COLORADO STATE UNIVERSITY
EXTENSION

COLORADO CORN

Best Management Practices For Colorado Farms

Best Management Practices for Colorado Corn
June 2020
Extension Bulletin XCM574A

AGRICULTURAL
WATER QUALITY
PROGRAM

Principal authors:
Troy Bauder, Extension Specialist, Colorado State University
Erik Wardle, Agricultural Water Quality Program Manager, Colorado State University
Reagan Waskom, Director of the Water Institute, Colorado State University

Contributing authors:
Kirk Broders, Colorado State University
Todd Gains, Colorado State University
Frank Peairs, Colorado State University
Joel Schneekloth, Colorado State University

In association with:
Colorado Corn Growers Association
Agricultural Water Quality Program
Colorado Department of Agriculture
Colorado Department of Public Health and Environment

Special acknowledgement to the following reviewers:
Bruce Bosley, Colorado State University Extension
Ron Meyer, Colorado State University Extension
Thia Walker, Pesticide Education Safety Specialist
Robert P. Wawrzynski, Colorado Department of Agriculture
Phil Westra, Colorado State University Extension

Layout:
Jessica Potter, Colorado Department of Agriculture

Editors:
Diane DeJong, Colorado State University
Christina Welch, Colorado State University

Published by Colorado State University Extension in cooperation with Colorado Department of Agriculture June 2020.

TABLE OF CONTENTS

INTRODUCTION

Corn is an amazing plant – its ability to transform sunlight, water, and carbon into grain and biomass is astoundingly efficient. Grain yields of over 500 bushels per acre have been documented in the U.S. Corn growers are pretty amazing, too – they use their management and production skills to produce over 160 million bushels of grain and 3.3 million tons of silage each year in Colorado on a little over 1.3 million acres[1].

Each year Colorado corn growers face a variety of production challenges, including pests and environmental stresses that can limit yields. Stressors include drought, heat, cold, hail, insects, weeds, as well as soil and plant borne diseases. As stewards of the land, crops, and livestock they raise, growers continually watch for these and other potential problems. Being able to recognize and correct or control problems before they cause economic yield losses is paramount.

U.S. growers are producing higher yields on fewer acres with fewer inputs per bushel. As a result, consumers in the U.S. continue to enjoy plentiful, high quality food, fiber, and fuel at a lower price point than most places in the world. At the same time, consumers say that they increasingly base their purchasing decisions on “evolving drivers” - health and wellness, safety, social impact, experience, and transparency. Thus, growers face increased scrutiny in their fertilizer, pesticide, manure, and irrigation practices. Regulatory agencies and others are evaluating agriculture’s contribution to nonpoint source pollution and how it can best be controlled. Fortunately, research has helped to develop tools that corn growers use to produce their crops in ways that improve their potential for profitability, while still protecting the environment.

Best management practices (BMPs) are production methods, structures, and management practices designed to protect water quality while maintaining economic returns. Voluntary adoption of these practices by corn producers will help prevent contamination of water resources, improve public perception of the industry, and perhaps eliminate the need for further regulation and mandatory controls.

Specialists at Colorado State University developed this guide as a tool for producers to use in diagnosing and solving common production problems. It is not designed to replace expert advice from crop consultants or to replace more in-depth resource materials, but rather to help recognize and mitigate corn problems as they appear in the field during the growing season. Additionally, this guide is intended to heighten awareness of the water quality benefits that can be obtained by selecting the appropriate combination of best management practices for each individual farm.

The Colorado Corn Growers Association encourages producers to enhance their stewardship of land and water resources and has supported the development of this guide. To obtain a copy or to provide input, contact:

CSU Water Quality Program
Soil and Crop Science Dept.
Colorado State University
(970) 491-0447
waterquality.colostate.edu

---

1. Colorado Annual Bulletin, 2017 USDA National Agricultural Statistics Service; Values from 2016.

Best Management Practices

Best management practices (BMPs) are production methods, structures, and management practices designed to protect water quality while maintaining economic returns. Voluntary adoption of these practices by corn producers will help prevent contamination of water resources, improve public perception of the industry, and perhaps eliminate the need for further regulation and mandatory controls.

HYBRID SELECTION

Colorado corn production records date back to 1879, when Colorado farmers planted 23,000 acres and yields averaged about 20 bushels per acre. In 2015, there were over one million acres of hybrid corn planted in Colorado, with some yields exceeding 300 bushels per acre.

Most yield gain is due to improved genetics. Producers must continually adopt new hybrids on their farms to stay competitive. The right combination of well-adapted corn hybrids is fundamental to a profitable corn production system.

Selecting Hybrids

When choosing hybrids, consider varieties based on at least the past two years' performance over a range of locations and climatic conditions, because conditions change from year to year. Growers can reference the Colorado State University Corn Performance Trials to choose from the highest yielding hybrids at extsoilcrop.colostate.edu/CropVar/corn, or obtain data from their local seed dealers.

On-farm hybrid tests can also be useful in evaluating hybrid performance characteristics such as lodging, dry down, harvestability, and disease and insect resistance, however, on-farm tests are considered less reliable for yield results. Results of on-farm strip tests can be statistically reliable for determining yield performance, provided there are 10 or more different locations of the strip tests.

In limited water situations, consider results from both dryland and irrigated variety trials. If a variety performs well in both dryland and irrigated conditions, it will usually perform well in limited water situations.

General important hybrid selection factors include:

- Yield potential and consistency
- Maturity
- Stalk quality
- Disease and insect resistance
- Root lodging resistance
- Drydown

Corn Market Classes

Dent Corn – yellow or white, it's the majority of corn grown in the U.S. Dent corn is used to make ethanol fuel, corn syrup and sweeteners, corn starch, and industrial products.

Sweet Corn – primarily used for human consumption because it contains more sugar than other types of corn and is harvested when the plant is still immature and the kernels are soft. Corn-on-the-cob and canned corn are sweet corn.

Popcorn – a special kind of corn with a hard outer layer that allows enough pressure to build within the kernel so that it "pops" when heated when the moisture inside the kernel turns to steam.

Specific-trait Corn – includes blue, white, high-oil, waxy, high-amylose, high fermentable, and other corns used in the production of food products such as corn bread and tortillas. These corn hybrids are grown for their specific milling, baking, biofuel, or nutritional characteristics.

Seed company field trial with different hybrid maturities.

Dryland Considerations

Season length is a primary factor in yield potential, when water is not limiting. However, when relying on natural precipitation, water limits yield potential, not season length. Thus, shorter and mid-season hybrids are typically recommended for dryland. Choose hybrids that develop their leaf area slowly, as these tend to minimize early season water use.

The increase in dryland corn acreage during the past decade has improved the information available for making better hybrid decisions for non-irrigated production. The Crops Testing Program at CSU has conducted dryland trials since 1995, with private companies also now putting more emphasis on testing hybrids suited for non-irrigated production.

Bt Hybrid Selection Guidelines

- Know which hybrids are conventional, approved for EU export, or not yet approved for EU export. Take seed company-grower agreements seriously and be aware of all requirements.
- Select hybrids that will work well in the area. The added Bt traits should not affect hybrid performance.
- Ask for insect control data that are specific for the Bt “events” a hybrid contains. It is better to compare insect control by event rather than by hybrid.

Genetically Engineered Hybrids

Genetically engineered hybrids, also known as genetically modified organisms (GMO), give growers additional tools for managing pests and may soon offer other value-added traits. Seed companies insert genes into several hybrids for a number of traits, such as herbicide tolerance or resistance to a common pest like European corn borer (ECB). Presently, consumer resistance to genetically modified crops limits the potential market for corn grain in Europe and other places. However, the advent of herbicide-resistant corn hybrids has been rapidly accepted in the U.S., because it gives growers expanded weed control options. In some cases, these hybrids reduce pesticide applications and allow the use of more environmentally friendly chemicals.

Bt Corn

Corn hybrids with one or more Bt genes are known as “Bt corn.” These hybrids contain inserted genes from the soil inhabiting bacteria *Bacillus thuringiensis* (Bt), that produces an insecticidal protein. There are many different Bt corn hybrids available that can offer variable control to corn borers and other corn insect pests. Using Bt hybrids can reduce or eliminate the need for insecticide applications.

As mandated by the EPA, Bt corn growers must implement insect resistance management practices to preserve the usefulness of the Bt toxin for pest management. The primary resistance mitigation measure for Bt crops has been the use of refuges. A refuge is a prescribed portion of the total acreage planted to a non-Bt variety. A refuge helps prevent resistance by maintaining an insect population that is susceptible to the Bt protein. If or when a resistant adult insect should emerge, it is likely that it would mate with susceptible insects and produce vulnerable offspring.

The use of Bt hybrids is a profitable and effective approach to European corn borer (ECB) management in years of heavy corn borer activity and in areas with consistent year-to-year activity. However, research and experience shows that using non-Bt hybrids with insect scouting and properly timed insecticide applications is also a profitable and effective approach to managing ECB.

The most likely zone in eastern Colorado for profitable use of Bt corn hybrids to control ECB is the Eckley, Wray, and Wuaneta areas. These hybrids are also a good choice for late-planted or late-maturing crops in the Yuma, Clarkville, and Holyoke areas. Using superior non-Bt hybrids, along with proper scouting and timed insecticide application, is more profitable in the Burlington, Bonny Dam, and Kirk areas.

Bt "events" targeting corn rootworm, corn borers, western bean cutworm, and several other caterpillar species are available. No events are available for spider mites. (Table 1) shows the major Colorado corn insect pests and the expected effect of commercially available Bt events.

Hybrid Maturity

Long-term studies show a clear yield and profit advantage for growing full-season hybrids that use the entire growing season to reach maturity when adequate moisture is available. Shorter season hybrids may be used to vary pollination dates, reducing potential environmental stresses such as high air temperatures, drought, and low soil water availability. Planting hybrids with different maturities ensures further genetic diversity in the crop, which can minimize certain pest problems or environmental stresses for which no specific resistance or tolerance is available.

Ideally, grain corn reaches maturity (maximum kernel dry weight or "black layer") one to two weeks before the first killing frost in the fall. To compare maturity of corn hybrids, some companies use relative maturity (RM), while others use comparative relative maturity (CRM) ratings. A CRM rating is relative, such that a 110-day hybrid may take less than 100 days to reach black layer in a hot year, or more than 125 days during a cool growing season.

Growing degree units (GDU), also referred to as "heat units" or "growing degree days", are useful for making direct hybrid maturity comparisons across different seed companies. These units measure how much heat

Table 1. Major Corn Pests and Expected Effect With Bt Corn

Corn Pest	Effect
Armyworm	Variable
Corn rootworm adults	No control
Corn rootworm larvae	Control
Corn leaf aphid	No control
Corn earworm	Control
Cutworms	Variable
European corn borer	Control
Fall armyworm	Variable
Grasshoppers	No control
Southwestern corn borer	Control
Western bean cutworm	Variable
Wireworms	No control

Growing Degree Units (GDU)

- GDU= (Max. daily temp up to 86 degrees F) + (Min. daily temp)/2 – 50 degrees F
- Corn does not grow below 50 degrees F.
- Growth rate decreases above 86 degrees F.
- Growth rate increases with temperatures ranging from 50 to 86 degrees F.
- A corn plant must accumulate a certain amount of heat energy to reach maturity.
- The total amount of heat needed is relatively constant for a given hybrid.
- Corn hybrids with different maturities require different GDU.

Table 2. Colorado Growing Degree Units (GDU) and Comparative Relative Maturity (CRM) Relationship

GDU	CRM
2810	117
2680	112
2630	110
2550	105
2530	105
2450	100
2400	100
2350	97
2320	96

is accumulated for plant growth over a 24-hour period. Cumulative GDU from planting date to black layer are used to indicate the maturity requirement of a given hybrid and can be used for valid comparison from year to year under different climatic conditions. Be aware that hybrids are often rated for GDU to silk, black layer, and 20% grain moisture.

On Colorado's eastern plains, full-season hybrids generally require 2,700 GDU to reach maturity, medium-season hybrids need 2,500 GDU, and early-season hybrids require 2,300 GDU. To get more localized GDU information, weather station data can be found at coagmet.com.

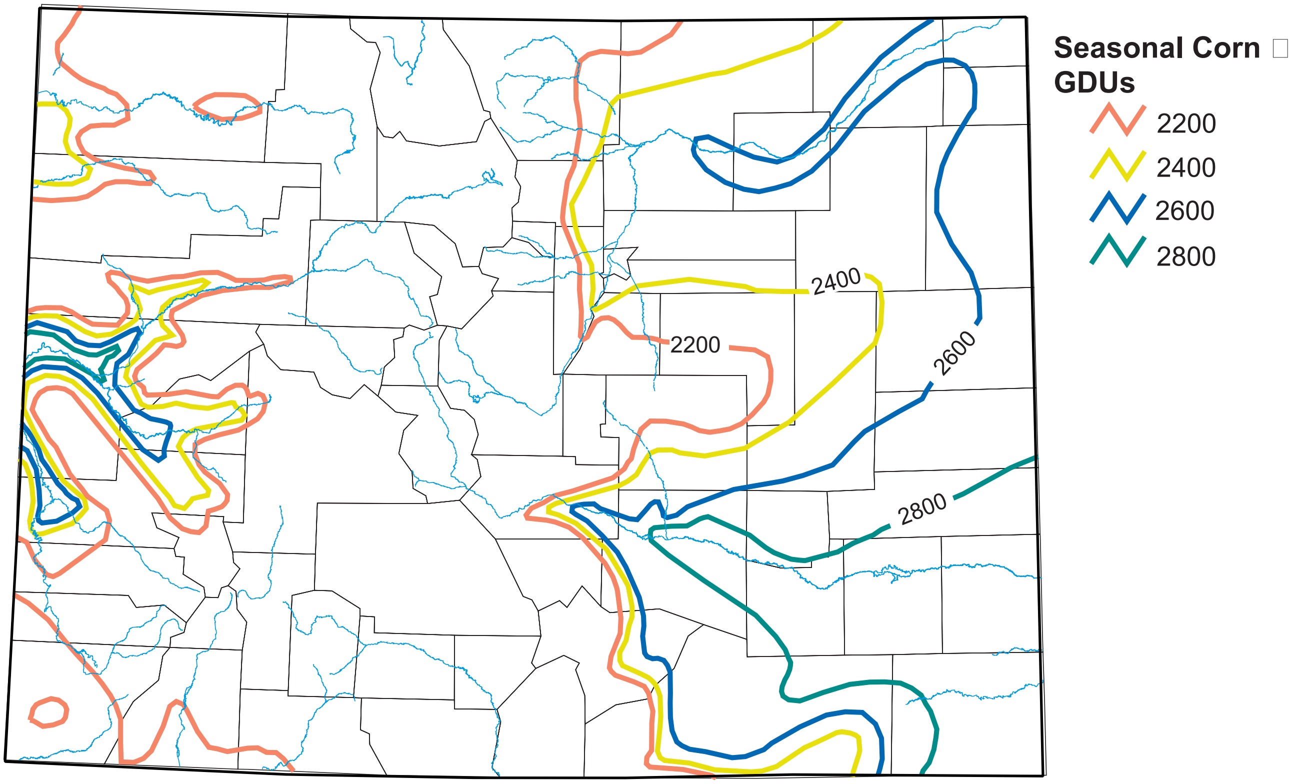


Figure 1. Average GDU for Colorado corn-growing regions.

PLANTING GUIDE

Optimum Planting Date

The optimum planting date (Table 3) is a small window of days expected to achieve the longest effective growing season in the area. The given range is based on long-term weather records of both the average spring frost free date and an average fall killing frost date. In order to manage field work and unpredictable spring weather, begin planting slightly before the optimum planting date.

Planting at the optimum time results in earlier plant emergence and ground cover, which increases competitiveness against later emerging weeds. Planting within optimum planting dates can help increase net returns without adding production costs. Earlier planted corn often has better stalk quality and may reduce the exposure to European corn borer, however, earlier planting may increase the chance of seedling blights.

In general, plant corn by the calendar, not soil temperature, since soil temperatures can fluctuate markedly in the spring. However, when soil temperatures are below 50 degrees F, little germination will occur. If planting is significantly delayed past the optimum date, yield potential is reduced (Figure 2) and a grower may want to reduce the nitrogen fertilizer applied, reduce seeding rates, and change to earlier maturing hybrids.

Table 3. Optimal Corn Planting Dates in Colorado

Region	Date Range
NE Plains	April 20 - May 15
SE Plains	April 15 - 30
W Slope Valleys	April 20 - May 10
S Platte	May 1 - 15
Front Range	May 1 - 20
Ark Valley	April 20 - May 5
E Plains Dryland	May 10 - June 1

Dryland Considerations

The optimum planting date for dryland corn is 10–14 days later than irrigated corn in Colorado, usually around the second week of May. Water availability, not season length, limits yield in dryland corn. Planting later may save soil water for later in the growing season.

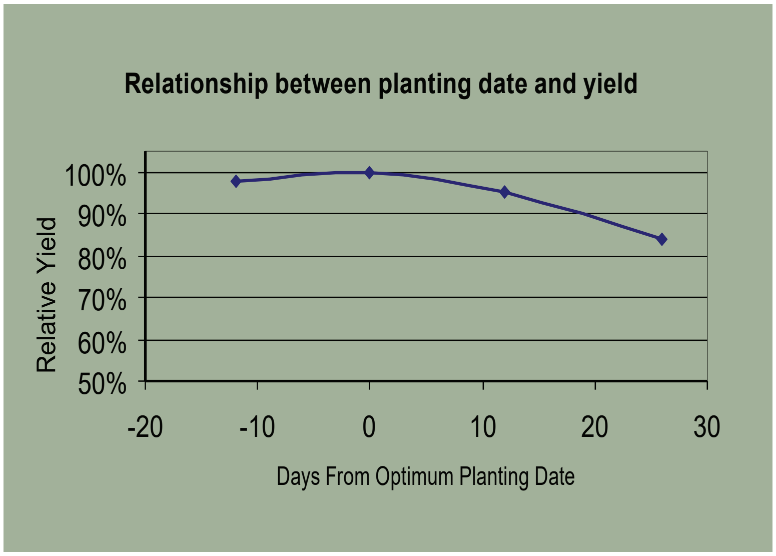


Figure 2. Relationship between planting date and yield.

Corn planter.

BMP

Adjust planting, tillage, and harvest dates to help minimize weed, insect, and disease problems.

Corn seedling damaged by frost.

If a killing frost prematurely kills a corn field, silage or grazing may be the only salvage strategies. However, always test for nitrates.

Applying starter fertilizer while planting in a reduced tillage system.

Spring Frost Damage

The severity of late spring frosts to corn depends on whether plants experience lethal cold temperatures, at or below 28 degrees F, or "simple" frost, warmer than 28 degrees F. Simple frost damage to corn is usually minor and limited to death of above-ground plant parts because the growing point of a corn plant remains below ground until about the five-leaf (V5) stage. Corn can easily recover from this type of damage early in its development and suffer little yield loss. When air temperatures drop to 28 degrees F or less for more than a few hours, the growing point region of a young corn plant can be injured or killed, even if it is still below the soil surface.

Yield loss due to early season frost damage in corn is related primarily to the degree of stand loss, not to the degree of leaf damage. Before assessing damage, allow the plants time to recover. While some corn leaves darken and wither within a day after frost occurs, the true extent of plant damage may not yet be discernible until three to five days after the frost.

Surviving corn plants should show new leaf tissue expanding from the whorls, while dead corn plants will show no growth. Examining the growing point of the plant will also help assess the damage. If the growing point has a white fleshy appearance, the plant will recover. If mushy and discolored, the plant is dead.

Late-Planted Corn

When wet spring weather significantly delays planting, or if replanting is necessary, switching to early- or medium-maturity hybrids may be justified. As planting is delayed, the yield difference among full-, medium-, and early-season groups becomes smaller. Full-season hybrids may not reach physiological maturity before the first fall frost with delayed planting. Frost before the grain reaches black layer results in lower yield, lower test weight, higher grain moisture levels, and lower grain quality. Consider switching to earlier-maturity hybrids when the calendar date is 20 or more days after the optimum planting date for the area. This is a critical decision that impacts producer risk and profitability, especially in areas of the state where shorter growing seasons may limit yield. Planting full-season hybrids too late incurs the risk of cool weather and fall frost damage before maturity, but switching to early-maturity hybrids too soon can result in lost yield and profit.

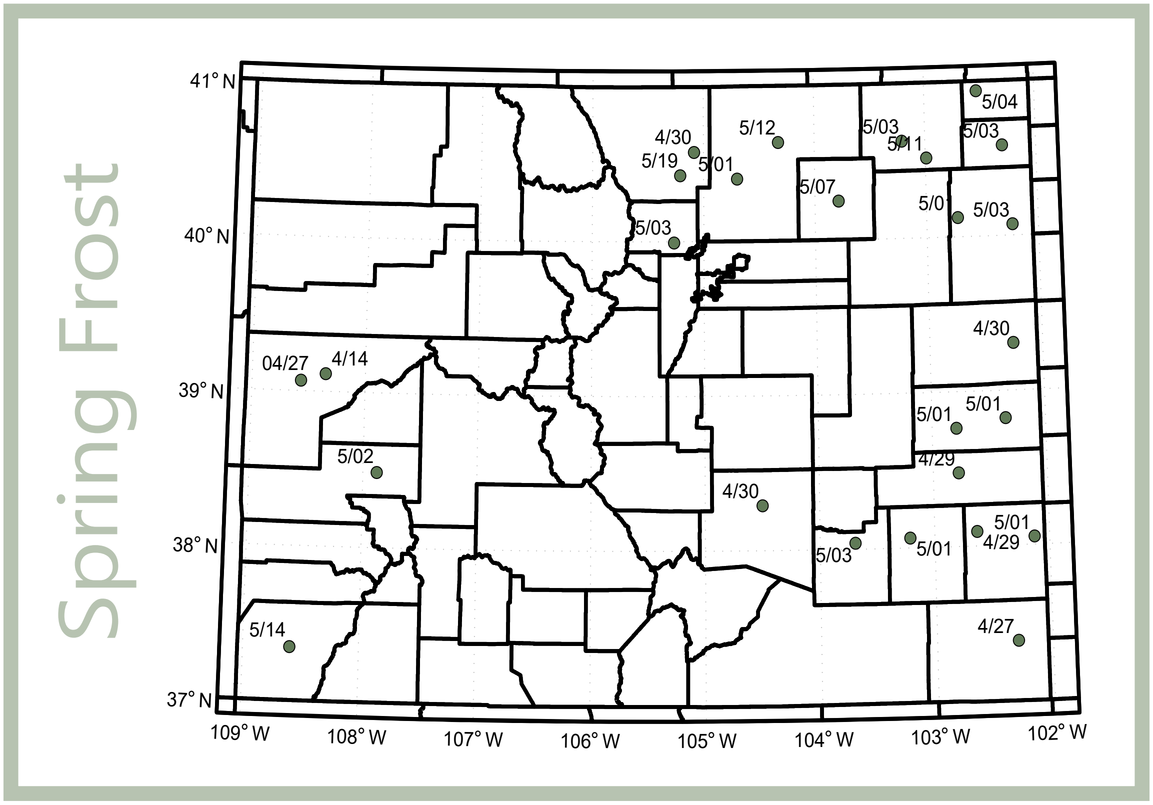


Figure 3. Average dates in Colorado for last spring killing frost (28 degrees F). An 80% probability exists that the last spring killing frost will occur on or before these dates.

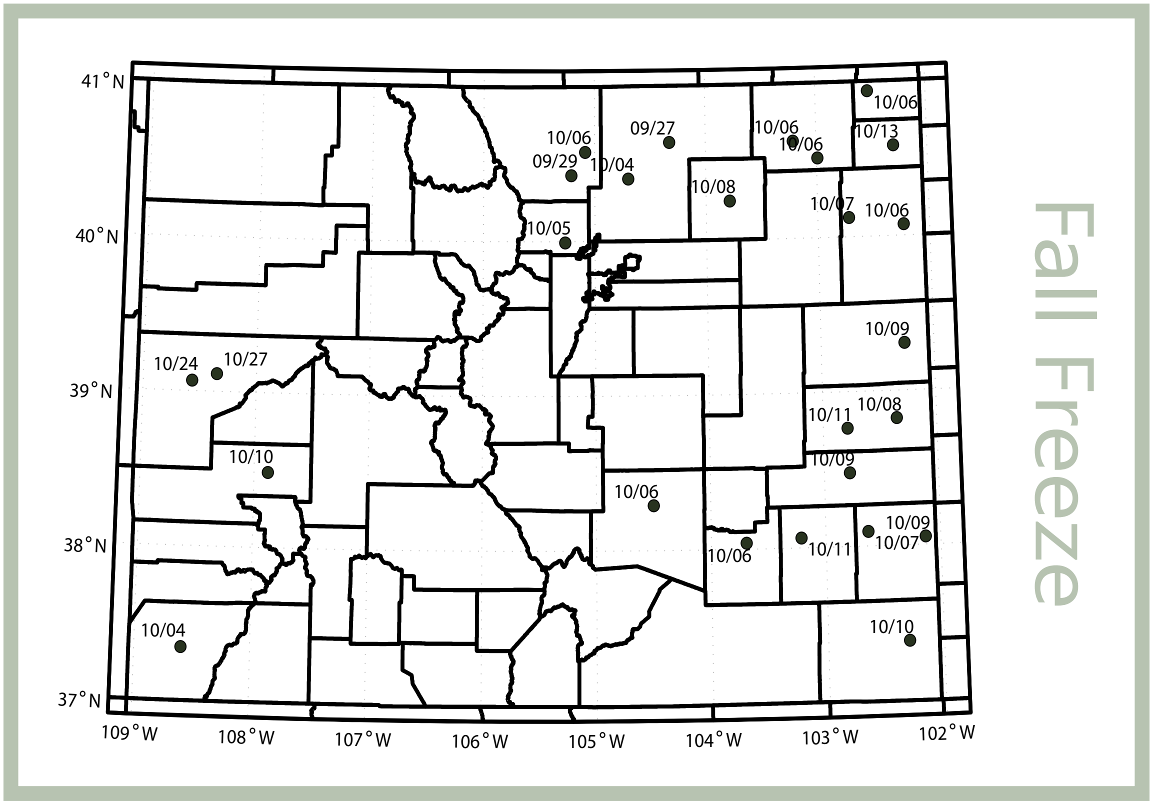


Figure 4. Average dates in Colorado for first fall freeze (28 degrees F). An 80% probability exists that the first fall killing frost will occur by these dates.

Plant Population

The best place to get the correct plant population for a given hybrid is from your seed dealer. Many irrigated operations routinely plant between 30,000 – 38,000 seeds per acre. Some success has been achieved with higher seeding rates on very productive fields with high yield potential. Optimum plant population can be field-specific and should be adjusted according to other factors that impact yield such as yield history, fertility, weed pressure, flex ear ability, and irrigation. For most growers, the risk of planting too few seeds is greater than planting too many. Modern hybrids generally handle crowding of higher populations well, but seed costs are a critical consideration when looking at higher populations (Barr et al., 2013; Xue et al., 2017).

Population planting guidelines:

- In general, plant 5% to 10% more seeds than the target population to compensate for germination or seedling losses.
- Boost target plant populations by 10% to 15% when planting early-maturity hybrids or for silage corn.
- Increase planting rates up to 15% above target stands when planting into poor seedbed conditions, or very early planting into cold soils
- Know general regional soil and climatic conditions and make adjustments to plant populations based on the risk of severe soil moisture deficiency. Consult your seed representative to help fine-tune planting rates for current local conditions.
- Maintain the planter by replacing worn parts and by making adjustments to plant at the desired population with consistent seed spacing.
- Consider using planter monitoring technology, such as seed drop monitors, that can provide in-cab data on skips, doubles, population, and row unit performance.

Counting Plant Population

When planting 30-inch rows: 1/1000 of an acre equals 17 feet 5 inches. This means the number of seeds counted in a planted length of 17 feet 5 inches, multiplied times 1,000, will equal the number of seeds planted per acre (Ex: 26 seeds counted = 26,000 seeds/acre.)

Increasing seed depth as little as a 0.5 inch can often eliminate uneven emergence when seed zone soil moisture is marginal.

In Colorado, there is little research-based evidence that row spacing narrower than 30 inches will increase yields enough to offset the costs of switching to narrower rows.

Dryland Considerations

Skip row planting may be an option as a drought strategy.

Seed Depth

Proper planting depth for seed corn is 1.5 to 2.5 inches. However, herbicide, soil condition and moisture, and planting date can alter this ideal range slightly shallower or deeper. Planting depths below 3 inches may result in significant yield loss. It is especially critical to make sure seed is planted into moisture. Check and calibrate the planter before planting season starts and then check seed drop and depth several times during each day of planting. Some agribusinesses offer planter unit calibration clinics to provide assistance with checking planter equipment.

Narrow Row Spacing

Corn planted in narrow rows — 22, 20, or 15 inches of space between rows — has the potential to produce higher yields in highly productive environments. The yield advantage associated with growing corn in narrow rows ranges from about 8% in the northern areas of the Corn Belt to almost no change in the southern Corn Belt. More recent research in the Corn Belt has shown little evidence of consistent yield benefits from narrow rows. However, other benefits may be worth consideration, such as quicker canopy close and associated weed control benefits (Barr et al., 2013).

Before changing row spacing, consider factors such as: number of corn acres, yield level, potential increase in yield, tire size, equipment size, and age and condition of current equipment. Costs of switching to narrower spacing must be offset by increased yields and increased net returns.

General Planting Considerations

Planting in a strip-till field.

- Adjust harvest, tillage, and planting equipment under conditions of substantial surface crop residue so that residue cover is distributed uniformly over the row area after planting. Well-adjusted row cleaners on planters can help ensure uniform stands.
- Create as little surface compaction as possible prior to planting.
- Avoid working wet ground and creating cloddy seedbeds.
- Don't plant earlier than normal. Seed fungicide treatments only provide 10–14 days of protection under "normal" conditions.
- Plant the best quality seed lots first.
- Plant the best (highest yielding) fields first.
- Use recommended herbicide application rates to avoid corn injury.
- Consider seed-applied or planter-applied insecticide for protection against wireworm and seedcorn maggot if their presence is certain. Check bag label for seed treatment applied.
- If soil conditions are unusually dry at planting, aim for a seeding depth that maximizes soil moisture uniformity in the seed furrow.
- After planting, closely monitor corn emergence and rotary hoe if soil crusting prevents uniform corn emergence.

Uneven Emergence

Uneven stands typically yield less than even stands due to competition of plants at two different growth stages next to one another. Older plants generally outcompete younger plants for light, water, and nutrients. In some cases, late-emerging plants are more vulnerable to silk clipping by corn rootworm beetles that can interrupt pollination and reduce kernel set on the ears.

To help prevent uneven emergence, avoid excessive tillage trips that dry or compact the seedbed. Check seed depth during planting in several areas of the field. If contact between seed and soil is poor or seeding depth isn't uniform, adjust seed openers and/or press-wheel pressure.

Slower planting speed may also improve uniformity. Approximately 5 mph is optimum for most conditions. A change in secondary tillage operations may improve soil conditions for more uniform planting.

Uneven emergence.

If one half or more of the plants in the stand emerge three weeks late or later, then replanting may increase yields by up to 10%. Base replant decision by comparing the estimated economic return of the increased yield to replanting costs and the risk of emergence problems with the replanted stand.

Filling in Poor Stands

If stand loss is 50% or greater, growers can either replant the whole field or fill in the existing stand and accept resulting uneven emergence. If growers can determine the final stand within two weeks after planting, filling in the existing stand may be an option.

Fill in new seed as uniformly as possible so yields will be similar to a replanted stand. If filling in a poor stand three weeks after the initial planting, yield potential is typically 10% less than replanting completely and starting over with an even-emerging stand. Balance possible yield increases against the additional cost of tillage, seed, and elevator dockage.

Evaluate non-uniform emergence by comparing growth stages. If the delay in emergence is less than two weeks, replanting will have minimal effect on yield, regardless of the uneven pattern.

Replanting and Late Emergence

Late-emerging plants have higher grain moisture content at harvest that can possibly result in harvested grain with varying moisture levels. Late plants also lodge more due to smaller stems, weaker stalks, and fewer brace roots. Adjusting settings on combines during harvest for variable ear sizes between early and late plants is difficult. However, problems range from minimal, with a 1.5-week delay in emergence, to serious, with a three-week emergence delay.

Nodal Root System

A healthy kernel, seed roots, and mesocotyl are vital until the nodal roots (permanent roots) are well established. Energy reserves from the kernel move through the connecting mesocotyl "pipeline" to the seedling's stalk and leaf tissues. If the mesocotyl or seed is damaged prior to substantial nodal root development, seedlings will either die or be severely stunted. The importance of the seed reserves and the mesocotyl declines as the nodal roots develop.

A healthy kernel, seed roots, and mesocotyl.

Corn stand establishment refers not only to the success of germination and emergence, but to critical initial formation of the nodal root system. Poorly established nodal roots leave the corn crop susceptible to various early season stresses that may injure the seedling, seed roots, and mesocotyl. Vigorous nodal root establishment is largely dependent on initial nodal root growth from about the two-leaf (V2) to six-leaf (V6) stages. Severe stress during this period can cause a healthy, emerging corn field to die or stunt over a few weeks.

Soil temperature and moisture content are two interacting factors that influence how early-season stress affects stand establishment. When early nodal root development is significantly delayed, other stress factors (especially soil insects and diseases) have more time to damage the seed and mesocotyl and injure or kill young seedlings.

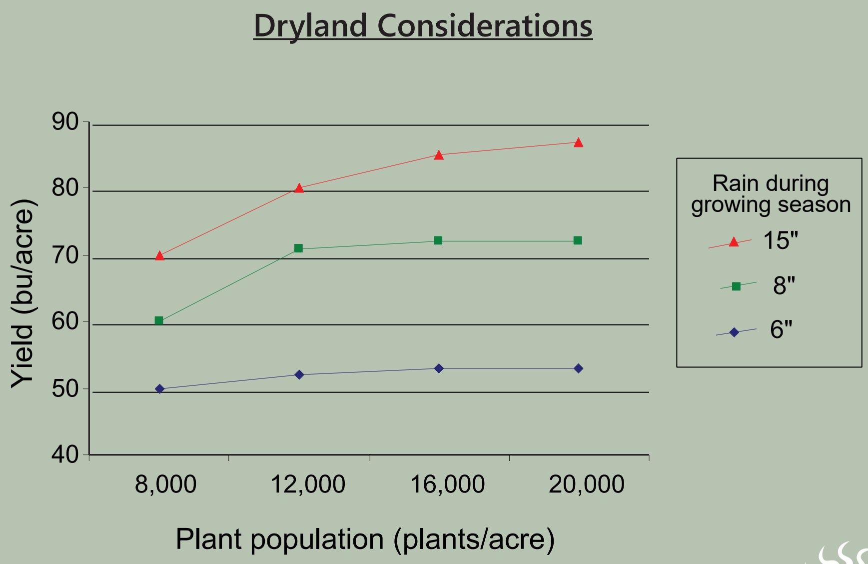


Figure 5. Dryland corn yield relationship to plant population and rainfall.

Stresses that affect nodal root formation include:

- below-ground insect feeding (wireworm, seedcorn maggot, grub)
- seedling blights
- seed rots
- fertilizer injury (starter fertilizer, anhydrous ammonia)
- excessively dry or wet soils

Growth Stages & Diagnostics

Diagnosing Corn Health

Top corn yields are achieved by providing optimum inputs to match growing conditions and by avoiding yield losses from pests and other abiotic stresses. Weeds, diseases, insects, nematodes, water stress, cultivator damage, wind, compaction, salinity, and herbicide damage are only a few of the routine problems growers may encounter in any given year.

While good management can help to avoid some of these problems, the best way to avoid yield loss is to scout corn fields regularly and correctly diagnose problems. Early and correct diagnosis allows producers to manage problems before they cause economic losses. This chapter is intended to help growers diagnose problems at certain growth stages to improve management of pests and other yield-limiting factors.

Supplemental information to help diagnose includes:

- Tissue samples of affected and healthy plants
- Images of affected and healthy plants
- Soil samples for salinity, nematodes, and nutrients
- Soil probes for compaction and moisture levels
- Irrigation water samples for salinity and toxins

Healthy corn field.

Table 4. Flowchart for Identifying Crop Problems and Defining Crop Needs

Determine normal corn characteristics and appearance for each growth stage. Describe the abnormality and note symptoms and signs.		
	Non-living	Living
Determine causes		
	Mechanical (tillage), physical (climate), or chemical (pesticide, fertilizer).	Disease, nematodes, insects, or mites.
Determine patterns		
	Uniform damage over a large area and/or uniform patterns on individual plants or plant parts.	Scattered damage on one or only a few plants.
Determine time sequence		
	Damage does not spread to other parts of the plant or to other plants. There is a clear line between healthy and damaged tissue.	Progressive spread over plant, onto other plants or over an area with time.

Growth Stage Determination

From the moment a corn seed is planted, it undergoes continuous biochemical and physiological changes until harvest. Understanding corn growth and development is valuable for making correct management decisions at specific growth stages throughout the growing season.

This book uses the "leaf collar" system to describe growth stages. This method divides growth stages between vegetative and reproductive stages (Table 5).

Table 5. Leaf Collar System for Corn Growth Stages

Vegetative Stages	
VE	Emergence
V1	First leaf
V2	Second leaf
V(3-22)	3rd-22nd leaf
VT	Tassel

Reproductive Stages	
R1	Silking
R2	Blister
R3	Milk
R4	Dough
R5	Dent
R6	Maturity or black layer

The vegetative stages are based upon the number of fully exposed leaves with collars. The collar appears as a light green line on the back of the leaf between the leaf blade and the sheath. Normally a plant at a given growth stage will have additional leaves partially visible, but without distinct collars. The reproductive stages are identified by the development of the kernel and its parts.

Due to variability in soil type, moisture, and even planting date, all plants in a given field will not be at the same stage at the same time. A field is considered at a given stage when 50% or more of the plants are in or beyond a given stage.

The leaf collar system is different from the system used by National Crop Insurance Service hail adjustors, often called the "horizontal leaf system" or "droopy leaf system." This system typically will be one to two leaf stages greater than the leaf collar system for the same plant.

Figure 6. V3 three-leaf stage.

Planting to Emergence

Corn begins germination when the primary root or radicle first emerges from the swollen seed, which under favorable conditions will occur within 24 to 36 hours after planting. Emergence can occur in four to five days after planting in warm, moist soils, but may take two weeks or longer when soils are cool or dry.

The first plant part emerging though the soil surface is the *coleoptile*. The plant above ground grows from the embryonic plant, or *plumule*, contained in the *coleoptile*. Once in sunlight, elongation of the *coleoptile* stops and new leaves emerge from the tip. The growing point, or stem apex, of the plant remains protected 1.0 to 1.5 inches below ground until the V6 growth stage. The *radicle* and the *lateral seminal roots* develop directly from the seed. The l*ateral seminal roots* will make up only a fraction of the total root system, but are significant until the *primary root system*, often called *nodal* or *crown*, develops. The *primary root system* begins to develop at V1 approximately 1.0 to 1.5 inches below ground.

Corn seedling emerging through crust.

Table 6. <u>Troubleshooting Planting to Emergence</u>

Symptom	Possible Cause
Seed missing	
	Planter skips
	Eaten by birds, rodents, or other animals
Seed does not germinate	
	Poor seed quality
	Cold soil temperature
	Planted in dry soil
	Poor seed bed
	Poor seed-to-soil contact
	Seed rot
Seed germinates, but doesn't emerge	
	Fertilizer burn
	Damping off
	Seed planted too deep in cold, wet soil
	Soil crusting due to rain or high sodium
	Chemical injury
	Seedcorn maggot
	Seedcorn beetle
	Wireworm
	Rodents or birds
	soil pathogens

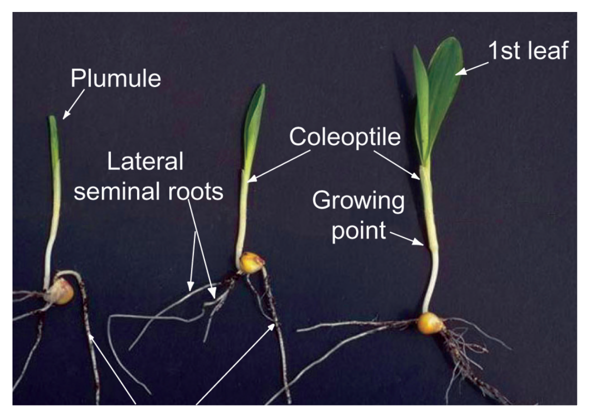


Figure 7. Early corn plant development.

Planting – VE Management Tips

Band nutrients, especially phosphorus, to help early plant vigor when cool soil and a small root system can slow growth.

Consider soil temperature when deciding whether to irrigate and cultivate. Drier soil warms up faster during the day, but does not retain heat at night as well as moist soil, which may impact the severity of an early season frost.

Emergence to Knee-High

Corn at the V3 growth stage has three clearly visible leaf collars. Little stem elongation has taken place and the seminal root system has ceased growing. Ear and leaf shoots are forming and will be complete by V5. The growing point remains protected below the soil surface.

V3 three-leaf stage.

Knee-High

Depending on the hybrid, the V6 growth stage occurs when 400 to 650 growing degree units (GDU) have accumulated since planting. Due to differences in hybrid, soil fertility, weather, and other environmental factors, a V6 plant ranges from 8 to 24 inches.

VE – V6 Management Tips

Evaluate soil nitrogen needs (see page 68).

Scout for 1st generation corn borer larvae and egg masses.

Table 7. Troubleshooting Emergence to Knee-high

Symptom	Possible Cause
Physical injury	
	Early hail
	Lightning
	Cutworm, army cutworm, pale western cutworm, white grubs, false cinch bugs, thrips, grasshoppers
	Onion wrapping or buggy whip
	wind damage
Poor vigor and slow growth	
	Weather conditions
	Soil compaction
	Nematodes, wireworm, rootworms, and other root-feeding insects
	Shallow-planted corn, compacted soil that leads to rootless corn syndrome
	Nutrient deficiencies of N, P, or Fe
	Cool temperatures causing purple corn
	Drought
	Excessive moisture
	Weeds

V6 six-leaf stage.

With six visible leaf collars, the V6 plant has a more elongated stalk than previous stages and will begin rapid growth and nutrient uptake. The nodal root system is now developing rapidly and is the major source of water and nutrients. The growing point and tassel are now above ground and can be damaged by hail, frost, or other weather damage.

V6 – V10 Management Tips

Although water demand is increasing, the soil can be allowed to deplete to 60% of available water.

At V10, a corn plant can undergo some water stress without significantly impacting grain yield.

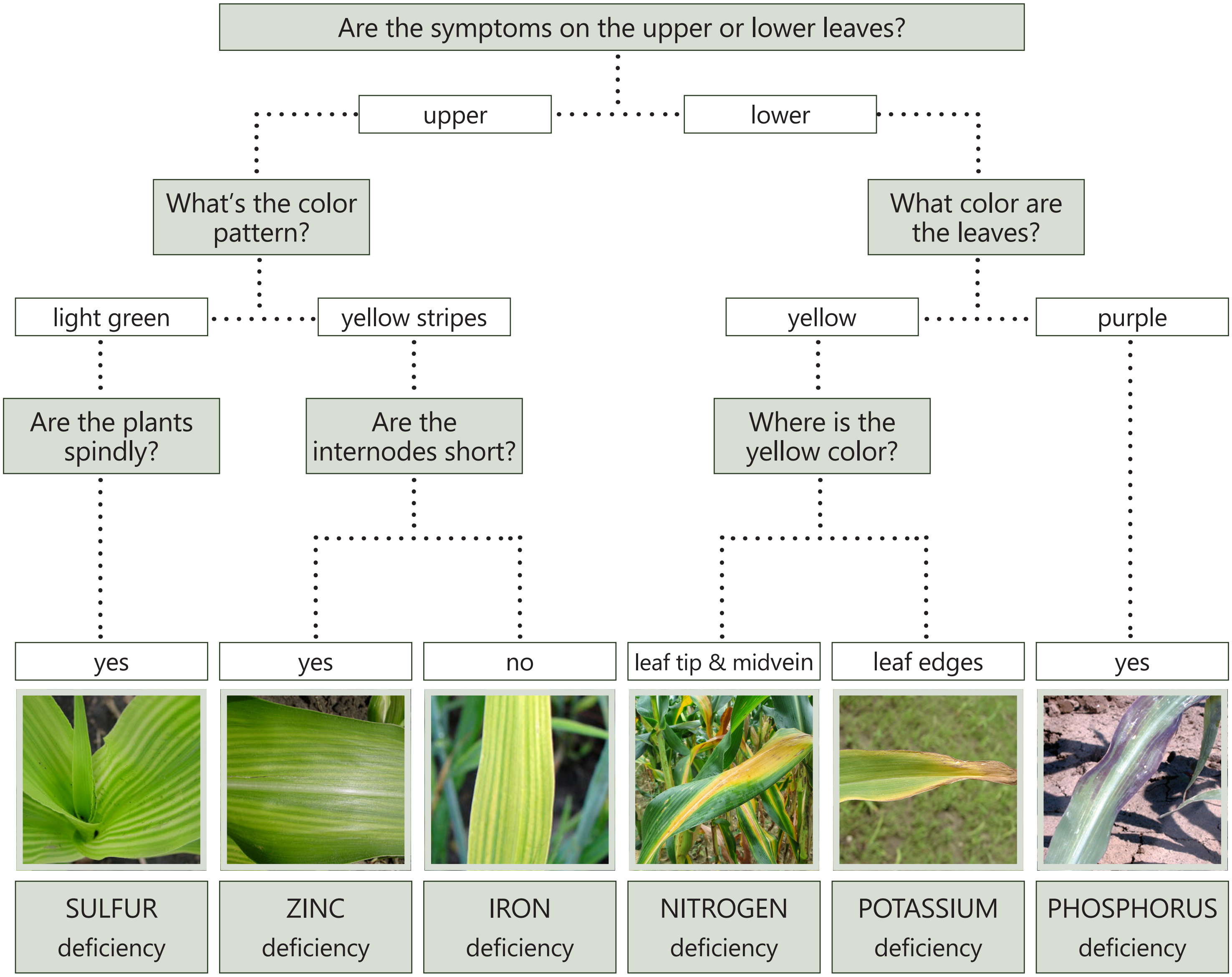


Figure 8. Diagnosing nutrient deficiency symptoms.

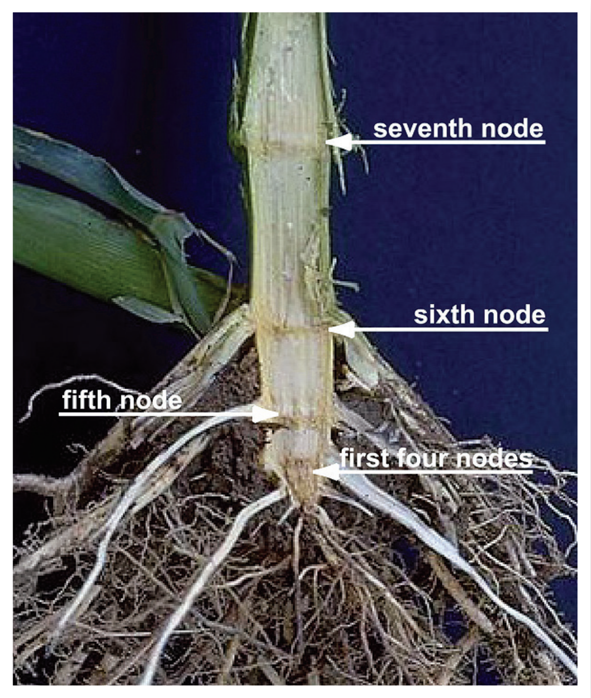


Figure 9. Identifying leaf growth stages starting around V7 becomes more difficult as the lowest leaves may have already deteriorated. For precise identification, it is often necessary to dissect plants lengthwise and count leaf nodes from the bottom of the plant upwards.

Knee-High to Tassel

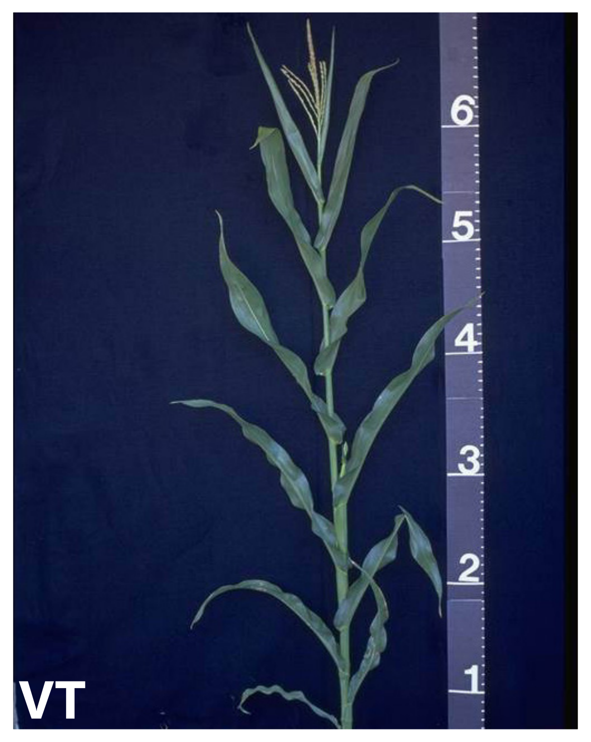
At V10, the corn plant undergoes rapid growth and dry matter accumulation, and gains a new leaf stage every two to four days. Nutrient and water uptake are increasing to meet growth demand.

During the final leaf stages, V15 to V22, a corn plant's development varies due to hybrid. During later vegetative stages, the upper ear shoot develops rapidly. Brace root development should be obvious by late vegetative growth. Brace roots support the larger plant and help meet increased water and nutrient needs.

Tassel

The tassel is perhaps the most identifiable part of a corn plant, but this growth stage has some distinct boundaries. The tassel stage (VT) is considered completely initiated when the last branch of the tassel is fully visible, and it ends when the silks first appear. Although the tassel is a reproductive structure (holding the male flowers), VT is considered a vegetative growth stage because the female flower (silks) emerges shortly after the tassel. The time between VT and R1 is typically short, two to three days, but varies considerably between hybrids. It is not uncommon to see significant variability in tassel

V10 ten-leaf stage.



VT tassel stage.

development within a field, representing the variety of environmental impacts on corn growth.


Tassel at VT.


Tassel at R1.

Table 8. Troubleshooting Knee-High to Tassel

Symptom	Possible Cause
Physical injury	
	Banks and two-spotted spider mites, grasshoppers, thrips, armyworm, corn earworm, western bean cutworm
	1st generation corn borer
	Wind damage
	Hail
Lodging	
	Rootworm
	Herbicide damage: 2, 4-D, dicamba, dinitroanilines
	High winds
Poor growth	
	N, S deficiency (yellow plants)
	P deficiency (purple plants)
	Water deficiency
Drought appearance	
	Compaction
	Drought
	Salinity
	Poor irrigation uniformity
Leaf damage or burn	
	Herbicide drift
	Leaf disease
	Late herbicide damage
	nhydrous or liquid fertilizer application

V12 – VT Management Tips

The plant now requires 100% of reference ET (page 82). Water demand is peaking (Table 21) and weather conditions during this time of year – high temperatures, low humidity, wind, and long days – put a high ET demand on fields.

Keep a close watch on spider mite control, especially during hot, dry weather.


Early hail damage.


Foliar salinity damage from sprinkler application.

Ear shoot at early tassel.

VT – R1 Management Tips

Tassel initiation begins a period where the corn plant is highly sensitive to a variety of environmental stresses, particularly weather-related.

Hail damage at this time can greatly impact grain yield. Corn plants are most vulnerable to hail damage through R1.

Adjust irrigation schedules to avoid water stress.

Scout for adult corn rootworm beetles feeding on silks, especially in continuous corn. Generally, clipped silks require 0.5 inch of exposed, uninjured silk tissue for pollen germination to occur.

Silking

Visible silks outside the husks mark the beginning of the silking (R1) stage. The plant is now in reproductive development, changing its photosynthetic capacity from building a factory (the corn plant) to assembling the product (grain). Each ear can have up to 1,000 potential kernels, although only 400 to 600 kernels actually form. The dust-like yellow pollen that falls from the anthers of the tassel represents millions of pollen grains. Each grain contains the male genetic material necessary for fertilizing one potential kernel. In order for a potential kernel (ovule) to be pollinated, pollen must travel from the male flower (anthers hanging from the tassel) to the female stigma (silk) leading to each ovule.

Blister

Blister (R2) stage is identified by fertilized kernels that no longer have an attached silk and resemble a blister in shape with a pointed nub at the top. Pollinated silks are turning brown and drying out. The success of pollination can be observed by carefully peeling the husks off an early R2 ear and gently shaking the ear upside down. Kernels with detached silks have successfully fertilized, and those with attached silks have not fertilized.

Milk

Kernels that are mostly yellow and contain milky white fluid identify the milk (R3) stage of development. Starch accumulation creates a milky fluid as the kernels rapidly

R2 blister stage.

R3 milk stage.

accumulate dry matter. Depending on the hybrid, R3 occurs 18 to 22 days after silking. Kernel moisture content is approximately 80%.

Dough

When the kernel's milky inner fluid changes to a pasty or doughy consistency due to continued starch accumulation in the endosperm, the plant is considered to be at R4. Kernels at R4 have accumulated close to half of their dry matter and are at about 70% moisture.

Dent

Dent (R5) is one of the most obvious stages to identify. As the kernels dry down, a hard white starch layer forms at the top of the kernel. When the kernel approaches maturity, this starch layer (also known as the "milk line") will move down towards the base of the kernel as it accumulates dry matter and loses moisture. Beginning dent kernels have about 55% moisture content.

The progress of the starch accumulation can be checked by pressing a kernel with a thumbnail. Full dent arrives when nearly all kernels have dented. Some hybrids have a more pronounced dent than others.

R1 – R3 Management Tips

Although not as sensitive as during pollination, kernel abortion can occur due to severe water stress.

Nitrogen and phosphorus uptake is still rapid, however, the plant has started moving these nutrients from the stalks and leaves to the grain.

Utilize tissue testing (ear leaf) or a chlorophyll meter if nitrogen deficiency is suspected. Researchers have measured grain yield increases to nitrogen applied as late as R3 when soil nitrogen was insufficient for maximum yields.

Inspect kernel set on ears throughout the field and begin assessing yield potential.

The appearance of ears can be very misleading because husks and cobs will continue to lengthen even if kernel set is incomplete. Although row number is determined by V12, kernels per row are sensitive to environmental stresses from V12 through R1. Incomplete kernel set may be caused by both unsuccessful pollination and kernel abortion.

Severe water stress can still cause kernel abortion, although not as easily as at the blister stage.

R4 dough stage.

R5 dent stage.

R4 – R5 Management Tips

Water use by the plant is rapidly declining with shorter, cooler days and senescing plant tissue. Depending on soil type and system, the final irrigation should be planned or already complete.

Nutrient uptake has dramatically slowed, but nutrients are moving from the plant to the grain. Subsequently, nitrogen deficiency symptoms often appear on lower leaves as N is moved out of these leaves first to the grain. The degree of these late-season symptoms can be hybrid specific, but do not always indicate that the plant had an insufficient nitrogen supply for maximum yield.

An early frost prior to maturity will lower yield by reducing or halting dry matter accumulation and often cause drydown problems for harvest.

Maturity

Corn reaches physiological maturity at R6 when kernels have accumulated maximum dry matter, the hard starch layer has advanced completely to the cob, and by the formation of a brown or black layer at the base of the kernel. Kernels on the ear will mature progressively from the tip to the base. Once the black layer has formed, the kernels are no longer accumulating dry matter or water. Depending on the hybrid, the moisture content should be 30-35%.

Heat Stress and Drought

The potential yield loss from heat stress or drought may result from a combination of possibilities:

- Delayed silk emergence plus a shorter pollen shed duration results in asynchrony (poor timing) of pollen shed and silk availability.
- Silks not receptive to pollen grain germination because of silk desiccation.
- Abortion of fertilized ovules during the first week or two after pollination.
- Pollen viability itself is commonly not an issue during drought stress unless temperatures surpass 100 degrees.

R4, R5, and R6 kernels.

Table 9. Troubleshooting Tassel to Maturity

Symptom	Possible Cause
Poor growth or yellowing	
	Nutrient deficiency
	Leaf blights
Leaf damage	
	Corn leaf aphid
	Wind, hail
	Diseases
	Salinity
	Early first frost
	Leaf miner
	Air pollution
	Grasshoppers
	Spider mites
Poor pollination or ear damage	
	Corn earworm
	Smuts
	Rodents, raccoons, birds
	Corn rootworm adults clipping silk
	Western bean cutworm
	Drought/heat stress
Lodging	
	Root rot complex
	High winds
	No brace roots - due to chemical damage, poor planting depth, or insect damage

Lodging

The consequences of root lodging depend on the growth stage of the plants at the time damage occurs. In addition, root systems already limited or damaged by soil compaction, soggy soils, or corn rootworm feeding have limited recovery.

The younger the corn, the more plants are able to "straighten up" following severe root lodging without noticeable curvature, or "goose-necking," of the plant stalk.

Late hail damage.

Drought-affected corn.

R6 Management Tips

Scout fields to determine maturity and harvest date depending on planting date, season length, variety, and stalk condition.

Early harvest and mechanical drying is rarely profitable in Colorado. Research has shown that field drying maintains yield stability.

Older and taller corn plants are less likely to straighten up, but will instead goose-neck as the upper stalk internodes continue to elongate. The goose-necking results from a hormonally driven response to the nearly horizontal position of the lodged plant.

Severe root lodging.

Large areas of goose-necked corn are a challenge to harvest and often increase harvest loss of grain if stalks or ears break off before being captured by the combine header.

As corn begins to pollinate, plants are near full height, and recovery or straightening up from root lodging is not likely. Severe lodging at or during pollen shed can greatly reduce seed set of the downed plants because silks are often covered by leaves of other fallen plants. The photosynthetic stress imposed on the lodged plants because of shading may limit the survival of fertilized ovules on the ears.

Contributing factors to lodging include:

- Strong winds.
- Severe corn rootworm injury, especially in later-planted corn.
- Excessively wet and cold soils during initial nodal root formation for early-planted corn.
- Excessively dry or cloddy soils during initial nodal root formation for later-planted corn.
- Nematode injury on sandier soils.
- Nitrogen deficiency in corn where earlier significant nitrogen loss had occurred earlier.
- Compaction from tilling wet soils.
- Wet soils at the time of the wind damage that made it easier for the roots to be “pulled” by the force of the wind.

“Goose-necked” corn plants.

INTEGRATED PEST MANAGEMENT

Integrated pest management (IPM) combines chemical control with cultural and biological practices to form a comprehensive program for managing pests. This approach emphasizes preventative measures to maintain pests below the economic threshold while using the minimum amount of pesticide necessary.

Pest management decisions affect both producer profitability and the environment. Determining whether a pest control measure is warranted and which control method is best is the basis of a sound pest management program. Integrated pest management follows a decision-making process that helps producers arrive at the best answer to their pest problems.

Ask these questions to reach a pest management decision:

- Will increased yield significantly offset the cost of control?
- Are non-chemical control methods available and practical?
- If pesticide application is the only method available, are there choices of products to consider?
- Can the pesticide be applied in a way that reduces rate, maximizes effectiveness, and minimizes harm to natural beneficial organisms, pollinators, and non-target species?
- Does the product label contain groundwater advisories or other environmental caution statements?
- Are chemicals and control methods rotated to avoid buildup of pest resistance?

IPM practices include:

- Monitoring pest and natural enemy populations.
- Using beneficial insects and other biological controls.
- Selecting pest-resistant crops and varieties.
- Timing planting and harvest dates to minimize pest damage.
- Rotating crops.

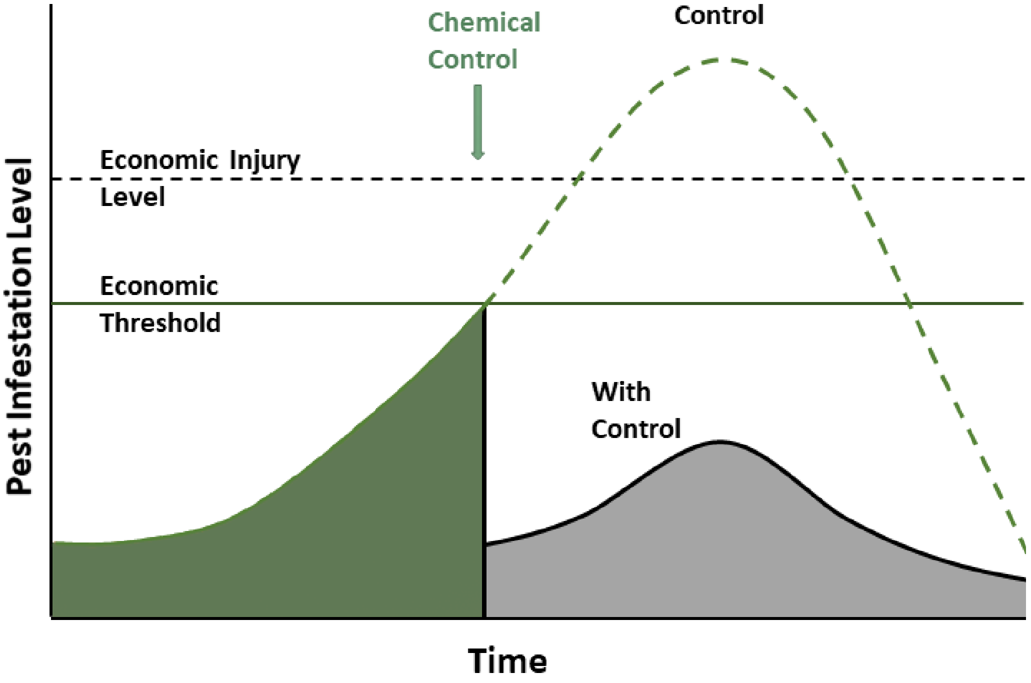


Figure 10. Economic or action threshold is the pest infestation level at which it usually pays to take remedial action.

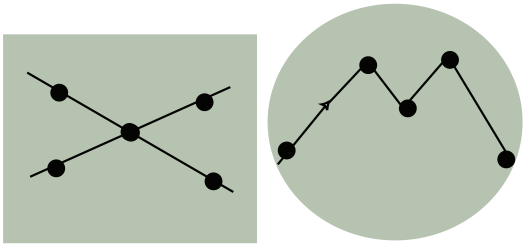


Figure 11. Scouting patterns: x-shaped (left) and m-shaped (right).

Record Keeping and Scouting

Systematic record keeping is essential to a successful IPM program. A field history, including past crops, pests, weed infestations, compaction, fertility, and irrigation practices is helpful before beginning a scouting program. These records will be combined with the current year's records to develop a complete field history. Knowing field history and trouble spots can be helpful in planning an appropriate scouting route.

Most fields should be walked in an x-shaped or m-shaped pattern (Figure 11), taking time to get well into the field. After corn tassels, it is more efficient to use an x-shaped pattern, moving up or down rows to sample at least five unique points. Only checking field edges can give a misleading indication of crop status.

Useful equipment for field scouting can include:

- Record sheets, pencil, and clip board or smartphone/tablet/laptop to record data.
- Digital or smartphone camera.
- Reference materials (paper or digital) for pest identification, nutrient deficiency symptoms, growth stages, etc.
- Field map (paper or digital, GPS) to identify field location.
- Pocket knife, pliers, shovel (for digging seed, weeds, plants, etc.).
- Soil probe (for checking soil moisture, irrigation uniformity, compaction, or collecting samples).
- Magnifying glass.
- Plastic bags (for collecting plant, soil, or pest samples).
- Cooler (to keep samples fresh).

Record keeping and scouting take time and organization and growers should candidly assess their capacity to perform these tasks and, if necessary, hire a consultant.

Checking the youngest and oldest corn can alert growers to early indications of pest problems.

Advantages of growing corn in crop rotation may include:

- Better weed control and fewer difficult-to-control weeds.
- Ability to rotate herbicides and other pesticides to avoid pest resistance.
- Reduced buildup of soil insect and disease organisms.
- Genetic identity is preserved by eliminating volunteers.
- Reduced N fertilizer requirement following legumes.

Crop Rotation

Continuous cropping of any single crop species eventually limits yields due to buildup of soil insects, disease organisms, and weeds. In Colorado, the need for soil insecticide treatment for western corn rootworm is eliminated by rotating fields on which corn is grown. Goss's wilt is becoming a more important disease problem in some areas of Colorado, and, like stalk rot, inoculum can be transmitted from previous crop residues. Continuous no-till corn production is especially problematic when conditions favor the development of these diseases. Genetic resistance, coupled with rotation and tillage, is currently the most effective tool for managing these two diseases. Stalk rot in corn is also more commonly seen on continuous corn fields with soil compaction problems.

Research in the midwestern U.S. shows that corn grown following soybeans will yield 10% to 15% higher than corn grown following corn. Crop rotation will generally provide yield benefits regardless of the second or third crop. However, the benefits are most pronounced following legumes such alfalfa, especially in reduced tillage systems on poorly drained soils.

Pesticides and Water Quality

The agricultural chemicals known as pesticides – insecticides, herbicides, nematicides, and fungicides – are important tools for most corn producers, but they must be handled cautiously. Unfortunately, pesticides often are found in surface waters receiving agricultural runoff, particularly after a heavy spring rainfall. Fortunately, a number of corn management and pesticide application practices can be used to reduce the potential of water contamination.

Pesticides may volatize, break down, adhere to plant tissues, drift, or be carried away to surface water after application (Figure 12). After reaching the soil, pesticides may be taken up by plants, adsorbed to soil particles, broken down to other chemicals, or in some cases be moved off-target to water resources.

Pesticide properties – which include toxicity, persistence, soil adsorption, and solubility – only indicate the probability of leaching or runoff. Soil, site, and management factors must also be considered. Even if pesticide prop-

Disadvantages of corn in crop rotation may include:

- Increased management, equipment, and labor costs.
- Reduced market opportunities for alternative crops.

Dryland Considerations

Continuous corn is not recommended in dryland situations. Dryland corn can be successfully grown in a variety of rotations, but research has shown that corn following wheat is a good rotation, allowing for 9 to 10 months of moisture storage before planting (e.g. wheat-corn-fallow; wheat-corn-proso millet-fallow). Weed control following wheat harvest until fall is critical in this scenario. Consider any combination of crops that adapt to your environment and fit your equipment, budget, and overall livestock feed requirements.

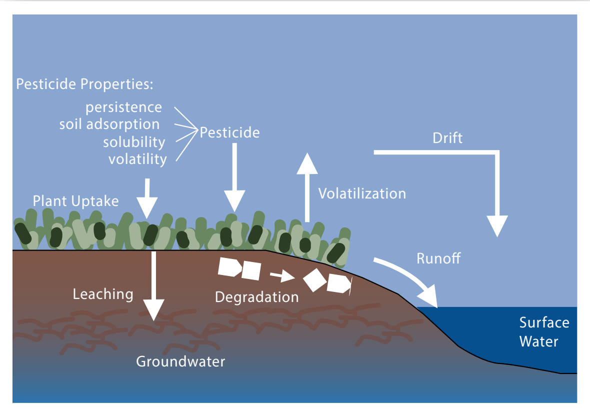


Figure 12. Pesticide fate after application.

Pesticide Labels

All pesticides are regulated by the U.S. Environmental Protection Agency (EPA) and the chemical label is, in effect, the law. In most cases, the precautions on the chemical label are adequate to protect water resources from contamination. However, it is possible for a pesticide to reach surface or groundwater, even when used according to the label. Chemicals that have a higher potential to contaminate water are identified on the label by a groundwater or surface water "Advisory Statement." Producers should take special care when using these chemicals and observe the prescribed use restrictions around wells, surface water, or shallow groundwater.

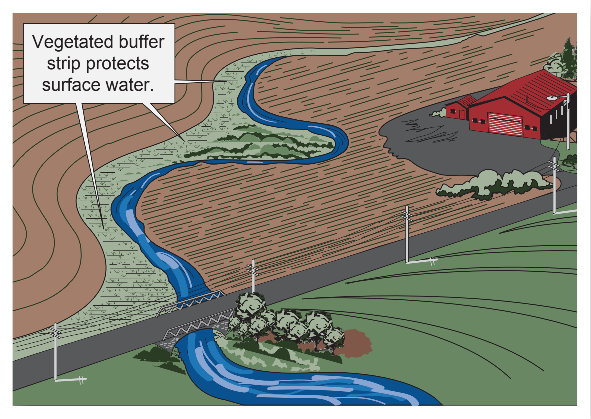


Figure 13. Pesticide application buffer zone.

BMP

Maintain pesticide application equipment in good working condition and calibrate frequently to ensure recommended rates are applied.

erties indicate little environmental risk, pesticides may still end up in water resources if other factors favor movement. However, in most cases, good management will keep water contamination to a minimum.

Sites with vulnerable water resources require selection of pesticides least likely to move off-target, or alternative pest management measures. Proper management of soils, water, and pesticides by agricultural producers can help reduce adverse water quality impacts.

Pesticide Application

Focus pesticide management on good practices at application. Surface water proximity should be considered prior to pesticide application. Observe a setback or buffer zone a safe distance from wells, streams, ponds, and lakes where no chemicals are applied. The actual setback required will depend upon the mobility of the chemical, slope, and likelihood of runoff (Figure 13). Additionally, land management practices such as reduced tillage are important for protecting surface water quality. Establish grass filter strips and waterways on the down-gradient side of fields that drain directly to drainage areas and streams and lakes.

Conservation tillage practices that increase the amount of crop residue on the soil surface can reduce runoff volume and velocity, resulting in less erosion and pesticide movement. Strongly adsorbed chemicals tend to adhere tightly to soil particles and will move only on eroding sediments. Reduced tillage systems are highly recommended on all erosive soils. However, in some cases increased pore size and infiltration, coupled with increased herbicide use, may favor pesticide leaching. Where groundwater is shallow and domestic wells are nearby, these trade-offs should be assessed.

The application method used to apply pesticides can influence leaching or runoff potential. Soil injection or incorporation makes the pesticide most available for leaching, but less likely to cause surface water contamination. In general, pre-plant and pre-emerge treatments on clean-tilled soil are more subject to surface loss than post-emerge treatments when crop cover reduces runoff.

Pesticide Storage, Mixing, and Loading

Storage, mixing, and loading of pesticides and fertilizers in their concentrated forms poses the highest potential risk to surface or groundwater from agricultural chemicals. In the past, the common procedure was to mix and load chemicals at a single, uncontained location with little thought to surface or groundwater proximity. Farmers may be liable for cleanup of these sites, even after selling the property, if mishandling of agricultural chemicals results in environmental contamination.

BMPs

Minimize agricultural chemical waste. Consider these tips:

- Purchase only the amount of chemical needed for each season.
- Avoid overwinter storage by returning unused chemicals to the dealer.
- Mix only the exact amount of chemical needed for the immediate job.
- Properly calibrate sprayer at least annually.
- Use compatible rinsate as make-up water for the next spray batch.
- Use mini-bulk and two-way containers to eliminate container waste.
- Reduce rinsate water by mixing chemicals and cleaning equipment at the application site.
- Recycle empty pesticide containers whenever possible.
- Reduce pesticide waste by using direct injection spray systems and mini-bulk containers.
- Reduce storm water handling problems by roofing mixing pads and secondary containment.
- Keep good records to track chemical supply and need.

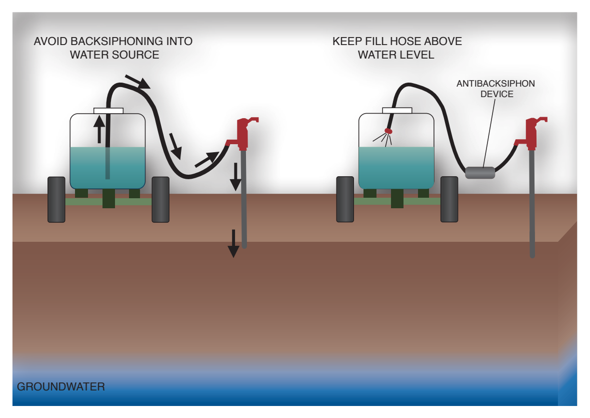


Figure 14. Use antiback siphoning device and keep hose above fluid level in tank to pre vent contaminating wells with pesticides.

BMPs

Avoid site contamination by mixing and loading chemicals at the application site.

- Take a nurse tank to the field for mix and wash water.
- Stay a safe distance from any wells or surface water.
- Avoid mixing repeatedly at the same spot in the field.
- Take precautions to prevent spills of chemicals during field mixing.

INSECT PESTS

Insect pests cost Colorado corn producers millions of dollars each year in lost yields and control measures. Essential to sound management decisions are proper identification of the insect pests, field scouting to determine insect population density and growth stage, and knowledge of management options. Scout fields more efficiently by knowing insect life cycles, environmental conditions favoring pest outbreaks, areas of the farm most susceptible to insect pressures, and corn growth stages (Table 10) most susceptible to insect damage.

Dryland Considerations

Three insect pests commonly cause economic damage to dryland corn:

- Corn earworm
- Southwestern corn borer
- Western bean cutworm

Other insect pests that attack, but rarely at levels justifying control include:

- Banks grass mite
- Pale western cutworm

Western corn rootworm can be controlled effectively through rotation.

Table 10. Corn Insect Pest Activity by Corn Growth Stage

Insect	Pre-germination	Germination to V4	V5 to Silk	Silk to Maturity
Alfalfa webworm		Seedling		
Armyworm				Leaf
Banks grass mite			Leaf	Leaf
Corn blotch leafminer			Leaf	Leaf
Corn earworm			Leaf	Silk, Ear
Corn leaf aphid			Leaf, Tassel, Silk	Leaf
Dingy cutworm		Seedling		
European corn borer			Leaf, Stalk (1st Gen)	Leaf, Stalk, Silk, Ear (2nd Gen)
Fall armyworm			Leaf	Silk, Ear
Flea beetles		Seedling		
Grasshoppers			Leaf	Leaf, Silk, Ear
Northern corn rootworm			Tassel, Silk (Larvae)	Leaf (Beetles)
Pale western cutworm		Seedling		
Seedcorn beetle	Seed			
Seedcorn maggot	Seed	Seedling		
Southwestern corn borer			Stalk	Stalk, Silk, Ear
Thrips		Seedling		
Two-spotted spider mites				Leaf
Variegated cutworm		Seedling		
Western bean cutworm			Tassel,Silk	Silk, Ear
Western corn rootworm			Roots (Larvae), Tassel, Silk (Beetles)	Leaf, Silk, Ear (Beetles)
White grub	Seed	Seedling		
Wireworm	Seed	Seedling		

Seedcorn maggot. K. Gray, Bugwood (top); Bugwood (bottom).

Seedcorn Maggot (*Delia platura*)

Larvae size: 0.25 inch long

Description: Maggots are yellow-white and tapered. Adults are small flies.

Life cycle: Maggots feed on a corn seed kernel resulting in weak plants or no germination. Feeding occurs two to three weeks before pupating into one-fifth inch adult flies. In early spring, a large amount of organic matter and decaying vegetation attracts egg-laying female flies. Cool and damp soils can delay germination and extend the seed's vulnerable period. Scout where there are poor emergence, gaps, or skips. If there is extensive damage, consider options such as replanting.

Management: Seedcorn maggot symptoms include damaged corn seeds or seedlings, or the surrounding soil may contain small (0.25 inch) yellow or white seedcorn maggot larvae.

Use insecticidal seed treatments if a soil insecticide is not used for other soil pest problems.

Wireworm. K. Gray, Bugwood (bottom).

Wireworm (several species)

Larvae size: 0.50 to 1.00 inch long

Description: Hard-shelled and yellow-brown, however, early larvae are small and white. Adult beetles are brown to black, elongated, and tapered at each end.

Life cycle: Larvae can take from two to five years to mature. Wireworms pupate in the soil and emerged adults remain in soil until spring. Larvae feed on germinating corn seed and seedlings and may eventually bore into the stalk.

Management: Insecticidal seed treatments are effective against moderate wireworm infestations. Conventional soil insecticide applications may be required to protect seedlings from heavy infestation.

Dingy Cutworm (*Feltia jaculifera*)

Larvae size: 1.00 to 1.25 inches long

Description: Larvae are brown and mottled with a broad, grey stripe with lighter V-shapes at each segment. Adults are brown with bean-shaped markings.

Life Cycle: Dingy cutworms overwinter as larvae and begin feeding in spring on early leaves or may cut off plants at or below the soil surface. They are found in fields with residue.

Management: Consider chemical control if 1 in 20 (5%) plants are damaged, and cutworms are present.

Dingy cutworm. H. Royals, Bugwood (bottom).

Pale Western Cutworm (*Agrotis orthogonia*)

Larvae size: 1.00 inch long

Description: Larvae are grayish-white with two brown bars on the front of the head.

Life cycle: Larvae live under the soil surface and prefer loose, dry soils. Outbreaks usually occur after several consecutive dry springs – ones that receive less than 10 days of at least 0.25 inch of rain. More rain and wetter soils drive the cutworms to the surface, exposing them to predators and parasitism. Mature larvae burrow into pupal chambers in the soil and emerge as moths in late July. Cutworm larvae feed on small seedlings below ground or enter older plants causing death at the growing point. Infestation in corn is most common following sod, alfalfa, or small grains.

Management: Because outbreaks are sporadic, treatment is limited to pesticides, making early detection critical. Consider chemical control if 1 in 20 (5%) plants are damaged, and cutworms are present. Soil crusting can reduce treatment effectiveness.

Pale western cutworm.

Variegated Cutworm (*Peridroma saucia*)

Larvae size: 1.50 to 1.75 inches long

Description: Larvae are gray to dark brown with a row of yellow spots along the back and a broad orange stripe along each side. Most have a dark W-shape on the abdomen's tip. Adult moths have light tan forewings with black marks and two pale eye-like markings on the middle of each forewing. Hind wings are silver-white.

Life cycle: Pupae overwinter to emerge as adults in spring. Moths lay eggs in clusters on dead twigs, plant stems, and leaves. Eggs hatch in four to nine days and larvae feed up to 40 days. Once mature, larvae pupate and overwinter in soil. Cutworms feed on leaves at night

Variegated cutworm. W. Beck, Bugwood (bottom).

and may feed on ear silk and tips, and the center of the stem down to two to three inches below the soil surface. Defoliation indicates its presence.

Management: The variegated cutworm is seldom a serious pest in field corn in Colorado.

Banks grass mite. F. Schweissing, Bugwood (top).

Banks Grass Mite (*Oligonychus pratensis*)

Size: Barely visible, approximately 0.02 inch

Description: Banks grass mites (BGM) have a greenish, round body with eight legs. Overwintering females are bright orange.

Life cycle: Fertilized females overwinter in winter wheat and other grasses and either walk or get windblown into corn. Mites feed and damage plants by piercing plant cells with mouthparts to draw out juices.

Management: The first indication of infestation is discolored leaves with webbing from the bottom of the plant upwards. Preserving naturally occurring spider mite predators by avoiding broad spectrum pesticides is critical to proper management of spider mite problems in corn.

Available miticides are either preventive or reactive, and treatment guidelines differ for the two groups. Use of preventive miticides is based on field history and expected risk of mite infestation. Risk factors include extended periods of hot, dry weather, scarcity of mite predators, expected insecticide use, and crop growth stage. The simple guideline for reactive chemical treatment is to treat if damage is visible in the lower one-third of the plant and mite colonies are present on the lower two-thirds of the plant.

Chemical control guidelines can be found in the High Plains IPM Guide - CSU Cooperative Extension Bulletin 564A or at HighPlainsIpm.org.

Two-spotted spider mite. D. Cappaert, Bugwood (both).

Two-Spotted Spider Mite (*Tetranychus urticae*)

Size: Barely visible, less than 0.02 inch

Description: Two-spotted spider mites are eight-legged and greenish with two darker regions on either side of abdomen.

Life cycle: The life cycle from egg to adult can be as short as six days in temperatures greater than 80 degrees F and less than 50% relative humidity.

Management: Identify by webbing on plant and early damage of yellow spots on top of leaves. Advanced damage includes drying up of leaf tips, margins, and leaves. Mites prefer hot, dry weather, so properly irrigate to avoid drought stress. Predatory insects include the predatory mite Amblyseius fallacies and the black ladybird Stethorus. Use similar treatment guidelines as for banks grass mite..

Corn Leaf Aphid (*Rhopalosiphum maidis*)

Size: 0.06 to 0.10 inch

Description: Aphids are blueish-green and wingless, with short antennae and purple patches on the base of prominent cornicles. Aphids begin feeding in whorls, and spread to upper leaves and the tassel. In addition to corn leaf aphid, other aphids seen on corn include bird cherry-oat, greenbug, and corn root.

Life Cycle: Corn leaf aphids can complete 10 generations per year and may build up to heavy populations on tassels and leaves.

Management: Aphids usually cause little physical damage, but they are vectors for barley yellow dwarf and maize dwarf mosaic virus. Aphid's excreted honeydew can cause mold growth.

Non-chemical control: includes predacious insects like ladybird beetles and parasitic wasps. Chemical treatment is rarely needed due to the effectiveness of predator control, however, heavy infestations on tassels have been reported to affect pollination and some research data has indicated reduced yields.

Corn Earworm (*Helicoverpa zea*)

Larvae size: 1.50 to 2.00 inches long

Adult moth size: 1.00 to 1.50 inches

Description: Larvae varies from yellow, pink, green, or black. Covered with microspines, the body is marked with alternating light to dark stripes. It always bears a yellow-brown head capsule. Adults are buff to greyish-brown.

Life cycle: Off-white eggs are laid in spring. Eggs are deposited singly, usually on leaf hairs and corn silk. First-

BMP

Purchase the correct amount of product needed and return unopened containers for credit. Whenever possible, use mini-bulk or small-volume refillable containers to avoid container waste.

Corn leaf aphid. B. Christine, Bugwood (bottom).

Corn earworm. R. Croissant, Bugwood (top); S. Brown, Bugwood.

generation larvae feed on corn whorls in early summer, giving a ragged appearance. Serious, early-season infestations are rare. Corn earworms are migratory, causing infestation timing and generation numbers to vary. However, most problems in field corn occur after silking when moths deposit eggs on silk, which larvae feed on. Older larvae bore through to the ear and feed on the tip. Feeding on tip causes loss not only by earworms, but opens a channel for birds and pathogens.

BMP

Avoid repetitive use of the same pesticide(s) with the same chemistry to reduce potential resistance development and pest spectrum shifts.

Management: Non-chemical control includes predacious insects including ladybird beetles and parasitic wasps, and diseases such as the *Bacillus thuringiensis* (Bt) bacterium and the *Heliothis polyhedrosis* virus.

Chemical treatment is rarely economically practical in field corn, but Bt hybrids offer some control.


Fall armyworm. R.J. Bauernfeind, Bugwood (bottom).

Fall Armyworm (*Spodoptera frugiperda*)

Larvae size: 1.50 inches long

Description: Larvae can vary from light tan or green to almost black with a white, inverted Y-shape on the front of the head. They have three cream-colored stripes running down their backs with a wider dark stripe and wavy yellow-red stripe on each side. Adults have dark and light grey forewings mottled with light and dark spots. Hind wings are grayish- to pinkish-white.

Life cycle: Fall armyworm migrates from the south into Colorado every year and usually are not a problem until the latter part of the growing season.

Feeding: While fall armyworms will feed on corn in all growth stages, they mainly feed late season in ears. They feed during the day and night, but are most active in the morning or late afternoon.

Management: Several insecticides are available to treat heavy infestations. A new Bt event has shown effectiveness against fall armyworm.

BMP

Destroy alternate pest breeding sites and hosts during the off-season and at off-site locations to interrupt pest life cycles in order to reduce potential recurrences.

European Corn Borer (*Ostrinia nubilalis*)

Larvae size: 1.00 inch long

Description: Larvae are cream to pinkish with small, round, brown spots. Adults have buff-colored forewings with darker, wavy lines running across their wings. Males are noticeably darker and less yellow than females.

Life cycle: European corn borers (ECB) have two generations each year:

First generation – Overwintering larvae emerge as moths in late May to early June. These moths lay masses of 15 to 30 eggs on corn leaf undersides, near the midrib. This generation emerges as moths in mid-July to early August and lays eggs for the second generation.

Second generation – Larvae feed on leaves near the hatching site and move on to whorls and leaf sheaths, giving the "shot hole" appearance. Mature larvae bore into the stalk and second generation larvae will feed on the ear that may result in dropped ears, broken shanks, corn stalk breakage, castings appearing like sawdust (frass), and holes in the stalks.

European corn borer tunneling and feeding causes physiological stresses to corn plants, reducing ear size, grain quality, and yield. Other consequences of ECB damage include stalk breakage, ear drop, and poor harvestability.

Management: European corn borer is a significant pest in eastern Colorado, mostly in sprinkler irrigated corn in the northeast.

Research has shown a close association between ECB damage and stalk rots such as fusarium and gibberella. If an insecticide is needed, treatment timing is critical and can be difficult. The insecticide should be applied after hatch but before the larvae reach the stalk. This stage is not always easy to determine, since egg laying may last three to four weeks. Growers should begin scouting their fields after experts in the surrounding area predict that egg laying is 25% complete. Growers should repeat scouting every three to five days. Overall, it's a good idea to scout early and periodically for these problems to avoid surprises at harvest. Treatment for first generation ECB is considered economical when 25% of plants have feeding damage or live larvae are present in whorls. Treatment for second generation ECB should be considered when 25% of plants are infested with egg masses or larvae. After pollination, this percentage should be raised to at least 50 % infestation to justify chemical treatment.

Non-chemical control: Early planted corn is more attractive to first generation egg-laying females, while second generation females are more attracted to late planted

European corn borer. J. Solomon, Bugwood (top); Bugwood (bottom).

BMP

Protect naturally occurring pest control organisms by using insecticides that are less toxic to beneficial insects and pollinators.

BMP

Follow all label directions for storing, mixing, and disposing of agricultural chemicals and their containers.

Dryland Considerations

Southwestern corn borer problems can be controlled by Bt hybrids.

corn. Bt corn is effective against ECB in Colorado (see page 7 for guidelines). Fields with significant levels of stalk damage should be scheduled for early harvest.

Naturally occurring predators and parasites like lacewing larvae, wasps, ladybird beetle larvae and adults, feed on eggs and just-hatched larvae. Pathogens include the fungus Beauveria bassinia and the protozoan Nosema pyraustae.

Grasshoppers

Pest species:
Melanoplus differentialis – differential grasshopper
Melanoplus sanguinipes – migratory grasshopper
Melanoplus bivitattus – two-striped grasshopper
Melanoplus femurrubrum – red-legged grasshopper
Camnula pellucida – clear-winged grasshopper

Life cycle: Grasshopper eggs overwinter and hatch into nymphs in late May and early June. By August, nymphs are adults. A number of different grasshopper species may attack corn in Colorado when warm, dry weather favors rapid development.

Management: Chemical treatment may be justified if there are more than 20 nymphs per square yard in the field margins. Foliar applied insecticides are effective if corn is infested at economically damaging levels.

Differential grasshopper D. Cappaert, Bugwood (top); Migratory grasshopper S.I. Lee, Bugwood (bottom).

Southwestern Corn Borer (*Diatraea grandiosella*)

Larvae size: 1.00 to 1.25 inches long

Adult moth size: 0.75 inch

Description: Larvae are dull white with dark spots in a regular pattern along the body. Spots are not found on overwintering southwestern corn borers. Adult moths are pale yellow. The southwestern corn borer is found only in southeast Colorado, rarely occurring as far north as Burlington.

Life cycle: There are two to three generations a year. In spring, overwintering larvae pupate and emerge in about 10 days. The new moth lays eggs for the first generation. The first generation of larvae feeds on the growing point of a new plant causing "dead heart," the

Southwestern corn borer. CU, Bugwood (top); H. Royals, Bugwood (bottom).

second generation burrows into the stalk, girdling the inside a few inches above soil. The girdling causes lodging. The overwintering larvae then burrows in the stalk below ground.

Management: Early maturing varieties, crop rotation, and early planting may reduce second generation damage. Stalk destruction by chopping or tillage in fall and winter helps to mitigate first generation damage but only if practiced area-wide. Chemical control is economically justified when 25% of plants have egg masses or new larvae. Bt corn hybrids can be effective.

BMP

Provide worker safety features such as gloves, showers, protective clothing, fire extinguishers, and spill cleanup kits.

Armyworm (*Pseudaletia unipuncta*)

Larvae size: 1.00 to 1.50 inches long

Description: Larvae are smooth, dark-gray to greenish-black with five length-wise stripes. The head has net-like markings.

Life cycle: Adult moths lay eggs on lower leaves of grass crops and may have one or more generations per year. Armyworms hide from sunlight so feeding is at night or during cloud cover. Feeding occurs mostly on lower leaves of grasses and most damage occurs late into the season. Armyworm outbreaks occur only occasionally because they have many natural enemies that usually prevent the development of economically significant infestations.

Management: If the lower third of the plant is damaged before dent stage, consider chemical control.

Armyworm.

Western Bean Cutworm (*Richia albicosta*)

Larvae size: 1.50 inches long

Adult moth size: 0.75 inch long

Description: Larvae are dark brown with a faint diamond shape on their backs. Mature larvae have three dark stripes on the first segment behind their heads. Adult moths are brown with creamy white stripes on the leading edge of the wings. Hind wings are a light color.

Western bean cutworm has become a serious pest of dryland and irrigated field corn in northeastern Colorado.

Western bean cutworm.

Dryland Considerations

The number of plants infested to justify control of Western bean cutworm has not been determined but is probably about twice that of irrigated.

Life cycle: Mature larvae overwinter in soil, pupate in spring, and moths emerge in late June to mid-July. Eggs are in clusters of 4 to 200 on the tops of the upper corn leaves. Eggs start as white, and thinly ringed in red. They change to brown and then to purple-black just before hatching. This process takes about five to seven days. If corn is not tasseled, western bean cutworm feeds on pollen in the developing tassel. If corn is tasseled, the cutworm feeds on silk. It prefers ear tips in corn and may tunnel through husks to reach the ear. Feeding on developed ears causes the most yield loss, up to 30% to 40%.

Management: If more than 8% of the plants have egg masses and the crop is 95% tasseled, chemical control may be necessary. Spider mite outbreaks often follow chemical treatment.

Western Corn Rootworm (*Diabrotica virgifera virgifera*)

Western corn rootworm. S. Bauer, Bugwood (top); W. Beck, Bugwood (bottom)

Larvae size: 0.50 inch

Adult size: 0.25 inch

Description: Slender, white larvae with brown heads and a dark plate on the top side at its end.

Life cycle: Western corn rootworm eggs overwinter in the soil and hatch in late spring, moving to nearby corn root hairs and small roots to feed. By July, larvae pupate and emerge as beetles with black and yellow-striped wings. Adults feed on silks.

Management: Corn growers currently use six strategies for limiting rootworm damage:

1. Crop rotation
2. Planting transgenic Bt hybrids
3. Planting treated seed
4. Application of soil insecticides at planting
5. Post-emergence application of larval insecticides (granular, chemigation, and aerial)
6. Application of insecticides mid-season to control adult rootworm beetles to prevent egg laying, and thus reduce rootworm damage the following season

BMP

Scout crop fields at least weekly after insect infestations are first predicted or observed. Be sure pests are properly identified before control measures are implemented.

However, each approach has limitations. In some growing areas in the Midwest, northern and western rootworms have adapted to rotational practices, rendering that strategy less effective. Soil insecticides are estimated to be applied on 25% of the U.S. and the Colorado corn crop.

Like Bt corn for control of the European corn borer, which has been grown since the mid-1990s, the rootworm Bt hybrids incorporate genes from the soil bacterium Bacillus thuringiensis that produces insecticidal proteins. Rootworms are killed after feeding on roots of engineered plants, but before the insect causes significant damage. It is important to note that the rootworm trait is not effective against corn borer, and vice versa. Some hybrids have both traits and are effective against both pests.

Chemical control guidelines can be found in CSU Cooperative Extension's Colorado Weed Management Guide (XCM 205).

Pesticide Handling and Safety

Improperly handled pesticides can pose threats to human and environmental health. Always read and follow all pesticide label instructions. See page 34 for pesticide handling and safety BMPs.

Aerial application of pesticide.

CORN DISEASES

Management

Corn diseases caused by fungi, bacteria, viruses, nematodes, and mycoplasms in Colorado are minimized by good management decisions made prior to the growing season regarding hybrid and seed selection, crop rotation, and tillage practices.

Good weed control, fertility, and irrigation practices throughout the growing season, coupled with prompt harvest of corn damaged by wind, hail, or insects, can help minimize yield losses associated with the common corn diseases in Colorado.

Seedling Blights

Damping off and other seedling blights generally are caused by soil-dwelling fungi such as pythium, fusarium, diplodia, rhizoctonia, and others. These fungi may cause seed to rot before germination or the seed may germinate and the seedling becomes infected. Damping off is favored by cool, wet soil and is often first seen in low-lying or poorly drained areas in the field. Heavy plant residue on the soil surface favors damping off by keeping soils cooler and wetter. Delayed emergence caused by compaction, crusting, or planting too deep can also predispose seedlings to infection.

Damping off is generally controlled by seed treatments. Avoid deep planting on wet soils cooler that 50 degrees F to minimize occurrence of this disease.

Viruses

Numerous viruses cause corn diseases. Some may seed borne, whereas others may be transmitted by insects such as aphids. In general, yield reductions caused by viruses have been minimal in Colorado because of the use of resistant hybrids and good weed management. Nevertheless, new viruses may occasionally emerge and result in damaging losses. For example, the high plains virus, transmitted by the wheat curl mite, caused damage to several susceptible corn hybrids in the early 2000s. This disease has largely been controlled by the use of resistant hybrids, but it still remains a threat to sweet corn and wheat.

Disease Management Practices

- Select hybrids with resistance to diseases common in your area.
- Plant high quality seed treated with a seed fungicide.
- Avoid planting too early into cold, wet soils.
- Avoid higher than recommended plant populations for the hybrid selected.
- Deep rip fields to reduce soil compaction.
- Rotate fields regularly to crops other than corn.
- Apply N,P,K and micronutrient fertilizers according to soil test recommendations.
- Control grassy weeds in and around corn fields to destroy host sites.

Damping off damage to corn stands.

Chemical control guidelines can be found in the High Plains IPM Guide at wiki.bugwood.org/HPIPM:Main_Page.

Nematodes

Nematodes are microscopic roundworms that live in the soil. Several species of nematodes may feed on corn roots, but only a few are capable of causing significant damage. Nematodes may become a problem in fields that are not regularly rotated to another crop. Symptoms may occur throughout the growing season and generally appear as stunted plant growth, uneven stands, chlorosis, and small or poorly fill ears. Often these symptoms will appear as patches in the field where nematode numbers are highest. Corn roots dug up in those areas often appear stunted, malformed, and may have discolored lesions. However, these symptoms may be confused with those caused by other problems. The only way to verify a nematode problem is by analyzing a soil and root sample.

Nematodes. NRCS.

Bacterial Leaf Streak

Bacterial leaf streak, caused by *Xanthomonas vasicola pv. vasculorum* (syn X. *campestris pv zeae*), was confirmed for the first time in the United States in 2016, and the disease has been confirmed in Colorado. There is currently limited information about this disease and what impacts it may have on corn production. It is not known where it survives the offseason, how and when initial infection occurs, or how it is secondarily spread.

Bacterial leaf streak.

Several other corn diseases can cause similar symptoms which can complicate diagnosis. Symptoms of bacterial leaf streak on corn plants are narrow, wavy-edged lesions that range in length from less than an inch to several inches long. They may be tan, brown, or orange in color and occur between the veins of the leaf. Sometimes the lesions occur close to the midrib; in other cases, they occur across the leaf blade. Disease symptoms have been observed as early as growth stage V7 with lesions appearing on lower leaves first (2018, Broders, et al.).

Goss's wilt.

Goss's Wilt

Goss's wilt (*Clavibacter michiganese* subsp. *nebraskaense*) is widely distributed in northeastern Colorado and can result in significant losses. The disease is aggravated by growing susceptible hybrids, continuous cropping, and reduced tillage practices. The bacterium overwinters in previously infected corn residue and may be moved from plant to plant during the growing season by splashing water. Corn leaves may be infected at any growth stage. Symptoms appear as long, gray-green to black lesions.

As lesions age, they gradually fade to tan. Plants may wilt as if under drought stress. Premature death may occur, limiting yield by up to 50%. Genetic resistance is available in hybrids, and growers may reduce incidence by crop rotation and tillage.

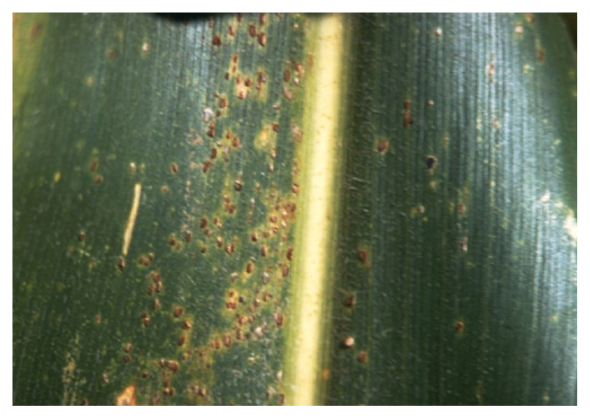
Common smut.

Common Smut and Head Smut

There are two problem smuts that occur in Colorado corn. Common smut (*Ustilago zeae*) damages all parts of the corn plant. This fungus is spread by the wind, and spores infect the plant through wounds. Common smut overwinters in corn residue or soil and is often seen following hail or other injury. This disease is favored by excess N from fertilizer or manure. Some hybrids are less susceptible to common smut than others. Growers should avoid mechanical injury to corn during cultivation and maintain proper soil fertility levels to minimize impact.

Head smut.

The other smut that can be a problem in Colorado is head smut (*Sporisorium holci-sorghi)*. It is commonly found to cause damage in tassels and ears. Different than common smut, head smut is systemic, infecting the plant through soil borne spores. Low soil moisture and soil temperatures between 70 degrees F to 82 degrees F are optimum for infection, which cause stunting and ear abortion. Adequate soil N during early growth stages may limit susceptibility, but the disease is best managed by rotation and resistant hybrids.



Common rust.

Common Rust

Common rust (*Puccinia sorghi*) initially results in yellow flecks on the leaves. Eventually, reddish blisters or pustules, filled with fungal spores, form on the upper and lower leaf surfaces. Most hybrids have some resistance to common rust, but the problem is seldom severe enough to warrant hybrid selection on this basis. Fungicides are available for use in years with infections above economic thresholds, but they must be applied early to be effective.

Stalk Rots

Several different organisms may be associated with stalk rot. The main fungal pathogens found in Colorado are *Gibberella zea* and several fusarium species (in the *Gibberella fujikoroi* complex). Symptoms of stalk rot often appear after pollination. Affected plants die prematurely, and the stalks are prone to breaking or lodging during high winds and rainstorms. Internal tissue in the lower portion of the stalk appears shredded.

Fusarium stalk rot.

Bacterial soft rot, caused by *Erwinia chrysathemi,* is an emerging problem. Symptoms often appear in midseason when plants suddenly fall over. The damaged stalks are bleached and develop a soft, slimy, malodorous rot. Bacterial stalk rot is often associated with the use of surface water (river, lake, impounded water) for irrigation.

Stalk rots are controlled by a combination of resistance and cultural practices that include proper seed rates, insect control, balanced fertility, and drought avoidance. Early harvests may be necessary on fields that show a high (10% to 15%) stalk rot incidence.

WEEDS

Weed management in corn is often more complex than insect and disease management due to the number of different weed species that occur in any one field. Uncontrolled weeds cause yield loss, harbor insects and disease organisms, cause harvest problems, and may decrease silage quality. Weeds that tend to prevail in cultivated corn fields are often highly competitive with young corn plants.

The integrated pest management (IPM) approach to weed management includes crop rotation, weed and weed seed scouting and mapping, tillage, and herbicide spot treatment or banding. As important tools for weed control, herbicides presently account for approximately 65% of all pesticide use in Colorado. Rather than rely exclusively on herbicides for weed control, producers can save money and manage weeds by incorporating all appropriate management measures.

Herbicide resistance has become a problem for some corn growers in Colorado. Globally in corn, 61 different herbicide-resistant weed species have been reported, including pigweeds, kochia, and others. In the U.S., glyphosate resistance has increased in the last 10 years, with at least eight species, including kochia, reported to have glyphosate-resistant populations in Colorado. Instead of increasing herbicide rates, producers must accept the need to rotate both crops and herbicide chemistry.

A major issue facing global corn production is the lack of new herbicide mode of action discoveries over the past 20 years. This means that growers must make wise use of existing herbicides to avoid weeds developing resistance to multiple herbicides, at which point few options will exist for effective weed control. Such a situation currently exists for wheat producers in Australia, with the effect that growers are desperate for any new weed management tools.

Growers must know the weed species in each field, the location and severity of weed infestations, and the options for managing the most yield-limiting weeds. Early-season weed scouting and mapping, followed by a late-season weed survey, can help growers obtain an accurate assessment of weed species, location, and infestation severity.

Research has shown that if weeds are kept out of corn fields for the first five to seven weeks after emergence, later weed infestations will not significantly reduce yields. Successful tools to improve early corn competitiveness against weeds include:

- delayed planting dates
- narrow row spacing
- good seedbed preparation
- soil fertility management

Dryland Weed Considerations

Research at Akron, Colorado, has found that higher populations (19,000/A) and decreased row spacing to 15 inches improves weed management. Late emergence of weeds probably will not decrease current year yields, but will build the weed seed bank for future years.

Rotate weedy fields to a crop that is more competitive against the major weed problem. For example, going from corn to a solid-seeded forage legume such as alfalfa can effectively reduce wild proso millet.

In general, since broadleaf weeds are easier to control with post-emergence herbicides, often there is a shift in no-till fields to grassy weeds. Rotation to a broadleaf crop can help control grassy weeds.

Barnyardgrass.

Barnyardgrass (*Echinochloa crus-galli*)

is found throughout Colorado, but especially in irrigated or wet areas. The grass has flat, smooth, and broadleaf blades and smooth, flattened, branched stems that are reddish to purple at the base. Bristly spikelets are green or purple. Plant height ranges from eight inches to five feet tall. This grass reproduces by seed but has the ability to root at the nodes and reestablish after a light cultivation. Seed can spread through irrigation water.

Buffalobur. A. Knight, Bugwood (top); G. Frisoe, Bugwood (bottom)

Buffalobur (*Solanum rostratum*)

is a seed-producing annual found in Colorado in cultivated fields, meadows, pastures, and waste areas. It serves as a host for the Colorado potato beetle. Each alternate, hairy leaf is sectioned into five to seven lobes. Yellow flowers develop into a spiny bur.

Canada thistle.

Canada thistle (*Cirsium arvense*)

is an introduced, colony-forming perennial weed with a deep and extensive root system. The branched stem can be one to five feet tall, topped by purple, or occasionally, white flowers.

Heavy infestations can reduce corn yields up to 80%. Herbicides are most effective when applied at the bud stage and full regrowth.

Field bindweed.

Field bindweed (*Convolvulus arvensis*)

is an introduced perennial weed found throughout Colorado. Arrow-shaped leaves are alternate on the twining stems. White or pink flowers are bell- or trumpet-shaped. Field bindweed reproduces by seeds that remain viable in the soil for decades, and has a very resilient, long taproot.

Field bindweed and Canada thistle must be controlled using translocating herbicides applied when plants are actively growing. Fields with heavy infestation are good candidates for Roundup® Ready corn.

Green foxtail (*Setaria viridis*)

is found in cultivated fields and waste areas throughout Colorado. It has an erect stem with or without branches. This foxtail has a hairy ligule and slightly rough leaf margins. Leaves can be 2 to 10 inches long and the seed head is dense and bristly. This plant grows from 8 to 24 inches tall and reproduces by seed.

Green foxtail. W. VanDyk Evans, Bugwood (top)

Yellow foxtail (*Setaria glauca*)

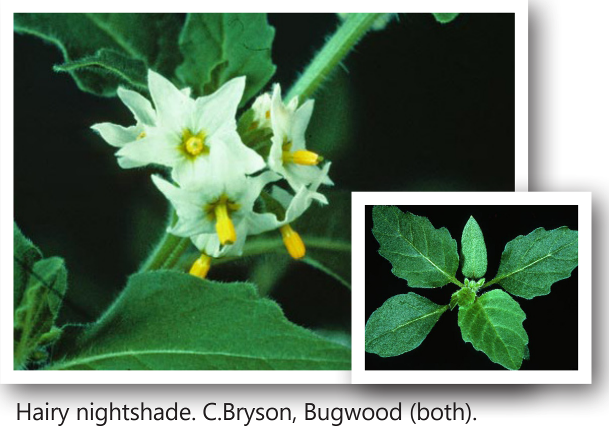
is found in cultivated fields and waste areas throughout Colorado, but it is not as common as green foxtail. This grass has an erect stem that tends to be taller than green foxtail. Height ranges from 12 inches to 3 feet. Smooth leaves have distinct long hairs on the leaf margin and fuzzy, yellowish-brown spikelets. It reproduces by seed.

Foxtails are warm-season grasses. Increasing early crop vigor can decrease competition.

Yellow foxtail. R. Videki, Bugwood (top); D. Doohan, Bugwood (bottom)

Hairy nightshade (*Solanum sarrachoides*)

is a seed-producing annual found in eastern Colorado. The plant grows prostrate with alternate, oval, dark green leaves. Leaves and stems are covered with tiny hairs and may feel sticky to the touch. Flowers have olive green berries, and the plant grows up to 1.5 feet tall.



Hairy nightshade. C.Bryson, Bugwood (both).

Johnsongrass (*Sorghum halepense*)

is a perennial weed resembling forage sorghum that is found in southeastern Colorado, but is moving north. Seed heads are large, purplish, and loosely arranged. The plant can grow from two to five feet high and reproduces both by seeds and rhizomes. Cultivation can help with control, but cultivation tools must be cleaned after going through weed patches.

Johnsongrass. S. Dewey, Bugwood (top); H. Schwartz (bottom).

Kochia.

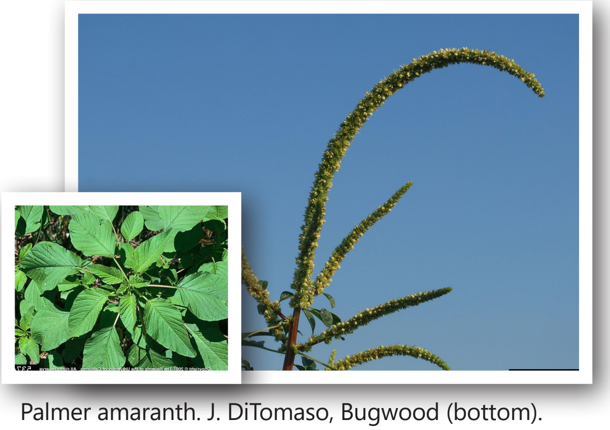
Kochia (*Kochia scoparia*)

is an introduced annual found throughout Colorado. Leaves are alternate, long and narrow, and attached directly to the reddish, erect stem. This plant reproduces by seeds that are spread by windblown plants tumbling in autumn. Up to 50% of kochia in Colorado is resistant to triazine and ALS herbicides. In recent surveys (2011-2013) of kochia from eastern Colorado, between 10% and 20% of collected samples were resistant to glyphosate, and approximately 10% were resistant to dicamba.

Lambsquarters. A. Knight, Bugwood (top).

Lambsquarters (*Chenopodium album*)

is found throughout Colorado in cultivated fields and waste areas. Leaves are alternate, with lower leaves more oval-shaped than upper leaves. Flowers are found at the tip of the stem. Seedlings appear similar to redroot pigweed, but pigweed has a prominent midrib. The pink-purple stems can grow up to six feet tall. Lambsquarters is an annual and reproduces by seeds.



Palmer amaranth. J. DiTomaso, Bugwood (bottom).

Palmer amaranth (*Amaranthus palmeri*)

is native to the southwestern U.S. It has been a problematic weed species in cotton and soybean production in the southeastern U.S. for nearly 20 years but has recently been found in eastern Colorado. The petioles are as long as the leaves, giving the plant a poinsettia-type appearance in early growth stages. This plant grows from one to six feet tall, and the ovate leaves often have a V-shaped variegation. Palmer amaranth is dioecious, meaning that a plant has only either male or female flowers. Flowering structures are one to two feet long.

Palmer amaranth is normally well controlled by glyphosate, but glyphosate resistance is now widespread in this species in the southeastern U.S.

Prostrate pigweed. J. DiTomaso, Bugwood (both).

Prostrate pigweed (*Amaranthus blitoides*)

is found throughout Colorado in cultivated fields and waste areas. Smooth, pale, oval, and alternate green leaves attach to branching stems that form a mat. An annual, this plant grows 12 to 18 inches long and reproduces by small, black, shiny seeds.

Redroot pigweed (*Amaranthus retroflexus*)

is found throughout Colorado in cultivated fields and waste areas. Small green flowers are densely clustered in bristly seed heads growing from the stem. This plant can grow from one to six feet tall and has a reddish taproot. An annual, this plant reproduces by small, black, shiny seeds and resistance to triazine herbicides is increasing in Colorado.

Redroot pigweed. A. Knight, Bugwood (top).

Russian thistle (*Salsola iberica*)

is an introduced annual found throughout Colorado in cultivated fields, roadsides, and waste areas. This plant is round and bushy and the first leaves are soft and slender, replaced by short (0.5 inch) and spiny leaves. It reproduces by seeds spread by tumbling windblown plants. A second species of Russian thistle exists, *Salsola kali*, that tends to resemble asparagus in growth habit.

Russian thistle. A. Knight, Bugwood (bottom).

Sandbur (*Cenchrus longispinus*)

is a warm-season annual grass found in cultivated fields and waste areas, particularly on sandy soils. Sandbur grows from eight inches to three feet tall and reproduces by seed that spreads primarily by animals or machinery.

Sandbur is a difficult problem in no-till fields and may require tillage or Roundup Ready® corn to control. Seeds germinate throughout the growing season. However, control of early season seedlings will promote higher corn yields.

Sandbur. A. Knight, Bugwood (top).

Shattercane (*Sorghum bicolor*)

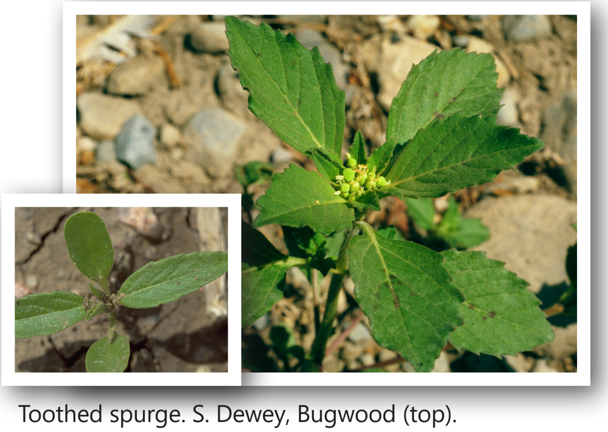
is an annual weed thought to have developed from outcrossing of sorghum with Johnsongrass. It is found in irrigated areas in eastern Colorado. Shattercane is a grass with long (one to two feet), wide leaves and an erect stem. The plant can grow up to 12 feet high and reproduces by seeds that are black in color. Rotating to small grains, alfalfa, or perennial grasses will help control shattercane.

Shattercane.

Common sunflower.

Common sunflower (*Helianthus annuus*)

is found in Colorado on roadsides, in fields, and in waste areas. Alternate, toothed, oval or heart-shaped leaves are rough and large. The stem is erect, stout, branched, and covered with stiff hairs. It can reach up to nine feet tall. Sunflower is an annual, reproducing by seeds.



Toothed spurge. S. Dewey, Bugwood (top).

Toothed spurge (*Euphorbia dentata*)

is found in eastern Colorado fields and waste areas. Leaves are opposite, one to three inches long, oval, hairy, and toothed, and attached to a somewhat woody stem. Stems can grow to be two feet tall. All plant parts exude milky juice. Toothed spurge is an annual, reproducing by seeds.

Velvetleaf.

Velvetleaf (*Abutilon theophrasti*)

is an introduced annual found mainly in Morgan and Weld counties in cultivated fields, pastures, fence rows, and waste areas. The occurrence of velvetleaf in western Colorado is increasing. Heart-shaped, alternate leaves grow up to five inches or more wide and attach to an erect, branched stem. The stem and leaves are covered with tiny hairs. Yellow flowers form seed pods arranged in a disk, with each pod containing flat seeds. Velvetleaf grows up to seven feet high.

Quick shading by the crop canopy and management that increases crop competitiveness combined with early tillage help to suppress the growth of velvetleaf.

Wild buckwheat. G. Frissoe, Bugwood (top).

Wild buckwheat (*Polygonum convolvulus*)

is an introduced annual found throughout Colorado in irrigated areas, fields, and waste areas. Seedling plants have distinctive heart-shaped leaves. The plant is sometimes confused with bindweed, but instead of showy flowers, it has small, greenish, white flowers that produce shiny, black seeds.

Wild proso millet (*Panicum miliaceum*)

is found in cultivated fields throughout eastern Colorado. It is a grass with hairy leaf blades that measure from 0.50 to 0.75 of an inch. The dark, shiny seeds are borne on a spreading 6- to 12-inch panicle. This grass can grow up to 2 to 6 feet tall. Wild proso millet reproduces by seed spread by birds, equipment, and irrigation water. Crop rotation, cultivation, and narrow rows are effective controls for this annual grass.

Wild Proso Millet.

Witchgrass (*Panicum capillare*)

is an annual found in cultivated fields and waste areas, particularly on dry, sandy soils. This grass has hairy leaf blades and sheaths, and a stout, erect stem, six inches to two feet tall. Witchgrass reproduces by seed spread by tumbling seed heads.

Witchgrass. S. Dewey, Bugwood (bottom).

Dryland Weed Considerations

Non-irrigated corn production in Colorado requires catching, retaining, and using precipitation efficiently. Because this tight water budget does not allow for tillage during the growing season, and preferably none between corn and the previous crop (usually wheat), herbicidal weed control is critical.

Herbicide resistance or tolerance occurs in some weed species (kochia, pigweed) to the more economical soil-applied herbicide products. The effectiveness of these products is spotty in dryland situations due to unpredictable precipitation. However, resistance to glyphosate is increasing in kochia and some pigweed species, and IPM practices are recommended to manage herbicide resistance.

Silage Considerations

Growing silage instead of grain corn is a potential strategy on fields with perennial weeds, such as Canada thistle and bindweed. Following the earlier silage harvest, time remains to control perennial weeds while they are still growing with effective herbicides before the weeds become dormant.

HERBICIDE INJURY AND IDENTIFICATION

Even when herbicides are applied according to the label, plant injury can occur. However, many times herbicide injury results from:

- herbicide carryover from previous crop applications.
- herbicide drift from nearby applications.
- improper application of labeled herbicides.

Herbicide injury symptoms can be confused with nutrient deficiencies or toxicities, waterlogged soils, mechanical damage, cultural damage, frost or wind damage, or pest damage. Hybrids may vary in their response to herbicides.

Look for patterns in the field associated with soil types and with overspray at field borders or overlap patterns from application equipment. Crop advisers, commercial applicators, and other experts can help farmers determine why the injury happened. Operator error (high rates, wrong chemical, and overlaps) can be the cause, but the interaction of temperature, crop vigor, moisture, and soil type often combine to cause injury, even when the chemical is properly applied. Many times, the corn plant will recover when growing conditions become more favorable.

BMP

Follow all Pesticide label instructions to ensure safe, proper, and effective use of these products. In fact, it is a violation of Federal law to use any product in a manner inconsistent with the labeled instructions.

Herbicide Injury Symptoms and Causes by Mode of Action and Chemical Family

Growth Regulators

PHENOXY ACID

Example: 2,4-D

Injury Symptoms	Injury Cause
Rolled leaves	Applied to rapidly growing corn
Fused brace roots	Applied too late
Stalk bending & brittleness	
Missing kernels	

2, 4-D injury. UMN, Bugwood.

BENZOIC ACID

Example: dicamba (Banvel)

Injury Symptoms	Injury Cause
Similar to 2,4-D	Same as 2,4-D
	Variable hybrid sensitivity

Dicamba injury.

Imidazoline injury. UMN, Bugwood.

Amino Acid Synthesis Inhibitors

IMIDAZOLINE

Example: imazethapyr (Pursuit)

Injury Symptoms	Injury Cause
Stunted	Drift, carryover
Emerging leaves trapped, yellow to translucent	Misapplied to non-tolerant corn
Root pruning	

Glyphosate injury.

AMINO ACID DERIVATIVE

Example: Glyphosate (Roundup)

Injury Symptoms	Injury Cause
Yellow, then brown foliage	Misapplied to non-tolerant corn
Growing point necrosis, then plants die	

Glufosinate injury.

PHOSPHORIC ACID

Example: glufosinate (Liberty)

Injury Symptoms	Injury Cause
Pale, yellow, or purplish leaves	Applied too late
Water-soaked lesions	Misapplied to non-tolerant corn

Primsulfuron injury. M. Van Gellel, Bugwood.

SULFONYLUREA

Example: primsulfuron (Beacon)

Injury Symptoms	Injury Cause
Stunted, yellow to translucent leaves	Variable hybrid sensitivity

Lipid Synthesis Inhibitors

CYCLOHEXANEDIONE

Example: sethoxydim (Poast)

Injury Symptoms	Injury Cause
Chlorotic to necrotic new leaf tissue	Misapplied to non-tolerant corn

Sethoxydim injury. UMN, Bugwood.

Seedling Growth Inhibitors

DINITROANILINE

Example: trifluralin (Treflan), pendimethalin (Prowl)

Injury Symptoms	Injury Cause
Stunted plants	Carryover
Roots short and thickened	Misapplied to non-tolerant corn
	Over-application

Trifluralin injury. UMN, Bugwood.

ACETANILIDE

Example: alachlor (Lasso), metalachlor (Dual), propachlor (Ramrod), pyroxasulfone (Zidua)

Injury Symptoms	Injury Cause
Poor emergence	Over-application
Stunting	Delayed corn emergence
Leaf-out before emergence	Variable hybrid sensitivity
Leaf entrapment	

THIOCARBAMATE

Example: EPTC (Eradicane, Butylate (Sutan+)

Injury Symptoms	Injury Cause
Leaf entrapment	Cool, wet soils
Buggy whipping	Over-application
Stunting	Variable hybrid sensitivity

Triazine. Purdue.

Photosynthetic Inhibitors

TRIAZINE

Example: atrazine, Simizine (Princep)

Injury Symptoms	Injury Cause
Yellow and brown leaf tissue	Cool, wet soils
	Crop oil synergy

Bromoxynil injury. M. Van Gessel, Bugwood.

NITRILE

Example: bromoxynil (Buctril)

Injury Symptoms	Injury Cause
Yellow or spotted leaf tissue	Crop oil synergy

Chlorophyll Inhibitors

IOXAZOLE

Example: isoxaflutole (Balance)

Injury Symptoms	Injury Cause
Whitened tissue	Over-application on cool, wet, or sandy soils
Poor emergence Stunting	

Isoxaflutole injury. A. Hagar, Bugwood.

Cell Membrane Disrupters

BIPYRIDYLIUM

Example: paraquat (Gramoxone)

Injury Symptoms	Injury Cause
Limp, water-soaked lesions	Drift
Spotting	

Paraquat injury.

SOIL FERTILITY

Nutrient Requirements

Corn plants require at least 17 nutrients in sufficient quantities for proper nutrition (Figure 15). Using the sun's light and heat as an energy source, the corn plant uses nutrients to build simple sugars into the more complex molecules necessary for its growth and development.

Corn plants obtain carbon, oxygen, and hydrogen from the atmosphere and from water and air in the soil. The 14 mineral nutrients are absorbed by plant roots from the soil. Depending upon soil type and region of the state, only two to six of these nutrients are needed in supplemental quantities through fertilizer or manure in Colorado. The remaining nutrients are supplied from the weathering of soil minerals, organic matter mineralization, irrigation water, and rainfall. Essential elements for plants are required in varying quantities. For example, a bushel of corn removes approximately 0.8 pound of nitrogen, but only 0.001 pound of zinc, an 800-fold difference.

The key to profitable fertility management in corn production is determining available soil nutrients and then deciding what additional nutrients are required to maximize efficient grain or silage production. The most re-

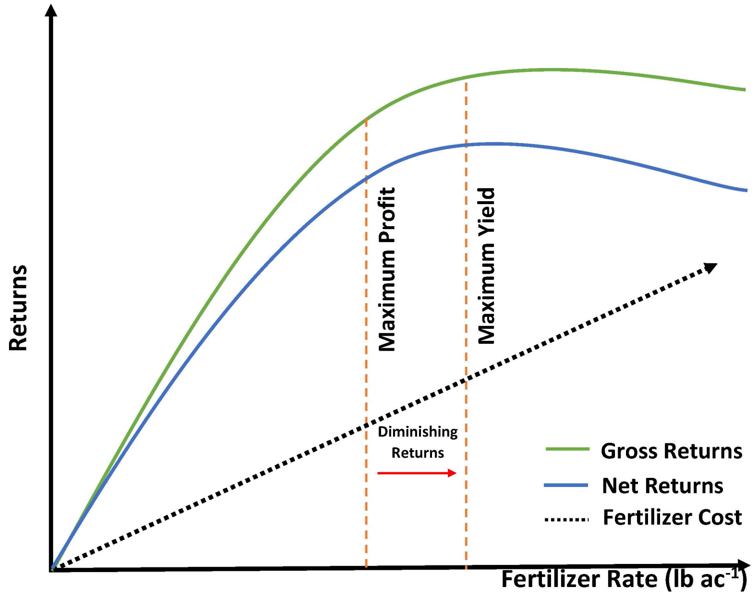
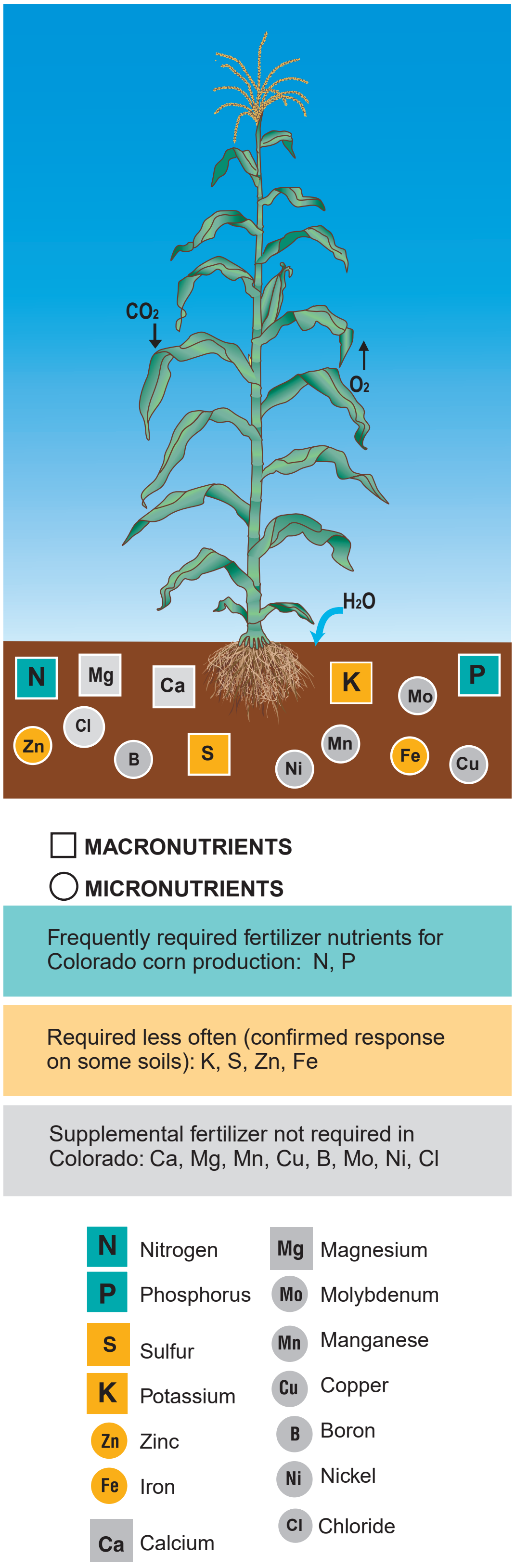


Figure 15. Relationship of fertilizer rates and economic returns in corn. For most added fertilizer nutrients, corn yield increases rapidly at first and then levels off. The most economical yield if often not the maximum achievable yield and will depend upon corn and fertilizer price.



Frequently required fertilizer nutrients for Colorado corn production: N, P

Required less often (confirmed response on some soils): K, S, Zn, Fe

Supplemental fertilizer not required in Colorado: Ca, Mg, Mn, Cu, B, Mo, Ni, Cl

Figure 16. Essential plant nutrients. © Modified from the International Fertilizer Industry Assoc.

liable way to determine nutrient needs is through soil sampling. As (Figure 15) shows, the most profitable fertilizer rate is not always the one that gives maximum yield.

4R Nutrient Management

1. Right Source
2. Right Rate
3. Right Time
4. Right Place

The **Right Source** refers to the selection of a nutrient source that will supply what a field needs while considering localized characteristics such as soil chemical and physical properties. The **Right Rate** focuses on understanding crop demands, available soil nutrients, fertilizer use efficiency, and economics to determine how much fertilizer to apply. Determining the **Right Time** for nutrient application includes assessing the time of plant nutrient uptake, the dynamics of soil nutrient availability and loss, and field logistics. **Right Place** considers crop root zone and root development, as well as spatial variability, tillage systems, and the role of soil chemical properties.

4R Nutrient Management

The 4R nutrient management concept recognizes the importance of local stakeholder control of what exactly "right" means. Including site-specific information (soil, weather, cropping system, tillage) is critical for the success of any nutrient management plan.

Visit nutrientstewardship.org for more information.

N deficiency symptoms appear first on older leaves. Yellowing starts at the leaf tip and moves in a "V" pattern down the midrib towards base.

Nitrogen (N)

Nitrogen (N) is the essential nutrient that most frequently limits corn yields in Colorado. Corn requires more added N from fertilizer or other sources than any other nutrient. Approximately 1.2 pounds N from soil or supplemental sources is required to produce one bushel of corn. Nitrogen management is also closely tied to irrigation management since N is mobile in the soil as nitrate (NO_3). Nitrogen can be lost in surface runoff or leached below the crop root zone leading to economic losses and environmental impacts. Sound irrigation management is one key to reducing these losses.

Nitrogen cycle facts:

- NO_3 is very water soluable and moves easily (leaches) in soil.
- NH_4 is adsorbed to soil particles and does not readily leach.
- NH_4 converts rapidly to NO_3 when soil temperature is over 56 degrees F.

Nitrogen in Corn

- Plants take up nitrogen in the ammonium (NH_4+) and nitrate (NO_3-) forms.
- Nitrogen is mobile within the plant and will move from older to younger tissues.
- Added N fertilizer can become unavailable to corn through leaching and runoff, loss to gaseous forms (volatilization and denitrification), or conversion to organic forms.

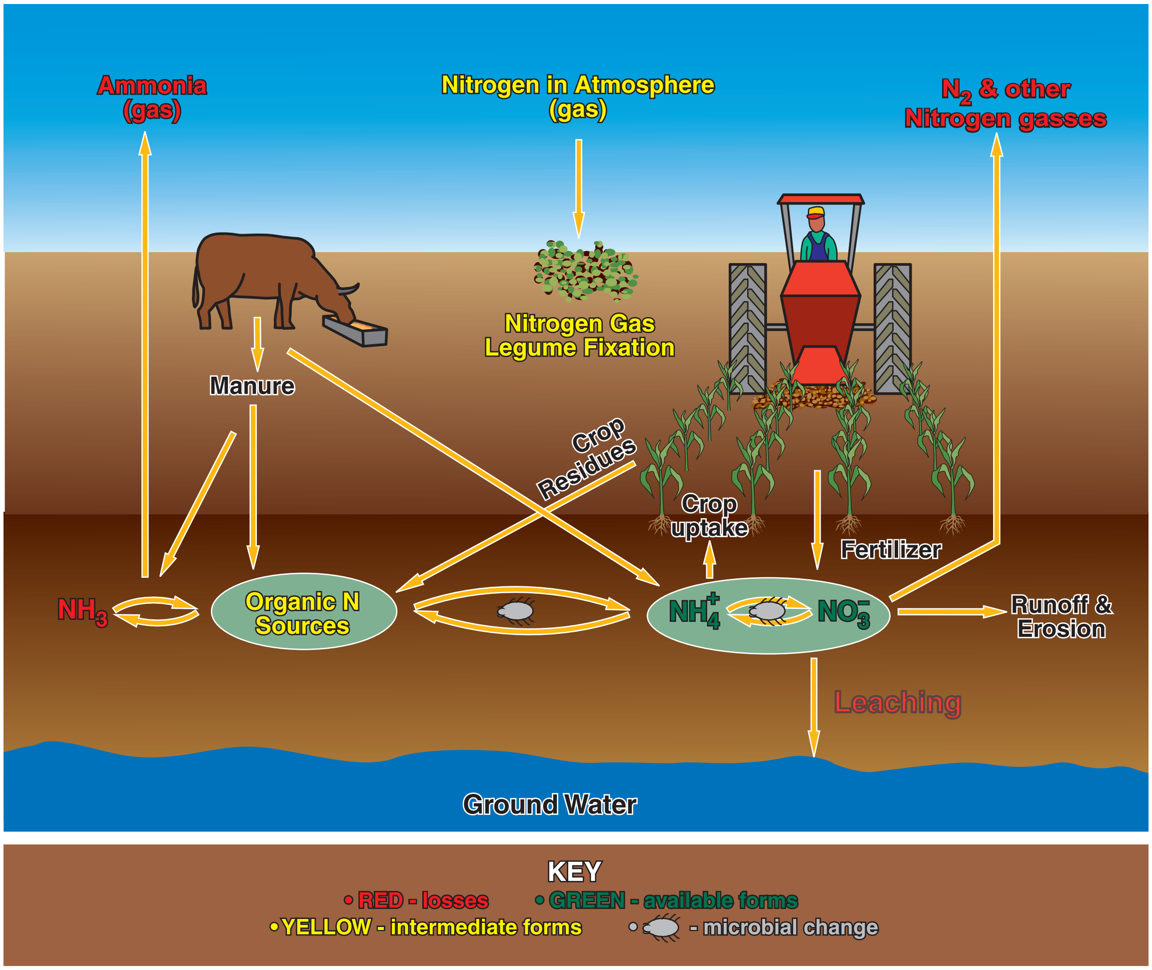


Figure 17. The Nitrogen cycle in soil.

- NO_3- and NH_4+ become available from sources other than fertilizer and manure, such as crop residues,soil organic matter, legume fixation, and atmospheric deposition.

Determining Correct Nitrogen (N) Application Rates

Each bushel of corn harvested contains 0.80 to 0.90 pound of N and each ton of silage contains approximately 7.5 pounds of N per ton silage (35% dry matter). Research has shown that the following equations closely predict corn N requirements in most situations. Since the gross N requirement is based on yield expectation, use an accurate yield history when determining N rate. Yield expectation should be based on the average 5-year yield history for each field, plus 5%.

Use the N requirement calculation below to compare recommendations from soil testing laboratories. If the recommendations vary greatly, ask the lab to explain their procedures for calculating N requirements and their philosophy of nutrient management (i.e. build soil N, meet annual crop needs).

Groundwater and Nitrate-Nitrogen (NO_3-N)

- Groundwater in irrigated areas along the South Platte River frequently contains greater than 10 ppm NO_3-N. That amounts to over 27 pounds N per acre-foot of water applied.
- Crediting irrigation water NO_3-N towards a nitrogen requirement can help remove nitrates from groundwater and lower fertilizer costs.

N Fertilizer Requirement Calculation

1. Total N required for yield expectation:

   Grain: total N required = (yield expectation in bushels/acre x 1.2) + 35

   Silage: total N required = (yield expectation [wet weight basis] in tons x 7.5) + 35

2. Subtract soil organic matter from total N required:

   Grain: organic matter credit = (yield expectation in bu/acre x 0.14) x % organic matter

   Silage: organic matter credit = (yield expectation in tons x 0.85) x % organic matter

3. Subtract residual soil NO_3-N from total N required:

   Soil NO_3-N credit = 8 x average soil NO_3-N ppm

4. Subtract manure credit (Table 12).

5. Subtract irrigation water credit (Irrigation Nitrate Credit box).

   Irrigation water NO_3-N ppm x 0.223 pound N/acre-inch x inches irrigation water

6. Subtract legume credit (Table 12).

Example:

- 225 bushels/acre grain yield expectation
- 1.5% organic matter
- 12 ppm NO_3-N in soil
- 15 ppm NO_3-N irrigation water
- No manure or legume

Total N needed = (225 bushels/acre x 1.2) + 35	= 305 pounds N/acre
Organic matter credit: (225 bushels/acre x 0.14) x 1.5%	= 47
Residual soil credit: 8 x 12 ppm NO_3-N	= -96
Irrigation water credit: 15 ppm NO_3-N x 0.223 lb x 15″ H_2O	= -50
Net N fertilizer required:	**= 112 pounds N/acre**

Irrigation Water Nitrate Credit: NO_3-N ppm x 0.223* x H_2O inches = N credit (pounds/acre)

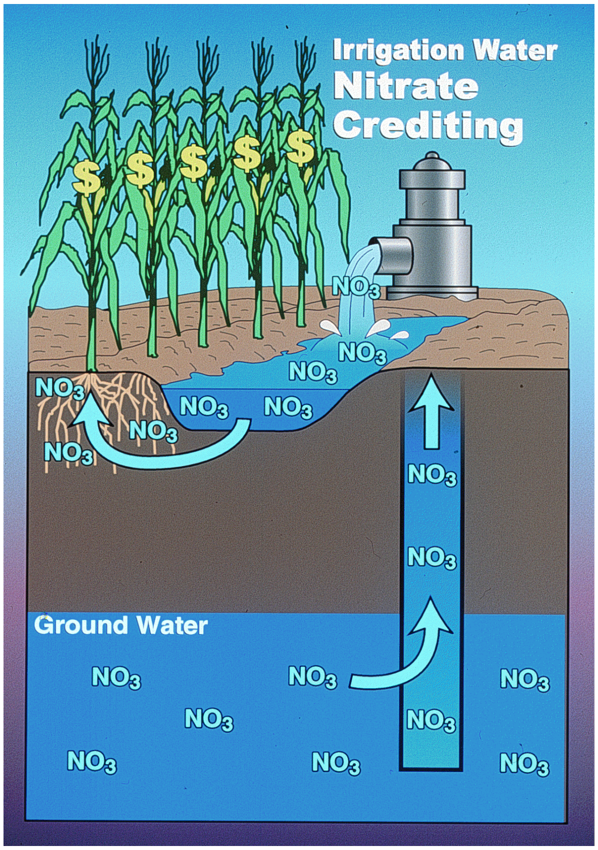


Figure 18. Crediting irrigation water nitrate is a BMP that can reduce nitrogen fertilizer rates and protect water quality.

BMP

Identify fields with a high potential for leaching or runoff and employ all appropriate BMPs on these fields to reduce contamination of water supplies.

Table 11. Soil Sample Nitrate Credit

Soil layer sampled	Sample thickness	Measured NO_3-N	Calculations
inches		ppm	
0 - 8	8″	20	8 x 20 = 160
8 - 24	16″	8	16 x 8 = 128
	24″		**288 ppm**
288 ppm / 24″ = 12ppm			

Soil Sampling for N

- Surface sample should be to tillage depth.
- Sample subsurface to a minimum of two feet deep. The N fertilizer requirement equation performs best when a three to four feet sample depth is included.
- Take 15 to 20 cores from a uniform area (no more than 40 acres).
- Thoroughly mix cores together and save one pint for a composite analysis.

Determining Nitrate Credits

Irrigation water nitrate credit

1. Determine the nitrate-nitrogen (ppm NO_3-N) content of the irrigation well water by field test kits or laboratory analysis. Initially, sample water twice a year to account for seasonal variability, and then annually.
2. Estimate the amount of water to credit. Most N uptake in corn occurs by milk stage (R3). Therefore, credit water applied before mid-August. Reasonable water credits in Colorado are: Northeast Colorado, 15 inches; Central High Plains, 17 inches; Southern High Plains and Arkansas Valley, 19 inches.

* acre-inch = 0.223 lb N for each ppm (mg/L) of NO_3-N

Table 12. Nitrogen Credits for Previous Crops and Manure Applications

Crop		lb N/A credit*
Alfalfa	>80% stand	100 - 140
	60 - 80% stand	60 - 100
	0 - 60% stand	0 - 60
Sweet clover and red clover		80% of credit for alfalfa
Dry beans		30
Sugar beets**		50
Manure		**lb N/ton credit*** **
	dry basis	as is
Beef	10	5 (at 50% DM****)
Dairy	15	3 (at 20% DM)
Poultry	25	20 (at 75% DM)

*For the second year, use 1⁄2 of the first year N credit.
**Sugar beets are included due to the incorporation of beet tops. They are not a legume crop.
***For the second and third years, use 1⁄2 and 1⁄4 of the first year N credits, respectively.
****Dry matter.

Nitrogen Uptake in Corn

- Corn absorbs the majority of its N during rapid growth between V8 (8-leaf) and R3 (dough) growth stages.
- Nitrogen uptake period is rapid between V8 (8-leaf) and VT (tassel) growth stages and sidedress N should be applied just before this period for maximum efficiency.
- Corn yield potential is determined as early as V4 (4-leaf), when ears begin forming. Therefore, any nutrient deficiency at this time can reduce yield potential.
- Corn hybrids vary slightly in N accumulation patterns.

Pre-Sidedress Nitrate Test (PSNT) Guidelines

- Sample field when corn is approximately 12 inches tall (V6 growth stage).
- Collect a minimum of 15 to 20 randomly located 12-inch soil core samples from a uniform area or a 40-acre field.
- Equal numbers of samples should be taken from the furrow and the shoulder of the bed about four inches from row, (Figure 20). Avoid previously applied fertilizer in bands, especially on minimally tilled soils.

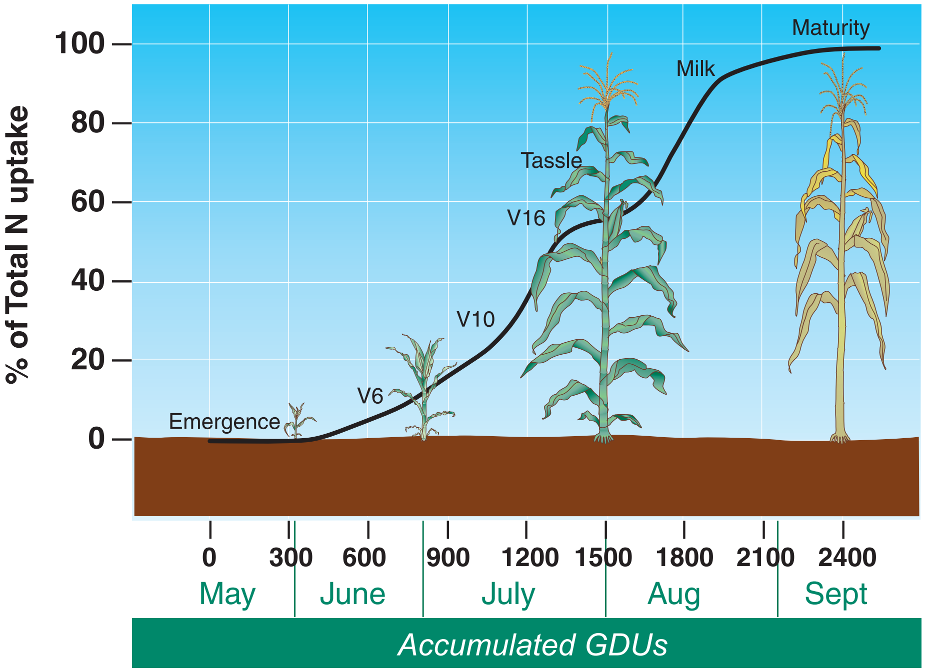


Figure 19. Generalized nitrogen uptake pattern in corn.

N Uptake and Application Timing

Since N is not stable in soil and becomes less available for crop uptake over time, application timing is important. As (Figure 19) shows, much of the N uptake occurs in a relatively short time period. If N is insufficient during this period, yield loss will occur. Apply nitrogen immediately before or during this period to result in higher uptake by the crop and less nitrate lost to leaching, runoff or transformations to unavailable forms.

An application schedule that applies a small amount of N early in the season (preplant or starter) followed by later, in-season applications of higher amounts of N is ideal. This schedule takes care of the small, but important, early season N needs and maximizes uptake by applying N during the rapid growth and N requirement period.

In-season N Assessment Tools

The pre-sidedress nitrate test (PSNT) is an in-season N assessment tool for determing the need for additional N fertilizer. This is a useful test for growers who split apply N or apply supplemental sidedress N to manured fields. Usually N fertilizer recommendations are based on pre-plant soil samples taken in the fall or in the early spring. However, most N uptake by corn occurs in midsummer from the V8 growth stage to tassel (Figure 19). Mineralization of N from manure or other organic matter, N immobilization, and nitrate leaching can significantly change soil N availability. By com-

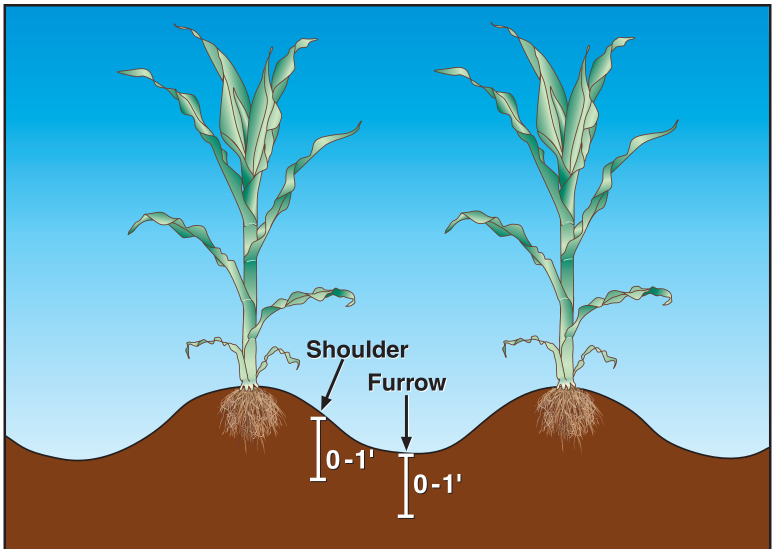


Figure 20. Pre-sidedress nitrate test (PSNT) sampling positions.

plementing preplant soil testing with PSNT, growers can better predict yield response from N fertilizer, saving unnecessary fertilizer costs.

Colorado State University researchers found that when the top foot of soil contains at least 20 ppm NO_3-N at the V6 growth stage, the probability of a yield increase to additional N is low under typical conditions. If the PSNT level is lower than 20 ppm NO_3-N, sidedress N should be applied. The PSNT shows only if soil N is adequate, but not how much is needed. Assess the yield potential and pre-plant soil nitrate levels to determine how much additional N is needed if the PSNT is below 20 ppm.

Another in-season N assessment tool is canopy sensors. Various reflective sensors have been developed to measure leaf greenness and thus, indirectly, nitrogen status. Corn leaf greenness is controlled by leaf chlorophyll concentration, which indicates the nitrogen status of the crop. Chlorophyll content can be measured directly with hand held instruments or with sensors attached to leaf tissue. Increased understanding of remote sensing and imagery related to plant nitrogen content is making regular field mapping a good tool for some growers. Satellite or drone imagery can be used to assess nutrient status as well as moisture stress. When coupled with GPS software and variable rate application, N rates can be adjusted to account for field variability during the growing season.

BMPs

Use sidedress or in-season fertilizer application for at least 40% of the total N applied to irrigated crops on fields with sandy soils.

Use fall planted cover crops, such as rye or triticale, to scavenge excess N left in the soil after a poor crop.

Mix and store N fertilizers at least 100 feet away from wells or any water supply.

Table 13. Nitrogen use efficiency according to timing of application

Highest	Sprinkler applied during rapid growth
	Sidedress just before rapid growth
	Post-plant incorporated
	Pre-plant incorporated
Lowest	Fall application for next year's crop

Phosphorus (P) in Corn

- P is available to plants as H_2PO_4- and HPO_4^2-.
- P is mobile within the plant, but largely immobile in soil.
- P is involved in plant energy transformations.
- Corn removes 0.32 pound P_2O_5/bushel (15.5% H_2O) and 3.5 pounds P_2O_5/ton (65% H_2O) of silage.

Phosphorus deficiency. Symptoms appear as leaf purpling, particularly along leaf edges of young plants, along with slower growth and stunted plants. California Fertilizer Association.

BMPs

- Band-apply P fertilizer within four inches of the row to increase uptake efficiency.
- Incorporate surface-applied P fertilizer or manures into the soil, especially where any potential for surface runoff or erosion exists.
- Maintain a buffer, where fertilizer and manure are not applied, a minimum of 50 feet from surface water and drainage channels.

Phosphorus (P)

Second to nitrogen, phosphorus (P) is typically the next most yield-limiting nutrient for corn production in Colorado. However, the amounts of P necessary for optimal production are significantly lower than N. Phosphorus availability is strongly affected by soil pH and can be limited by in alkaline (high pH), especially in calcareous soils.

Phosphorus cycle facts:

- Most P in soil is unavailable for plant uptake (< 1% plant available).
- 85% of P is in mineral form (< 1% of this plant available).
- 15% P is in organic form (40% to 50% of this will become plant available).
- Maximum available P is at pH 6.2 (slightly acidic).
- High pH soil will fix applied P and naturally occurring P, making it unavailable to plants.

Phosphorus (P) Placement and Rate

Banding phosphorus fertilizer is more efficient than broadcast applications (Figure 22). When banded, less P is lost to fixation in high pH soils or becomes available for runoff.

Because P is immobile in soils, young corn plants with limited root systems often show deficiency, especially in cool, wet soil. Therefore, placement near the roots ensures maximum uptake. Subsurface band placement is also critical for no-till situations.

(Table 14) provides phosphorus fertilizer application rates for two soil test procedures: AB-DTPA and NaHCO3, performed on neutral to high pH soils that are calcareous. Other extraction methods, Mehlich and Bray-1, are better suited for neutral to acidic soils and are used by some commercial laboratories.

The relative levels provided in (Table 14) are based upon the probability of a yield increase to P fertilization. Low testing soils have a high probability that P fertilizer will produce higher yields, but the probability decreases rapidly as soil test P increases. However, a band application of 10 to 20 pounds P2O5/acre with 5 to 10 pounds

Table 14. Suggested P Application Rates for Irrigated and Dryland Corn

	Relative Soil P Level			
Soil Test Method	Low	Medium	High	Very High
	ppm P in top 12 inches of soil			
AB-DTPA*	0-3	4-7	8-11	>11
NaHCO$_3$**	0-6	7-14	15-22	>22
Bray P-1$^+$	0-5	5-15	11-30	>30
Mehlich-3^{++}	0-10	11-31	31-56	>56
Application Method	**Fertilizer Rate (pounds P_2O_5 /acre)**			
Banded	40	20	0	0
Broadcast	80	40	0	0

For more precise rates, use the equations below. Notice that rates can be reduced by half through band application.

*Ammonium bicarbonate (DTPA) extraction for basic calcareous soils. P rate (banded pounds P_2O_5/acre = 48-5x (AB-DTPA-P).

**Sodium bicarbonate (Olsen's) extraction for basic calcareous soils P rate (banded pounds P_2O_5/acre = 48-2.5x (NaHCO$_3$-P).

+Bray and Kurtz P-1 for acid and neutral soils.
Source: University of Nebraska, NebGuide G74-174-A.

++Mehlich extraction for acid and neutral soils.
Soil P level source: Servi-Tech Labs.

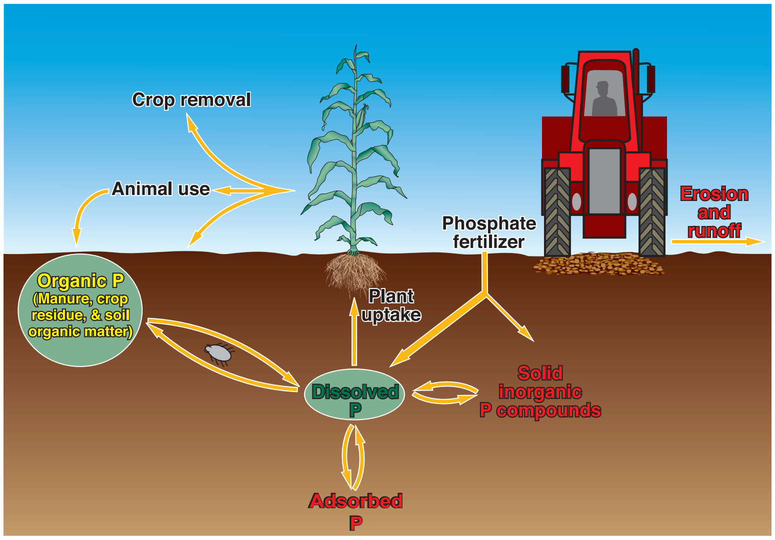


Figure 21. The Phosphorus (P) cycle in soils.

Colorado Phosphorus Index (P-Index)

erams.com/one-water-solutions/project/phosphorous-index-tool

The Colorado Phosphorus Index (P-Index) is a risk assessment tool for off-site cropland phosphorus loss. The P-Index tool will not quantify the amount of P transported, but instead, ranks the relative potential of P transport off-site. This helps determine if it is appropriate to apply nutrients to a particular field or if the risk is too great.

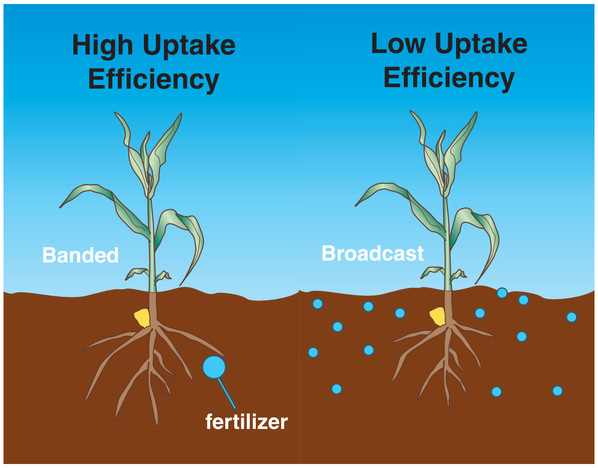


Figure 22. Banded vs. broadcast P fertilizer uptake efficiency.

N/acre may increase early growth of corn plants on some high testing soils but may not result in a yield increase. Divide large, non-uniform fields into smaller fertility management units based upon yield potential or soil type and fertilize according to P levels determined through soil analysis.

Potassium is mobile in plants.

Potassium (K) in Corn

- Most Colorado soils have adequate K.
- Potassium is taken up by the plant as the K+ ion.
- Grain harvest removes approximately 0.25 pound K_2O/bushel, and silage harvest removes 8 pounds K_2O/ton.

Potassium (K)

Although potassium (K), or potash fertilizer, is a macronutrient, it is not often required on Colorado soils. Deficient situations are more commonly found in sandy fields with low organic matter levels. Fields frequently used for silage production are more likely to need K, because four to five times more K is removed by silage than grain. Bailing and removing corn stalks also can remove significant amounts of K.

Irrigation water in Colorado also may contain some K and beef manure contains approximately 30 to 40 pounds K_2O/ton. Both are sources of K that can be taken up by the plant.

Broadcast application potassium chloride (KCL) is an accepted method for correcting K-deficient situations. Some starter blends also contain K, but the cost per unit is often much higher. Starter fertilizer blends that contain more than 20 pounds/acre of N and K should not be applied with the seed. Recommended placement is two inches to the side and two inches below the seed (Figure 21).

Sulfur deficiency symptioms. Yellowing starts at the leaf tip and moves in a "V" pattern down the midrib towards base.

Sulfur (S)

Sulfur (S) is a nutrient adequately supplied by Colorado soils and irrigation water in many situations. Both surface and well water contains appreciable SO_4-S and may supply adequate S for corn. Sulfur application decisions should not be made based on a soil test alone, growers should also invest in an irrigation water analysis test. Only sandy soils with less than 1% organic matter, and less than six ppm SO_4-S in the applied irrigation water, may respond to S fertilizer application.

Because plants only utilize the sulfate form (SO_4) of sulfur, applying the elemental form may not be an effective nutrient source for the first year it is applied. Band application (2 inches x 2 inches) of SO_4-S or other S fertilizers are most effective. Ammonium thiosulfate (12-0-0-26S) is an effective material for a starter at planting. An application of 5 to 10 pounds per acre is adequate for band applied S on responsive soils. Double rates when broadcast application must be used.

Micronutrients

Corn plants use micronutrients in small amounts, however, deficiencies can be just as yield limiting as macronutrient deficiencies. Zinc (Zn) and Iron (Fe) are the only two micronutrients with confirmed deficiencies in Colorado. There have been no confirmed deficiencies of boron (B), copper (Cu), manganese (Mn), Cobalt (Co), molybdenum (Mo), or chloride (Cl) in Colorado corn. Zinc and iron availability decreases with increasing soil pH.

Zinc (Zn)

Zinc deficiencies are often found on soils that have been leveled for irrigation where subsoil is exposed or on soils with high levels of free lime. Most Zn deficiencies are usually reported on soils with pH levels higher than 7.0. Several sources of Zn fertilizer are available, but the material needs to be at least 40% to 50% water soluble to be effective. Banding of zinc sulfate or an equivalent source is a very effective application procedure, especially on high pH soils.

Iron (Fe)

Iron deficiencies also occur on leveled or eroded sites where the subsoil has been exposed or on highly calcareous soils (pH higher than 7.8). Correcting iron-deficient soil can be difficult. For fields with severe Fe deficiency, hybrid selection may be a good option. Check with your seed dealer for availability of corn hybrids that are more tolerant to Fe deficiencies. Foliar spray application of a 1% ferrous sulfate solution at 20 to 30 gallons per acre is not always completely effective in correcting chlorosis, and several applications may be necessary. Generally, soil applications of most liquid Fe fertilizers are not economical for corn on Colorado soils. Broadcasting Fe fertilizers is also ineffective, but seed-row applied granular fertilizer has been shown to correct deficiencies. Incorporation of manure or biosolids in exposed subsoils may correct both Zn and Fe deficiencies and is the best remedy for Fe deficiency when needed.

Sulfur (S) in Corn

- Deficiency is uncommon in most Colorado soils.
- Sulfur is immobile in plant.
- Uptake is in the form of the sulfate ion (SO_4).
- Irrigation water frequently contains SO^4.

Zinc deficiency in corn.

Iron deficiency in corn.

Manure

Livestock manure is an excellent nutrient source for corn production. Although manure is typically applied to meet nitrogen requirements, it also contains significant amounts of phosphorus, potassium, zinc, and iron. Manure also improves soil tilth, water holding capacity, and infiltration.

While manure offers many benefits for soil health and fertility, it also poses risks. Continuous over-application of manure can result in increased salinity, degradation of surface water from phosphorus runoff, or groundwater nitrate contamination. Growers should always apply manure based upon crop nutrient need determined by soil testing and reasonable yield expectations. Use the Colorado P-index to determine appropriate application rates where soil test P is high or runoff may impact surface water bodies.

BMPs

- Incorporate manure after application to minimize N volatilization losses, reduce odor, and prevent runoff.
- Manure should not be applied to soils testing “very high” for soil P.
- Limit solid manure application on frozen or saturated ground to fields not subject to runoff.
- Liquid effluent should not be applied to frozen or saturated ground.
- Consider composting manure where practical and economically feasible.
- Plant permanent vegetation strips around the perimeter of surface water and erosive fields to catch and filter runoff nutrients and sediments.
- See “BMPs for Manure Management” (CSU Bulletin 568A).

Stover Bailing and Removal Considerations

Corn stover – the stalks, leaves, and cobs left over after grain harvest – has significant value in many systems as animal feed and bedding. However, there is also value in respect to their ability to hold soil moisture and prevent erosion. The crop nutrients removed with the stover also have significant value, especially when repeatedly removed over multiple years. Potassium (K) and nitrogen (N) have higher removal rates with corn stover than phosphorus (P).

Silage Considerations

When growing silage corn frequently in a rotation, soil fertility management has a few special considerations. When silage is harvested, the entire plant is removed and all the nutrients and crop residue go with it. Because of this removal, silage corn has a higher N requirement than grain corn, and other nutrients (especially potassium) may need more frequent and higher rates of application. Equally important, silage harvest removes valuable crop residues (leaves, stalks). Loss of these materials makes the soil more prone to erosion and over time and can deplete organic matter. Fields in these rotations will benefit from manure or compost applications and winter cover crops to help maintain their long-term productivity.

Dryland Considerations

Dryland corn production requires the same basic nutrients as irrigated but in smaller amounts because of reduced yield potential. Nitrogen and phosphorus applications will produce the most consistent economical yield responses with zinc being necessary in many areas. Use the same equation provided in on page 54 to calculate N rates with a reasonable yield expectation. Except in the wetter areas of Eastern Colorado, yield responses to N applied above 100 pounds N/acre are unusual. Because dryland corn production requires no or reduced tillage in Colorado, placement is critical to prevent P fixation and N losses to immobilization with higher residue and volatilization if surface applied. Surface or subsurface banding N is most effective to prevent N losses while subsurface banding P is essential.

In no-till situations many growers prefer to apply most, if not all, N and P at planting. This strategy works well as long as N, K, and S rates are kept below 20 pounds/acre total if placed directly with the seed (pop-up). When placed at least two inches away from the seed, the full N supply can be applied without hurting germination and stand.

Because soils in dryland corn production areas typically don't have applied manure, their organic matter levels tend to be lower than soils in irrigated areas. This leads to a much greater need for zinc fertilizer, therefore, dryland corn producers should pay close attention to soil zinc levels.

IRRIGATION

Corn can consume up to 30 inches of water (Table 15) in Colorado, depending on location and weather. Effective precipitation during the growing season can vary widely, averaging from 4 to 12 inches across the state. In Colorado's arid climate, irrigation is needed for maximum yields. Good irrigation management requires understanding the relationships between crop plants and their environment. Producers are faced with providing adequate water to optimize corn growth and yield, while minimizing the environmental consequences of leaching and runoff.

Soil Water Holding Capacity

Soils serve as a water storage reservoir for plants, but only part of the water that soil holds is available to plants. Following a heavy rain or irrigation, soil can become saturated, temporarily storing water that drains away fairly quickly to reach field capacity (Figure 23). Soil also holds water that is not available to plants, below the permanent wilting point. The soil water between the permanent wilting point and field capacity is plant available. The top 50% of this water is considered readily available water. As water depletes below half of available, it becomes less obtainable and the plant undergoes stress.

Soil Texture

Soil texture strongly influences the amount of plant available water. As clay content increases, so does the total water holding capacity. In fine-textured soils, more of this water is held tightly and is unavailable to plants. Since soils are products of natural processes, textures have some variation in their water holding capacities.

(Table 16) shows typical ranges of allowable depletions for soils found in Colorado. Refer to a local soil survey for the most accurate value. The allowable depletion is based upon the typical rooting depth for the growth stage, the median available water holding capacity, and the appropriate depletion percentage for the growth stage.

Table 15. Estimated Seasonal Water Use for Major Colorado Corn Growing Areas

	Seasonal Corn Water Use	
Location	Grain	Silage
Burlington	26.2	25.2
Delta*	26.0	25.0
Fruita*	26.3	26.3
Holly	26.3	25.3
Greeley	23.9	22.9
Larmar	27.4	26.4
Olathe*	24.6	25.6
Rocky Ford	26.5	25.5
Walsh	29.3	28.3
Iliff	24.5	23.5
Wray	24.5	23.5

Source: Schneekloth, J. and A. Andales. 2009. Seasonal Water Needs and Opportunities for Limited Irrigation for Colorado Crops. Colorado State Fact Sheet 4.718. Data calculated from May 1st to September 30th from 2000 to 2014.

*missing data

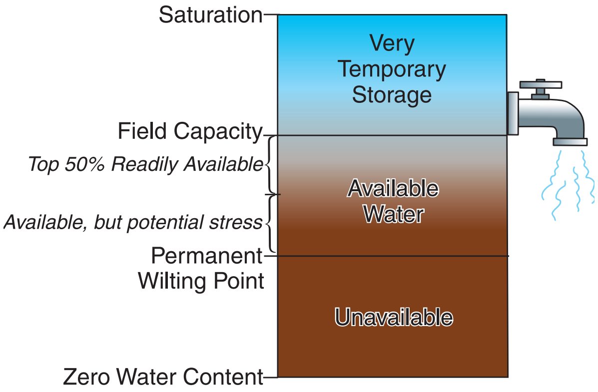


Figure 23. Soil water availability. Modified from "Managing Irrigation & Nitrogen to Protect Water Quality, University of Nebraska,"

Table 16. Allowable Rootzone Moisture Depletion in Colorado Soils.

Soil Texture	Available water inches / foot		V6	V12	Tassel	R1	R3
	Low	High	------------ inches water in rootzone ------------				
Coarse sands	0.6	0.8	0.5	0.8	0.9	1.1	1.7
Fine sands	0.8	1.0	0.6	1.1	1.1	1.4	2.2
Loamy sands	0.8	1.2	0.7	1.2	1.3	1.5	2.4
Sandy loams	1.2	1.5	0.9	1.6	1.7	2.0	3.2
Fine sandy loams	1.5	2.0	1.1	2.1	2.2	2.6	4.2
Sandy clay loam	1.6	2.1	1.2	2.2	2.3	2.8	4.4
Silt loams	2.0	2.5	1.5	2.7	2.8	3.4	5.4
Silty clay loams	1.8	2.4	1.4	2.5	2.6	3.2	5.0
Clay loam	1.6	2.0	1.2	2.2	2.3	2.7	4.3

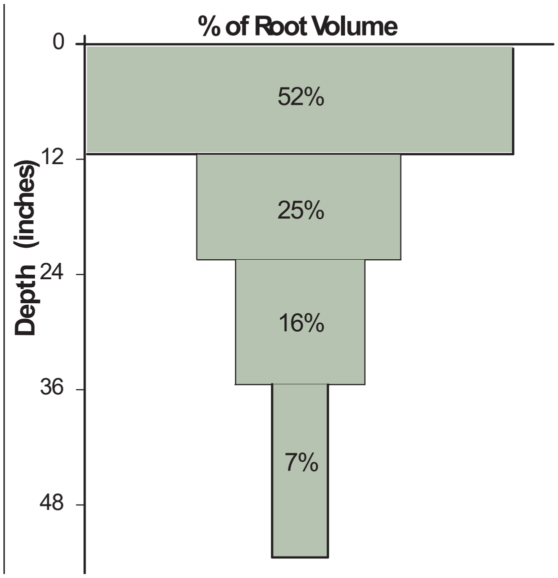


Figure 24. Corn rooting volume vs. rooting depth. Average rooting density of 115 irrigated Colorado cornfields without any root restrictions (compaction) as observed post-harvest from 1982 to 2001. Mike Peterson, NRCS.

Moisture blocks give a more accurate estimate of soil moisture, while the hand/feel method can reveal field uniformity problems.

Root Depth

Although corn plant roots frequently reach four to six feet deep by maturity, the average maximum rooting depth is about four feet. However, most water is extracted from the top three feet of the rooting zone. Figure 24 shows that corn will not extract water uniformly throughout its entire root zone depth, since over 75% of the roots occupy the top two feet of soil, and nearly 95% of the roots are in the top three feet. A maximum depth of three feet should be used for irrigation scheduling for the majority of the season, unless local knowledge or experience suggests otherwise. Irrigations should be timed according to the appropriate rooting zone for a given growth stage shown in (Table 17).

Estimating Soil Moisture

Estimating soil moisture status helps growers determine when to irrigate and how much water to apply. Moisture can be estimated through a variety of methods and technologies. Consider using at least one of these approaches to increase the effectiveness of irrigation scheduling.

1. The hand/feel method is a fast and inexpensive way to estimate soil moisture in several locations throughout a field but requires some experience. Sampling the soil by hand/feel in the spring when

the soil profile is generally at field capacity, and conversely, sampling dryland in the fall when the soil is at permanent wilting point, are good ways to “calibrate” your hand to the feel of these moisture levels.

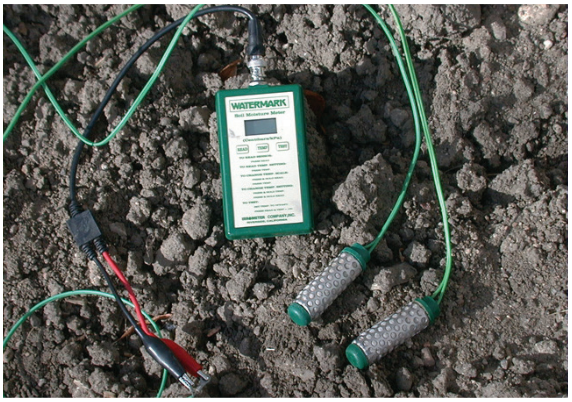
2. Soil moisture blocks measure electrical resistance within the block, which is affected by the moisture content of the soil. A drier soil will have a greater resistance than a moist soil. The two types of moisture blocks are gypsum and granular matrix blocks (WaterMark®). Fine-textured soils require gypsum blocks, since the structure of the block more closely resembles the soil structure. Use the granular matrix block for sandy soils. Place moisture blocks in at least two locations that include irrigation start and finish points, and at depths of 6, 18, and 30 inches.
3. Another relatively low-cost method to measuring soil moisture is a tensiometer. Tensiometers are hollow plastic tubes with a porous tip. They are filled with water and dye, sealed, and placed into the soil. A gauge allows tension in centibars to be read. As water is being taken up by the plants, water in the instrument is pulled out, increasing the tension pressure reading in the gauge. A higher tension reading indicates a drier soil; a lower tension reading indicates a wetter the soil.
4. Time Domain Reflectometry (TDR) measures soil moisture by calculating volumetric water content from electrodes. The two prongs of the hand-held probe are placed into the soil. The two prongs are electrodes and have an oscillating frequency between. The smaller the frequency the probe measures the greater the soil moisture in the soil. The value is then converted in the probe to a percent moisture. These probes are very accurate but may be considered too expensive for most corn producers unless high value crops are used in rotation.
5. Capacitance probes are being used with more frequency in irrigated agriculture. These probes often have sensors at multiple depths to allow a single sensor to provide information for different layers of the soil profile.

Most soil moisture technology can now provide remote data access through radio or cellular networks, allowing

Table 17. Corn Growth Stage and Rooting Depth for Irrigation Schedule

Growth Stage	Approximate GDU Accumulation	Approximate Rooting Depth for Irrigation Scheduling (inches)*
Emergence	100	3 - 6
V3	250	8 - 12
V6	450	18 - 24
V9	650	28 - 32
V12	845	28 - 32
V15	1000	34 - 36
Tassle	1150	36 - 42
Silk (R1)	1300	36 - 42
Dough (R4)	1825	36 - 42
Dent (R5)	2100	36 - 42
Mature (R6)	2500	36 - 42

*Assumes an unrestricted root zone where conditions allow roots to fully develop unhindered. Additionally, root depth for scheduling is assumed to be less than the maximum rooting depth to capture the root zone where majority of water uptake occurs.



Soil moisture blocks.

Estimating soil moisture by the hand/feel method.

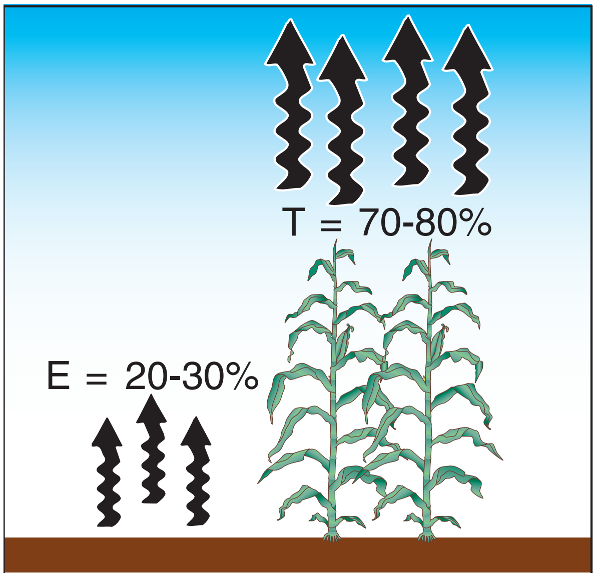


Figure 25. Percentages of seasonal evaporation and transpiration within ET.

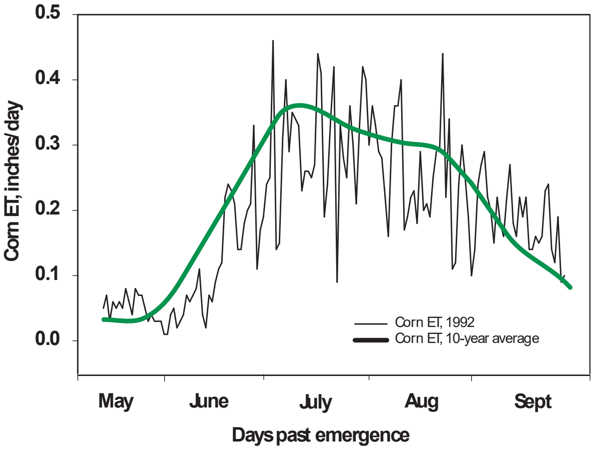


Figure 26. Daily vs. 10-year average ET in Burlington, CO.

users convenient information on current field conditions. This can be especially useful on large farms or where fields may be spread out. Proper installation, calibration, and maintenance of all soil probes is critical for reliable and consistent soil moisture information. Sensors can be purchased and installed by the landowner, or numerous entities also offer installation and data access services for a fee. For the most accurate information, sensors should be calibrated in local soils, or, at a minimum, soil texture should be taken into account when interpreting data. In fields with variable soils, installing more than one sensor (or group of sensors) is important to account for differences throughout the field.

Evapotranspiration (ET)

Evapotranspiration is the sum of evaporation from the soil surface and transpiration from the leaves, processes that are simultaneous. Transpiration accounts for most of the ET during the growing season and the remaining is from evaporation (Figure 25). At planting, nearly all ET comes from evaporation, while at full canopy cover, more than 90% of ET comes from transpiration.

During evaporation, liquid water vaporizes and moves from the evaporating surface (soil and wet vegetation). Since the amount of sun reaching the soil and vegetation surfaces determines the level of evaporation, crop residue reduces evaporation. (Figure 27) shows average daily evaporation rates impacted by wheat straw mulch. In fields under full irrigation, crop residue has potential to reduce soil moisture evaporation losses by up to 40% across the season. Although residue did not reduce soil evaporation losses as significantly under limited irrigation and dryland in these results, high residue traps winter precipitation, maintains soil infiltration, and reduces soil erosion.

Transpiration occurs when liquid water in plant tissues vaporizes, predominately through small openings on the leaf called stomates. Only a small fraction of all water taken up through the roots is actually used by the plant, most is lost by transpiration.

Weather Effects on Daily Evapotranspiration (ET)

Solar radiation, air temperature, humidity, and wind speed all impact ET rates. Direct solar radiation and ambient air temperature provide energy to vaporize water. The difference between the water vapor pressure (relative humidity) at the evaporating surface and the surrounding atmosphere is the driving force to remove water vapor from the soil or plant. As ET proceeds, air surrounding the leaf or soil surface becomes gradually saturated to 100% relative humidity, and ET slows down. This is why faster wind speeds greatly increase ET by replacing saturated air close to the plant or soil surface with drier air from above.

Maximum ET rates occur on hot (greater than 90 degrees F), cloudless, windy days with low humidity. On hot days, a full corn canopy can use up to a half inch of water per day. In contrast, during cool (less than 80 degrees F), cloudy, and calm days, ET rates can be 0.1 inch or less. Given the potential for considerable differences in ET rates due to Colorado weather, a reliable source of ET is valuable in estimating irrigation needs.

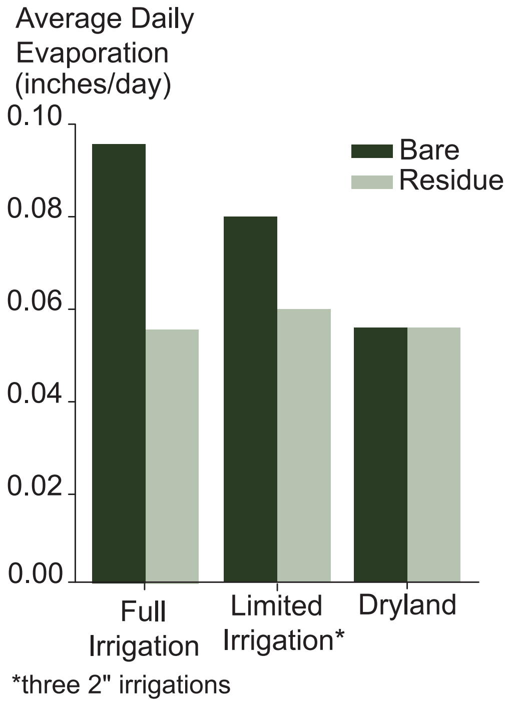


Figure 27. Average daily evaporation rates impacted by wheat straw mulch (3 tons/acre). © R.W. Todd

Table 18. Average Daily Corn Water Use (ET) in Colorado

Growth Stage	Delta/Olathe	Grand Valley	Front Range	Northeast/ Lower S. Platte	Central High Plains	Ark Valley
			Average ER (inches/day)			
Emergence (VE)	0.04	0.06	0.04	0.04	0.04	0.05
3-leaf (V3)	0.06	0.08	0.05	0.06	0.06	0.06
6-leaf (V6)	0.13	0.15	0.08	0.12	0.10	0.12
9-leaf (V9)	0.15	0.18	0.14	0.15	0.17	0.18
12-leaf (V12)	0.28	0.30	0.22	0.25	0.28	0.30
15-leaf (V15)	0.31	0.35	0.27	0.32	0.34	0.36
Tassle (VT)	0.29	0.35	0.26	0.29	0.32	0.35
Silk (R1)	0.28	0.34	0.25	0.27	0.31	0.34
Blister (R2)	0.28	0.31	0.24	0.26	0.30	0.34
Milk (R3)	0.25	0.30	0.23	0.26	0.28	0.30
Dough (R4)	0.22	0.26	0.20	0.26	0.28	0.28
Dent (R5)	0.18	0.20	0.15	0.18	0.20	0.20
Maturity (R6)	0.09	0.09	0.08	0.10	0.12	0.12

Corn water uses changes dramatically across the growing season (Table 18). Water use increases rapidly from six-leaf (V6) to tassel, peaks around blister (R2), and rapidly declines after early dent (R4). Evapotranspiration for stages not given in (Table 18) can be estimated by extrapolating between stages. Data for ET in many areas of Colorado can be found at coagmet.colostate.edu.

Curling leaves by midmorning and darkening color on days that do not reach 85 degrees F are symptoms of water stress at all stages.

Critical Growth Stages

The most sensitive growth stages for water stress are during the reproductive growth stages of tassel emergence (VT) to dough (R3) (Table 19). Also, at V4 growth stage corn initiates ear shoots and determines ear size. Colorado research in the late 1970s found that corn had the highest grain yield response when irrigated during the late vegetative and pollination period. Other recent research confirmed this and found that timing irrigations with critical growth stages can reduce water use of corn by 50% while reducing yields by only 30%. Irrigating during pollination produced the most yield response compared to any other growth stage.

Some water stress during vegetative growth stages helps save soil water without significantly reducing grain yields. During vegetative growth the root zone is rapidly expanding to meet its water needs, but if corn is well watered, with frequent irrigations, the root system may not fully develop into the subsoil.

BMP

Apply only enough irrigation water to fill the effective root zone.

Table 19. Allowable Soil Moisture Depletion for Fully Irrigated Corn at Various Growth Stages

Growth Stage	Allowable depletion of available water (%)	Water use & notes on water stress
Emergence to V4	50	V4 is critical (50%) - because of shallow rooting depth
V4 to V16	60-70	Can tolerate more water stress
V16 to Dough	50	Tasseling and silking until grain is fully formed are critical growth stages and yield will be reduced if water is short
Dough to Maturity	60-70	Water use is rapidly declining

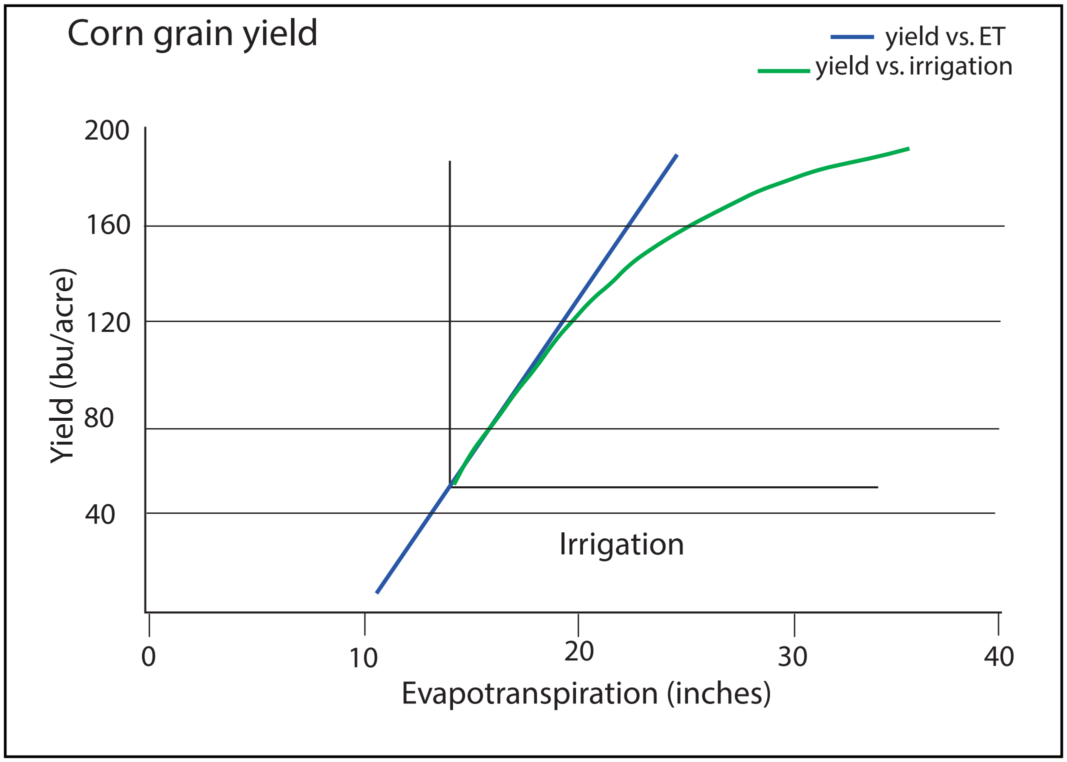


Figure 28. Grain yield vs. ET and irrigation.

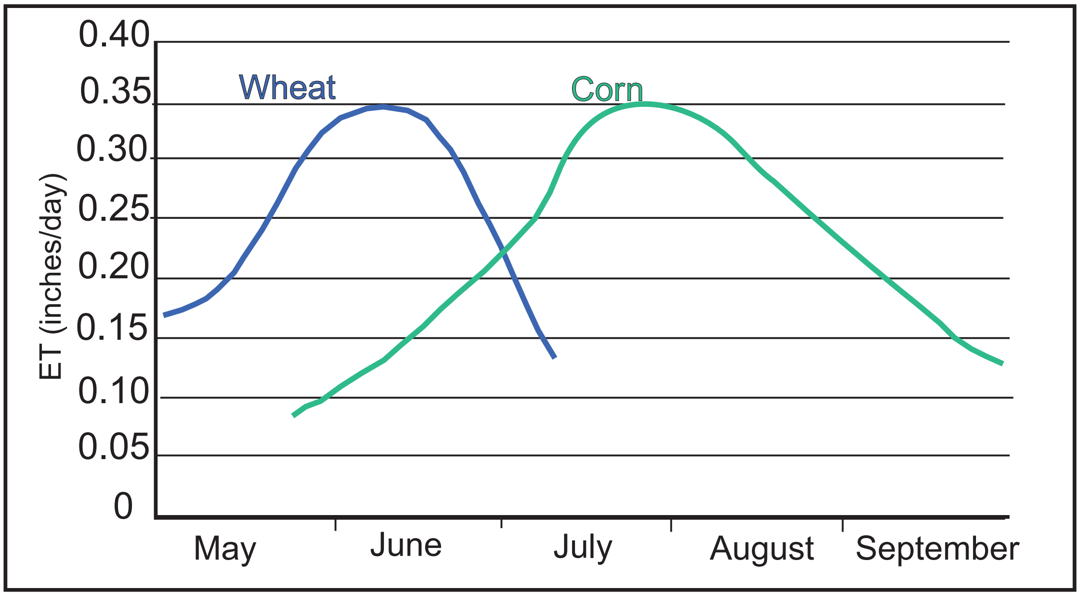


Figure 29. Corn and wheat ET.

(Figure 28) demonstrates that as maximum ET is approached, each inch of irrigation water responds with less grain yield than the previous inch. Deep percolation increases and rain water use decreases because there is less room to store and utilize water.

Limited Water Management

In below normal precipitation years, fields with low well capacity or limited allocation often have insufficient water to meet corn ET demand, causing a reduction in yields. Planting an entire field with a single crop may increase water use beyond what the system can apply, necessitating early irrigation. While irrigating early increases soil moisture storage for the critical time period, possible deep percolation during the early portion of the growing season can waste water. Producers are left with few choices:

- Leave a field fallow or plant dryland crops on some fields to allow full irrigation on others, resulting in reduced yields in the dryland portion.
- Split fields into two or more sections and plant crops with different water use patterns and critical time periods that take advantage of each crop's peak ET.

With low capacity systems, splitting the system with different crops allows growers to irrigate fewer acres at a single time. (Figure 29) demonstrates that when wheat ET demand is high, corn has a lower ET, allowing water to be concentrated on the wheat crop. Once wheat has matured, ET for corn is increasing and water can be moved to corn. Splitting a field into two crops allows more flexibility with limited water supplies.

With less irrigated acres, the system can better meet crop water use and better use stored soil moisture and precipitation. Meeting crop water needs during critical periods by improving management may result in higher yields with less water.

Why schedule irrigation?

Scheduled irrigation can help avoid over-watering costs from:

- leached nitrogen resulting in extra fertilizer inputs
- pumping and labor
- salinity and water logging impacts that include yield loss and long-term productivity
- local aquifer depletion

Scheduled irrigation can help avoid under-watering, which can result in yield loss.

Weather Station Sources Irrigation Scheduling

Corn water use information helps producers understand how quickly available soil water is being depleted and how to estimate the next irrigation event. The CSU Colorado Climate Center collects daily climate data from a network of weather stations located in irrigated agricultural areas throughout Colorado (Figure 30). Daily ET rates for various crops are available at coagmet.colostate.edu. In most cases, growers should use ET from the nearest weather station or a nearby station that has similar location characteristics, like topography and percentage of irrigated crops in the area. If a farm lies between two stations, use the average of the two.

Irrigation Scheduling: Atmometers

Another source for ET is an atmometer. An atmometer acts as mini-weather station that, when properly installed, provides reference ET (ETr) at a reasonable cost and with little effort. Studies show that an atmometer will provide ETr values that closely match ETr calculated from weather station data. The ability to provide reliable ET makes atmometers especially

Atmometer advantages:

- Simple to use
- Low maintenance
- Provide visual estimate of crop water use
- Relatively inexpensive

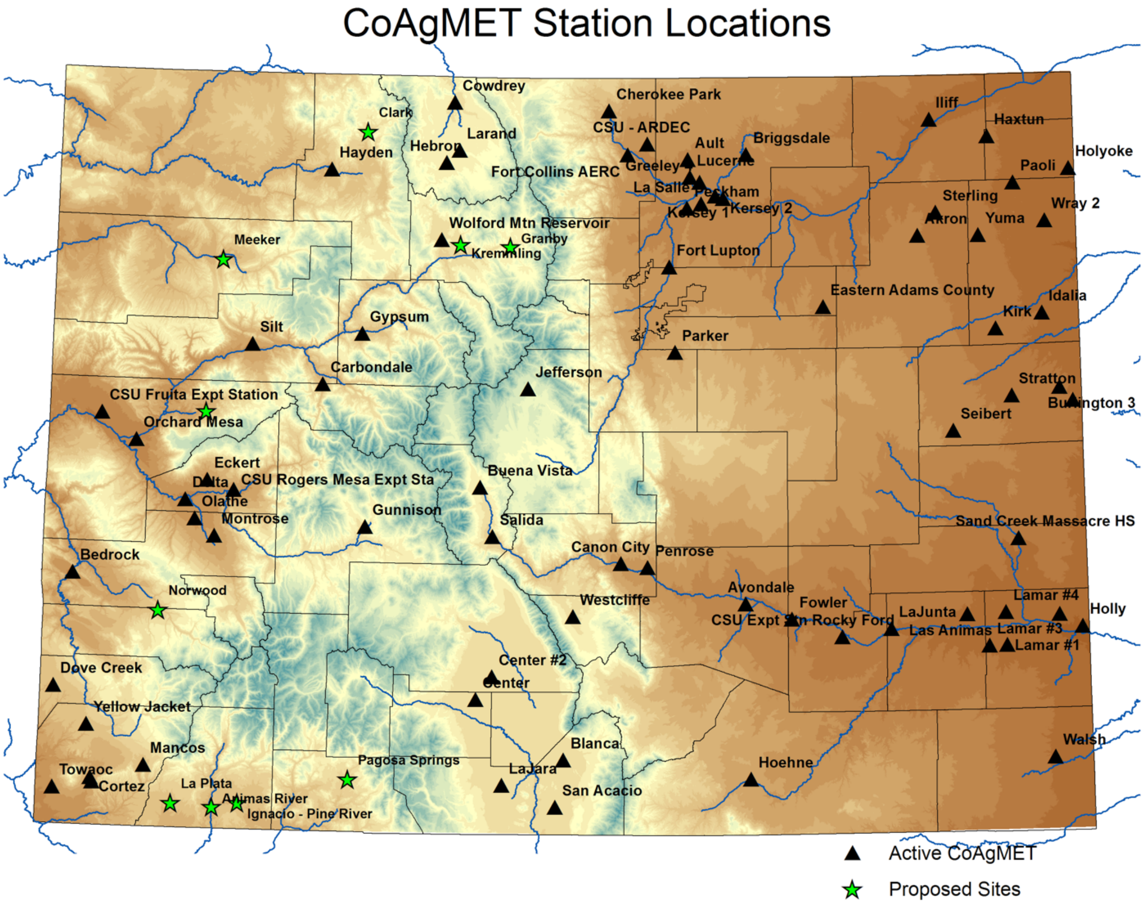


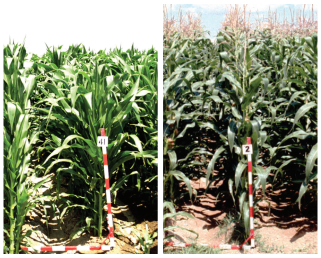
Figure 30. CoAgMET (Colorado Agricultural Meteorological Network) station locations.

15% of ETr (Kc = 0.15)

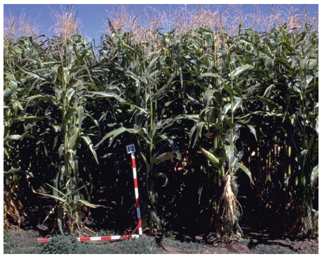
20% of ETr (Kc = 0.20)

40% of ETr (Kc = 0.40)

65% of ETr (Kc = 0.65)



100% of ETr (Kc = 1.0)
V12 to Tassle



80% of ETr (Kc = 0.80),
Early Dent

70% of ETr (Kc = 0.70),
Late Dent

45% of ETr (Kc = 0.45)
Mature Cob

useful for areas that do not have nearby weather stations. At atmometer can complement other scheduling methods such as soil moisture monitoring and hand/feel. Like a rain gauge, the information is displayed on a sight tube mounted in front of a ruler on the instrument. A consultant or grower can install an atmometer to help schedule irrigations for fields within a several-mile radius.

Atmometers provide reference ET at field locations where they are installed.

Irrigation Scheduling: Crop Coefficient Guide

Reported ET rates are sometimes given as “reference ET (ETr).” Atmometers also provide ETr. Reference ET needs to be adjusted to get actual corn water use by multiplying it by a coefficient (Kc). The following photographs can be used to estimate the crop coefficient (Kc) to determine corn ET for various stages of development. Photos: H. Duke, USDA-ARS

Three irrigation events that require special consideration are preseason, first crop irrigation, and the final crop irrigation.

Irrigation Scheduling: Preseason Irrigation

Determining if preseason irrigation is needed and how much water to apply is necessary to conserve water and for ensuring that a crop will not fail due to lack of water. Preseason irrigation has advantages for low capacity systems that “get behind” later in the year and to replace

Table 20. Average Annual Growing Season Precipitation

	-------------------- Growing Season Precipitation* in Inches --------------------								
City	Off-season precipitation	Apr	May	Jun	Jul	Aug	Sep	Total Growing Season	Total Annual
Sterling	3.1	1.4	2.8	2.8	2.4	1.7	1.2	12.2	15.3
Greeley	3.5	1.6	2.5	1.8	1.4	1.0	1.1	9.3	12.9
Central High Plains	3.5	1.7	2.9	2.7	2.8	2.0	1.3	13.3	16.8
SE High Plains**	4.6	1.4	2.5	2.2	2.4	2.1	1.2	11.8	16.3
Rocky Ford	2.8	1.4	1.9	1.4	2.0	1.6	0.9	9.1	11.9
Fruita	4.4	0.8	0.7	0.5	0.7	0.9	0.9	4.5	8.8
Olathe	3.4	0.6	0.7	0.5	0.7	1.0	1.0	4.4	7.8

*Average of minimum
**Springfield/Walsh

depleted subsoil moisture during periods of low crop water use. However, during an average year, some corn-growing areas of Colorado will receive enough precipitation during the off-season (Table 20) to bring the soil profile water content close to field capacity by June 1, and preseason irrigation is unnecessary for most soils. Filling the profile earlier in the year does not allow for subsequent rainfall storage in wetter months, but does increase pumping costs and the potential for leaching. A better strategy is to determine if preseason irrigation is needed near planting time rather than earlier in the year. If soil moisture is close to, or near field capacity, then preseason irrigating is not recommended.

Irrigation Scheduling: First Irrigation

The first irrigation is recommended when the soil moisture reaches 50% of plant available in the active root zone in the last portion of the irrigated field. As shown in (Table 16), the root zone is small early in the year and less water is required to bring it to field capacity. However, applying smaller amounts of water is more practical with center pivot than surface irrigation systems.

Using the known soil moisture, estimate the crop ET for the number of days that it takes to complete irrigating a field and subtract that from the amount of moisture in the soil. If that amount is less than 50% available, it is time to irrigate. If it is above 50% available, then you can wait with the first irrigation. Keep in mind that the root zone is rapidly expanding during vegetative growth, but roots will not grow through dry subsoil. Available soil moisture for various growth stages and soils are provided in (Table 16) and average ET rates are found in (Table 18).

Symptoms of drought stress by increasing levels of severity:

- Minor leaf rolling during the heat of the day
- Leaf rolling for many hours of the day
- Leaf rolling from sunup to sundown, plus a grayish cast to the leaves
- Leaf death (bleached straw-color leaves)
- Dead corn plants

Table 21. Average Water Use for Given Growth Stages to Maturity

Growth Stage	Approximate Days to Maturity	Approximate GDUs to Maturity	Approximate ET to Maturity* inches
Blister (R2)	45	1050	11.5
Dough (R4)	35	700	8.5
Beginning Dent	24	600	5.5
Full Dent (R5)	14	400	3.0
Maturity (R6)	0	0	0.00

*Varies according to areas of state

Irregular areas are due to decreased wetted diameter of in-canopy sprinklers. D. Yonts, Bugwood.

Irrigation Scheduling: Last Irrigation

The final irrigation should be properly timed for several reasons. Over-irrigating results in unused soil moisture that causes harvest difficulties and increases soil compaction potential. Under-irrigating may reduce test weight and yield. The tables below are provided to help growers time the last irrigation event. The amount of ET required to reach maturity for several crop growth stages is provided in (Table 21). Producers can estimate the final irrigation by comparing the water use to maturity in (Table 21) to the allowable water balance in (Table 22). If soil moisture equals or exceeds the water requirement to maturity, then additional irrigation is not required.

Center Pivot Irrigation Systems

Since center pivots were first introduced in 1947, irrigation uniformity has increased and lower operating pressures have decreased pumping costs. Pivot irrigation of corn offers several advantages over furrow. Generally, growers can achieve improved application efficiency of 20% to 60% by converting to center pivot, saving valuable water and reducing the potential for nitrate leaching. Additionally, growers can more accurately “spoon feed” nitrogen through center pivots during the maximum uptake period, potentially improving yield and nitrogen uptake.

Select sprinkler packages according to slope and soil type to correctly match nozzle application rate to soil intake rate and to reduce runoff. A common misconception about sprinkler packages is that in-canopy sprin-

Table 22. Allowable Soil Water Depletion for Corn at Maturity

Soil Texture	Available Water Capacity		Minimum Allowable Soil Water Balance
	Low	High	
	Inches per foot		inches water per root zone
Fine sands	0.8	1.0	1.4
Loamy sands	0.8	1.2	1.6
Sandy loams	1.2	1.5	2.2
Loam	1.7	2.5	3.4
Silty loams	2.0	2.5	3.6
Clay loam	1.6	2.0	2.9

Table 23. Water Losses of Three Sprinkler Packages

	*Above canopy	*In canopy	*LEPA**
		water loss in inches	
Air evaporation and drift	0.03	0.01	0.00
Net canopy evaporation	0.08	0.03	0.00
Plant interception	0.04	0.03	0.00
Evaporation from soil	Negligible	Negligible	0.02
Total water loss	0.15	0.08	0.02
Percent water delivered onto soil	85%	92%	98%

*Single one-inch application. USDA research in Texas.
**LEPA - Low Energy Precision Application
Source: Schneider and Howell, 1995

Table 24. Peak Application Rate and Potential Runoff with Three Wetted Diameter Sprinkler Packages

	Wetted diameter	Peak Application Rate	**Potential Runoff
	feet	inches/hr	%
LEPA	3	40	40
In canopy	6	21	24
Above canopy	50	2.5	0

*700 GPM center pivot on silt loam soil.
**Field slope = 0 - 1%. Runoff potential increases with increased slope.

klers (drop nozzles) greatly reduce evaporation, drift loss, and water use. However, this water savings is overstated (Table 23) and if not properly designed and managed, in-canopy sprinklers can reduce yield due to poor uniformity and runoff. In-canopy sprinkler management includes circular row layout (increasing uniformity) to prevent sprinklers from hanging on plants when crossing rows. Major evaporation loss from above-canopy sprinklers (Table 23) was not due to drift or evaporation from sprinklers, but from plant canopy evaporation. However, canopy evaporation can be beneficial by cooling the plant.

Above-canopy sprinklers have lower application rates than those in the canopy or Low Energy Precise Application (LEPA) systems (Table 24). Nozzles placed farther into the canopy decrease wetted diameter due to decreasing the water's lateral travel distance and from canopy interference. With greater wetted diameters for above-canopy irrigation, the potential for runoff is less. The intensity of irrigation determines potential runoff, as well as nozzle placement. With the increased potential for runoff, producers must incorporate basin tillage to capture and prevent irrigation water from moving. In the canopy, the maximum distance between nozzles should be five feet for better application uniformity. If nozzles are further apart, application will be irregular, affecting crop growth and yield. In addition, with nozzles placed four or two feet high, most water falls three feet from the nozzle compared to more uniform distribution with nozzles placed at seven feet (Figure 31).

Surface/Furrow Irrigation

Watering corn by furrow or surface irrigation has been practiced for almost as long as people have irrigated corn. Since water flows downhill and most fields have some slope, furrow irrigation can be accomplished at a relatively low cost on many soil types and situations.

The disadvantages of poorly managed furrow irrigation include low application efficiency, poor application uniformity across the field, and high labor requirements. Excess water can leach nitrogen and other soluble agricultural chemicals below the root zone where they may contaminate ground water. Poor uniformity can result in inadequate water for corn growing on the lower end of the field and over-irrigation in other areas, increasing the potential for salinity problems (Figure 32). Low-efficiency systems require more water to meet a crop's water needs, adding further complications during dry years. However, furrow irrigation can be managed to minimize these impacts through a variety of technologies and techniques (Table 25). Growers should choose a variety of these techniques based upon site-specific conditions, experience, and budget. All these adjustments can improve or decrease uniformity depending upon how they are implemented and on field conditions. Polyacrylamide (PAM) is an environmentally safe, water-soluble polymer that works by binding clay and silt particles together, enabling them to settle to the furrow bottom. PAM has been studied for many years and found to be both environmentally safe and effective, reducing soil loss from 30 to 90%.

Surge Irrigation

Surge irrigation is the intermittent application of water used to improve distribution uniformity along a furrow. Surge irrigation can save both time and water over conventional irrigation. Another benefit of surge is the ability to improve uniformity, getting more water to the end of the field without over-irrigating the top of the field. Uniformity is essential when trying to alleviate the effects of salinity.

BMPs

- Reduce water application rate to ensure no runoff or deep percolation occurs during chemigation.
- Avoid chemigation when crop does not require irrigation.
- Adjust irrigation schedule to account for water applied during chemigation.
- Monitor and inspect chemigation equipment and safety devices regularly to determine proper function.

Surge irrigation.

BMP

When leaching of soluble salts is necessary to maintain productivity, time leaching to coincide with periods of low residual soil nitrate.

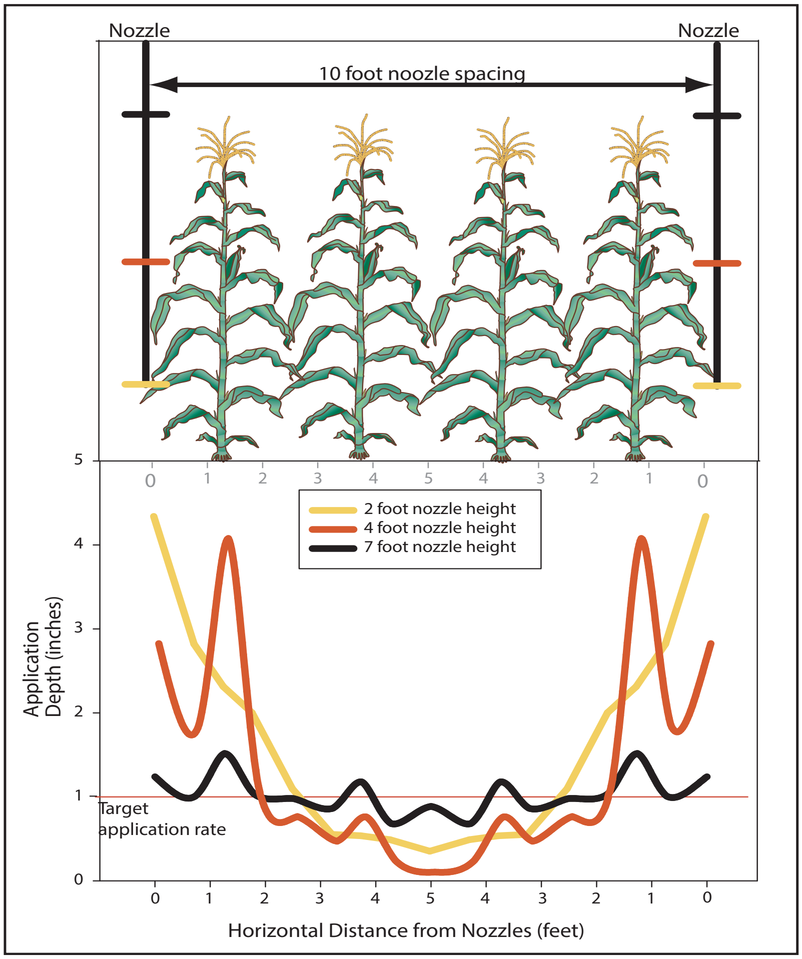


Figure 31. Effects of nozzle placement in the canopy on distribution of water.© F.L. Lamm, Kansas State University

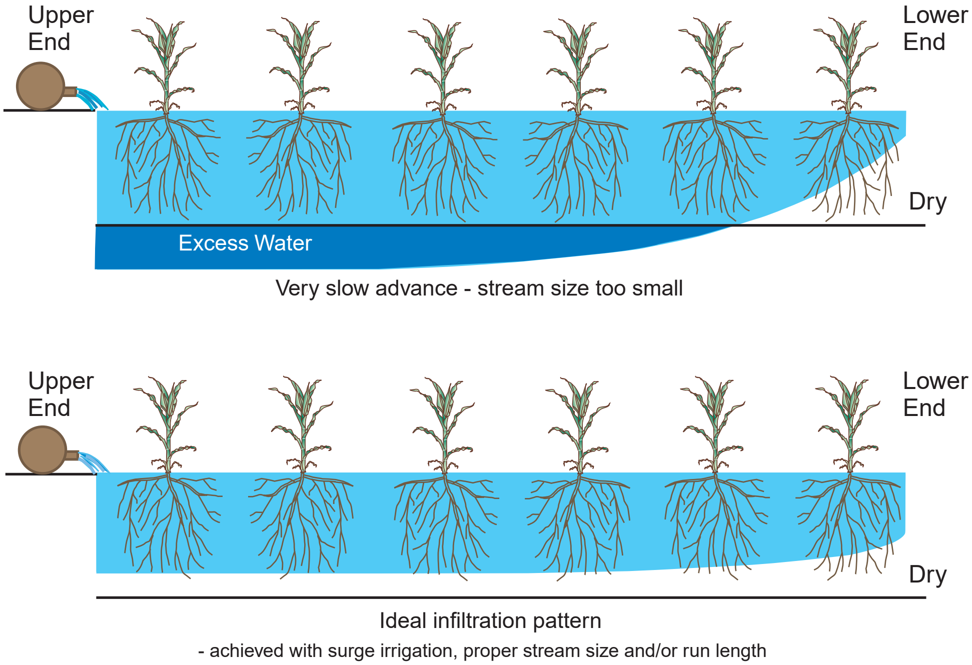


Figure 32. Surface irrigation infiltration patterns.

Table 25. Technologies and Techniques to Improve Surface Irrigation

Practice	Benefit(s)	Management Notes
Row length	Proper row length improves uniformity.	Leveled fields should be approximately 660′ on coarse and 1300′ on fine textured soils.
Stream size	Should be adjusted for slope and texture, and rate doubled when using PAM.	Easy management to adjust with both siphon tube and gated pipe.
Length of set	Allows irrigator ability to control volume of application.	Should be adjusted for stream size and run length. 12-hour standard is convenient, but not appropriate for many situations.
Furrow packing	Can increase advance rate 15-20% on some soils.	More effective when using a designated furrow forming/packing tool than when driven with tractor.
Alternate row irrigation	Reduces gross irrigation by 46%, net by 29%. Allows for rainfall storage in dry row.	Not appropriate for steep slopes or soils with infiltration problems.
Surge irrigation	Can greatly improve uniformity and can improve efficiency by 10 - 30%.	Once learned, reduces labor requirement.
Crop residue	Increases infiltration. Reduces erosion.	Furrow irrigation can be accomplished under conservation tillage with appopriate management changes.*
Polyacrylamide (PAM)	Reduces erosion by up to 90%. Increases lateral wetting and infiltration.	Must increase stream size to maintain advance times. PAM concentration should be 10 parts per million (ppm) in advancing water for optimum results.

*See Guidelines for Using Conservation Tillage Under Furrow Irrigation TR 15-10 at http://waterquality.colostate.edu/

Furrow irrigation with PAM (top), and without PAM (bottom)

Water Quality and Salinity

Although water quantity usually gets more attention in irrigated corn production, water quality can be equally important. Shallow ground water and some surface waters often have high dissolved salts, sodium, and other specific ions that require special management to minimize production problems.

Corn is more sensitive to salinity (Table 26) than other grain crops like sorghum, wheat, or barley, but less sensitive than most vegetables. This sensitivity is most acute during the seedling stage. To reduce the effects of salinity on corn yields, irrigate with better quality water early in the growing season, if available (ditch vs. ground water.) If plants are on bed center, irrigate every other row early, driving salt accumulation to the bed's edge. If irrigating with an overhead sprinkler, don't irrigate on hot, windy days and either irrigate at night or use LEPA systems or properly spaced drag hoses.

Yield impacts from salinity vary greatly with management, soil type, and weather during the season. However, some dissolved salts in irrigation water are beneficial, reducing or negating the need for fertilizing with nitrogen, sulfur, or boron. (See fertility chapter for details.) Always base management decisions on knowledge of actual water quality results by having water periodically tested by a laboratory, and consult a professional crop advisor for interpretation.

Salinity effects in corn.

Table 26. Corn Sensitivity to Salinity

Potential yield reduction to corn from saline water

	0%	10%	25%	50%
		EC*dS/m		
Grain	1.1	1.7	2.5	3.9
Silage	1.2	2.1	3.5	5.7

*Electrical conductivity

Specific ion toxicity levels to corn

	Toxicity level Low mg/l or ppm	 High
Boron	<1	>2
Sodium***	230	460
Chloride***	<350	>700
Bicarbonate***	<400	>400

***Potential foliar damage from sprinkler irrigation

TILLAGE

Tillage in corn production aids in controlling weeds, managing residue, manipulating the physical condition of soil, and creating ridges or beds to aid furrow irrigation. A variety of tillage systems can accomplish these goals, but the erosion potential among them varies highly.

Corn grows well under a variety of tillage systems. Because of its relatively large seed size and seedling vigor, corn does not require a finely prepared, residue-free seed bed. Good seed-to-soil contact and proper seed depth are more important and can be accomplished by properly adjusted press wheels or other seed covering devices. Over-preparation of the seed bed causes more stand problems through excessive soil drying, increased crusting, and greater potential for soil compaction.

Tillage Systems

Producers should evaluate their entire crop rotation scheme before changing tillage systems. The ideal tillage practices will maintain or boost corn productivity, minimize input costs, and protect soil and water resources for following generations of corn producers. Steps to reduce the intensity and frequency of tillage operations can have long term benefits for sustainable crop production.

Moldboard or Conventional (Clean) Tillage

Moldboard plow, or disk twice in fall or spring, followed by mulch, plant, and cultivate. Other tillage operations may be included in this system such as land leveling, ripping, and roller packing.

Advantages	Disadvantages
Suited for most soils	High erosion potential
Well-tilled seedbed	High compaction potential
"Clean" furrows for surface irrigation	High fuel, equipment and labor costs
	High soil moisture loss
	No remaining residue cover

Tillage systems choice depends on various factors:

- Soil erodability - soil texture, slope, organic matter levels
- Irrigation system
- Available equipment
- Rotation with other crops

Tillage system choice impacts:

- Soil organic matter levels
- Soil compaction
- Pest control options

See CSU Extension's "Guidelines for Using Conservation Tillage Under Furrow Irrigation, Technical Report TR02-6."

Moldboard plowing.

Reduced or Conservation Tillage (no-till, strip-till, vertical tillage and other systems)

Any tillage system that leaves at least 30% residue cover on the soil surface prior to planting.

Advantages	Disadvantages
Less erosion potential than moldboard or other clean-till systems	Stalk chopping necessary for chiseling
Chisel plow adapted to poorly drained soils	Potential for compaction with disking under wet conditions
Lower fuel costs than moldboard plow	Potential for soil borne disease carry over
Saves soil moisture and can reduce need for early season irrigation	

Reduced tillage systems can be more profitable than more traditional moldboard plowing systems. The economics of conservation tillage systems have been studied extensively in other parts of the country, often with positive returns on investment. The financial benefits of reduced fuel use, fewer hours on tractors and equipment, and reduced labor costs lead many growers to consider switching to a conservation tillage system. Of course, these reduced costs will not result in grower profits without maintaining comparable yields and quality.

In furrow-irrigated systems, additional considerations include irrigation uniformity and eliminating time spent moving water through the field manually, with a shovel in hand. Poor irrigation and increased labor costs if forced to walk the field can offset some of the financial benefits of conservation tillage. A six-year analysis (Table 27) of three tillage systems (conventional/plowed, minimum, and strip-tillage) on a flood irrigated production field near Fort Collins, documented the agronomic and economic impacts of these systems. Results found comparable yields with plowed ground could be maintained with reduced tillage, and increased profits can occur due to the reduced input costs.

Dryland Consideration

No-till is more critical to profitable dryland corn production than to any other dryland crop grown in Colorado. Weed free, untilled seedbeds help maximize limited dryland moisture reserves. Dryland corn should not be cultivated for weed control, because cultivation prunes roots and increases evaporative water loss.

Moldboard plowing versus no-till.

No-Till

No-till leaves the majority of crop residue on the surface and the soil largely undisturbed. Generally, the only time soil is disturbed in this system is at planting.

Advantages	Disadvantages
Conserve moisture	Special equipment needed
Greatly reduced erosion	Greater reliance on herbicides
Increase organic matter	Potential for soil borne disease carry over
Lower overall fuel costs	
Less overall equipment	

Planting corn in high residue.

Strip Tillage

Strip-till differs from no-till in that narrow strips are cleared of crop reside to increase soil warming and drying either before or during the planting operation. Corn is planted in the tilled strips.

Advantages	Disadvantages
Conserve moisture	Requires a large horsepower tractor
Reduced erosion	Potential for soil borne disease carry over
Increase organic matter	
Lower fuel costs than	
Less overall equipment	

Strip tillage.

Table 27. Six Year Average - Gross and Net Income

Tillage Type	Returns per Acre (Gross Income)	Return to Land and Management (Net Income)
Conventional Tillage	$963	$369
Minimum Tillage	$848	$345
Strip Tillage	$940	$428

Vertical tillage.

Figure 33. Effect of shallow wheel traffic compaction on a corn plant's root system under actual field conditions. This corn was sampled about 60 days after planting on a clay loam soil with fall plow/spring chisel tillage to approximately 10 inches.

BMP

Reduce traffic and tillage activity, especially on wet soils. Compacted soils increase runoff and erosion potential.

Vertical Tillage

Vertical tillage can be used as a single operation prior to planting. These implements generally consist of flat disks that slice residue, break surface compaction, and cause some surface mixing. Vertical tillage does not bury significant amounts of residue like a traditional disk.

Advantages	Disadvantages
Conserve moisture	Requires a larger horsepower tractor
Reduced erosion	
Increase organic matter	
Lower overall fuel costs	
Less overall equipment	

Compaction

Soil compaction occurs when soil particles are pushed closer together by external forces, such as wheel traffic and tillage, reducing pore size and number. An ideal soil typically contains approximately 50% pore space by volume. The rest of the volume is comprised of about 49% mineral matter (sand, silt, or clay) and 1% organic matter. The pore space is filled with some combination of air and water (soil solution) that contains the nutrients and aeration for corn roots to grow.

Compacted soil decreases soil drainage and aeration, increases runoff and erosion potential, increases power requirements, and may inhibit root development and ultimately reduce yields. Soils low in organic matter and under excessive secondary tillage are most prone to compaction. All soils are at highest risk of compaction when moisture is near field capacity.

The left photo in (Figure 33) shows a corn root system with no inter-row tractor wheel traffic or wheel traffic directly over the row. Root growth occurs throughout the profile close to the soil surface to almost five feet deep. The right photo shows a root system after three passes of a tractor wheel on each side of the row with no wheel traffic over the row. Note the absence of root growth in about 60% of the tilled layer due to inter-row wheel traffic compaction, causing a negative impact on uptake of immobile nutrients such as P and Zn. This is a good example of why banding is often more effective than broadcasting these nutrients. There was still good root growth into the subsoil because a root-restricting hard pan was not present.

Strategies to Avoid Compaction

Some compaction is unavoidable under most corn production systems. However, certain strategies can minimize the severity of compaction to tolerable levels:

- Reduce traffic, especially on wet soil. Wet soil has less soil strength making air and water spaces easier to eliminate.
- Reduce tillage activity. Over-tilling causes compaction and crusting.
- Use tractors with lighter axle weights when possible for operations with lower power requirements.
- Reduce tire pressure to reduce surface compaction. Low-pressure tires will spread out the weight, reducing surface compaction, but may increase the area compacted.
- Restrict equipment to specific traffic lanes in the field. Keep traffic restricted to field ends during harvest.
- Promote stable soil structure by maintaining organic matter through retaining crop residue, applying animal manures or other organic waste products, or by growing small grains with grass-like root systems and green manure crops.
- Mix tillage practices and operations every few years using a variety of implements. Periodic change in tillage systems may decrease soil compaction.
- Alternate crops that have deep tap roots (alfalfa, clover, and sunflowers) creating channels for water and other crop roots to follow.

Compaction Symptoms

- Smaller plants with narrow leaves
- P deficiency – purple-tinged leaves
- Other nutrient deficiencies
- Premature water stress
- Increased lodging

Compaction from Wheel Traffic

- Soils are most prone to compaction when moisture is near field capacity.
- Eighty percent of soil compaction from wheel traffic occurs at the first pass.
- Surface and shallow compaction are primarily controlled by the pressure applied at the soil surface (tire pressure).
- Deeper compaction (below the normal tillage zone) is caused by heavier axle loads and traffic over wet soils.

No-till ripper post harvest. Ripping is most effective in dry soils.

Compaction Identification

- Shovels, soil probes, rods or a penetrometer can be used to identify compacted soil.
- Hard soil does not always mean compacted soil. Soil strength is a function of density and moisture, as soil moisture greatly affects the resistance of a soil to measuring tools.
- Directly examine root systems using a backhoe and shovel.
- Consult with a NRCS, crop adviser, or Extension personnel for advice.

Compaction Remediation

- Compaction is usually caused by mechanical forces and requires mechanical means to correct.
- Shallow (<10”) compaction can be corrected with a chisel, but deep compaction may require deeper ripping or subsoiling.
- The soil must be dry to rip or the operation will be ineffective or cause more compaction.
- Subsoiling is expensive and should only be done where serious compaction exists.

HARVEST

Silage Harvest

Corn silage harvest should begin before physiological maturity, at mid to late dent for silage quality and proper dry matter. Ideal moisture for ensiling in pits and covered piles is from 65% to 70%. This moisture content varies with hybrid and growing conditions but occurs somewhere around one-half to two-thirds milk line (Table 28). As harvest is delayed from full dent to black layer, crude protein levels decline, fiber levels increase or remain constant, and digestibility tends to decrease. Dry, over-mature plants will produce silage with drier grain and harder seed coats, more starch, and fewer sugars.

Cutting height also influences silage quality. Research by Pioneer Agronomy Sciences (Curran & Posch, 2000) showed that silage digestibility improved 2.2% when cut at 20 inches versus 4 inches. Percent starch, net energy (adjusted NE_L), and total digestible nutrients (TDN) also improved when cutting height was increased. However, silage yield at 30% dry matter was lowered 0.19 tons for every inch of cutting height above 4 inches. Growers should base cutting height upon market demands. More recent research supports this idea, but quality impacts are dependent on variety and other factors. In addition, cutting height does not appear to impact quality of brown midrib (BMR) varieties, and therefore, cutting them low (approximately 4 inches) makes the most sense (Kung Jr. et al., 2008; Ferraretto & Shaver, 2015). If corn tests high for nitrate, ensiling corn can reduce nitrate level by 30% to 60%.

Grain Harvest

An advantage of growing corn in Colorado is the excellent fall drying weather. These drying conditions allow field drydown to storable moisture levels (13% to 15.5%) in most areas of the state without the added expense of mechanical drying. Reports of dry matter losses from field drying have been largely disproved. Harvest schedules should be based upon grain moisture, stalk quality, and ear retention after black layer. Assess stand condition for stalk rot, corn borer, and western corn rootworm damage. Fields with damage severe enough to increase lodging potential from wind should be harvested earlier. Otherwise, hybrid maturity and planting date should dictate which fields will dry down first. Another consid-

Milk line is the moisture level in the kernel as it dries and hardens from top to bottom. It can be identified by pressing on the side of the kernel with your thumbnail.

Grain Storage Considerations

- Store grain at a moisture content of 14% or less.
- Level the top surface of the grain.
- Aerate in the fall to cool the grain to 40 degrees F.
- Check and record grain temperature every 21 days. Aerate as soon as any increase in temperature is evident.
- Aerate in spring until grain is at 60 degrees F.
- Try to maintain less than 10 degrees F difference between average outdoor temperature and grain temperature.
- Check for insects in the fall, spring, and summer. If treatment is necessary, use proper procedures.

Table 28. Approximate Silage Moisture at Different Maturity Stages

Maturity Stage	Approximate Moisture
Early Dent	73%
1/2 milk-line	66%
3/4 milk-line	63%
No milk-line	60%

*Source: Weirsma and Carter, University of Wisconsin, 1993.

eration is soil moisture (drier is better), as significant soil compaction can occur with heavy equipment (trucks, grain carts) during the harvesting season.

Post-Harvest Considerations

Assessing yields shortly after harvest is a good idea while the season is fresh in growers' minds. Observations from the combine operator, as well as yield monitor maps, can be extremely useful in locating problem areas. Once the crop is harvested, there are a number of decisions that will impact next year's crop:

- Post-harvest tillage, what should be done in the spring vs. fall
- Grazing or baling of stover and unharvested grain
- Soil sampling for next year's crop
- Planting a cover crop following silage to prevent wind erosion

Yield Estimation Work Sheet

A number of yield prediction methods exist, but the yield component method (YCM) is probably most used (Table 29). This method can be used by the time that kernel development has reached the late milk to early dough stages (R3 to R4). Under "normal" conditions, this point occurs about 25 days after pollination is complete. Estimates made earlier in the kernel development period risk being overly optimistic if subsequent severe stresses cause kernel abortion prior to milk stage (R3).

Crop uniformity greatly influences the accuracy of any yield estimation technique. The less uniform the field, the greater the number of samples that should be taken to estimate yield for that field. There is a fine line between fairly sampling disparate areas of the field and sampling randomly within a field so as not to unfairly bias the yield estimates up or down.

Table 29. Yield Component Method (YCM) Work Sheet

Method	Example
1. Measure length of sample corn row equal to 1/1000 of an acre: • 43,560/row spacing in feet • Result/1000	43560/2.5 feet (30 inches) = 17,424 feet 17,424 feet/1000 = 17.5 feet
2. Count number of harvestable ears in sample row length result from step 1.	33 ears in 17.5 feet of sample row
3. Count number of complete kernel rows per ear on every fifth ear in sample row. Calculate average rows per ear.	16 average kernel rows per ear
4. Count number of kernels per row on each ear from step 3. Calculate average kernels per row.	34 average kernels per row
5. Multiply harvestable ears/row (step 2) x rows/ear (step 3) x kernel/row (step 4). Result divided by 90.	33 x 16 x 34 = 17,952 17,952/90 = 200 bu/A

RECORD KEEPING

Good recordkeeping is the backbone of sound pest, nutrient, and irrigation management programs. It may be tempting to think that management details of crops and fields will be remembered over the years, but memories often fail and are of no use in legal or regulatory matters. There are numerous software and web-based farm data management products available to help streamline and organize records. Many operations already take advantage of these resources to manage an increasing volume of farm production data. Depending on personal preference, simple paper records can still also be useful.

Records help explain yield problems or successes that can help make future decisions more profitable. Sound recordkeeping is even more critical as advances in genetically modified crops continue and markets demand higher standards of purity.

Yield records should be kept by:

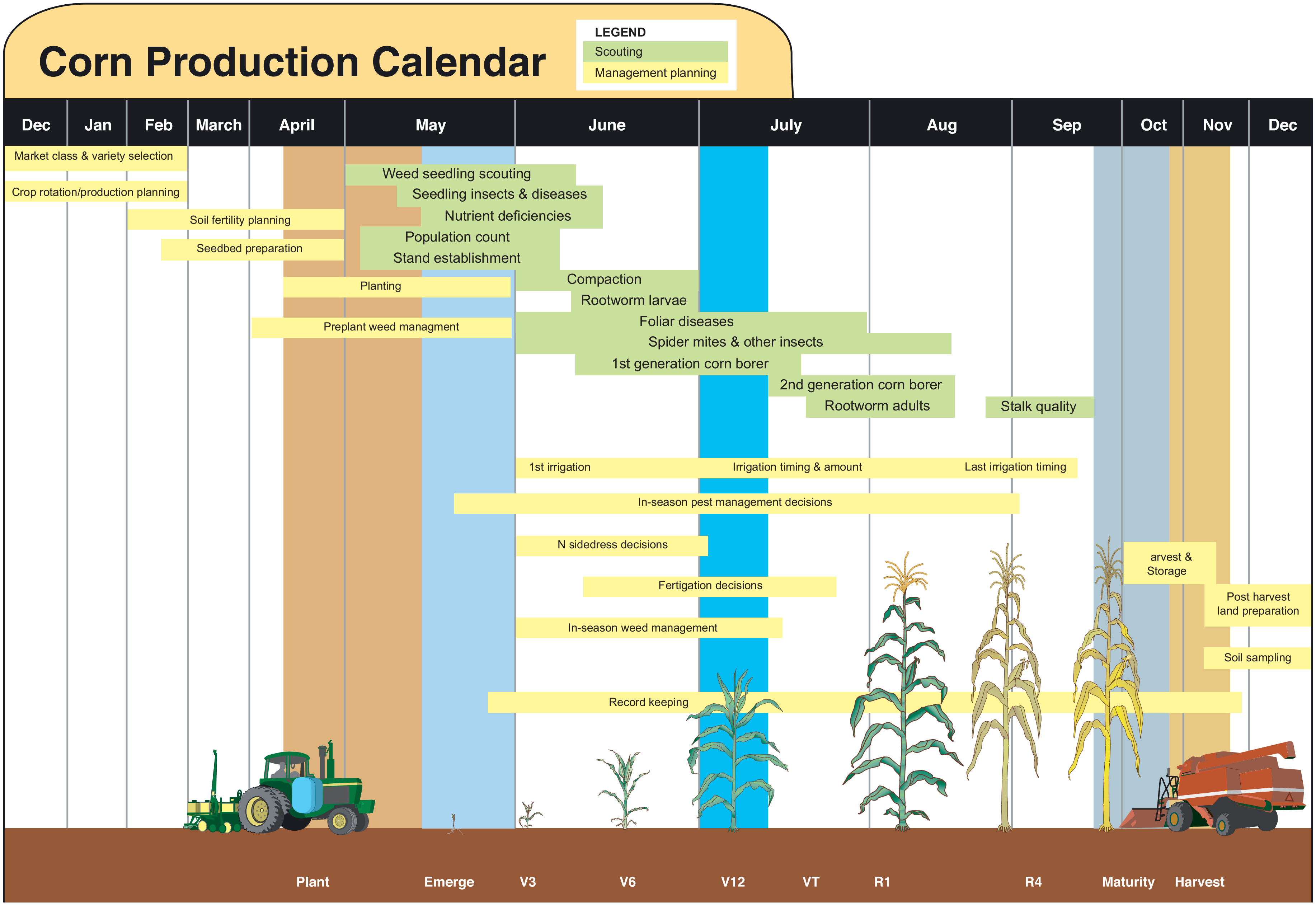
- Field
- Hybrid
- Weed/insect control package
- Fertilizer rate and amounts
- Soil type
- Tillage
- Irrigation scheme
- Other management differences

Record Keeping Checklist

Preseason/planting:			
✓	Previous crop rotation	✓	Preplant herbicide application*
✓	Preplant fertilizer application	✓	Preplant irrigation
✓	Planting date, hybrid, seeding rate	✓	At planting rootworm control
Emergence to knee-high:			
✓	Emergence date, stand count	✓	Post-emergence herbicide products/rates/dates
✓	Sidedress nitrogen date/rate	✓	Scouting observations
✓	First irrigation date		
Knee-high to tassel:			
✓	Irrigation dates/rates	✓	Insecticide product/rates/dates*
✓	Fertigation dates/amounts	✓	Scouting observations
✓	Tassel appearance		
Tassel to maturity:			
✓	Kernel development/maturation dates	✓	Success of insect and weed control
✓	Final irrigation rate/date	✓	Appearance of black layer (maturity)

*Federal law requires specific records to be kept for all restricted use pesticide (RUP) applications

Corn Production Calendar



USEFUL FACTS, FIGURES, AND CONVERSIONS

Sprayer Calibration

Calibration of spraying equipment is important to ensure application of the proper dosage. Sprayer calibration should be checked daily or whenever changing chemicals. Applying incorrect amounts may do more damage than good.

Adjustable factors which determine calibration and affect application rate are: 1) speed, 2) pressure, 3) nozzle size and type, or a combination of the three. Speed is the easiest and most common adjustment.

Three Calibration Methods

Method 1
Nozzle spacing = inches between nozzles.
Speed = MPH x 88.

Test several nozzles to ensure uniformity and replace any that have >10% variation from the average of all nozzles.

- Measure nozzle flow rate (gal/nozzle/min):
  ounces collected for 1 min from 1 nozzle
  / 128
- Calculate gallons per acre:
  gal/nozzle/min x 12 x 43,560
  / nozzle spacing x speed

Method 2
Spray 660 feet at the desired speed and pressure.

Determine the amount of spray discharge (water) traveling this distance:

- Calculate gallons per acre:
  gallons used in 660 feet x 66
  / Swath width (ft)

Method 3
Fill spray tank and spray a specified number of feet.

After spraying, refill tank and measure the quantity of material needed for refilling.

- Calculate gallons per acre:
  43,560 x gallons sprayed
  / Distance sprayed x swath width (ft)

Useful Equivalents

- 1 acre = 43,560 square feet
- 1 acre-foot = 325,851 gallons
- 1 acre-inch = 27,154 gallons
- 1 gallon of water = 3.785 liters
- 1 cubic foot = 7.48 gallons = 62.4 pounds of water
- 1 cubic foot per second (cfs) = 449 gallons per minute (gpm) = 1 acre-inch per hour = 2 acre-feet in 24 hours

Corn Test Weight Facts

- Test weight of corn determines the weight of a bushel volume of grain (1.244 cubic feet).
- Test weights determined on dry corn (15.5% moisture) can indicate whether the grain crop reached full maturity.
- The standard test weight used to convert weight of grain to bushels of grain (volume) is 56 pounds per bushel, the minimum test weight for USDA No. 1 corn.
- The minimum test weight for USDA No. 2 corn is 54 pounds per bushel.

Corn Seed Facts

- Corn seed averages 1,360 seeds per pound or 68,000 seeds in a 50-pound bag. (This average is somewhat hybrid and lot specific. Always check the bag label).
- Corn seed typically contains 76,160 seeds per bushel.

Determining Grain and Silage Yields

1. Determine the harvested acreage, grain weight, and grain moisture.
2. Calculate pounds of dry matter: grain weight x (1 – grain or silage moisture %).
3. For grain, convert dry matter to 15.5% moisture: divide dry matter by 0.845 (1 – 15.5% = 0.845) or

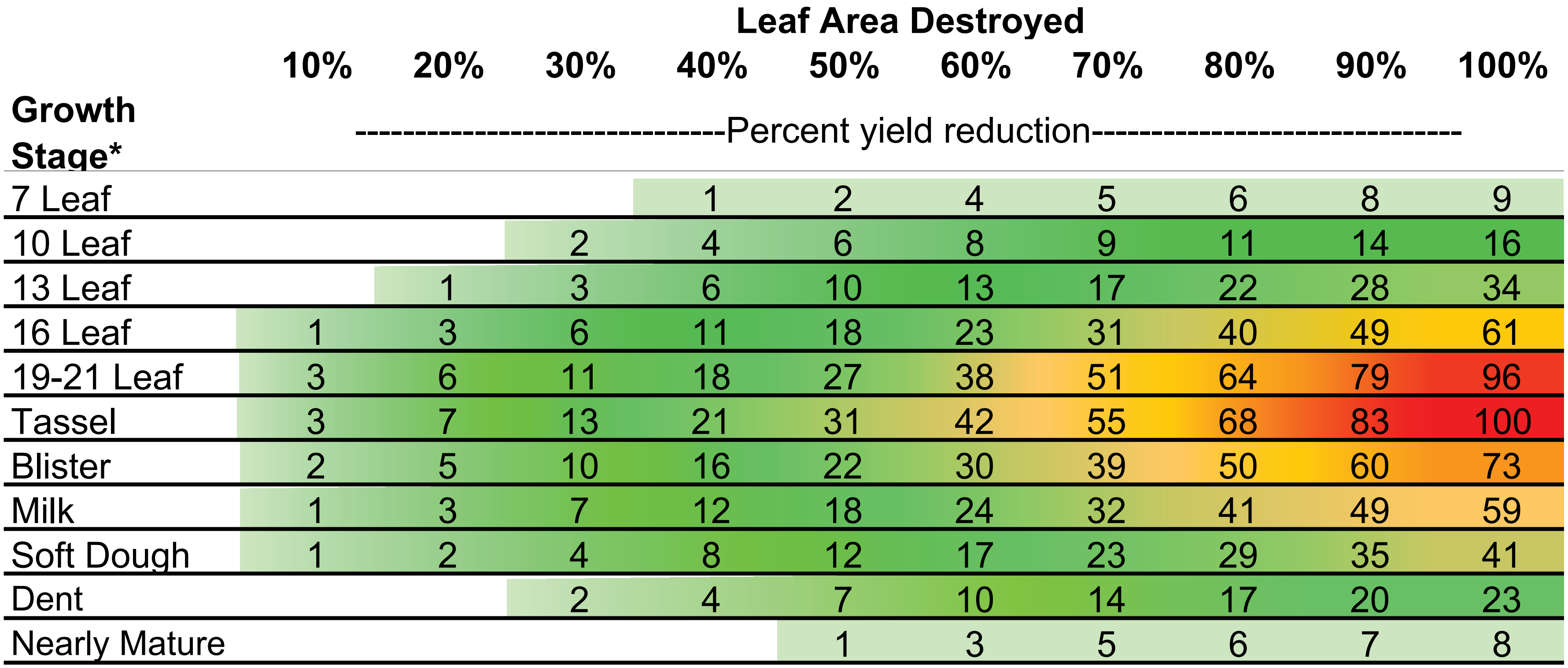
   For silage, convert dry matter to 70% moisture: divide dry matter by 0.30 (1 – 70% = 0.30).
4. Calculate total bushels: for grain, divide test weight at calculated 15.5% moisture by 56 pounds per bushel.
5. Calculate bushels per acre: divide total bushels by harvested acreage.

Example:

1. Total grain weight from 1.38 acres is 15,000 pounds at 22% grain moisture.
2. 15,000 pounds grain weight x 0.78 (1 – 0.22 = 0.78) = 11,700 pounds dry matter
3. 11,700 pounds ÷ 0.845 = 13,846 pounds at 15.5% moisture
4. 13,846 pounds ÷ 56 pounds per bushel = 247 bushels at 15.5% moisture
5. 247 bushels ÷ 1.38 acres = 179 bushels per acre at 15.5% moisture

National Crop Insurance Services Hail Damage Assessment

National Crop Insurance Services hail adjustors utilize the "horizontal leaf method" to assess leaf loss from hail damage, instead of the "collar method" described in Chapter 3. Rather than use the uppermost leaf collar (collar method), hail adjustors identify the uppermost leaf that is 40% to 50% exposed and whose tip points below the horizontal. Typically, a given "horizontal leaf" growth stage will be one to two leaf stages greater than the "collar method." Figure 34 shows corn yield reduction due to leaf loss at different growth stages based on the "horizontal leaf method."



	Leaf Area Destroyed									
Growth Stage*	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
	Percent yield reduction									
7 Leaf				1	2	4	5	6	8	9
10 Leaf			2	4	6	8	9	11	14	16
13 Leaf		1	3	6	10	13	17	22	28	34
16 Leaf	1	3	6	11	18	23	31	40	49	61
19-21 Leaf	3	6	11	18	27	38	51	64	79	96
Tassel	3	7	13	21	31	42	55	68	83	100
Blister	2	5	10	16	22	30	39	50	60	73
Milk	1	3	7	12	18	24	32	41	49	59
Soft Dough	1	2	4	8	12	17	23	29	35	41
Dent			2	4	7	10	14	17	20	23
Nearly Mature					1	3	5	6	7	8

***Growth stages use "horizontal leaf method" and are 1–2 stages greater than the "collar method."**

Source: National Crop Insurance Services, 2015 Corn Leaf Loss Instructions

Figure 34. Corn yield reduction due to leaf removal.

COLORADO STATE UNIVERSITY
EXTENSION

COLORADO
CORN

Best Management Practices For Colorado Farms