding injury.
- If a problem is detected, contact and report immediately to your local seed dealer and to NDSU Extension Entomology.

Cutworms

Lepidoptera: Noctuidae

For more information, consult the NDSU Extension publication E830 (revised), "The Armyworm and the Army Cutworm," at www.ag.ndsu.edu/publications/crops/the-armyworm-and-the-army-cutworm.

Life Cycle

Several species of cutworms cause problems to corn in the northern Great Plains, such as black cutworm (Figure 24), dingy cutworm, army cutworm and red-backed cutworm. Adult cutworms are moths, and have dark wing colors (brown to gray) with markings and about a 1½ inches long wing length.

Cutworms have one generation per year. Depending on the species, cutworms overwinter as eggs (for example, red-backed cutworm), young larvae (for example, dingy cutworm) or migrate (for example, black cutworm) into North Dakota. Eggs hatch in April or early May, and young larvae (or caterpillars) feed at night on weeds and volunteer plants before the corn crop emerges.

Larvae molt six times and grow larger with each instar. A mature cutworm larva is about 1½ inches long and the size of a pencil in width. Cutworms are most noticeable from late May through mid-June, except for the army cutworm, which is active in April through May.

After cutworms complete their development in late June, they burrow deeper into the soil and make a small pupal chamber. Adult moths emerge from August through early September. Adults mate and females lay eggs on or just below the surface of loose, dry soil; weedy stubble; or fallow fields, depending on the species.

Damage

Feeding injury by these cutworms normally occurs in late May to mid-June. Cutworm damage first appears on hilltops, south-facing slopes or in areas of light soil, which warm earlier in the spring.

Figure 24. Black cutworm moth. (J. Kalisch, University of Nebraska)

Figure 25. Black cutworm larva and feeding injury to corn. (J. Kalisch, University of Nebraska)

Larvae will cut young corn plants in the seedling to the V5 stage, and later feed on developing corn leaves, creating holes (Figure 25). Cut plants that are drying and lying on the soil surface are a good indicator of cutworms.

When disturbed, cutworms curl up or hide under soil debris. As damage continues, fields will have areas of bare soil where plants have disappeared.

Pest Management

Some criteria that may help predict cutworm problems are: 1) field history of cutworm damage, 2) surface crop residue from reduced or minimum tillage, 3) bottomland or low spots in field, 4) fair to poor drainage or 5) near shelterbelts with grassy ground cover. Because eggs of the cutworms are laid during late summer in North Dakota, soil moisture at this time is important for their winter survival. Growers should be cautious when planting corn following pasture, alfalfa or clover sites; survival may be greater at these locations.

Begin scouting for cutworms when corn is up to a stand and continue until late June. The action threshold for cutworms lumps all species of cutworms together. **When 2% to 3% of the plants are cut and small larvae (less than ¾ inch) are present, a treatment is justified. The threshold increases to 5% cut plants when larvae are greater than ¾ inch.**

An application rate of 15 to 20 gallons of water per acre by ground application is recommended. Cutworm larvae feed actively at night, so an evening insecticide application is best.

The transgenic Bt corn with Vip3A and Cry1F have control against black cutworms and partial control again dingy cutworms.

Grasshoppers

Orthoptera: Acrididae

Life Cycle

Grasshoppers are generalists and feed on a wide range of agricultural crops, such as corn, small grains, flax and sunflowers (Figures 26 and 27). Grasshoppers overwinter as eggs, and nymphs start to emerge in late April to early May, with peak egg hatch in mid-June.

Nymphs (young grasshoppers) (Figure 26) will go through five molts before transforming into adults (Figure 27). The length of time from egg to adult is 40 to 60 days. Adults of crop-damaging species become numerous in mid-July, with egg laying usually beginning in late July and continuing into the fall. Eggs are deposited in a variety of noncrop areas, including ditches, shelterbelts and weedy fall fields.

Damage

Adults and nymphs feed on green leaf tissue, creating holes on corn leaves, except for the midrib. Seedling corn plants can be 100% consumed by high populations of nymphs. In late summer, adults can consume the entire corn leaf except the midrib, and even chew into the husk and developing kernels (Figure 27).

Pest Management

Grasshopper outbreaks usually coincide with several years of low rainfall and drought periods. Cool, wet weather increases the diseases that infect and kill grasshoppers, such as Summit disease caused by a fungal pathogen (Figure 28). Scout corn for leaf defoliation from nymphs during the seedling stage and from adults during July to September.

For corn, the "threatening" rating (Table 21) is considered the action threshold for grasshoppers, and would indicate a need to treat with an insecticide. Grasshopper thresholds are based on the number of grasshoppers (adults or nymphs) per square yard. Four 180-degree sweeps with a 15-inch sweep net equals 1 square yard. The infestation ratings are listed in Table 21.

Figure 26. Grasshopper nymph. (P. Beauzay, NDSU)

Figure 27. Red-legged grasshopper (adult) on corn ears. (J. Knodel, NDSU)

Table 21. Threatening levels of nymphs and adults for corn.

Rating	Nymphs per Square Yard		Adults per Square Yard	
	Margin	Field	Margin	Field
Light	25-35	15-23	10-20	3-7
Threatening*	50-75	30-45	21-40	8-14
Severe	100-150	60-90	41-80	15-28
Very Severe	200+	120	80+	28+

*Action threshold.

Figure 28. Grasshopper infected with Summits disease. (J. Knodel, NDSU)

European Corn Borer

Lepidoptera: Pyralidae

European corn borer (ECB), *Ostrinia nubilalis* (Hübner), populations decreased significantly after the widespread adoption and planting of Bt corn hybrids for ECB. These Bt corn hybrids have a high dose for killing larvae that ingested the Bt toxin in the plant tissue. Recently, growers have planted more acres of non-Bt corn in North Dakota, which could increase densities of ECB populations slowly in North Dakota.

Life Cycle

Adults are straw-colored moths about 1 inch long. Wings have wavy brown lines across the wings that form a triangle when the moth is at rest (Figure 29).

European corn borers overwinter as full-grown larvae in corn stalks, corn cobs, weed stems or other cornfield debris. Full-grown larvae are 1 inch long and vary from pinkish gray to pale brown with numerous dark spots and a black head (Figure 30). Larvae undergo five stages or instars. Spring development resumes when temperatures exceed 50 F. The larva pupates in late May through June, and a moth will emerge from the puparium in seven to 10 days.

Figure 29. Female European corn borer moth. (J. Knodel, NDSU)

Figure 30. European corn borer larva in stalk. (J. Knodel, NDSU)

In North Dakota, ECBs have two biotypes: one generation per year (univoltine) and two generations per year (bivoltine). The univoltine ECBs are more numerous and distributed throughout the state. The univoltine ECB has one flight and peak emergence occurs during early to late July. The bivoltine ECBs primarily are present in the southeastern and south-central areas of the state. This bivoltine ECB has two flights:

- First flight peaks early to late June and represents the first generation of larvae feeding on the corn leaves in whorl-stage corn, and third to fifth instar stages can bore into stalks
- Second flight peaks early August and represents the second generation of larvae tunneling into stalks, ears or ear shanks

After emerging, moths spend the daylight hours in weeds and grasses in field edges, along fencerows or roadside ditches, or within the cornfields. Vegetation at these sites collects rain or dew droplets more effectively than the corn plants. Moths drink this water. Also, mating occurs as the females attract large numbers of males at these sites.

The females lay their eggs on the undersides of the leaves near the midvein. A female can lay an average of two egg masses per night for 10 days. Eggs take three to seven days to hatch. When larvae are about 10 days old, they reach a length about equal to the diameter of a dime and begin to tunnel into the midvein of the leaf, then burrow into the stalk.

Damage

Yield losses due to ECB infestations primarily are due to larval tunneling in stalks, ears or ear shanks. Larval tunneling can reduce corn yield, kernel numbers and grain weight. Tunneling also caused physiological stress, causing broken stalks, poor ear development and ear drop.

Early in corn growth, prior to tasseling, larvae often feed on the developing corn leaves in the whorl, creating "shot holes" in leaves (Figure 31). This damage becomes more apparent as the leaves lengthen and emerge further from the whorl.

Figure 31. European corn borer larval feeding in whorl stage corn, creating shot holing. (T. Baute, Ontario Ministry of Agriculture, Food and Rural Affairs, Canada)

Larvae enter the stalk during the third-instar stage (Figure 32). With persistent autumn winds and dry conditions, tunneling in stalks and ear shanks increases the risk of stalk breakage and dropped ears.

Injury of this lepidopteran pest can increase the chances of disease infections in the stalks and kernels. For example, the fungi *Fusarium* spp. and *Gibberella* spp. are introduced into the corn ears by the ECB larvae.

Pest Management

Managing ECB in North Dakota is a challenge due to the lengthy emergence interval of the moths from the different biotypes. 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 mid-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

Figure 32. Entry hole into corn stalk by European corn borer larva.
(T. Baute, Ontario Ministry of Agriculture, Food and Rural Affairs, Canada)

undersides of leaves; for whorl, leaf or tassel feeding; and for active larvae. Observing ECB moth activity around field margins or within the field, or trapping moths with commercially available pheromone traps (Figure 33) 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. In a corn field, borers usually still are feeding outside the stalk no more than 10 to 14 days, which is when they should come into contact with a foliar application of insecticide.

Once the borers tunnel into the stalk, it is too late to control them with a foliar applied insecticide. Because of the long potential infestation window (mid-June to mid-August) and difficult timing of insecticide treatments, many growers in the region have used Bt corn on their farm for ease of managing corn borers.

Figure 33. Pheromone trap for European corn borer.
(V. Calles-Torrez, NDSU)

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 that 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.

Field scouting should begin on non-Bt hybrids in mid-June and continue to mid-August. **One general treatment threshold that can be used is when 40% to 50% of the plants in dryland corn or 25% to 35% 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 of infested plants, number of live larvae per infested plant, cost of insecticide treatment and expected value of the corn (Table 22).

Recently (May 2019), ECB resistance to the Bt corn hybrid expressing the Cry1F (trade name Herculex 1) protein was confirmed in 2018 ECB populations collected from Nova Scotia, Canada. The geographic spread of ECB resistance in Canada is unknown. ECB resistance has not been detected before.

The following strategies are recommended to reduce the risk of ECB populations developing resistance to Bt proteins:

- Plant the structured refuge requirement that accompanies the chosen Bt corn hybrid.
- Avoid purchasing or planting Bt corn hybrids that use the single Bt Cry protein (Cry1F or Cry1Ab alone) or a stacked hybrid in which one of the proteins is the Cry1F.
- Plant Bt corn hybrids that express two different modes of action.
- Scout your non-Bt or Bt corn field for ECB moths and egg masses.

Contact your seed dealer and your extension agent/extension entomologist if you experience any heavy infestation or unexpected damage from ECB in Bt or non-Bt corn fields.

Table 22. Economic threshold (corn borer/plant) when factoring crop value and control costs.

Control Costs[2] ($/acre)	Value of Corn Crop[1] ($/acre)								
	200	250	300	350	400	450	500	550	600
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 (bushels/acre) X projected price ($/bushel)
[2] Control costs = insecticide price ($/acre) + application costs ($/acre)

Wireworms

Coleoptera: Elateridae

Life Cycle

Wireworm larvae are hard, smooth, slender, wirelike worms varying from 1 to 2 inches in length when mature (Figure 34). They are yellowish white to coppery, with three pairs of small, thin legs behind the head. The last body segment is forked or notched.

Figure 34. Wireworm larvae. (M. Boetel, NDSU)

Figure 35. Wireworm adult. (K. Wanner, Montana State University)

Adult wireworms are bullet-shaped, hard-shelled beetles that are brown to black and about an inch long (Figure 35). The common name "click beetle" is derived from the clicking sound that the insect makes when attempting to right itself after landing on its back.

Wireworms usually take three to four years to develop from the egg to an adult beetle. Most of their life cycle is spent as a larva in the soil. Generations overlap, so larvae of all ages may be in the soil at the same time. Wireworm larvae and adults overwinter at least 9 to 24 inches deep in the soil. When soil temperatures reach 50 to 55 F during the spring, larvae and adults move nearer the soil surface.

Adult females emerge from the soil, attract males to mate, then burrow back into the soil to lay eggs. Females can re-emerge and move to other sites, where they burrow in and lay more eggs. This behavior results in spotty infestations throughout a field. Some wireworms prefer loose, light and well-drained soils; others prefer low spots in fields where higher moisture and heavier clay soils are present.

Larvae move up and down in the soil profile in response to temperature and moisture. After soil temperatures warm to 50 F, larvae feed within 6 inches of the soil surface. When soil temperatures become too hot (greater than 80 F) or dry, larvae will move deeper into the soil to seek more favorable conditions.

Wireworms inflict most of their damage in the early spring, when they are near the soil surface. During the summer months, the larvae move deeper into the soil. Later, as soils cool, larvae may resume feeding nearer the surface, but the amount of injury varies with the crop.

Wireworms pupate and the adult stage is spent within cells in the soil during the summer or fall of their final year. Adults remain in the soil until the following spring.

Damage

Wireworm infestations are more likely to develop when corn follows grasses, including grain crops or pastures. Wireworms damage crops by feeding on the germinating seed or the young seedling. Damaged plants soon wilt and die, resulting in thin stands. In a heavy infestation, bare spots may appear in the field and reseeding is necessary.

Pest Management

No easy sampling methods are available to estimate wireworm infestations. Two methods are:

- **Soil sampling** — Sample 20 well-spaced 1-square-foot sites to a depth of 4 to 6 inches for every 40 acres being planted. If an average of **one wireworm per square foot is found, insecticide treatment would be justified**.
- **Solar baiting** — Put out bait stations in September two to three weeks before freeze-up or in the spring before planting. Randomly place 10 to 12 stations per 40 acres in the field. Place 1 cup of wheat and 1 cup of shelled corn into a nylon sock and bury the sock 4 to 6 inches deep. Dig up the sock after 10 to 14 days and look for wireworms in and around the germinating bait bag. **If an average of one or more wireworm larvae is found per station, insecticide treatment would be justified.**

Several insecticides are approved for use as seed treatments or in-furrow treatments to protect corn seeds from wireworms and other soil insect pests, such as seed corn maggots. Insecticides applied to the seed just before planting time are an inexpensive means of reducing wireworm damage to growing crops.

For maximum benefits, treat the seed shortly before seeding; prolonged storage after seed treatment may reduce germination. If on-farm treaters are used, be sure they are calibrated properly to apply the recommended dosages.

Soil-applied insecticides also are used to prevent damage to plants from soil insect pests. They are applied as a preventive measure because rescue treatments generally are ineffective. The use of these products should be based on some knowledge of wireworms being present in soil, which is determined by field scouting and trapping. Using soil insecticides or seed treatments strictly as insurance against crop damage is discouraged.

Diseases in Corn

Seedling blights, roots rots, foliar diseases, stalk rots and ear rots all can be observed in commercial corn fields in North Dakota. However, only a few of these diseases may cause economic losses for corn producers. The next section provides information on how to identify and manage common corn diseases in the state.

Seed Decay, Seedling Blight and Root Rot

The first field symptom often observed early in the growing season is stand loss. Although abiotic disorders can reduce stand, so can fungal and fungal-like organisms. The two primary pathogens responsible for stand establishment problems in North Dakota are *Pythium* and *Fusarium*. Both pathogens cause root discolorations impacting nutrient flow of the plant (Figure 36).

Pythium is a soil-borne pathogen that is favored by cool, wet weather early in the growing season. Fusarium can be soil-borne and seed-borne and has a wide range of favorable conditions. Damage from both pathogens is increased when plants are stressed (poorly drained soils, cold and wet soils, compacted soils, deep planting, early planting and poor-quality seed).

The risk of these problems can be reduced by planting high-quality seed into soil conditions that allow for quick emergence. Fungicide seed treatments also can reduce seed- and root-associated problems, but they have only a few weeks of effective residual.

Figure 36. Corn seedlings (V6-V8 stage) with root discolorations caused by *Fusarium*. (A. Friskop, NDSU)

Most corn seed is sold pretreated. Further information on the effectiveness of chemistries on pathogens can be found in the NDSU Extension publication PP622, "Field Crop Plant Disease Management Guide."

Foliar Diseases

The most common leaf diseases in North Dakota (based on survey efforts) are common corn rust, northern corn leaf blight, and Goss' leaf blight and wilt (hereafter: Goss' wilt). Other economically important leaf diseases in the U.S. such as gray leaf spot and southern corn rust have not been readily observed in North Dakota.

Common Rust

The common rust pathogen does not overwinter in North Dakota and spores are blown into the state from southerly winds. The most diagnostics sign of the common rust pathogen are pustules filled with brown to deep-red spores (Figure 37).

The pustules most commonly are found on leaves but also may occur on midribs, ear sheaths and the stalk. Common rust is favored in 75 to 85 F temperatures and dew (or other prolonged leaf moisture). Most corn hybrids in North Dakota have adequate resistance and fungicides generally are not needed in commercial fields.

Figure 37. Corn leaf with common corn rust. Note pustules filled with brown to deep-red spores. (A. Friskop, NDSU)

Northern Corn Leaf Blight

The northern corn leaf blight (NCLB) pathogen overwinters on corn residue. Lesions of NCLB are cigar shaped, have a tan center and can be up to 6 inches in length (Figure 38). The centers of older lesions may have the presence of black to gray spores.

Prolonged periods of moisture, high humidity and temperatures between 64 and 81 F favor NCLB development. Most northern hybrids have adequate resistance to reduce NCLB risk. Crop rotation and tillage can have a significant effect on reducing the amount of in-field spore sources.

Fungicides also are labeled for NCLB management and can be used if the disease risk is moderate to high in a field (susceptible hybrid, corn-on-corn system and disease has been detected across the field prior to tasseling). Information on fungicides can be found in the NDSU Extension publication PP622, "Field Crop Plant Disease Management Guide."

Figure 38. Corn leaf with tan, cigar-shaped lesions of NCLB. Middles also look dusty due to growth of the fungus.
(A. Friskop, NDSU)

Goss' Wilt

Goss' wilt is the most important corn disease in North Dakota. The disease has increased in prevalence across the state and can be found in most corn-growing regions.

Goss' wilt is caused by a bacterium that overwinters on corn residue and some grassy weeds. Symptoms of Goss' wilt primarily occur on the leaves in North Dakota. Lesions will be water-soaked (light green, greasy) with wavy margins often having freckles embedded in the lesion tissue (Figure 39).

Infected leaf tissue eventually will turn necrotic (brown) and may be confused with nutrient deficiencies and leaf scorch (Figure 40). However, necrotic lesions due to Goss' wilt will have water-soaking on the margin of the leaf and bacterial ooze may be present within a lesion.

Goss' wilt is observed in pockets, on field margins or across the entire field (often in irrigated fields). Strong thunderstorms, hail, wind and sandblasting provide injury to corn plants, allowing

Figure 39. Corn leaf with Goss' wilt lesion. Note the characteristic wavy leaf margin with water-soaking and freckles. (A. Friskop, NDSU)

Figure 40. Pocket of Goss' wilt in the field. Disease progression has advanced, causing severe necrosis of plant tissue.
(A. Friskop, NDSU)

the bacterium to enter. Warm (75 to 85 F) and humid weather promote Goss' wilt development.

Yield loss due to Goss' will largely depends on timing of the infection and susceptibility of the hybrid. In North Dakota, yield losses in excess of 40% have been documented on susceptible hybrids. The best management tools for Goss' wilt include hybrid resistance, crop rotation and tillage (when appropriate). Fungicides are not efficacious and copper hydroxide products are inconsistent.

Common Smut

Another common disease in North Dakota is common smut. This fungus overwinters in the soil or corn residue. Infection most frequently occurs on the areas of the plant that are actively growing, especially from wounds caused by hail, sand blasting, wind and insects.

White-gray irregular galls can appear on infected leaves, stalks, ears or stalks (Figure 41). When opened, the galls will have black powdery spores that can be displaced easily. The disease often does not need management because it doesn't pose an economic threat to field corn.

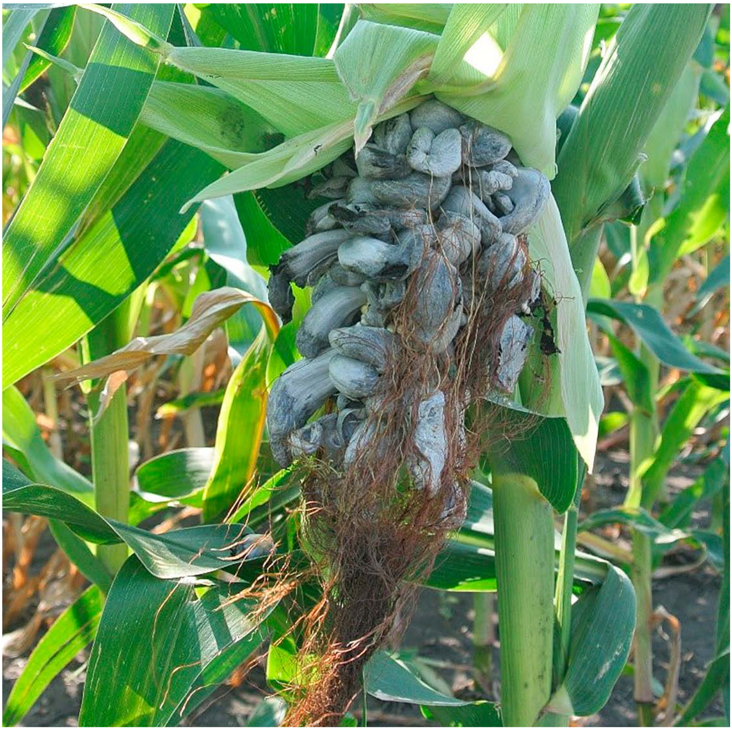

Figure 41. Corn ear with gray-white galls of the common smut fungus. (A. Friskop, NDSU)

Ear Rots

Ear rots have several causes and most are caused by fungal pathogens. Ear rots in North Dakota commonly are associated with injury (hail, insects, animals) and wet weather late in the growing season.

Infected kernels may appear white, pink, black or green, depending on the fungi that have colonized the injured areas of the ear. The two most common fungi associated with ear rot in North Dakota are *Cladosporium* and *Fusarium*. Black-green mold growth often is associated with *Cladosporium*, while white, pink and purple mold growth often is associated with *Fusarium* (Figure 42).

Management of ear molds includes using less susceptible hybrids, crop rotation, tillage (if appropriate), reducing insect damage, timely harvest of fields and proper storage of moldy grain (below 50 F and below 15% moisture).

Figure 42. Ear damaged by hail and insects with colonization by Fusarium (white fluffy growth). Green-black growth is another fungal saprophyte. (A. Friskop, NDSU)

Stalk Rots

Stalk rots occur to some extent in North Dakota each year. Fungi are common causes of stalk rots, with *Fusarium* and *Giberella* being the most important stalk rots in North Dakota. Infection occurs through roots and wounds on the stalks or near leaf attachments. Disease development is favored by crop stressors, including water stress, nutrient deficiency and other biotic or abiotic factors.

Symptoms of stalk rot include premature lodging in the field, discoloration of stalk tissue near the internodes and shredding of stalk (pith) tissue (Figure 43). Yield losses occur due to poor filling of ears, early ear drop and stalk breakage. Management includes reducing crop stress, selection of hybrids with good standability (stalk strength), and prioritizing harvest on fields with severe lodging.

Figure 43. From left: Corn stalk compromised by fungal pathogen next to healthy corn stalk. Note pith degradation of infected stalk. (A. Friskop, NDSU)

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 dry bean, soybean, sunflower or canola, so alternating corn with these crops helps break the disease cycles.

Corn has some important and damaging diseases in common with small-grain crops. Gibberella (*Fusarium graminearum*) stalk rot of corn is caused by the same fungus that causes head scab in small grains.

This fungus survives very well on corn residue and is a source of inoculum for 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, humid weather occurs during the heading and flowering stages of small grains. Avoiding corn-on-corn systems will help reduce risk for residue borne diseases such as NCLB and Goss' wilt.

Harvesting Grain Corn

Estimating Corn Grain Yield

Prior to harvest, estimating yield may be useful. You have 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.

The steps of this method are:

Step 1. Count the number of harvestable ears in a row length equivalent of 1/1000 acre.

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 the butt or tip that are less than half-size. Calculate the average.

Step 4. Use values in previous steps in the following formula.

$$\text{Yield (bushels per acre)} = \frac{[(\text{number of ears}) \times (\text{number of rows}) \times (\text{number of kernels/row})]}{90}$$

A numerical constant for kernel weight is figured into the equation to calculate grain yield. Because weight per kernel will vary depending on hybrid and environment, the yield equation should be used only to estimate relative grain yield. For example, grain yield will be overestimated 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

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%, with no drying required. Corn grain will spoil and you have a potential of a silo fire if corn is stored in a silo at moisture contents below 25%. Grain corn can be stored at moisture contents up to about 23% if kept near or below freezing.

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

The optimum moisture content for limiting mechanical damage during harvest is about 22%. Increased damage occurs below and above this moisture content. Harvesting at moisture contents of 30% and above results in poor kernel separation from the cob. Combining at moisture contents of 15% or lower results in high levels of cracked and broken kernels.

Combine cylinder speed and cylinder-concave clearance also are important factors determining mechanical damage at harvest. Damage increases significantly with increasing cylinder speed. Your best option usually is to follow the recommendations in the operators 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, ¾-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%. If harvest conditions are excellent, a good operator should be able to keep losses well below 3%. 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% 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 ¾-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 (Figure 44).

Loss of ears can be reduced only 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.

Figure 44. Excessive cob loss prior to or at harvest evident in a field where residue was burned in the spring prior to planting.
(J. Ransom, NDSU)

Drying and 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% for short-term storage during winter and to 13.5% for long-term storage. Corn at moisture contents up to about 22% can be stored if the corn temperature is maintained below 30 degrees.

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 in northern states to minimize moisture migration and enhance storability.

Stored grain should be checked at least every two weeks if the corn temperature is above 30 degrees, and at least monthly while corn and outside temperatures average below freezing. 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 from a high-temperature dryer, the meter will give an erroneously low reading.

A temperature adjustment must be used, either manually or automatically by the meter, if the sample is not at the standard temperature, which is usually about 75 degrees. A moisture meter should be checked periodically against a reference, such as where the grain is marketed or other meters, to assure that accurate readings are being provided.

Accurately measuring the moisture content of hot grain is difficult. Your best option is 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.

This is only an estimate because 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, you need to keep the corn cool. An aeration system delivering a uniform airflow of about 0.25 to 0.5 cubic feet per minute per bushel (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 23. The allowable storage time is approximately doubled by reducing the corn temperature by 10 degrees.

Table 23. Approximate allowable storage time for shelled corn based on 0.5% maximum dry-matter loss.
(Transactions ASAE 333-337, 1972.)

Grain Temp.	Corn Grain Moisture (%)						
	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 vary 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 overdried. Other dryers use grain diverters or multiple metering rollers to vary the flow of corn across the drying column.

In multistage, 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 among 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 cooling 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 that 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 3- to 4-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 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.

However, variations occur 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 also will increase the airflow, which increases the drying speed. Stirring allows grain depths of up to 6 to 8 feet.

Grain stirrers tend to sift fine materials to the bin floor, so cleaning the bin floor periodically is important.

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 damage to 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% energy savings and a 50% to 75% increase in dryer capacity.

The dryer capacity increases because the corn is dried only to about 17.5% 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 and is allowed to temper without airflow for four to six hours, then is cooled during a 12- to 24-hour period. Condensation forms along the bin wall, which rewets some corn during the tempering period and extensive condensation occurs on the bin roof during cooling, which drips onto the corn.

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.

Condensation also will occur on the bin roof and drip onto the corn. The amount of condensation is related to the temperature difference between corn temperature and the outdoor temperature. Condensation can be reduced by partially cooling the corn in the dryer and not doing in-storage cooling when outside temperatures are about 40 degrees or colder.

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%.

An airflow rate of at least 1.25 cfm/bu will dry 21% moisture content corn to about 15% in about 36 days under average upper Midwest October conditions. Drying speed is related to the airflow rate, so at an airflow rate of 1 cfm/bu, drying will take about 45 days.

NA/LT drying works very well during October but is not efficient with typical mid- to late-November weather conditions. Natural air drying 21% moisture content corn to 18% under November conditions will take about 70 days with an airflow rate of 1.25 cfm/bu. Heating the November air by 5 degrees reduces the final corn moisture content to 14.6% moisture and reduces the drying time to 52 days.

However, because November has only 30 days, 43% of the corn still is not dried after running the fan and heater the entire month. Adding more heat will overdry the corn without substantially increasing the drying speed.

A stirring device in the bin is required if more than a 5-degree temperature rise is used. The drying fan will warm the air 3 to 5 degrees, depending on fan type and operating conditions. This needs to be considered in designing a system.

Corn can be held during winter and dried in the spring. Based on average late-April conditions when the average temperature exceeds about 40 degrees, 21% moisture corn can be dried to about 15% in 41 days using an airflow rate of 1 cfm/bu. Based on average May conditions, the corn can be dried to about 13% moisture in 35 days using the same airflow rate.

This is a good option instead of drying during mid to 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 Corn Related Publications

- **Soil Fertility Recommendations for Corn** (SF722)
  www.ag.ndsu.edu/publications/crops/soil-fertility-recommendations-for-corn/sf722.pdf
- **North Dakota Weed Control Guide** (current year W253)
  www.ag.ndsu.edu/weeds/weed-control-guides/nd-weed-control-guide-1
- **North Dakota Field Crop Insect Management Guide** (current year E1143)
  www.ag.ndsu.edu/publications/crops/north-dakota-field-crop-insect-management-guide
- **North Dakota Field Crop Plant Disease Management Guide** (current year PP622)
  www.ag.ndsu.edu/publications/crops/2018-north-dakota-field-crp-plant-disease-management-guide
- **North Dakota Corn Hybrid Testing** (current year A793)
  www.ag.ndsu.edu/varietytrialS/corn
- **The Armyworm and the Army Cutworm** (E830)
  www.ag.ndsu.edu/publications/crops/the-armyworm-and-the-army-cutworm
- **Integrated Pest Management of Corn Rootworms in North Dakota** (E1852)
  www.ag.ndsu.edu/publications/crops/integrated-pest-management-of-corn-rootworms-in-north-dakota/e1852.pdf
- **Corn Ear Molds: Basic Questions and Answers** (PP1451)
  www.ag.ndsu.edu/publications/crops/corn-ear-molds-basic-questions-and-answers

- **Corn Response to Phosphorus Starter Fertilizer in North Dakota** (A1851)
  www.ag.ndsu.edu/publications/crops/corn-response-to-phosphorus-starter-fertilizer-in-north-dakota
- **Utilizing Corn Residue in Beef Cattle Diets** (AS1548)
  www.ag.ndsu.edu/publications/livestock/utilizing-corn-residue-in-beef-cattle-diets
- **Harvesting, Storing and Feeding High-moisture Corn** (A1484)
  www.ag.ndsu.edu/publications/livestock/harvesting-storing-and-feeding-high-moisture-corn
- **Corn Growth and Management Quick Guide** (A1173)
  www.ag.ndsu.edu/publications/landing-pages/crops/corn-growth-and-management-quick-guide-a-1173
- **Grain Drying** (AE701)
  www.ag.ndsu.edu/publications/crops/grain-drying/ae701-grain-drying.pdf
- **Grain Drying and Storage** (NDSU Extension website)
  www.ag.ndsu.edu/graindrying

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