5-2009

Best Management Practices for Corn Production in South Dakota

David Clay
South Dakota State University, david.clay@sdstate.edu

Kurtis D. Reitsma
South Dakota State University

Sharon Clay
South Dakota State University, sharon.clay@sdstate.edu

EC929

Best Management Practices for Corn Production in South Dakota

Best Management Practices for Corn Production in South Dakota

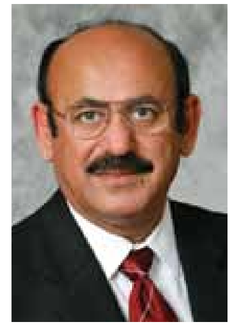
South Dakota Cooperative Extension Service
SDSU

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

Published by South Dakota State University, College of Agriculture and Biological Sciences, AgBio Communications Unit, Box 2218A, Brookings, South Dakota 57007

EC929. 2,000 copies printed and distributed by South Dakota Cooperative Extension Service at a cost of $8.68 each. May 2009.

About 5 million acres of South Dakota land—close to 10% of our state's land resources—are devoted to corn production. This fact alone makes it clear just how important corn production is to the economy of the state of South Dakota. But throw in recent developments in South Dakota's corn-based ethanol industry, and the result is an even further elevation of corn—an elevation to a most prominent position within the economy of our state.



For the last century, the intensity of farming management has continued to escalate. This best management practices manual has brought together some of the best of both old and new technology. It is my belief that this manual will be a significant reference and resource for every South Dakota corn producer.

To all who participated in the development of *Best Management Practices for Corn Production in South Dakota*, I both extend my appreciation and offer a commendation for a job well done.

Latif Lighari, Ph.D.
Associate Dean and Director
South Dakota State University
South Dakota Cooperative Extension Service
Professor of Agricultural Education
College of Agriculture and Biological Sciences

South Dakota corn producers are some of the most productive in the nation. Our state ranked sixth in the nation in production of corn for grain in 2007 and has led the nation in planted acres of genetically engineered corn hybrids since 2000. And yet, our corn producers face many challenges each year. Each producer must make the best decision on which corn hybrid to plant, choose the best fertilizer program, manage high input costs, expect seasonal hazards, deal with weeds and pests, and market the harvest for the greatest profit.

This manual presents the best management practices developed for the changing environment of corn production agriculture in South Dakota. From detailed, basic information on corn growth and development, through each phase of the corn production process, the authors and contributors have provided corn producers with an up-to-date and invaluable reference tool.

I extend my congratulations to the editors, reviewers, authors, and contributors for a job well done.

Bill Even
South Dakota Secretary of Agriculture

Editors

David E. Clay, Kurtis D. Reitsma, and Sharon A. Clay
Plant Science Department, South Dakota State University
Brookings, South Dakota 57007
For information, contact david.clay@sdstate.edu.

Coordination, Manuscript Editing, and Graphic Design

Eric Ollila, Publication Coordinator-Editor
Terry Molengraaf, Information Officer
AgBio Communications Unit
College of Agriculture and Biological Sciences, South Dakota State University
Brookings, South Dakota 57007

Reviewers, Authors, and Contributors (alphabetical order)

Troy Bauder, Research Scientist	Department of Soil & Crop Science, Colorado State University
Dwayne L. Beck, Research Manager	Dakota Lakes Research Farm, South Dakota State University
Sue L. Blodgett, Department Head	Plant Science Department, South Dakota State University
C. Gregg Carlson, Agronomist	Plant Science Department, South Dakota State University
Michael A. Catangui, Entomologist	Cooperative Extension Service, South Dakota State University
David E. Clay, Soil Scientist	Plant Science Department, South Dakota State University
Sharon A. Clay, Weed Scientist	Plant Science Department, South Dakota State University
Darrell L. Deneke, IPM Specialist	Cooperative Extension Service, South Dakota State University
Martin A. Draper, Plant Pathologist	Cooperative State Research, Education, and Extension Service
B. Wade French, Entomologist	Agricultural Research Service, United States Department of Agriculture
Billy W. Fuller, Entomologist	Plant Science Department, South Dakota State University
Robert G. Hall, Agronomist	Cooperative Extension Service, South Dakota State University
Curt A. Hoffbeck, Agronomist	Pioneer Hi-Bred International
Daniel S. Humburg, Biosystems Engineer	Agricultural and Biosystems Engineering Dept., South Dakota State University
Marie A. Langham, Plant Pathologist	Plant Science Department, South Dakota State University
Douglas D. Malo, Soil Scientist	Plant Science Department, South Dakota State University
Mike J. Moechnig, Weed Scientist	Cooperative Extension Service, South Dakota State University
Richard E. Nicolai, Biosystems Engineer	Agricultural and Biosystems Engineering Dept., South Dakota State University
Kurtis D. Reitsma, Agronomist	Plant Science Department, South Dakota State University
Bradley E. Ruden, Plant Pathologist	Plant Diagnostic Clinic, South Dakota State University
Thomas E. Schumacher, Soil Scientist	Plant Science Department, South Dakota State University
Dennis P. Todey, Climatologist	State Climate Office, South Dakota State University
Todd P. Trooien, Biosystems Engineer	Agricultural and Biosystems Engineering Dept., South Dakota State University
Hal D. Werner, Biosystems Engineer	Agricultural and Biosystems Engineering Dept., South Dakota State University
James A. Wilson, Pesticide Specialist	Cooperative Extension Service, South Dakota State University
Howard J. Woodard, Soil Scientist	Plant Science Department, South Dakota State University
Leon J. Wrage, Weed Scientist	Plant Science Department, South Dakota State University

Recognition and Acknowledgements:

South Dakota Corn Utilization Council
South Dakota Department of Agriculture
South Dakota Department of Environment and Natural Resources

Cover photos: USDA-NRCS and Kurtis D. Reitsma.

Table of Contents

List of Figures

List of Tables

Introduction

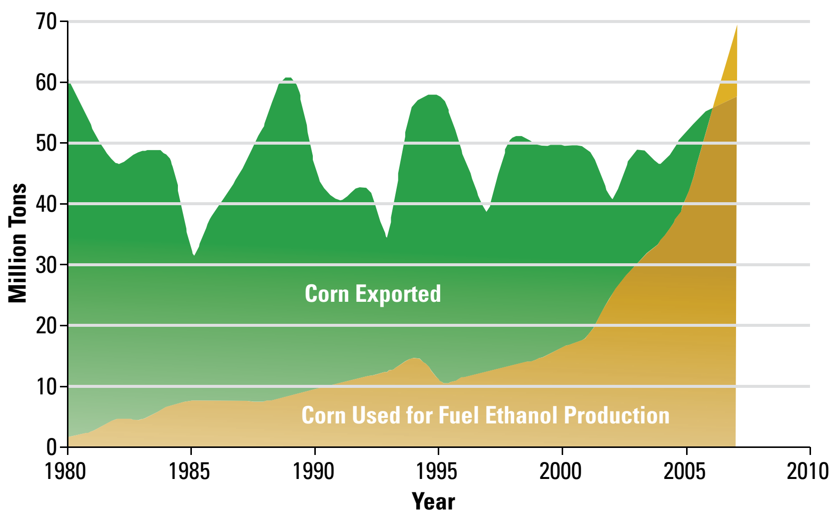
Early corn production techniques focused on maximizing yield and paid little regard to long-term sustainability. The effects of poor management practices were realized in the 1930s when drought reduced both plant growth and subsequent soil cover, leading to significant soil losses due to wind erosion. Wind erosion was so severe that people of the time referred to the Midwest and Great Plains as the "Dust Bowl" instead of as the "Cereal Bowl." The Dust Bowl era led to the development of farming practices that strive to improve the quality of soil, water, and other natural resources. Production practices continue to evolve as more is learned. The ingenuity of producers, scientists, agronomists, policy makers, and others continues to hasten the evolution of flexible best management practices (BMP) that are economically viable, modifiable for local management and conditions, and field tested. This publication provides a guide for selecting BMPs that consider both production and environmental-sustainability goals.

Management practices for improved water quality and long-term sustainability

- Efficient crop nutrient planning
- Efficient pest management strategies
- Careful use of agricultural chemicals
- Implementing practices that reduce soil loss
- Attention to impacts in sensitive areas

Since 1892, corn production acreage in South Dakota has increased from 180,000 to nearly 4.6 million acres. Initially, corn was grown primarily as a source of feed for livestock. More recently, corn uses have expanded to include plastics and fuel ethanol. Associated with these changes is agricultural intensification across the region. The adoption of BMPs can help ensure the long-term sustainability of South Dakota's natural resources.

U.S. corn used for fuel ethanol and export



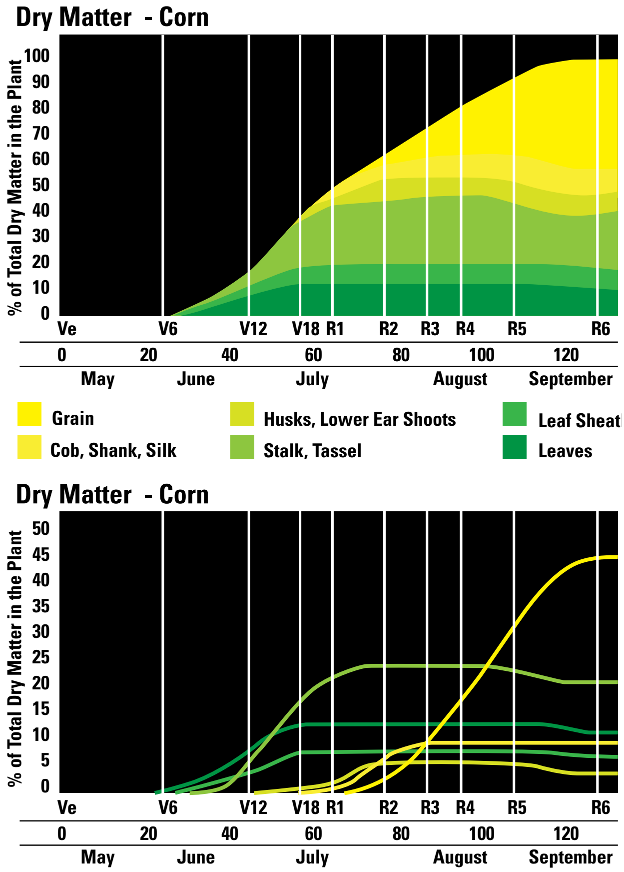
(Source of Data: Earth Policy Institute – http://www.earth-policy.org)

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 1
Corn Growth and Development

Corn growth is influenced by cultural practices and available natural resources. The rate of growth and development changes during the season (fig. 1.1). In South Dakota, water and nitrogen (N) are important resources that limit yield. Other factors that reduce yield include disease, insects, weeds, and deficiency of other plant nutrients. For example, disease and insect infestations can reduce water and nutrient uptake or severely damage the plant to the point of yield loss. Weeds compete with the crop for water, nutrients, and light. Stress from temperature and water extremes affects nutrient availability, often increasing pest population and occurrence and ultimately reducing plant growth.

Figure 1.1. Dry matter accumulation of corn

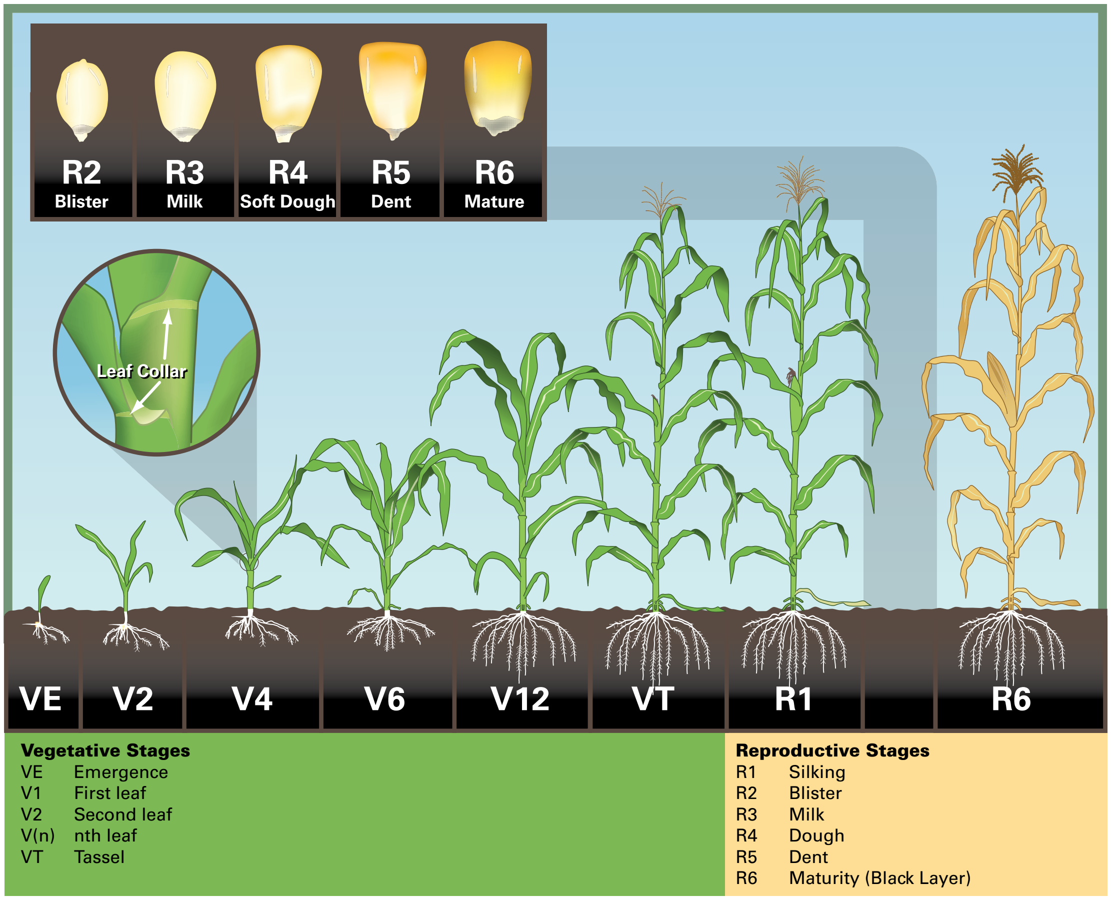


(Adapted from Ritchie et al. 1997)

Many management decisions consider stage of growth and development of the crop. Three examples of this: 1) some pesticide products are labeled for use only at certain stages, 2) fertilizer applied at the right time can provide a greater crop response, and 3) water stress at grain fill is more critical than at other stages. Management efficiency can be improved by matching the crop need to the treatment. Understanding how a corn plant grows and develops is important for maximizing efficiency.

Corn growth and development is divided into vegetative and reproductive stages. The "leaf collar" counting system is a common approach for identifying vegetative growth stages (fig. 1.2). Vegetative growth stages refer to the number of leaf collars up to tasseling (fig. 1.3). Reproductive stages begin at silking (R1) and end at maturity or "black layer" (R6).

Figure 1.2. Progression of corn growth and development using the leaf collar system

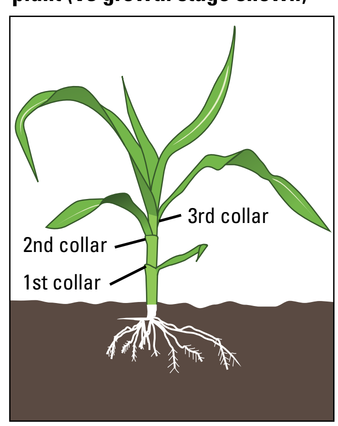


Emergence (VE) to Six-Leaf Stage (V6)

Under warm, moist conditions, corn will germinate and emerge 4 to 6 days after planting. Optimal temperature and soil water are critical at this time. Because seed needs to imbibe water to germinate, if soil water is limiting, emergence can be delayed. In residue-covered soils or if spring air temperatures are low, germination may be slow due to cool soil temperature. Soil temperatures at or below 50°F hinder seed germination. Shallow planting (<1½") into warmer soil can accelerate emergence but may result in other problems.

The first leafy structure that appears is the coleoptile ("spike"), followed by true leaves. Warm, moist, and well-aerated conditions promote vigorous growth and development. New leaves are produced at a single "growing point" near the tip of the stem. The growing point is below the surface of the soil for up to 4 weeks after planting. When the growing point is below the soil surface, the crop usually survives light frost or minor hail. However, the plant is most susceptible to flood damage during this stage.

Figure 1.3. Leaf collars on corn plant (V3 growth stage shown)



(Courtesy of Colorado State University)

Corn roots do not explore a significant volume of soil during early growth stages, but the roots do develop rapidly as the plant develops. Corn has two root types: seminal and nodal. Seminal roots are those that emerge immediately after germination and cease growth at V3 but continue to function throughout the life of the plant. Nodal roots are initiated at formation of the first node (V1) and continue to develop until kernel blister. By the V6 growth stage, nodal roots become the major supplier of water and nutrients.

If soil conditions are cool and wet early in the growing season, nutrient deficiencies, especially phosphorus (P), are common. The application of starter fertilizer will usually prevent this problem. If fertility levels are sufficient, early season nutrient deficiencies often disappear and usually do not reduce yield.

Scouting fields and taking action to control weed problems is crucial during early growth. Excessive weed populations can lead to significant yield loss, even if the plants and weeds are not directly competing for resources.

Six-Leaf (V6) to Eight-Leaf (V8) Stage

In South Dakota, corn usually reaches the V6 growth stage by early to mid-June. At the V6 stage, ear shoots begin to develop and the growing point is aboveground, increasing the potential for significant frost or hail damage. Fields should be scouted for N deficiencies, corn rootworm, and other root-pruning insects just prior to corn entering the V6 stage. Side-dressing N is most effective when applied between V6 and V8. Early control of root-pruning insects can reduce damage, but control options are limited; the best option is to plant resistant or genetically modified hybrids. If weeds are controlled with cultivation, cultivate at or near V6 to avoid root pruning.

Nine-Leaf (V9) to Twelve-Leaf (V12) Stage

At V10, the plant is growing rapidly, with new leaves appearing every 2 to 3 days. The plant requires substantial amounts of water and nutrients to maintain this growth rate. Stress from pests, heat, and lack of nutrients and/or water can slow development and reduce yield.

Twelve-Leaf (V12) to Tassel (VT) Stage

Hybrid maturity selection plays an important role at the V12 stage, when the potential number of kernels per ear and ear size are determined. Earlier-maturing hybrids will progress through these stages in a shorter time, resulting in smaller ears compared to later-maturing hybrids. If water and nutrient availability can support a higher population, yield differences between early hybrids and late hybrids can be equalized by increasing plant density or by increasing the population of earlier-maturing hybrids.

Stress between V12 and VT can reduce yields. Severe hail storms that strip leaves and break tassels can result in complete crop loss.

Silk (R1) Stage

At R1, the silks emerge and capture pollen shed from the tassel. Pollen captured by the silks fertilizes ovules on the cob within 24 hours, developing into kernels. Pollen shed typically occurs during early or mid-morning, when moisture and temperature conditions are favorable. This stage is one of the most crucial reproductive stages. Dry (low humidity) and hot (>95°F) conditions result in reduced fertilization and serious yield reductions. With no fertilization, ears are barren.

Insect pests, such as corn rootworm beetle (adult), destroy silks through feeding and can reduce yields (see fig. 1.4). To minimize losses, fields should be scouted for corn rootworm beetles at silking (R1) and controlled if populations exceed economic thresholds.

Figure 1.4. Silk clipping

Severe silk clipping will reduce yield.

(Photo courtesy of Mike Catangui, South Dakota State University)

Potassium (K) uptake is complete at silking, but N and P uptake continues. If N and P are limiting, the plant will attempt to compensate by moving these nutrients from older leaves into upper leaves or the developing grain. At this stage, N- and P-deficiency symptoms can be observed in lower leaves. Unfortunately, nutrient application at this or later growth stages will not make up for these deficiencies.

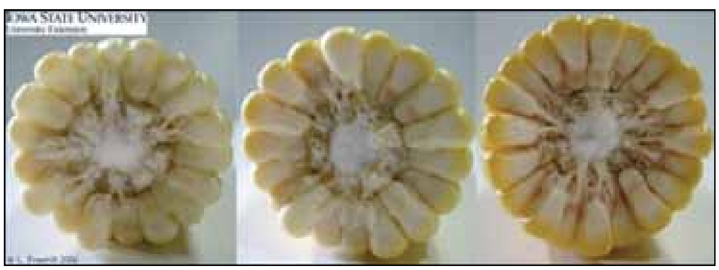
Blister (R2) to Maturity (R6)

After pollination, kernel formation begins. The kernel appears as a "blister" at the R2 growth stage. Starch begins to accumulate in the kernel as the plant initiates a period of kernel fill. Grain fill proceeds rapidly and the kernels take on a light yellow color as they enter the "milk" stage (R3). Although not as critical as the R1 stage, stress at this time can reduce kernel size and weight, and some kernels may still abort. As the kernels mature to the the dough (R4) stage, they change from a milky consistency to soft and sticky. At R4, the kernels have accumulated nearly half of their mature weight (fig. 1.5).

From R2 to R6, grain moisture content declines from 85% at R2 to approximately 55% at R5 (dent). Irrigation should cease at R2. Additional water at or after R2 does not enhance yield, slows dry-down, and may encourage stalk and grain diseases. A hard frost at R5 can kill the plant, thus stopping kernel development. Corn killed by frost prior to black layer (R6) usually has a low test weight and a slower dry-down rate. Selecting a hybrid that matures 2 to 3 weeks before fall frost reduces these risks. If early frost kills the plant, the crop can be harvested and ensiled as high-moisture grain for animal feed.

At "black layer" (R6), the area near the tip of the mature kernels appears dark. At R6, the grain is mature, with moisture contents between 30 to 35% (fig 1.6). If the crop is harvested for grain, allowing the crop to dry in the field reduces drying costs; but if left in the field too long, there is an increased chance of harvest loss. At 15% moisture, corn can be stored safely for up to 6 months. For long-term storage, to avoid spoilage, corn should be dried to 12% moisture .

Figure 1.5. Progression of kernel development



L to R: less to more developed.
(Photo courtesy of Iowa State University)

Hybrids have subtle differences in growth and development (with respect to number of leaves, ears, maturity, dry-down, and other traits). Early harvest is rarely profitable, due to drying cost or dockage. Corn can be left in the field if stalks maintain strength and if ear drop is not a problem. Harvest loss from lodging and ear drop can be significant in fields damaged by European corn borer or Western bean cutworm. In these situations, timely harvest to reduce harvest loss should be weighed against drying cost. Scouting to assess stalk condition, ear retention, and grain moisture is recommended.

Figure 1.6. Corn kernel at maturity (R6)

(Photo courtesy of Iowa State University)

The Federal Crop Insurance Corporation (FCIC) follows a variation of the leaf collar system for staging corn; a leaf is counted when 40 to 50% of the leaf is exposed. Table 1.1 provides comparisons between the two systems.

Table 1.1. Comparison: leaf collar and FCIC[1] corn growth staging systems for a 120-day (RM[2]) hybrid

FCIC	Leaf Collar	Description	Days/ Stage	GDUs/ Stage	Days after seeding	GDUs after seeding
---Emergence – Vegetative Stages---						
-	V0	Seeding to germination	5 – 10	100 – 150	5 – 10	100 – 150
-	VE	Coleoptile opens	2 – 4	66	7 – 14	166 – 216
V2	V1	1st leaf collar	3	66	10 – 17	232 – 282
V3	V2	2nd leaf collar	3	66	13 – 20	298 – 348
V4	V3	3rd leaf collar	3	66	16 – 23	364 – 414
V5	V4	4th leaf collar	3	66	19 – 26	430 – 480
V6	V4	4th leaf collar	3	66	19 – 26	430 – 480
V7	V5	5th leaf collar	3	66	22 – 29	496 – 546
V8	V6	6th leaf collar	3	66	25 – 32	562 – 612
V9	V7	7th leaf collar	3	66	28 – 35	628 – 678
V10	V7	7th leaf collar	-	-	-	-
V11	V8	8th leaf collar	3	66	31 – 38	694 – 744
V12	V9	9th leaf collar	3	66	34 – 41	760 – 810
V13	V10	10th leaf collar	3	66	37 – 44	826 – 876
V14	V11	11th leaf collar	3	66	40 – 47	892 – 942
V15	V12	12th leaf collar	3	66	43 – 50	958 – 1,008
V16	V13	13th leaf collar	3	66	46 – 53	1,024 – 1,074
V17	V14	14th leaf collar	3	66	49 – 56	1,090 – 1,140
V18	V15	15th leaf collar	2	48	51 – 58	1,138 – 1,188
	V17	17th leaf collar	2	48	55 – 62	1,234 – 1,284
	V18	18th leaf collar	2	48	57 – 64	1,282 – 1,332
	V19	19th leaf collar	2	48	59 – 66	1,330 – 1,380
	V20	20th leaf collar	2	48	61 – 68	1,378 – 1,428
	V(n)	*n*th leaf collar	-	-	-	-
	VT	Tassel extended – no silks	4	100	65 – 72	1,478 – 1,528
---Reproductive Stages---						
Silked	R1	Silked – pollen shed	4	100	69 – 76	1,578 – 1,628
Silks brown		Silks 75% brown	5	125	74 – 79	1,703 – 1,753
Pre-blister		No fluid in kernels	4	100	78 – 85	1,803 – 1,853
Blister	R2	Kernels are watery	4	100	82 – 89	1,903 – 1,953
Early milk		Kernels begin to yellow	4	100	86 – 93	2,003 – 2,053
Milk	R3	Kernels yellow; no solids	5	100	91 – 98	2,103 – 2,153
Late milk		Kernels contain semi-solids	4	100	95 – 102	2,203 – 2,253
Soft dough	R4	Kernels pasty	5	100	100 – 107	2,303 – 2,353
Early dent		Kernels begin to dent	5	100	108 – 115	2,403 – 2,453
Dent	R5	Kernels soft but dented	5	125	113 – 120	2,528 – 2,578
Late dent		Kernels dented but drying	5	125	118 – 125	2,653 – 2,703
Nearly mature		Kernel embryo not hard	5	125	123 – 130	2,778 – 2,828
Mature	R6	Black layer	5	125	128 – 135	2,903 – 2,953

All values are approximations, as the values may vary over years, production environments, and locations.

[1] Federal Crop Insurance Corporation (FCIC), operated by the United States Department of Agriculture, Risk Management Agency

[2] Relative maturity (RM)

(Adapted from USDA-FCIC, Corn Loss Adjustment Standard Handbook, 2007.)

Additional Information and References

Corn Production. 2007. Iowa State University, Agronomy Extension. http://www.agronext.iastate.edu/corn/.

Nielson, R.L. 1996. Drought & heat stress effects on corn pollination. Purdue University, Agronomy Department. West Lafayette. http://www.agry.purdue.edu/ext/corn/news/articles.96/p&c9635.htm.

Ritchie, S.W., J.J. Hanway, and S.J. Lupkes. 1997. How a corn plant develops. Special Report No. 48. Iowa State University of Science and Technology, Cooperative Extension Service. Ames. http://www.agronext.iastate.edu/corn/production/management/growth/.

United States Department of Agriculture, Federal Crop Insurance Corporation. 2007. Corn loss adjustment standard handbook. FCIC-25080 (11-2006). http://www.rma.usda.gov/handbooks/25000/2007/07_25080.pdf.

WeedSoft© crop growth stage learning module; Corn. 2007. University of Nebraska, Lincoln. http://weedsoft.unl.edu/Publications.htm.

Reitsma, K.D., S.A. Clay, and R.G. Hall. 2009. "Corn growth and development." Pp. 3–8. In Clay, D.E., K.D. Reitsma, and S.A, Clay (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 2
Corn Hybrid Selection

Selecting a hybrid is one of the most important decisions a producer makes. Hybrid selection should consider yield, maturity, resistance to disease and insect pests, and other traits important to individual production systems (Table 2.1).

Table 2.1. Common traits for evaluating a hybrid

- Hybrid maturity
- Yield potential
- Yield stability
- Lodging resistance
- Ear retention
- Disease resistance
- Insect resistance
- Herbicide tolerance
- Seed quality
- Dry-down rate
- Test weight

Hybrid Maturity

Growing-season length varies within South Dakota. Growers are encouraged to select hybrids that will reach physiological maturity, or "black layer," about 1 to 2 weeks before the average first killing frost. Comparing the maturity rating systems of different seed companies is difficult because the respective ratings systems are estimated and reported differently. One commonly used system is the Minnesota Relative Maturity (MRM) system. In the MRM system the hybrid is field tested for 3 years and compared to a group of standard hybrids with known relative maturities (RM). Hybrids with relative maturity ratings ranging from 75 to 115 days are suitable for South Dakota.

Another approach for selecting hybrids relies on accumulated "growing degree days" (GDD) or "growing degree units" (GDU). The base temperature used for calculating GDUs will vary by crop. The base temperature for corn is 50°F (corn growth is minimal below this temperature). The maximum temperature used also varies by crop; for corn it is set at 86°F (corn growth declines when the temperature exceeds 86°F). GDUs are calculated using the equation in Table 2.2. Accumulation of GDUs can be tracked with a thermometer during the growing season or is available for specific South Dakota sites at http://climate.sdstate.edu/climate_site/current_weather.htm.

When using GDUs to select hybrids, base the maturity selection on accumulated GDUs from planting to first fall frost (minus the adjustment value of GDUs to allow for grain dry-down). However, if the crop is to be harvested for silage, an allowance for grain dry-down is not needed. If planting is delayed, an earlier-maturing hybrid may be appropriate. Average accumulated GDUs for selected spring planting dates is provided by location in Table 2.3.

Table 2.2. Calculation of growing degree units (GDUs)

[1] $$GDU = \left(\frac{(MDH + MDL)}{2}\right) - 50$$

GDU[2] = growing degree units
MDH[3] = maximum daily high temperature (degrees Fahrenheit [°F])
MDL[4] = minimum daily low temperature (degrees Fahrenheit [°F])

[1] When selecting hybrid maturity based on GDUs, unless crop is to be harvested for silage, subtract accumulated GDUs for 10 days prior to first fall frost to allow for grain dry-down.
[2] GDU = growing degree day (GDD)
[3] MDH cannot be greater than 86°F; if MDH > 86°F then MDH = 86°F
[4] MDL cannot be less than 50°F; if MDL <50°F then MDL = 50°F.

Table 2.3. Average accumulated growing degree units (*GDUs)
"Years of data" range from 24 to 36 years (from 1970 to 2006) by location.

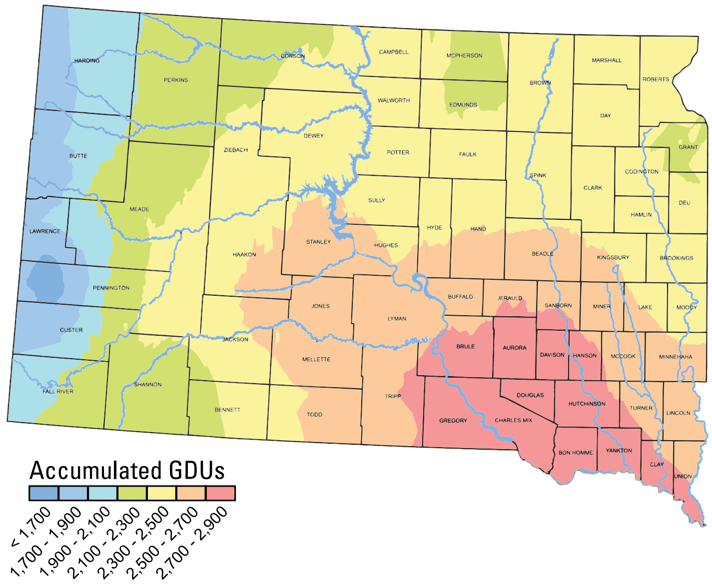
Weather Station	Years of data	Spring planting date						Adjustment for grain dry-down	Average date of first fall frost	
		May 1	May 11	May 21	May 31	June 10	June 20			
		average GDUs† to first fall frost of 32°F						GDUs‡	32°F	28°F
Aberdeen Arprt	36	2,389	2,305	2,195	2,072	1,928	1,763	163	Sep 22	Oct 1
Armour	32	2,832	2,730	2,599	2,458	2,296	2,104	330	Sep 30	Oct 21
Bison	29	2,326	2,243	2,143	2,038	1,906	1,756	199	Sep 25	Oct 15
Bridgewater	29	2,720	2,627	2,507	2,365	2,202	2,010	278	Oct 1	Oct 22
Britton	35	2,523	2,427	2,308	2,176	2,021	1,847	192	Sep 24	Oct 10
Brookings 2 NE**	36	2,220	2,149	2,052	1,938	1,803	1,644	143	Sep 21	Oct 11
Canton 4 WNW	31	2,687	2,589	2,458	2,316	2,153	1,960	250	Sep 27	Oct 16
Centerville 6 SE	36	2,554	2,464	2,348	2,213	2,054	1,868	212	Sep 24	Oct 18
Clark	35	2,441	2,363	2,259	2,142	2,002	1,839	224	Sep 30	Oct 15
Clear Lake	34	2,390	2,308	2,203	2,083	1,944	1,777	218	Sep 29	Oct 17
De Smet	33	2,572	2,485	2,376	2,254	2,105	1,930	250	Sep 30	Oct 17
Eureka	36	2,299	2,218	2,114	1,996	1,859	1,704	162	Sep 22	Oct 9
Faith	30	2,503	2,416	2,307	2,191	2,052	1,894	268	Sep 28	Oct 16
Faulkton 1 NW	33	2,454	2,368	2,264	2,143	1,996	1,834	213	Sep 25	Oct 10
Flandreau	34	2,332	2,254	2,152	2,031	1,889	1,724	199	Sep 26	Oct 14
Gettysburg	33	2,320	2,245	2,144	2,044	1,913	1,758	237	Sep 28	Oct 15
Gregory	35	2,682	2,586	2,464	2,336	2,180	2,000	273	Sep 29	Oct 19
Highmore 1 W	30	2,531	2,440	2,322	2,195	2,043	1,870	207	Sep 24	Oct 12
Huron Arprt	36	2,564	2,475	2,363	2,235	2,084	1,907	237	Sep 27	Oct 18
Ipswich	35	2,327	2,242	2,131	2,010	1,869	1,708	158	Sep 22	Oct 8
Kennebec	35	2,754	2,650	2,520	2,382	2,215	2,025	230	Sep 24	Oct 11
Madison 2 SE	36	2,427	2,348	2,242	2,119	1,973	1,805	214	Sep 27	Oct 19
Mellette	31	2,381	2,299	2,192	2,077	1,933	1,766	187	Sep 24	Oct 10
Menno	35	2,802	2,697	2,566	2,418	2,247	2,050	271	Sep 27	Oct 19
Milbank 2 SSW	28	2,426	2,344	2,233	2,108	1,956	1,789	220	Sep 27	Oct 17
Miller	35	2,596	2,507	2,393	2,270	2,120	1,947	266	Oct 1	Oct 15
Mission	35	2,439	2,362	2,261	2,148	2,012	1,850	236	Sep 26	Oct 13
Mitchell 2 N	29	2,718	2,627	2,509	2,377	2,217	2,030	287	Oct 1	Oct 22
Newell	35	2,337	2,265	2,170	2,056	1,927	1,778	229	Sep 26	Oct 14
Oelrichs	35	2,447	2,360	2,252	2,134	1,994	1,834	220	Sep 24	Oct 11
Onida 4 NW	34	2,573	2,480	2,363	2,236	2,085	1,916	246	Sep 27	Oct 15
Pollock	31	2,470	2,379	2,265	2,136	1,985	1,821	225	Sep 26	Oct 7
Rapid City 4 NW	29	2,340	2,268	2,171	2,069	1,941	1,793	247	Sep 30	Oct 24
Redfield 2 NE	26	2,399	2,312	2,204	2,080	1,935	1,770	196	Sep 23	Oct 11
Selby	35	2,323	2,247	2,144	2,030	1,896	1,738	188	Sep 25	Oct 11
Sioux Falls Arprt	35	2,592	2,501	2,387	2,254	2,098	1,912	245	Sep 28	Oct 20
Sisseton	35	2,456	2,369	2,256	2,132	1,983	1,814	237	Sep 29	Oct 18
Timber Lake	36	2,411	2,328	2,222	2,105	1,193	1,803	252	Sep 29	Oct 13
Tyndall	34	2,859	2,760	2,636	2,493	2,328	2,132	334	Oct 3	Oct 22
Vermillion 2 SE	27	2,895	2,796	2,646	2,496	2,318	2,114	327	Sep 29	Oct 24
Wagner	36	2,974	2,863	2,728	2,576	2,400	2,200	363	Oct 3	Oct 25
Watertown Arprt	32	2,344	2,266	2,163	2,046	1,904	1,741	155	Sep 23	Oct 11
Webster	34	2,415	2,333	2,227	2,105	1,964	1,804	214	Sep 29	Oct 14
Wessington Springs	34	2,814	2,729	2,612	2,475	2,314	2,129	366	Oct 5	Oct 27
Winner	35	2,906	2,800	2,668	2,529	2,362	2,170	385	Oct 3	Oct 23

* GDUs – based on a daily maximum and minimum of 86°F and 50°F, respectively, and a base temperature of 50° F (Table 2.2).
** Indicates Brookings 2 NE is located 2 miles northeast of the Brookings Post Office.
‡ GDUs that must be subtracted from any May 1 to June 20 date to allow for 10 days of dry-down before 32°F.
† Averages are based on "years of data" column or from 1976-2006. Averages are based on a range of values that are less and greater than the average; therefore, values lower or higher than average should be expected.
Adapted from Todey, D. and C. Shukla. 2007. South Dakota Climate & Weather. South Dakota State University.

The map in figure 2.1 shows the 30-year average accumulated GDUs (50°F basis) across the state during an "average" growing season (taking into account the probabilities of the last spring and first fall frost dates).

A third approach to hybrid maturity selection is the Comparative Relative Maturity (CRM) method. With this method, RM and GDUs are compared. No matter which method is selected, the most important factor for achieving the full genetic yield potential is to choose hybrids that are suited to local conditions. Hybrids that have either too long or short maturity may not reach their full yield potential. Growers are advised to consult their local county Extension educator or crop advisor to assist them in hybrid selection.

Figure 2.1. Thirty-year average accumulated GDUs (50°F basis)



This map was created from daily reporting National Weather Service Cooperative Observer Stations, considering the 50th percentile date of last spring frost and first fall frost for each reporting station between 1977 and 2006.

Yield Potential and Stability

Regardless of climate, fertility, pest, or weed problems, different hybrids have different yield potentials. Hybrids that are more resistant to stress have more stable yields. When considering a hybrid, yield data and climate conditions for the past 3 years should be considered. Hybrids with consistent yields under varying climate conditions are more desirable than hybrids with variable yields.

Another approach is to plant 15, 35, and 50% of acres with hybrids having 1, 2, and 3 years of yield data, respectively. This allows a producer to take advantage of a new hybrid without exceptional risk.

Corn yield trials are conducted annually by the South Dakota State University Crop Performance Testing Program. Results from those yield trials are available at http://plantsci.sdstate.edu/varietytrials/.

Table 2.4. Agronomic traits

Plant Development
- drought tolerance
- emergence
- seedling vigor

Yield & Harvestability
- root strength
- stalk strength
- plant height
- ear height
- kernels per row
- husk cover
- ear retention
- ear flex
- stay-green
- grain dry-down

Agronomic Traits

Agronomic traits represent the base genetics of the hybrid. Seed companies commonly rate the hybrid's yield, stalk strength, drought tolerance, and disease-resistance traits. One trait may be more important to a producer than another.

Emergence and seedling vigor indicate the ability of the plant to deal with stress early in the season. Hybrids that emerge quicker and have a greater early season vigor may be able to better cope with cool temperatures. This is especially important in high-residue no-tillage systems.

Harvestability is related to traits that impact dry-down rate, root and stalk strength, "stay-green," ear retention, and husk cover. Lodging and ear-drop can reduce yield simply by making it difficult to harvest the crop. Plants that stay green later into the season are likely to have increased stalk strength and reduced lodging. Ear retention indicates how strongly the plant holds the ear and resists ear-drop.

Although a hybrid might have a good genetic package for plant standability, there is no guarantee that it will not lodge or break. All hybrids are susceptible to stalk lodging, snapping, or breakage during periods of rapid stalk growth. Hybrids prone to stalk breakage have a longer period of susceptibility or exhibit a greater degree of damage during rapid growth. Strong winds, hail, insect damage, and stalk rots (exacerbated by insect damage and/or drought) can cause stalk breakage. Growth-regulator herbicides like 2,4-D and dicamba can affect a hybrid's ability to resist stalk problems.

Insect and Disease Resistance and Genetically Modified Crops

If disease or insect problems exist or are expected, resistance traits for that particular pest are important. To identify resistance to specific problems, check with your seed dealer.

Genetically modified crops (GMC) have become popular for managing insect and weed pests. Insects that present a threat to the crop (such as European corn borer, corn rootworm, and western bean cutworm) can be controlled by planting a hybrid genetically engineered to kill those insects. Genetically engineered hybrids that are tolerant to broad-spectrum herbicides can simplify weed control programs. It is recommended that the technology cost and marketability of the crop be considered prior to committing to a GMC. Information regarding GMC-approval status is available from the National Corn Growers Association (NCGA) online at http://www.ncga.com/biotechnology/main/index.asp.

Seed Quality

Prior to planting, seed should be checked for germination rates and weed seeds. Weed seed is generally not a problem, due to the large seed size and ease of weed seed removal with mechanical seed-conditioning equipment. All hybrid seed must have germination test results on the label. Cold test germination values of 85% or higher are desirable if planting in soil with temperatures less than 50°F. Most hybrid seed is treated with a fungicide. Seed should be inspected for nicks or cracks, as these conditions lower seed quality (thus increasing vulnerability to disease infection). Broken or cracked seeds may not germinate; poor quality seed should be returned to the dealer.

Additional Information and References

Hall, R.G. and K.K. Kirby. 2007 (revised annually). Precision planted corn performance trials. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD. http://agbiopubs.sdstate.edu.

Todey, D. and C. Shukla. 2007. South Dakota climate and weather. South Dakota State University. http://climate.sdstate.edu/climate.

Hall, R.G. and K.D. Reitsma. 2009. "Corn hybrid selection." Pp. 9–12. In Clay, D.E., K.D. Reitsma, and S.A, Clay (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 3
Corn Planting Guide

Obtaining maximum profit from a corn crop depends on the timely planting of an appropriate hybrid, at the proper depth, with a planter that evenly spaces the seed. The success of a corn crop is dependent on equipment maintenance, seedbed preparation, the development of a sound fertility and pest management program, and planting the seed. Early planting is best, but temperatures should be warm enough to assure quick germination and emergence, and late enough to avoid hard frosts. Planting-opportunity windows can be narrow due to spring rains or a late warm-up. Time spent in the off-season maintaining equipment and planning tentative season-long schedules can increase planting efficiency. This section discusses planter maintenance, planting date, replanting considerations, seeding rate, and planting depth.

Planter Maintenance and Preparation

A corn planter is a piece of precision equipment, with each component working together to place the seed in the ground at a uniform depth and with a uniform distance between seeds. Research has shown that the uniform spacing of seed can increase yields up to 20 bu/acre (Doerge and Hall 2000). Although they are conducted too late to correct an in-season problem, stand counts and population surveys can be useful for determining if planter calibration is needed. Growing conditions should also be evaluated, as poor seed quality or problems such as soil crusting, areas that are too wet or too dry, or cold soil temperatures for extended periods may be responsible for non-uniform stands.

Table 3.1. Planter maintenance checklist

- ✓ Review owner's manual.
- ✓ Replace worn parts.
- ✓ Calibrate seed meters.
- ✓ Calibrate planter fertilizer and pesticide applicators.
- ✓ Check down pressure springs.
- ✓ Maintain even and recommended tire pressure.
- ✓ Lubricate bearings and other moving parts.

Potential yield losses due to uneven stands can be estimated (Carlson et al. 2000). If planter calibration is necessary, always follow the manufacturer's instructions for calibrating seed metering equipment. Assistance is available from local Extension educators, crop consultants, or seed dealers.

During planting, it is important to place seed at the proper depth and ensure that the walls of the furrow are not smeared by the opener. Down-pressure tension should be adjusted if seed is not placed at the desired depth (1½ to 2") (see "Depth and Planting Options" section on pg. 15 of this publication). Closers or packing wheels should apply enough pressure for good seed-to-soil contact; too much pressure will compact the seedbed. Adjust down-pressure tension in consideration of soil moisture and residue conditions.

As no-till and reduced-till systems become increasingly popular, the planter takes on the additional task of manipulating soil and crop residue. Hence, there are more parts to wear out and maintain. Implements that manage residue on the planter are critical in no-till and other high-residue systems, as crop residue can interfere with openers and closures.

Planting Dates

The spring planting window generally ranges from late April to mid-June (Table 3.2). Historically, 10% of the corn acres in South Dakota are seeded by mid-May, continuing to mid-June. Seed germination depends on soil moisture and temperature. Care should be taken to avoid tillage and planting operations when soil is wet. Yields may or may not be reduced due to delayed planting. However, due to problems associated with compaction, "mudding" the seed in will reduce current and future yields.

As a general rule, corn should not be planted until the soil temperature (measured at 2" between 7 and 8 a.m.) approaches 50°F. In cold soil conditions (below 50°F), seeds will readily absorb water but will not initiate root or shoot growth; this leads to seed rots and poor emergence. If circumstances force planting before soil temperatures reach 50°F, it is recommended to consult with a reputable seed dealer or agronomist to select an appropriate hybrid (one where the seed has been treated with a fungicide).

Table 3.2. Suggested and historical dent corn planting dates in South Dakota by region

Approximate planting dates by reporting region						South Dakota reporting region
Suggested planting dates*			Historical acres planted, 1970–1994**			
Earliest	Latest	Desired range	10%	50%	90%	
May 4	June 5	May 12 – 26	May 10	May 26	June 9	Northwest
5	5	May 10 – 24	9	20	5	North Central
6	5	May 10 – 24	6	18	4	Northeast
April 29	June 8	May 12 – 24	May 12	May 25	June 10	West Central
May 3	5	May 6 – 26	9	20	5	Central
6	5	May 6 – 26	4	16	3	East Central
May 4	June 3	May 7 – 24	May 7	May 20	June 2	Southwest
April 29	8	May 3 – 17	10	22	7	South Central
27	10	May 1 – 15	6	15	2	Southeast

* Dates are best estimates obtained from historical and research data within a reporting region.
** Adapted from National Agricultural Statistics Service (NASS) – South Dakota Field Office.

Delayed Planting or Replanting Considerations

Delayed planting reduces the number of growing degree units (GDU) accumulated during the season, hindering the crop from maturing before the first fall killing frost (see Chapter 4). Corn killed by frost before maturity may not have completely filled kernels and has a slower dry-down rate, which can lead to excessive drying costs. If planting is delayed, late-maturing hybrids can lose up to 1.1 bu/acre per day compared to earlier-maturing hybrids that can be planted later in the season without realizing a loss (Table 3.3). The trade-off for planting earlier hybrids is that they have lower yield potentials.

The number of GDUs that a hybrid needs to reach physiological maturity is related to maturity ratings (Table 3.4.). Since GDUs are based on temperature (see Chapter 2), the amount of GDUs accumulated in the spring and fall are less than during the peak summer months. Available GDUs decline with later planting dates. However, corn will usually emerge quicker if soil temperatures are warmer.

Table 3.3. Yield response of corn to planting date

Relative Maturity (MN Rating)	------Average planting date-----					Daily yield loss from May 7
	April 17	April 27	May 7	May 17	May 27	
	------Average yield (bu/acre)---------					(bu/acre)
101 – 103 d. (early)	130	132	131	132	119	0.06
112 – 118 d. (late)	143	145	141	131	109	1.6
Average	137	139	136	131	114	1.1

Yield data collected from 1986 to 2001 (14 yrs*).
*No data for 1995 or 2000.
Southeast South Dakota Experiment Station, Beresford SD.
(Berg et al. 2001)

A "rule of thumb" is to plant 20% of fields with a full-season hybrid, 60% with a mid-season hybrid, and the remaining 20% with a short-season hybrid ("20-60-20 rule"). If planting is delayed, growers are urged to consult their seed dealer to determine if an earlier-maturing hybrid is warranted.

Table 3.4. Estimated accumulated GDUs required for corn

Growth Stage	RM* – 80 days (Early)	RM* – 95 days (Mid)	RM* – 110 days (Late)
	-------------GDUs-------------		
Emergence	110	110	110
R1 (silking)	1100	1250	1400
R6 (maturity)	1900	2200	2500

* Relative maturity (RM) of hybrid in days.

Seeding Rates

The optimal population for an area is influenced by available water, nutrients, and overall soil productivity. Even within a field, optimal populations may vary by soil type or landscape position. Low populations can lead to increased weed pressure (from lack of competition), whereas higher plant populations increase seed investment with little return. Achieving an optimal population throughout the field gives corn a competitive edge over weeds and can optimize grain dry-down time in the fall.

Optimal corn populations vary from 24,000 to 32,000 plants per acre. Higher-productive soils with sufficient drainage and available water can support higher populations. Data in Table 3.5 provide a guide for selecting optimal population rates.

Table 3.5. Influence of soil type and yield potential on target population and seeding rate

Yield potential by soil type	Target population (1,000 plants/acre)	Planting rate[1] (1,000 seeds/acre)	
		No-till	Tilled
High Yield Potential • deep loams • well drained	28 – 32	32 – 34	30 – 32
Moderate Yield Potential • clays – sandy loams • well to moderately drained	26 – 28	30 – 32	28 – 30
Low Yield Potential • droughty soils • somewhat to poorly drained • excessively drained	24 – 26	28 – 30	26 – 28

[1]Increase population by 10% for silage corn.

Some overall recommendations for seeding rate include the following:

- Increase populations by ≈10% for silage crops.
- Set seeding rates higher than target population to account for less than 100% germination and seedling mortality.
- Increase seeding rate by ≈ 2000 seeds/acre in no-till systems.
- Increase seeding rate by ≈ 2000 to 3000 seeds/acre in irrigated fields.

Depth and Planting Operations

Depending on field conditions at the time of planting, depth can vary from 1½ to 3 inches. Under optimal conditions, seed is commonly placed 1½ to 2 inches below the soil surface. In dry conditions, it may be advantageous to plant deeper (2 to 3"). If soil is very dry and rain is not expected, seed may be placed up to 3 inches deep. Planting deeper than 3 inches is not recommended, as reduced emergence rate may result. The likelihood of rain is an important factor when making planting depth decisions. If surface residue has been removed, rain can seal the surface of the soil, making it difficult for the developing plant to emerge.

Crop residue can affect seeding date (as soils warm slower in high-residue systems). Seed can be left on the surface when seed openers "ride-up" over residue. When seeding into areas with heavy residue, if moisture conditions are favorable, plant at least 1¼ inches deep. Check seed depth often in high-residue situations to make sure that seed is placed at the proper depth. Do not include surface residue when measuring seeding depth. Seed left on the surface or in the residue layer will not grow or properly develop. If residue is problematic, consider residue manager planter attachments.

Additional Information and References

Berg, R., D. DuBois, B. Jurgensen, R. Stevens, and G. Williamson. 2001. Date of planting corn. SE South Dakota Experiment Farm Progress Report 41:37–42. http://plantsci.sdstate.edu/Farm%20Reports/Beresford%202001/0105.pdf.

Carlson, C.G., T.A. Doerge, and D.E. Clay. 2002. Estimating corn yield losses from uneven spaced corn. SSMG-37 Clay et al. (ed.). Site-Specific Management Guidelines. http://www.ppi-far.org/ssmg.

Doerge, T.A. and T.E. Hall. 2000. The value of planter calibration using the MeterMax* system. Pioneer Hi-Bred International, Inc. Crop Insights 10:23. http://www.pioneer.com/web/site/portal/menuitem.268d86162ece78de3c3d48e7d10093a0/.

USDA-NASS. 2007. Annual Summary Bulletin. http://www.nass.usda.gov/sd.

Hall, R.G., K.D. Reitsma, and D.E. Clay. 2009. "Corn planting guide." Pp. 13–16. In Clay, D.E., S.A, Clay, and K. Reitsma (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 4
Seasonal Hazards – Frost, Hail, Drought, and Flooding

Frost

Corn is usually safe from frost until the 2-leaf stage (V2) because the growing point is below the soil surface. Soil temperatures can be different than air temperatures. Soil water content and residue cover affect soil warming and cooling. If frost damage is suspected, an assessment can be conducted by slicing the plant in half vertically. If the innermost part of the plant (the area with the newest growth) appears mushy or discolored (brown and/or black), the plant will likely not recover. Frost damage assessments should not be attempted until 3 days after the frost. Warm temperatures encourage the plant to resume growth, but cool temperatures will not. If an attempt at damage assessment is made before the plant has had time to recover, the assessment may not be accurate. Assessments conducted 3 to 10 days after frost are common. Frost damage can be spotty in a field, with the most-severe damage in low-lying areas of fields and little to no damage in higher areas.

Figure 4.1. Frost damage on corn

(Photo courtesy of Leon Wrage, South Dakota State University)

Figure 4.2. Corn seedling damage due to frost

(Photos courtesy of R.L. Nielson, Purdue University)

Hail

Hail can defoliate the crop and cause breakage or bruising of the stalk, creating entry sites for insects and diseases. The severity of the damage caused by hail is related to the size and duration of the hail. In most hail cases, the crop will recover; yield loss depends on the growth stage at the hail event and the severity of the damage. A hail event occurring when the growing point is belowground may only strip the emerged leaves. As the crop develops it becomes more vulnerable to leaf stripping. Damage to leaves and stalks can reduce yield if the movement of sugars from the leaves to the ears is restricted. Hail during ear development may result in a barren crop.

Figure 4.3. Hail damage to corn.

(Photos courtesy of R.L. Nielson, Purdue University)

Drought and Flooding

Water is essential to crop growth and development, but it must be available within an optimal range. Too much water can kill plants from lack of soil O_2 or can result in disease problems. As with frost, flooding may be site-specific in the low-lying areas. Drainage may be an option for frequently flooded areas. However, to determine the legality of drainage, local USDA-NRCS offices must be contacted prior to installing artificial drainage systems.

Drought also restricts corn yield. Dry conditions during silking will reduce kernel set and pollination. In a field that has both high and low landscape positions, drought will be noticed on hilltops and summits before the lower-lying areas are affected.

Conclusion

Weather conditions such as frost, hail, flood, or drought can severely reduce yields. Effects from these events are manageable to a certain extent, but loss can be expected when these events occur. The degree of loss depends on the severity of the event. Crop insurance has become a common component of corn production in the U.S.; the insurance provides the producer economic protection for uncontrollable events. Producers should consider crop insurance based on the consequences of crop loss.

Figure 4.4. Corn growing in flooded conditions

(Photo courtesy of University of Nebraska)

Figure 4.5. Drought impact on corn

Above: Drought stress prior to silking (R2).

Normal ear (left) and ears from corn in late vegetative stages through grain fill that have suffered from drought stress.
(Photos courtesy of The Ohio State University)

Additional Information and References

More information on South Dakota climate and weather information is available from the South Dakota Office of Climatology (http://climate.sdstate.edu).

Hall, R.G., T.P. Trooien, D.P. Todey, and D.E. Clay. 2009. “Seasonal hazards – frost, hail, drought, and flooding.” Pp. 17–20. In Clay, D.E., S.A, Clay, and K.D. Reitsma (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 5
Tillage, Crop Rotations, and Cover Crops

Historically, tillage and cultivation were used to manage residue, diseases, insects, weeds, and soil compaction. Tillage equipment that has been used includes molderboard plows, discs, cultivators, rippers, and chisel plows. Conservation practices and innovations in production tools (i.e., planters, herbicides, and genetically modified crops) provide farmers with the opportunity to minimize losses.

Table 5.1. Tillage systems for corn production

➤ Clean till <30% residue
- moldboard plow
- chisel/disk

➤ Conservation till >30% residue
- chisel plow
- disk

➤ Ridge till
- ridge building
- cultivate to maintain ridges

➤ No-till or strip till
- residue managers

Clean Till

Under normal conditions, clean tillage involves inverting the soil so that most of the residue is buried. Moldboard plowing followed by pre-plant disking is a common clean-till procedure (fig. 5.1).

Because crop residue is mostly buried, the soil surface is exposed to wind and rain, increasing the potential for erosion and loss of soil moisture. Of the tillage systems that will be discussed in this chapter, clean tillage carries the greatest potential for soil loss due to wind and water erosion (Table 5.2). Although erosion can be reduced by plowing in the spring, clean tillage still has a greater potential for erosion compared to conservation-tillage systems.

Clean tillage may be best suited for bottomland or poorly drained soils because it speeds soil heating and reduces soil water content. However, moldboard plowing can result in a plow pan that can restrict root growth. The use of deep rippers to overcome a plow-pan problem will provide only temporary relief.

Compaction can also be caused by grain wagons, combines, and trucks driving across the field. To minimize compaction, field traffic should be minimized. Excessive tillage can reduce soil water and can increase soil crusting and compaction. Due to erosion and compaction risks, moldboard plowing or excessive tillage is not considered a best management practice (BMP) for most crops in South Dakota.

Figure 5.1. Moldboard plowing wheat stubble in South Dakota

(Photo courtesy of Howard J. Woodard, South Dakota State University)

Table 5.2. Advantages and disadvantages of clean till

ADVANTAGES	DISADVANTAGES
Suited to most soils.	Erosion potential.
Well-tilled seedbed.	Compaction.
Pest control.	Fuel and labor costs.
Quick soil warm-up.	Soil moisture loss.
Mixes nutrients.	Reduced infiltration.

Conservation Tillage

Conservation-tillage systems leave at least 30% crop residue on the surface (Table 5.3). There are a number of implements that can be used in conservation tillage. The most common conservation-tillage systems are spring disking and chisel plowing (fig. 5.2).

Increasing the residue on the soil surface decreases the potential for erosion and soil water loss. Residue creates a barrier between the soil and the forces that cause erosion and soil water loss (i.e., wind, rain, and radiant heat energy from the sun). The amount of residue on the soil surface is directly related to evaporative water loss, available water, and the length of time needed for the soil to warm. Residue cover is indirectly related to the erosion potential. The amount of residue remaining on the soil surface can be increased by the following:

- Including a high-residue-producing crop in the rotation.
- Conducting tillage operations in the spring.
- Reducing the number of tillage passes.
- Using cover crops.
- Driving slower during tillage.
- Setting chisels and disks to work shallower.
- Using straight shanks and sweeps.

Figure 5.2. Chisel plowing wheat stubble

(Photo courtesy of USDA-NRCS)

Table 5.3. Advantages and disadvantages of conservation till

ADVANTAGES	DISADVANTAGES
Reduced erosion. Reduced cost. Mixes nutrients. Reduced water loss. Improved infiltration. Increased snow catch.	Stalk chopping may be necessary. Compaction (if disked in wet conditions). Delayed planting (if too wet).

Ridge Tillage

Ridge tillage is a conservation-tillage system where crops are grown on permanent beds (or "ridges") (fig. 5.3). With ridge tillage, the planter must be able to cut residue, penetrate the soil to the desired depth, and in many situations clear the ridge of the previous year's crop residue (stalks and root-balls). Following planting, cultivators are used to control weeds and rebuild and shape the ridges. Ridge tillage is well suited to relatively flat landscapes and is often furrow irrigated in arid climates.

In ridge tillage, crop residue and organic matter tend to accumulate between the ridges. If mechanical cultivation and ridge building take place during the growing season, these materials are generally mixed in the upper portion of the profile. Relative to clean tillage, ridge tillage will increase water infiltration and reduce runoff (Table 5.4). Nitrogen (N) leaching can be reduced by banding fertilizer into the ridge. Herbicides may be applied to the ridge, with cultivation used for between-row weed control. Two disadvantages of ridge tillage: 1) Specially designed equipment is needed. 2) Many view ridge-tillage as labor intensive.

In ridge tillage, it is recommended that soil samples for nutrient analysis be collected halfway between

Figure 5.3. Planting corn in a ridge-tillage system

(Photo courtesy of Keith Alverson, South Dakota corn producer)

Table 5.4. Advantages and disadvantages of ridge till

ADVANTAGES	DISADVANTAGES
Reduced erosion. Saves water. Lower fuel costs. Increased snow catch.	Light soils may crust. Not well suited to all rotations (alfalfa or small grains). Must have equal wheel spacing on all equipment and must have narrower tires.

the center of the row and the crop row. When applying fertilizers into the ridge, care should be taken to minimize direct contact with the seed. For sandy soils, the amount of N plus K_2O applied with the seed should not exceed 5 pounds per acre. This limit increases to 10 pounds per acre for fine-textured (clay) soils. The effectiveness of phosphorous (P) and potassium (K) applications is often improved by banding.

Strip Till

Strip till is a conservation tillage system where the seedbed (8 to 10" wide) is tilled and cleared of residue (fig. 5.4). Strip-till systems prepare a seedbed that is relatively free of residue, even in corn-following-corn situations. The spreading of residue at harvest can reduce residue interference at planting. Strip tillage may be conducted in the fall or spring. Spring strip till uses a tillage tool that tills strips ahead of planter seed openers. If strips are tilled prior to planting in a separate operation, it can be challenging to consistently follow the strip with the planter. If strips are tilled in a separate operation from planting, it is recommended to track the direction of travel of the tillage implement, following the same direction with the planter. Strip-tilled fields tend to warm faster than no-till fields.

Figure 5.4. Strip-tilled corn in South Dakota

(Photo courtesy of Dwayne Beck, South Dakota State University)

Table 5.5. Advantages and disadvantages of strip till

ADVANTAGES	DISADVANTAGES
Reduces soil erosion and runoff. Saves moisture. Reduced compaction. Increased snow catch.	Specialized equipment needed. Greater reliance on herbicides. Potential for disease and insect outbreaks. Reduced crop residue interference.

Strip tillage does not eliminate erosion, and following rainfall, erosion can occur down the strip (Table 5.5). Contour strip tillage should be considered in high-slope situations. In some strip-till systems, when strips are tilled in the fall or spring, fertilizer is applied in a band. Failing to follow the strips with the planter can affect fertilizer placement with respect to the seed. If P or K fertilizers are needed, they can be fall banded into the strips. As with any tillage system, N fertilizer should not be fall-applied until soil temperatures are below 50°F. Starter fertilizer can be used; however, the total amount of N + K_2O applied in contact with the seed should not exceed 5 pounds in a sandy soil and 10 pounds in fine-textured soils. Many producers have problems when attempting to plant into fall-created strips in rolling terrain. If the seed row is either too close or too far away from the fertilizer band, early growth can be compromised.

No-Till

Of the tillage systems discussed, properly managed no-till systems leave the most residue on the soil surface (fig. 5.5). Compared to other systems, no-tilled fields retain the most moisture, have the highest infiltration rates, and have the lowest erosion potentials (Table 5.6). The effects of no-tillage on erosion are attributed to increased water infiltration and reduced runoff. Considering the potential conservation and production benefits, no-tillage should be strongly considered by South Dakota producers.

In South Dakota, no-till systems have allowed for row crop production in the western regions. This expansion is the result of reduced soil water loss (compared with conventional-tilled systems). A consequence of no-tillage is reduced organic matter mineralization and higher water infiltration rates. Increased infiltration is thought to result from macropore development, as old root channels and earthworm trails are not disturbed by tillage. Increase N-fertilization rates are recommended (+30lbs. N/A) to overcome reduced soil organic matter mineralization rates.

No-till systems require optimization of planting and residue-management systems. Residue management begins at harvest, leaving as much residue in place as possible. Using stripper headers during grain harvesting both allows straw to remain upright and attached and prevents residue from being moved by wind or water. In corn this is accomplished by adjusting the strippers and rolls to keep the stalk intact and upright. Uniform chaff spreading is particularly difficult when using large headers. Straw and plant stems that are chopped into small pieces are difficult to distribute uniformly and have a tendency to be moved into piles by wind or water.

When planting in no-till systems, residue managers work best in situations where residue is uniform; when residue is not uniform, it is almost impossible to properly adjust residue managers on the planter. Moving residue is easier if it is cut before moving it. Single-disc fertilizer openers placed at the same depth and 2 to 3 inches to the side of the seed opener path can serve a dual purpose: cutting residue and placing the side-band fertilizer. When compared to conservation tillage, no-till soils generally remain cooler in the spring. Cooler soil temperatures can slow N and sulfur (S) mineralization. Placing nutrients like N and S as a side-band improves early season plant vigor.

The planter is the most important implement in a no-till system (fig. 5.6). Seed germination is improved when the seed is covered with loose material and firmly planted at the right depth in warm, moist soil. The basic corn planter was designed for use in well-tilled seedbeds. Consequently, modifications are needed to assure optimal seed placement. Almost all row-crop planters have openers that utilize 2 discs to open the seed slot. The seed-opener discs are often arranged so that the blades touch evenly at the front and have discs of equal size. Some manufacturers offset these discs so that one disc leads the other. Wiper/depth wheels can limit the problem of mud being brought to the surface and interfering with seed opener depth wheels. South American openers use offset double-disc openers with discs of different sizes; this design results in a differing angular momentum between the blades that is thought to improve the slicing action. All disc openers require sharp blades; if they are not sharp, the residue can be pushed (hair-pinned) into the trench, resulting in uneven germination and growth. Hair-pinning is worse when residue is cut into short lengths and soil structure is poor. Continuous, long-term no-till systems have less of a problem with this issue.

Once the seed is placed into the trench, it needs to be pressed into the soil and covered. In no-tillage systems, the best method is to separate the firming (seed pressing) and covering operations. Several companies make devices designed to press or lock the seed into the bottom of the trench. This speeds

Figure 5.5. No-till corn in South Dakota

(Photo courtesy of Howard J. Woodard, South Dakota State University)

Table 5.6. Advantages and disadvantages of no-till

ADVANTAGES	DISADVANTAGES
Greatly reduces soil erosion and runoff. Saves moisture. Lower fuel costs. Reduced compaction. Increased snow catch.	Specialized equipment needed. Greater reliance on herbicides. Slower spring soil warm-up and drying. Nutrient stratification. Potential for disease and insect outbreaks.

Figure 5.6. Planting corn in a no-till system

(Photo courtesy of Howard J. Woodard, South Dakota State University)

the rate at which the seed imbibes water and anchors it to the bottom of the trench. The lack of root penetration is often blamed on "sidewall" compaction, which can be traced to a poorly anchored seed. There are several companies that make aftermarket devices designed to press the seed into the bottom of the trench. In general, vertical wheels work better in most conditions; however, vertical wheels are more expensive and harder to mount than the type that uses a sliding piece of plastic.

Once the seed is firmly pressed into the bottom of the trench, the seed needs to be covered. Standard closing systems on corn planters are designed to work in tilled seedbeds by packing the area under and around the seed, while leaving loose material above the seed. Standard rubber or cast-iron closing systems normally do not function well in no-till systems because they have difficulty properly closing the trench in well-structured or wet soils. If the soil over the seed is packed too firmly, the corn plant may set its growing point too shallow; this makes the plant prone to damage from herbicides and late frosts. If the soil covering the seed is too loose, the seed trench may dry too fast, leading to stand loss. Many companies (e.g., Martin®, May-Wes®, Exapta®, Yetter®) make attachments designed to loosen the soil in the seed trench and place it over the seed. One reason that strip till may appear superior to no-till is that seed is planted into loose soil created by the strip-tillage operation, which allows for optimal operation of standard closing wheels.

Other attachments needed for conversion of a standard planter to a no-till planter are fertilizer openers and residue managers. The best fertilizer opener designs are single-disc openers with a depth-gauging and/or wiping wheel. These openers cut the residue and place fertilizer 2 to 3 inches to the side of the seed. In fine-textured soils, most of the N and P can be band-applied using this approach. However, in irrigated or sandy fields, limit N applied to one-third to one-half of the seasonal N requirement.

Using residue managers that cut residue before it is moved and replacing wide-depth wheels with narrow-depth wheels reduces the likelihood of planter plugging in heavy residue. Using a residue manager with a backswept design helps keep residue from wrapping. Cutting the residue allows the residue managers to split the mat of residue without tearing it apart, which is especially important under damp conditions. Cutting residue reduces soil disturbance because residue managers do not have to engage the soil, reducing problems with surface sealing or crusting, weed growth, and erosion.

There are many designs of residue managers. Test the ease of adjustment prior to selecting a residue manager. The bottom line with no-till seeding equipment is that it needs to work effectively. No-till systems are becoming increasingly popular. Additional information is available at www.sdnotill.com and at www.dakotalakes.com.

Compaction

Soil compaction decreases drainage and aeration, increases the potential for runoff and erosion, and can restrict root development. Wheel traffic and tillage can reduce pore space by crushing pores and by reducing pore size. Compaction can be most severe in wet clay soils. Tillage, especially moldboard plowing and disking, can lead to the development of a plow layer or plow pan (fig. 5.7).

Compaction caused by combines, grain wagons, trucks, and other equipment can cause problems in any system. To minimize yield losses due to compaction, field traffic lanes should be used and grain wagons and trucks should be left on the edges of the field. Once compaction occurs, it is very difficult to reverse.

Figure 5.7. Compaction created by a tandem disc

(Photo courtesy of Thomas E. Schumacher, South Dakota State University)

Deep tillage and incorporating deep-rooted crops can be used to remediate compaction problems. Deep tillage is most effective when soil is dry; however, deep tillage only provides a temporary reprieve. The best approach for managing compaction is to avoid unnecessary tillage and traffic, include deep-rooted crops in the rotation, outfit equipment with wide tires, reduce tire pressures, and leave grain carts and trucks at the edge of the field when harvesting.

Rotations

Weed, disease, and insect management can present challenges in all tillage systems. However, weeds that can be controlled with tillage in tilled systems must be controlled with herbicides in no-till systems. Corn-following-corn in no-till systems may be susceptible to disease and insect pressure because some of the pests may overwinter in last year's residues. These challenges can be addressed by using appropriate rotations. The use of genetically modified corn is helping to resolve weed and insect problems. A crop rotation is a sequence of crops planted year after year on the same piece of ground. Carefully planned crop rotations can help overcome compaction, disease problems, and weed species shifts. "Rules of thumb" for selecting rotation sequences are listed in Table 5.7.

Crop rotation and tillage need to be considered at the same time. Designing appropriate crop rotations is a mix of art and science. For any given situation, there will be a range of rotations that will be agronomically appropriate. Within this range there are rotations that have different characteristics in terms of risk (e.g., market availability, labor or machinery requirements, and other considerations specific to individual farming practices).

Management decisions must consider many different types of information. For example, potential yields and profitability must be considered when determining the rotational sequence. Many producers are considering increasing the amount of corn in the rotation. This decision should be based on the short- and long-term effects on profitability. There are several additional factors that should be considered when making this decision. First, there is a yield drag of about 5 to 15% for second-year corn relative to first-year corn (Duffy and Correll 2007). The greatest yield drags are typically measured between first- and second-year corn but can also be high when weather is unfavorable. Yield drags generally stabilize after third-year corn. Second, more N is needed following corn than soybean. The N-fertilizer recommendation for the crop following a soybean crop is reduced by the legume credit (40lb. N/acre), and this may be a substantial monetary saving compared to buying fertilizer. Third, soybeans generally yield more (5 to 8% more) when following 2 or more years of corn. Fourth, continuous corn can increase pest problems.

In the far southeast portion of South Dakota, corn yield is less likely to be reduced by water stress and is more likely to be reduced by disease and pest problems. Going from south to north increases the importance of soil temperature. Corn following a low-residue crop will experience warmer soil temperatures earlier than when following a high-residue crop such as corn. Water becomes more limiting as one travels from east to west.

In semi-arid climates, efficient water use is critical. Cropping more frequently with high water-use crops increases the cropping system intensity. Barley, winter wheat, field peas, and canola are low water-

Table 5.7. "Rules of thumb" for selecting a rotation sequence

- Grow only the crops that are suitable for your soil and climatic conditions.
- Understand the market conditions for your crops.
- To reduce pest problems, the same crop should not be grown in consecutive years.
- Select a rotation that minimizes pest problems.
- High-residue crops should be included in the rotation to store carbon.
- Estimate your cost of production and expected returns. Cost of production and expected returns can be estimated with a Web-based worksheet located at http://www.extension.iastate.edu/agdm/crops/xls/a1-20croprotation.xls.

use crops, while corn, soybean, and alfalfa are high water-use crops. Additional details for scoring water use and cropping intensity are available at http://www.dakotalakes.com/Publications/Div_Int_FS_pg6.pdf.

Increasing the crop-rotation diversity can improve the functioning of the agro-ecosystem (Table 5.8). When considering diversity, rotational crops need to compliment each other as much as possible to prevent problems with labor, equipment, disease, weed, and insects. Diversity increases by including as wide a variety of crop types as possible. Many commonly grown crops can be grouped:

- **Cool-season grass:** spring wheat, winter wheat, barley, durum wheat, oat, and winter rye.
- **Warm-season grass:** corn, sorghum, sudangrass, and millet.
- **Warm- and cool-season broadleafs:** field pea, lentil, canola, mustard, crambe, flax, safflower, chickpea, sugar beet, sunflower, dry edible, bean, soybean, and alfalfa.

Information for scoring rotational diversity is available at http://www.dakotalakes.com. When selecting a crop rotation, it is important to avoid potential conflicts between the seeding and harvest times of different crops (e.g., trying to seed one crop when harvesting another, or harvesting more than one crop at a time).

Table 5.8. "Rules of thumb" for increasing diversity in semi-arid regions of South Dakota

- Use soil survey information to evaluate soil water storage. Determine the appropriate cropping intensity based on this information.
- Manage crop residues to facilitate soil water storage.
- Manage crop nutrients to ensure strong crop competition with weeds and to achieve crop yield goals.
- Utilize legume crops and animal manure to increase energy efficiency and improve soil quality.
- Adopt techniques that minimize wind and water erosion.
- Anticipate the equipment and/or labor requirements for growing new crops.
- Cover crops can be used to increase crop rotation intensity and diversity.
- Perennial crops such as grass or alfalfa provide excellent weed suppression in a rotation, particularly if the crop following them is planted no-till with minimal soil disturbance.
- Consider the marketability of the commodity prior to planting a crop.

Cover crops

Typically planted during the summer or late summer to early fall, cover crops help reduce erosion and nutrient loss, and increase carbon storage (Table 5.9). Cover crops can provide forage for fall and winter grazing, but it is unlikely that a marketable commodity will be produced. Selecting a cover crop species or mix of species that germinates, emerges, and quickly establishes is essential to success. Equally important for the cover crop is the ability to cope with adverse growing conditions, while also being easy to kill before the commodity crop is seeded. Prior to planting cover crops, it is important to consider the following:

Table 5.9. Primary benefits of cover crops

- Improved soil quality
- Reduced erosion
- Improved carbon storage
- Reduced losses of nutrients
- Improved pest management

- The effect of the cover crop on water availability. In wet areas, cover crops can be used to reduce soil water content.
- The likelihood of cover crop establishment, considering growing season limitations.
- The cost of seeding and killing the cover crop.
- Establishment of a cover crop in dry or high-salt soils.
- The likelihood of the cover crop acting as a weed or harboring insects, diseases, and other pests.

The above concerns must be weighed against the benefits of improved soil health, reduced erosion, reduced nutrient loss, and improved insect and plant diversity.

Like any other crop, a cover crop will use water from the soil profile. In South Dakota, cover crops are most effective following a small-grain crop that is harvested early enough to allow for cover crop establishment. The difficulty of establishing cover crops following wheat or pea harvest is that there may not be sufficient levels of soil moisture to germinate seed and support crop establishment. Cover crop water use is usually not an issue unless a winter crop such as winter wheat is planned to follow and water is limiting. If a spring-seeded crop is planned, a cover crop can increase available water by acting as a snow catch.

Maximizing the return on investment from a cover crop requires paying attention to the cost of seed and killing the crop prior to seeding the commodity crop to follow. Cover crops can consist of a single species but are often a mix of several species. For example, a mix of oats, turnips, and radishes provides effective cover and grazing forage and reduces soil compaction. A legume blend including cowpeas, soybeans, annual sweetclover, and medic is an option that can add N as well as organic matter. Non-legume crops such as sorghum-sudangrass, millet, forage sorghum, or buckwheat produce more biomass, providing improved weed competition and soil tilth.

In many areas, high salts can limit seed germination and successful establishment. If soluble salts are not an issue, species selection is more flexible and may include clovers, medic, hairy vetch, dry bean, peas, wheat, rye, oats, turnips, radishes, and buckwheat. Species become more limited as soluble salt levels in the soil increase. For slightly saline soils, a mixture may include canola, lentils, and sugar beets; in 2007, the seeding cost for these crops was estimated at $9.30/acre. For moderately saline soils, a mixture may include sugar beets and barley; the estimated seeding cost for this group of crops was $6.30/acre in 2007. Strongly saline soils require crops that are more salt-tolerant, such as tall wheatgrass and barley; the seeding cost for this crop group was approximately $5.00/acre in 2007.

Planting cover crops in the northern Great Plains presents a number of challenges. Short growing seasons when planting follows fall harvest provides little time for establishment. Sowing in the spring is hampered by wet soils, cold conditions, and a short time to plant the primary crop. Integrating cover crops into cropping systems presents a number of benefits but requires additional management and investment. Cover crops should be planted as soon as possible, due to the short amount of time available for establishment. Considering the short growing period, seed production is unlikely and annuals in the cover crop will be killed by frost. Species that survive winter or cover crops sown before seeding a winter crop will need to be killed with tillage or herbicide, increasing the initial investment.

Depending on regional climate and cropping system, a cover crop may not be feasible every year. Opportunities for cover crops exist largely in systems where early harvested small grains are followed with corn, soybeans, or other spring-seeded crops. Many questions—regarding water, nutrient, and carbon cycling—associated with cover crops currently remain unanswered. Further study of these phenomena is required to develop refined recommendations. Characteristics of many potential cover crop species are shown in Table 5.10.

Table 5.10. Cover crops – common species and properties						
Species	**Erosion Reduction**	**Biological N Fixation**	**Supplemental Grazing**	**Reduce Soil Compaction**	**†Crop Type**	**Salt Tolerance**
Alsike Clover	Good	Yes	Fair	Good	CB	Poor
Annual Ryegrass	Fair	No	Good	Poor	CG	Fair
Barley	Good	No	Fair	Fair	CG	Good
Buckwheat	Good	No	Poor	Poor	WB	Poor
Canola	Fair	No	Fair	Good	CB	Good
Chickling Vetch	Good	Yes	Fair	Fair	CB	Poor
Cowpea	Poor	Yes	Fair	Fair	WB	Poor
Grain/Forage Sorghum	Good	No	Fair	Good	WG	Fair
Hairy Vetch	Good	Yes	Fair	Fair	CB	Poor
Lentil	Poor	Yes	Fair	Poor	CB	Poor
Millet	Good	No	Fair	Fair	WG	Poor
Mustard, Oriental/Brown	Fair	No	Fair	Fair	CB	Poor
Mustard, Tame Yellow	Fair	No	Fair	Fair	CB	Poor
Oat	Good	No	Fair	Fair	CG	Fair
Pea	Poor	Yes	Fair	Poor	CB	Poor
Radish	Poor	No	Good	Good	CB	Poor
Red Clover	Good	Yes	Fair	Poor	CB	Poor
Spring Rye or S. Wheat	Good	No	Fair	Fair	CG	Fair
Sugarbeet	Poor	No	Good	Good	CB	Good
Sunflower	Fair	No	Good	Fair	WB	Fair
Sweet Clover	Good	Yes	Fair	Fair	CB	Fair
Tall Wheatgrass	Good	No	Good	Fair	CG	Good
Turnip	Poor	No	Good	Good	CB	Poor
White Clover	Good	Yes	Fair	Poor	CB	Poor
Winter Rye or W. Wheat	Good	No	Fair	Fair	CG	Good
†Crop Type	CB	Cool-Season Broadleaf				
	WB	Warm-Season Broadleaf				
	CG	Cool-Season Grass				
	WG	Warm-Season Grass				

Adapted from USDA-NRCS, Cover Crop (Code 340), April 2008, Section IV, South Dakota Field Office Technical Guide.
Available online at eFOTG: http://efotg.nrcs.usda.gov/references/public/SD/SD340.

Additional Information and References

Dakotalakes.com. 2005. South Dakota State University, Dakota Lakes Research Farm. http://www.dakotalakes.com/.

Duffy, M. and D. Correll. 2007. The economics of corn on corn. Integrated Crop Management. IC-498. http://www.ipm.iastate.edu/ipm/icm/2007/2-12/economics.html.

Beck, D.L., D.E. Clay, and K.D. Reitsma. 2009. "Tillage, crop rotations, and cover crops." Pp. 21–30. In Clay, D.E., K.D. Reitsma, and S.A, Clay (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

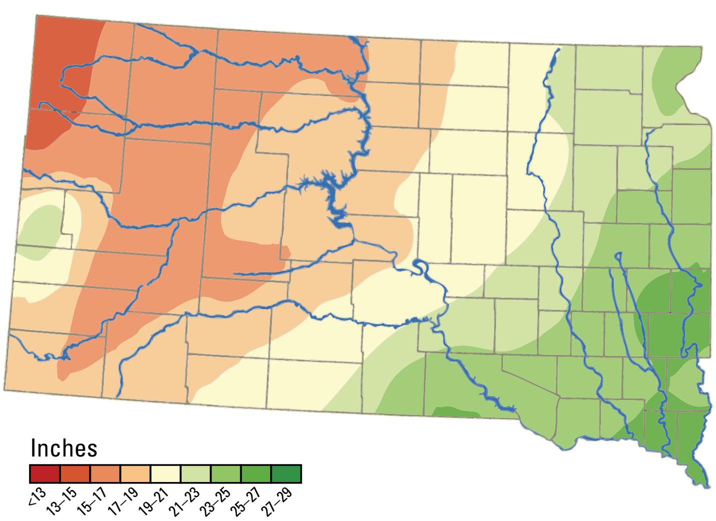
CHAPTER 6
Irrigation and Salt Management

In South Dakota, average annual precipitation ranges from less than 13 inches to nearly 30 inches, generally increasing from west to east (fig. 6.1). However, all regions of South Dakota can experience drought. Irrigation can reduce a crop's dependence on natural rainfall and improve yields. To best capitalize on investment in irrigation equipment, it has been suggested that one should increase plant populations on irrigated land by 2,000 to 3,000 plants per acre (Aldrich et al. 1975). This chapter discusses how much irrigation water to apply and how to manage the salts contained in the water. If you are planning a new system or expanding an existing system, equipment and management options should be discussed with your local irrigation equipment dealer or Extension educator. A permit may be required to irrigate in South Dakota. For permit requirements, contact the South Dakota Department of Environment and Natural Resources (DENR).

Soil-Water-Plant Relations

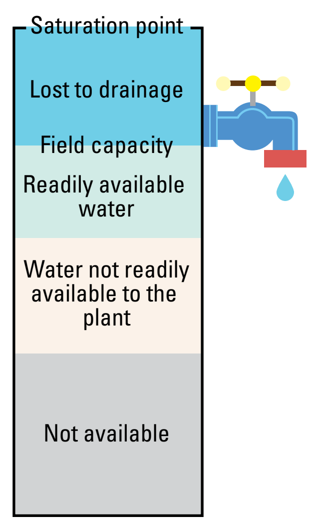
The amount of water retained and available for plant growth from the soil is dependent on the soil texture and organic matter content. Soil serves as a water storage reservoir for the plant, though not all soil water is available to the plant (fig. 6.2).

Figure 6.1. Average annual precipitation (in inches) in South Dakota, 1977–2006



(Courtesy of Kurtis D. Reitsma, South Dakota State University)

Figure 6.2. Soil water availability as related to saturation, field capacity, and permanent wilting point



(Courtesy of Todd Trooien, South Dakota State University)

Soil's water-holding properties are similar to a sponge: when a sponge is placed in a bucket of water, all the pores in the sponge are filled to the saturation point with water; when the saturated sponge is removed from the bucket, some of the water freely drains out of the sponge. When at its maximum water-holding capacity, soil is referred to as "saturated." After water has drained freely from the soil, the soil water content reaches "field capacity" (fig. 6.2). Water content can continue to decrease through plant uptake and evaporation until "permanent wilting point" is reached. Water held by the soil between field capacity and permanent wilting point is called "plant-available water" and varies by soil texture (Table 6.1).

Table 6.1. Ranges of plant-available water for different soil textures

Soil texture	Plant-available water (inch/ft. soil)
Fine sands	0.7–1.0
Loamy sands	0.9–1.5
Sandy loams	1.3–1.8
Loam	1.8–2.5
Silt loams	1.8–2.6
Clay loam	1.8–2.5
Clay	1.8–2.4

As soil dries and approaches permanent wilting point, the remaining water becomes more difficult for the plant roots to absorb. Corn is most susceptible to water stress when plant-available soil water is 50% or less. To maximize productivity, irrigation water should be applied to maintain water content between 50 to 100% of field capacity through the R3 growth stage. Usually, irrigation can cease by Aug. 15, but this date can vary depending on the growing season and region.

To be most effective, water must be applied to the zone containing a majority of the corn roots. Early in the growing season, the roots may be concentrated in the surface 12 inches. As the season progresses, roots can extend down to 5 feet. Most of the roots, however, are found in the surface 3 feet. Therefore, unless local knowledge or experience suggests otherwise, schedule irrigation according to the soil water content in the surface 3 feet.

The relative amount of water lost to transpiration (water lost from leaves to air) and evaporation (water lost from soil to air) changes during the year. At planting, evaporation is the most important water-loss mechanism; however, at corn tasseling, the major water-loss mechanism is transpiration.

Irrigation Scheduling

"Irrigation scheduling" is the process of predicting the amount and timing of the next irrigation. The amount of water applied at the next irrigation may be determined by irrigator preference, by timing, by amount of water contained in the soil, by soil characteristics, and by equipment capacity. When scheduling irrigation, it is important to realize that heavy irrigations (saturating at least the top 2 feet of soil) are typically more effective and take less time than several light irrigations. Wetting the soil to deeper depths also promotes deeper root development; light irrigations promote shallow rooting, which may lead to nutrient deficiency or lodging problems later in the season. The most widely used approach for irrigation scheduling is called the "Checkbook Approach" (Werner 1993). Whether using the Checkbook Approach or another method, soil water content should occasionally be measured.

The Checkbook Approach for Estimating Soil Water

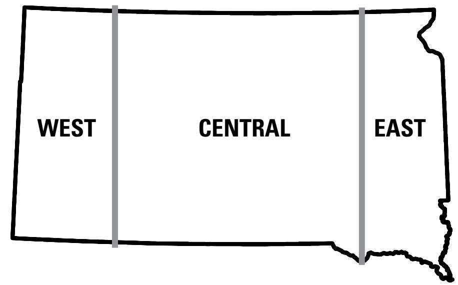
The Checkbook Approach is often called the "Water Balance Method." This method adds water received from rainfall and irrigation to the water balance and subtracts evapotranspiration (ET). To maximize productivity, the field should be irrigated before readily available water has been depleted. Detailed information for this approach is available at http://agbiopubs.sdstate.edu/articles/EC897.pdf. The Checkbook Approach utilizes the following tools:

- a rain gauge to measure rainfall and irrigation
- estimated ET figures
- soil moisture balance worksheets
- soil water content measurements (to validate checkbook balances)

Evapotranspiration, which is the loss of water from both evaporation and transpiration, is calculated using weather data (i.e., temperature, wind, and relative humidity) and crop information. Values of ET vary by climate across South Dakota (fig. 6.3 and Table 6.2). Daily values of corn ET are published on the South Dakota State Climatologist's website (http://climate.sdstate.edu/awdn/et/et.asp); if you are located close to a weather station, these are the most accurate estimates of ET. If a weather station is not located near your farm, ET can be estimated by measuring evaporation with an instrument known as an "atmometer" (Broner 1993).

For irrigation planning, South Dakota can be split into regions: West, Central, and East (fig. 6.3). Daily water-use estimates are used to calculate water use over the season (Table 6.3). For example, to estimate irrigation requirements, daily water-use values are summed and compared with your field's expected rainfall estimates (Table 6.2). The difference between daily water use and expected rainfall is the "irrigation potential" (examples of this calculation are presented in Table 6.3).

Figure 6.3. Evapotranspiration (ET) regions of South Dakota



(Courtesy of Todd Trooien, South Dakota State University)

Table 6.2. Estimated corn water use per day in South Dakota

Weeks after emergence	Western region			Central region			Eastern region		
	---------Maximum temperature °F---------								
	50–59	70–79	90–99	50–59	70–79	90–99	50–59	70–79	90–99
	----------Inches of water used/day----------								
1	0.02	0.04	0.07	0.02	0.04	0.07	0.02	0.04	0.06
3	0.03	0.06	0.09	0.03	0.05	0.09	0.02	0.05	0.08
5	0.05	0.1	0.17	0.05	0.1	0.17	0.04	0.09	0.15
7	0.08	0.16	0.27	0.08	0.16	0.27	0.07	0.15	0.23
9	0.1	0.2	0.33	0.1	0.19	0.34	0.09	0.18	0.29
11	0.1	0.22	0.35	0.1	0.21	0.36	0.09	0.2	0.31
13	0.1	0.2	0.32	0.1	0.19	0.33	0.09	0.18	0.29
15	0.07	0.15	0.25	0.07	0.15	0.26	0.07	0.14	0.22
17	0.05	0.11	0.17	0.05	0.1	0.18	0.05	0.1	0.15

(Modified from Werner 1993)

Table 6.3. Examples of estimating seasonal and future water use

A. Seasonal water use

In eastern South Dakota, when temperatures reach 90 to 99°F, seasonal crop water use is about 24.1 inches. At Brookings, the 30-year average precipitation during the growing season (May through Aug.) is 16 inches. Available water for the surface 3 feet of a silt loam soil is 6 inches. Readily available water is one-half of the available water, or 3 inches. Thus, 19 inches of water (16 inches + 3 inches) is available to the crop in an average year. The irrigation or precipitation needed to maximize yield is the difference between these values (crop water use minus available water): 24.1 – 19 = 5.1 inches.

B. Future water use

What is the potential water use next week (11 weeks after emergence) in the central region of state if the temperature is 85°F?

7 days x 0.21 inch/day = 1.47 inch

For the Checkbook Approach, rainfall should be measured at your location. The total (gross) rainfall should not be entered into the checkbook irrigation schedule; instead, use "effective rainfall," which is the amount of rain that actually soaked into the soil and is available to the crop. The effective rainfall is usually less than the measured rainfall.

Soil Water Measurement

Checkbook balances should be periodically checked against measured soil water content. Soil water status can be 1) estimated by the "hand-feel" method, 2) measured from soil samples by calculating the gravimetric water content, or 3) monitored with sensors.

1. The hand-feel method is fast and inexpensive. It involves "feeling" a soil of known water content and comparing that to a soil with unknown water content; available water is estimated by how the soil "feels" in your hand. Note that a "same" amount of available water for different soil textures will "feel" different, so you need to "calibrate" your feel to the different soil textures that are found in your fields. Obviously, hand-feeling is the least accurate method, but it can be effective with some practice.

2. Gravimetric water content is measured by collecting samples and calculating the weight difference between wet and oven-dried samples. Samples can be dried in a microwave oven using procedures detailed in Schneekloth et al. (2007). Drying with a microwave oven is much quicker than drying with a conventional oven and can provide moisture percentage estimates within an hour of collecting the sample. The percent moisture is calculated with the following equation:

$$\%\text{moisture} = \frac{(\text{wet weight soil} - \text{dry weight soil})}{\text{dry weight of soil.}} \times 100\%$$

3. Soil water content or status can also be measured with sensors placed in the soil. Two commonly used sensors are gypsum and granular matrix blocks (e.g., WaterMark®). For irrigation scheduling, sensors should be placed at multiple depths (6", 18", and 30") at both the start and endpoint of the irrigation system. When placing a soil moisture sensor, push a soil probe into the soil to the desired depth. With soil from that depth, make a thin slurry with soil and water, insert the sensor into the hole, and pour the slurry into the hole. The slurry will help ensure good contact between the soil and the sensor.

Another way to look at soil water is to consider "soil water depletion." Soil water depletion is the amount of water required to bring the root zone back to field capacity. When the soil is at field capacity, depletion is zero. Optimal irrigation efficiency is realized when irrigation water is applied in the amount equal to depletion. Runoff and deep drainage can result when water is applied in excess of depletion. Excess irrigation water application not only diminishes irrigation efficiency but also can result in nutrient and pesticide losses from runoff and leaching.

Critical Plant Growth Stages

Adequate soil moisture is needed for germination; therefore, if the soil is dry, irrigation may be needed to improve germination and seedling vigor. As the crop develops, moist soil is needed for root development. Check your fields by probing to ensure that there are layers of dry soil in the profile. Irrigation may be needed earlier than expected to wet deeper soil layers. Most irrigation systems cannot keep up with crop water demands during the later critical growth periods (VT to R3) (Werner 1993); therefore, planning is needed (Table 6.2). The first priority for irrigation should be a 3-week period starting just before tassel (VT) and ending just after silking.

Corn is less susceptible to water stress during later grain-development stages (R3). Soil water levels should be maintained to allow the crop to reach maturity (R6) but can be allowed to approach 70% depletion at this time. Terminating irrigation early does not promote early maturing and dry-down of the grain (Werner 1993).

Many soils contain 2 to 4 inches of water when they reach 60 to 70% depletion. Monitoring soil water content is a good indicator for deciding when to end irrigation. Depleting soil water at the end of the season minimizes the risk of nutrient leaching, allows you to take advantage of any off-season precipitation, and allows for surface-soil drying prior to harvest. Rather than terminating irrigation at a given date, monitor weather forecasts, crop development, and soil moisture.

Irrigation Systems

Commonly used irrigation systems are classified as surface, sprinkler, and micro-irrigation. Surface irrigation systems have been used for millennia. Surface irrigation is inherently non-uniform because the soil surface is used both for water conveyance and for water storage. Water is available to infiltrate into the soil longer at the top of the field, so more water is stored in the soil profile in that area. The uniformity of water distribution can be improved by minimizing the length of run. Short runs reduce the difference of infiltration time between the top and bottom of the field, improving water-distribution uniformity.

An alternative is to optimize the uniformity by increasing the water inflow rate to a maximum, without causing excessive soil erosion at the top of the field. This advances the water as quickly as possible across the field by reducing the difference in infiltration time. Other methods for increasing uniformity include surge irrigation, cutback irrigation, furrow packing (usually for the first irrigation), and the use of polyacrylamide (PAM) soil amendments.

Center pivot is the most popular irrigation method in South Dakota. Center-pivot systems can reduce labor requirements (compared to surface irrigation), increase distribution uniformity and irrigation efficiency (potentially, for the latter), and allow the effective application of fertilizer or pesticides with the irrigation water. With center-pivot systems, nozzles can be placed either on the pipe or at the top of or within the corn canopy.

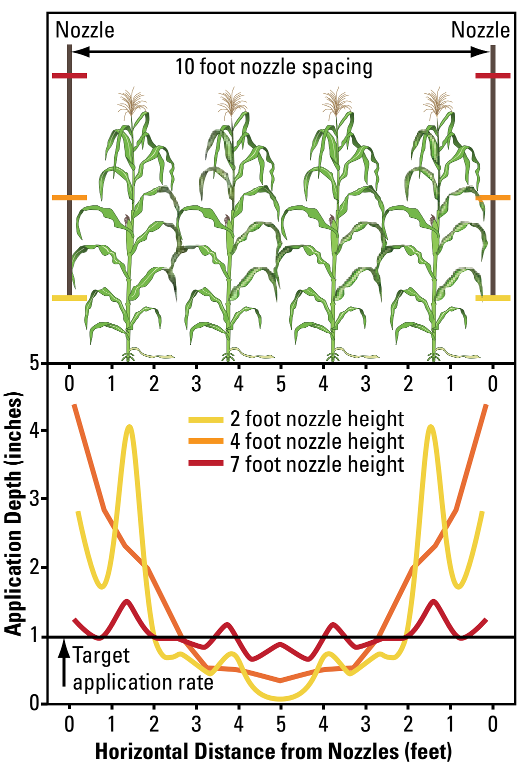
Historically, high-pressure systems had impact sprinklers widely spaced and mounted on the pipe. These systems were effective, but to generate the required operating pressure they required high energy inputs. As pressure inputs have been reduced, nozzle installation elevations have been moved closer to the ground. Drop hoses or pipes can be used to lower the nozzles to just above or even into the crop canopy. Where water supplies are greatly diminished and irrigation systems have limited capacity, nozzles have been installed as low as 2 feet above the soil surface. In some cases the pipe has been covered with a sock that drags on the ground (so that water is applied directly to the soil surface).

High-pressure systems reduce the amount of water that might be lost to wind drift or evaporation; however, losses due to wind drift and evaporation are small (as a percentage of the total amount of water applied). The danger of using low nozzle elevations is that runoff can occur. If you are considering installing nozzles near the soil surface, be sure that your soils have high infiltration rates (>0.25"/hr). In addition, nozzles must be spaced more closely together (approximately 5-feet apart).

Installing nozzles near the top of the mature corn canopy (approximately 7 feet) is a good compromise in many situations. This allows for a wider spread of water from the nozzles while still reducing wind drift and droplet evaporation (fig. 6.4).

Subsurface drip irrigation (SDI) is a type of micro-irrigation system. SDI systems have high water-use efficiency and have been used to irrigate

Figure 6.4. Nozzle placement in the canopy



(Courtesy of Colorado State University)

corn in the central and southern high plains of the United States. A disadvantage with these systems is that they are expensive to install. They are not commonly used in South Dakota but may be an option for areas poorly suited to center-pivot irrigation (e.g., some field shapes, small field sizes, and so on).

Managing Saline (salts) and Sodium Problems

Salts most often interfere with crop water uptake and can reduce yields and crop quality. To prevent salt accumulation in irrigated systems, monitor the salinity (i.e., total salt content—measured as electrical conductivity) and sodium content of water and soil. In addition, salt buildup can be hastened when several low irrigation applications are applied (compared with heavier applications). Yield impacts from salts (salinity) vary greatly with management, soil type, and weather conditions. If salinity problems are suspected, consult with an Extension educator or crop consultant.

Soil and water samples can be collected and analyzed for salts (electrical conductivity) and sodium (Na) content. The interpretation of the laboratory results depends on the laboratory method. Saline (salts) recommendations are based on laboratory tests that measure the electrical conductivity (EC) of the soil. As EC increases, so does the concentration of soluble salts. There are generally two laboratory methods for measuring EC: "saturated paste" and "1:1 soil to solution." The two approaches will not result in the same values. The South Dakota State University Soil Testing Laboratory uses the 1:1 soil to solution ratio approach to assess salt accumulation in soil.

Crops have different salt tolerances (Table 6.4), and salts affect plants differently based on growth stage. During germination, many plants are much more sensitive to salts than at later growth stages. To minimize salt-related germination problems, high-quality irrigation water can be used to leach soluble salts from the surface soil. High temperature, low humidity, and high winds increase evaporation and make the plant more susceptible to salinity problems, with symptoms appearing similar to water stress. High humidity benefits salt-sensitive crops more than salt-tolerant plants. High temperatures decrease any plant's ability to tolerate salt.

In dryland situations, salt problems most often occur in the low areas of fields. The most important management consideration for these areas is maximizing transpiration and minimizing evaporation (Franzen 2007). Salts can be managed in these fields in the following manners:

- Testing the salinity level and planting salt-tolerant crops.
- Using shallow tillage to minimize the mixing of surface and subsurface soils with high salt contents.
- Scheduling seeding when salt levels are low (spring).
- Minimizing salt accumulation by including deep-rooted long-season plants in the rotation. Late-maturing plants are beneficial because they mulch the soil, thus reducing the potential for surface evaporation. In addition, late-maturing plants reduce the potential for the capillary movement of salts to the surface.

Salt problems often occur in soils with poor internal drainage. Layers of low permeability restrict the flow of water "out the bottom" more slowly than evapotranspiration removes water from the upper profile. To avoid the accumulation of salts in irrigated situations, the soil must have adequate drainage capacity, even if your water quality is relatively good. Water must move freely through the soil, leave the root zone, and carry with it some salts. Without adequate drainage capacity, salts will build up over time and cause problems. In poorly drained situations, select salt-tolerant crops and/or install artificial drainage to remove excess water and salts from permeable soils. County, district, federal, or state drainage laws may apply to artificial drainage systems.

Table 6.4. Comparison of different approaches for assessing soil salinity problems

Crop	Threshold salinity 1:1 ratio	Threshold salinity Saturated paste	Saturated paste at 70% yield loss
	------------dS/m-----------		
Corn	1.3	1.7	4.2
Alfalfa	1.4	2.0	6.1
Soybean	2.4	5.0	6.5
Wheat	2.8	6.0	10.2

(Courtesy of Franzen 2007)

Salt accumulation in the soil profile can also be managed by applying extra water to leach the salts from the soil profile. The amount of water needed is referred to as the “leaching requirement” (LR).

$$LR = \frac{\text{Irrigation Water EC (dS/m)}}{\text{Acceptable Deep Drainage EC (dS/m)}}$$

LR is determined by measuring both irrigation water and acceptable deep drainage water and then placing those figures into the equation above. For example, if the irrigation water EC is 2 dS*/m and the acceptable deep drainage EC value is 6 dS/m (50% yield reduction), the LR is 0.33. A leaching requirement of 0.33 means that 33% more water (over the plant’s requirements) is needed. For example, if 3 inches of water are required by the plant, then the amount of water needed to meet the needs of the plant and to wash excess salts out of the profile is 4 inches ($4 = 3 + [3 \cdot 0.33]$). More information for managing saline soils is provided in Bischoff and Werner (1999).

Irrigation water can contain ions that are toxic to corn. In South Dakota, two ions of concern are sodium (Na) and boron (B). Na and B can reduce yields when their concentrations exceed 230 and 1 mg/L, respectively. In South Dakota, aquifers with high concentrations of Na may also have high concentrations of B. To determine the Na and B concentrations of your irrigation water, collect a representative pint of water and send it to an appropriate laboratory for analysis. The Olsen Biochemistry Laboratory on the campus of SDSU can perform an irrigation compatibility analysis of your irrigation water.

Managing Sodic Problems

Extreme care must be used in soils with high Na contents. Na destroys soils by dispersing soil colloids and destroying soil structure. In addition, high Na reduces water infiltration and permeability. Irrigating with water that had high Na concentrations has rendered some land in South Dakota useless. Na-affected soils often have very poor drainage, and Na-sensitive plants experience reduced growth. Nutrient-deficiency symptoms (resulting from high pH) and poor soil physical conditions are often observed in high-Na situations.

If an Na problem is suspected, contact your local Extension educator or crop consultant for advice. Suspected Na problems can be confirmed by testing soil and irrigation water for Na, calcium (Ca), and magnesium (Mg) content. Sodium-adsorption ratios (SAR) are calculated using these values and provide an indication of current or impending Na problems. The SAR ratio is the amount of cationic (positive) charge contributed to a soil by sodium (Na^+) compared to that contributed by calcium (Ca^{2+}) and magnesium (Mg^{2+}). The SAR is determined from a water extract of a saturated soil paste. An SAR value below 13 is desirable, but values above 8 can indicate the onset of a problem (if steps are not taken to reduce Na in the soil profile). If the SAR is above 13, Na can cause the deterioration of soil structure and water infiltration problems. Some labs report high Na levels as ESP (exchangeable sodium percentage). An ESP of more than 15 is considered the threshold value for a soil classified as sodic. This means that Na occupies more than 15% of the soil’s cation exchange capacity (CEC).

If Na is a problem, the long-term goal should be to prevent further degradation and reduce further addition of Na. Some options for managing sodic soils include planting Na-tolerant plants, improving drainage, and adding low-Na manure or gypsum or other sources of calcium. Elemental sulfur (S) is sometimes recommended to lower soil pH values. However, because soils in South Dakota typically resist pH change because of high buffering capacity, applications of elemental S may not provide any benefit to the soil. If gypsum ($CaSO_4 \cdot 2H_2O$) is present at deeper soil depths, deep tillage may help bring the gypsum to the soil surface. If drainage and soil amendments are not possible, consider an alternative land use, such as pastureland planted with salt- and Na-tolerant grasses.

* DeciSiemen per meter (dS/m) is a unit of conductivity equal to 1/10th mho. Conductivity of soil is often reported as millimhos per cm (mmho/cm) where 1 dS/m = 1mmho/cm.

Chemigation

One advantage of irrigating is the ability to apply fertilizers or pesticides with the irrigation system. This practice is commonly referred to as "chemigation." Fertilizer applied through an irrigation system must remain soluble in the irrigation water because precipitates form and nozzles, emitters, and fittings can become clogged. After fertilizer application, a short irrigation may be used to wash the fertilizer off the plant and lessen the possibility of fertilizer burn. If applying pesticides, the pesticide must be labeled both for corn and for application with the irrigation system.

When chemigating you must also protect the water supply. Backflow into a well or other water supply can have serious consequences for other users and make the water unusable for their applications. State law requires the use of an anti-backflow device when chemigating; examples of anti-backflow devices include such things as check valves and low-pressure relief valves (SDCL §34A-2A-3). Always read and follow the instructions on the product label and take precautions to protect yourself and others from exposure to chemicals.

When using chemigation to apply liquid nitrogen or other chemicals, you may not need water at the time you want to apply the chemicals. Apply the chemicals in a timely fashion, but use the least amount of water possible. High-capacity injection equipment, along with an irrigation system that can cover the field in the shortest period of time, is desirable for chemigation.

Additional Information and References

Aldrich, S.R., W. O. Scott, and E.R. Leng. 1975. Modern Corn Production. A&L, Champaign, IL.

Bischoff, J. and H. Werner. 1999. Salt salinity tolerance of common agricultural crops in South Dakota. FS903. South Dakota Cooperative Extension Service. http://agbiopubs.sdstate.edu.

Broner, I. 1993. Irrigation scheduling with atmometers. Colorado State University Extension. http://www.ext.colostate.edu.

Franzen, D. 2007. Managing saline soils in North Dakota. SF1087. North Dakota State University. http://www.ag.ndsu.edu.

Schneekloth, J., T. Bauder, I. Braner, and R. Waskom. 2007. Measurement of soil moisture. Colorado State University Extension. http://www.ext.colostate.edu/drought/soilmoist.html.

South Dakota Codified Law §34A-2A-3 (SDCL §34A-2A-3) Chemigation, promulgation of rules regarding standards and requirements. Rules promulgated pursuant to authority pursuant to SDCL §34A-2A-3. ARSD 74:02:09, Chemigation.

Werner, H. 1993. Checkbook irrigation scheduling. EC987. South Dakota Cooperative Extension Service. http://agbiopubs.sdstate.edu.

Trooien, T.P., C.G. Carlson, and H.D. Werner. 2009. "Irrigation and salt management." Pp. 31–38. In Clay, D.E., S.A, Clay, and K.D. Reitsma (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 7
Soil Fertility

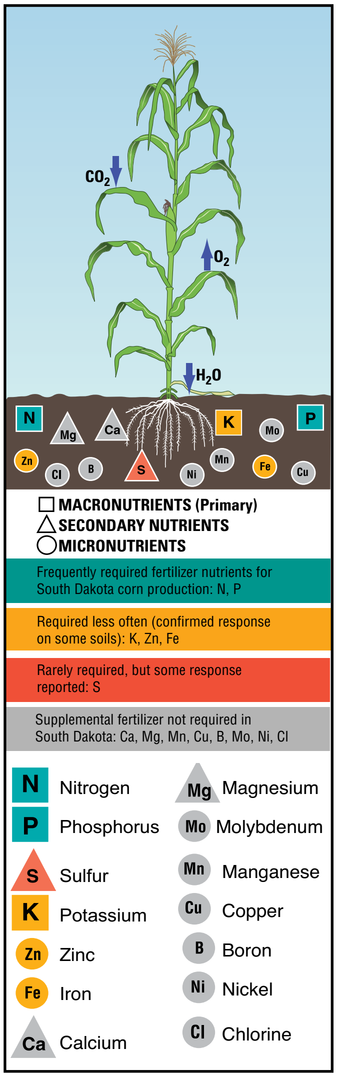
Corn requires sufficient amounts of at least 14 nutrients for optimal production (fig. 7.1). Soil fertility strategies should consider soil residual plant nutrients, cost of fertilizer relative to the value of corn, and management techniques that increase efficiency.

Different fertilizers have different concentrations of plant nutrients reflected in the grade or percent of each nutrient (%N, %P_2O_5, %K_2O). Commonly used fertilizers in South Dakota and their grades are listed in Table 7.1.

Table 7.1. Common fertilizers used in South Dakota

	----Percent----			
Dry fertilizers	N	P_2O_5	K_2O	
Ammonium nitrate	33	0	0	
Urea	46	0	0	
Diammonium phosphate (DAP)	18	46	0	
Mono-ammonium phosphate (MAP)	11	52	0	
Ammonium sulfate (21-0-0-24 S)	21	0	0	
Potassium chloride	0	0	60	
Potassium nitrate	13	0	44	
Liquid fertilizers	N	P_2O_5	K_2O	lb/gal.
Urea-ammonium-nitrate (UAN)	28-32	0	0	10.8
Ammonium polyphosphate	10	34	0	10.5
Multigrade (7-21-7)	7	21	7	10.7
Multigrade (9-18-9)	9	18	9	11.0
Gaseous fertilizers	N	P_2O_5	K_2O	
Anhydrous ammonia	82	0	0	

Figure 7.1. Nutrients required for corn growth and development



(Modified from Colorado State University)

Corn Yield Expectations

Fertilizer recommendations for nitrogen (N), phosphorus (P), and potassium (K) are based on expected yield or "yield goal." Calculating yield goals is complicated by improved genetics, which are gradually increasing crop yields. Further complications are introduced by rotations, which reduce the amount of available information for specific crops.

General guidelines for calculating yield goals include the following:

- It is not recommended to consider more than 10 years in yield goal calculations (Table 7.2).
- Abnormally high or low yield values should not be included in the calculation.
- To account for increasing yield potentials, some attempt should be made to standardize the data (Table 7.3). For example, a field with a yield of 140 bu/acre 10 years ago may now produce a yield of 160 bu/acre.
- Corn yields in South Dakota have been increasing at an annual rate of ≈2.0 bu/acre over the past 20 years.
- Managing for an optimistic, yet realistic, yield goal is important. Underestimating yield goal can lead to a gradual yield decline.
- Achieving full yield potential depends on management, climate, and soil, and will likely vary from field to field.

Additional information regarding yield goals is available in Reitsma et al. (2008).

Table 7.2. Estimating a yield goal from multiple years of data

Field records

Year	#Standardized yield (bu/A)	Conditions
1	136	Average
2	133	Average
3	126	Average
4	128	Average
5	126	Average
6	145	Average
~~7~~	~~*171~~	Excellent
8	163	Excellent
~~9~~	~~*112~~	Poor
10	129	Average

Base yield goal = 136

#Standardized yield considering average annual increase of 2 bu/A/yr.
*Outliers were removed to calculate average yield.
The yield goal + 10% recommendation:
136 • 1.10 = 150 bushel
Yield goal + moisture recommendation:
Full soil profile at planting
136 • 1.10 = 150 bushels
Average soil profile at planting
136 bushels
Poor moisture conditions at planting
136 – (0.10 • 136) = 123 bushels
Producers should be prepared to apply additional fertilizer N as an in-season side-dress if needed when using the soil moisture approach.

Table 7.3. Methods for estimating yield potential

- Remote sensing
- Field history (field)
  - Yield goal + 10% -- Add 10% to a multiple-year average where the maximum and minimum values have been removed.
  - Yield goal + moisture -- Adjust a multiple-year yield, after outliers have been removed, based on plant available water at planting.
  - County average
  - Productivity index

Soil Sampling

Soil samples are collected both to estimate nutrient levels in a field and to estimate the amount of residual nutrients in the soil. For accurate estimates, representative soil samples must be collected. Accuracy improves both by increasing the number of subsamples composited into a bulk sample and by avoiding areas of the field that do not represent the majority of the field (e.g., old feedlots, farmsteads, and fence lines). Details on soil sampling and sample handling are available in Clay et al. (2002) and Gelderman et al. (2005). "Rules of thumb" for soil sampling are provided in Table 7.4.

Table 7.4. "Rules of thumb" for soil sampling

- DO NOT sample dead furrows, turn-rows, waterways, terraces, old fence lines, farmsteads, feedlots, or any other areas that do not represent the field.
- Remove crop residue and debris before sampling.
- Sample when moisture conditions are suitable for tillage.
- Take enough samples to minimize error.
- Sample to represent old fertilizer bands in relation to the whole field.
- Nitrogen and sulfur recommendations are based on a 0-to-24-inch sample and may require an additional 24-to-48-inch depth increment.
- Analysis for phosphorus (P), potassium (K), and micronutrients are based on 0-to-6-inch samples.

Grid or management-zone soil sampling can be used to develop site-specific recommendations that can be used to generate field maps. These maps, in turn, can be used as a basis for precision fertilizer placement. In grid sampling, a composite sample from each point or cell is collected and analyzed. Grid or management-zone sample results can be compared with yield monitor data to make more precise decisions. Further details on precision nutrient management are available in Clay et al. (1997).

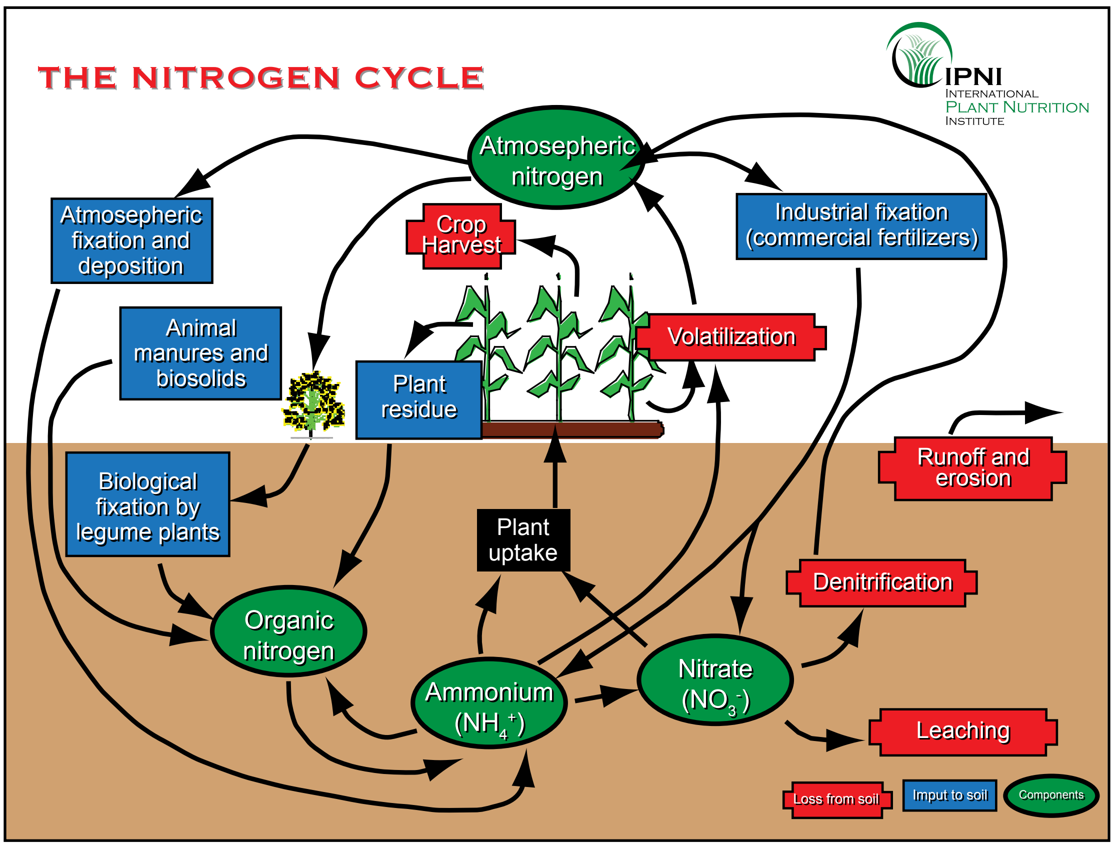
Nitrogen Recommendations

N applied to soil undergoes many transformations (fig. 7.2). In some situations, N can even be lost from the system before the plant can use it. N is mobile in the plant and will move from older growth to newer growth (translocation), resulting in a yellowing of older leaves (fig. 7.3).

The N recommendations for corn that is to be harvested for grain or silage are different (Table 7.5). For both corn and silage, though, the N-fertilizer recommendation is the difference between crop need and N credits. Credits that should be considered include residual soil test N, manure N, legumes (if grown within the previous 2 years), and irrigation water (see Tables 7.6 and 7.7 for additional information).

Residual soil N is estimated by analyzing a 0-to-24-inch sample collected in the spring. If a soil sample is not available, residual-soil N can be estimated using the long-term soil test average of 55 lbs. N/acre.

Figure 7.2. Important N transformations in agricultural soils



(Courtesy of International Plant Nutrition Institute)

Definition of Key Terms

Volatilization – loss of N from the profile as ammonia (NH_3) gas
Denitrification – loss of N from the soil as N_2 gas
Leaching – movement and loss of $N0_3$- from the root zone
Immobilization – microbial conversion of inorganic N (available) to organic N (unavailable)
Fixation – conversion of N_2 from the atmosphere to ammonia form N
Mineralization – microbial conversion of organic N (unavailable) to inorganic N (available)

The importance of measured residual-N value increases with the potential for the soil to contain a significant amount of NO_3^--N (fig. 7.4).

In sensitive areas, such as folds over shallow aquifers, an additional sample from the 24-to-48-inch depth should be collected. If soil test N exceeds 30 lbs. NO_3^--N/A in the 24-to-48-inch depth, 80% of that soil test N is included in the residual N credit (Gerwing and Gelderman 2005).

The manure N credit is best determined by sampling the manure. The sample should be representative of the source and should be taken after the material has been well mixed. If the manure is not sampled, N content can be estimated using values in Table 7.6.

Legume plants that form symbiotic relationships with *Rhizobium* sp. bacteria can provide a significant amount of N to the crop that follows. In situations where corn follows soybeans, a credit of 40 lbs. N/acre is recommended. Credits for other legume crops are provided in Table 7.7.

Additional information on N management is available in Reitsma et al. (2008).

Figure 7.3. Nitrogen deficiency in corn

Note the V-shaped chlorosis in older leaves and that the lowest leaves (the oldest leaves on the plant) are dead. *(Photo courtesy of Iowa State University)*

Table 7.5. Nitrogen fertilizer recommendation

Corn for grain

N = (1.2xRYG(grain)) - Credits

Corn for silage

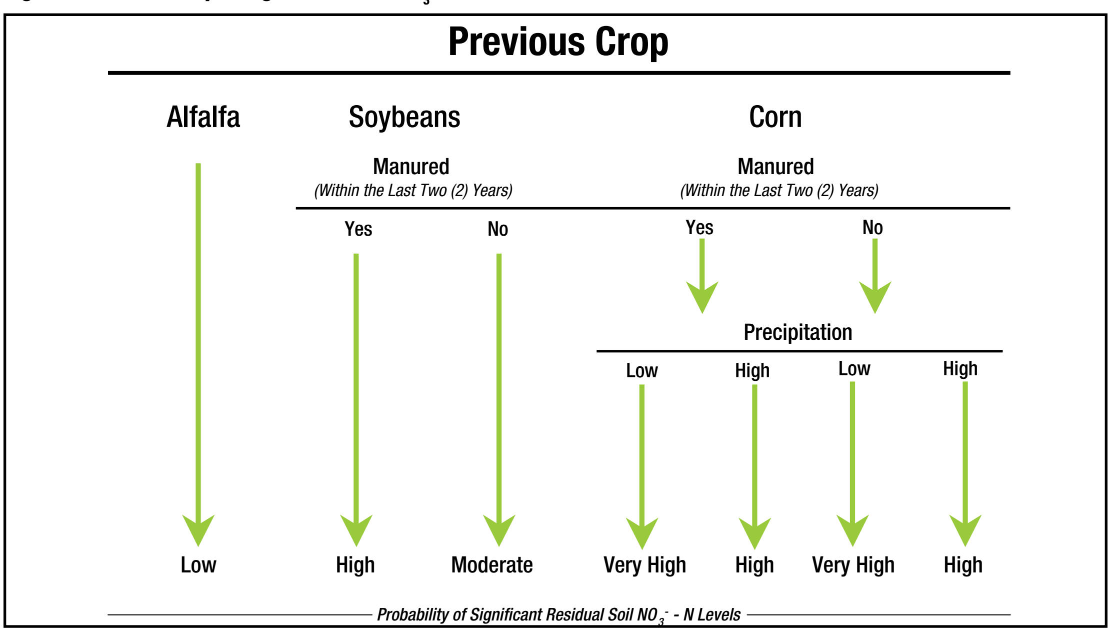
N = (10.4xRYG(silage)) - Credits

Where:

- N = estimate of nitrogen need (lbs/Acre)
- RYG(grain) = Realistic Yield Goal (bu/Acre)
- RYG(silage) = Realistic Yield Goal (tons/Acre)

(Adapted from Gerwing and Gelderman 2005)

Figure 7.4. Probability of significant soil NO_3^- – N level



(Courtesy of Reitsma et. al. 2008)

Table 7.6. Estimated nitrogen content of manure

Type of Livestock	Liquid Manure Nitrogen (N) lbs/1000 gal		Solid Manure Nitrogen (N) lbs/ton	
	$N_{ORGANIC}$	$N_{INORGANIC}$	$N_{ORGANIC}$	$N_{INORGANIC}$
Swine				
Farrowing	7	8	11	3
Nursery	11	14	8	5
Grow-Finish	-	-	10	6
Grow-Finish(deep pit)	17	33	-	-
Grow-Finish(wet/dry feeder)	21	39	-	-
Grow-Finish(earthen pit)	8	24	-	-
Breeding-Gestation	13	12	4	5
Farrow-Finish	12	16	8	6
Farrow-Feeder	10	11	5	5
Dairy				
Cow	25	6	8	2
Heifer	26	6	8	2
Calf	22	5	8	2
Veal calf	26	21	4	5
Herd	25	6	7	2
Beef				
Beef cows	13	7	4	3
Feeder calves	19	8	6	3
Finishing cattle	21	8	7	4
Poultry				
Broilers	50	13	34	12
Pullets	48	12	39	9
Layers	20	37	22	12
Tom turkeys	37	16	32	8
Hen turkeys	40	20	32	8
Ducks	17	5	13	4

(Adapted from Lorimor and Powers 2004)
These values should not be used in place of a regular manure analysis, as true nutrient content varies drastically depending on feeding and manure storage and handling practices. Use only for planning purposes.

Table 7.7. Nitrogen credits from previous legume crop

Crop	Population (Plants/ft^2)	[1,2]N Credit (lbs N/Acre)
Alfalfa or [3]Legume Green Manure	<1	0
	1–2	50
	3–5	100
	>5	150
Soybeans, edible beans, peas, lentils, and other annual legumes		40

[1]No-till corn into alfalfa or green manure crop: use half credit first year. Other tillage systems: use full credit.
[2]For second year following alfalfa and green manure crops: use half credit.
[3]Includes sweet clover, red clover, and other similar legumes.
(Adapted from Gerwing and Gelderman 2005)

Phosphorus

P-deficiency symptoms in corn appear as "purpling" of leaves and are most commonly seen during early growth stages (fig. 7.5). Symptoms may appear even though soil test P levels are high. Deficiency symptoms can result from either cool or dry soil conditions. For soils that test high for P, banding 30 lbs. P_2O_5 at planting may increase early growth but may not increase yield. In low to medium soil test P levels, a band application at planting will usually increase yields. A bushel of corn removes about 0.38 lbs. of P_2O_5. Based on this estimate, a 150 bu/acre corn crop removes 57 lbs. of P_2O_5.

P exists in solution, mineral, and organic forms (fig. 7.6). About 1% of P is in solution (plant available), whereas 85% is in mineral form and 14% is in organic form. Because P is constantly being transformed among the soil pools, P can be difficult to manage.

The optimal pH range for P availability is between 6.0 and 7.0. As soil pH values increase or decrease from the optimum, P becomes less available. Clay soils in the western part of the state often have high soil calcium (Ca^{2+}) levels, reducing soil test P levels. Irrespective of the soil test P values, these soils may not respond to P fertilizer.

Band applications of P, applied at planting, generally have higher efficiency than other approaches. Concentrating fertilizer P in a small area improves P availability, as there is less opportunity for the fertilizer P to be fixed. Rates can sometimes be reduced by one-third or more for band-applied P. However, reducing rates can result in a decline of soil test P over time. Equations for current recommendations are available at http://plantsci.sdstate.edu/soiltest/.

P recommendations are based on yield goal and laboratory results from a 0-to-6-inch soil sample. In South Dakota, P-fertilizer recommendations can be calculated from either the Bray-1 or Olson P methods. The Bray-1 (B1-P) method is used for acid soils (pH < 7), while the Olsen (O-P) method is used for basic soils (pH >7). Results from Mehlich III (MIII) soil tests, which are sometimes reported by soil testing labs in neighboring states, are similar to those obtained from the Bray-1 method.

The soil test results represent index values that coincide with a recommended P fertilizer rate. The rate of fertilizer P increases with yield goal and/or with declining soil test P values. As soil test P values increase, the probability that the crop will show a positive yield response from applied fertilizer P decreases. Corn grown in areas where soil test values are very low (B1-P and MIII-P, 0–5 ppm; O-P, 0–3 ppm) has an 80% chance of showing a yield response. Fertilizer P recommendations are calculated using the equations in Table 7.8.

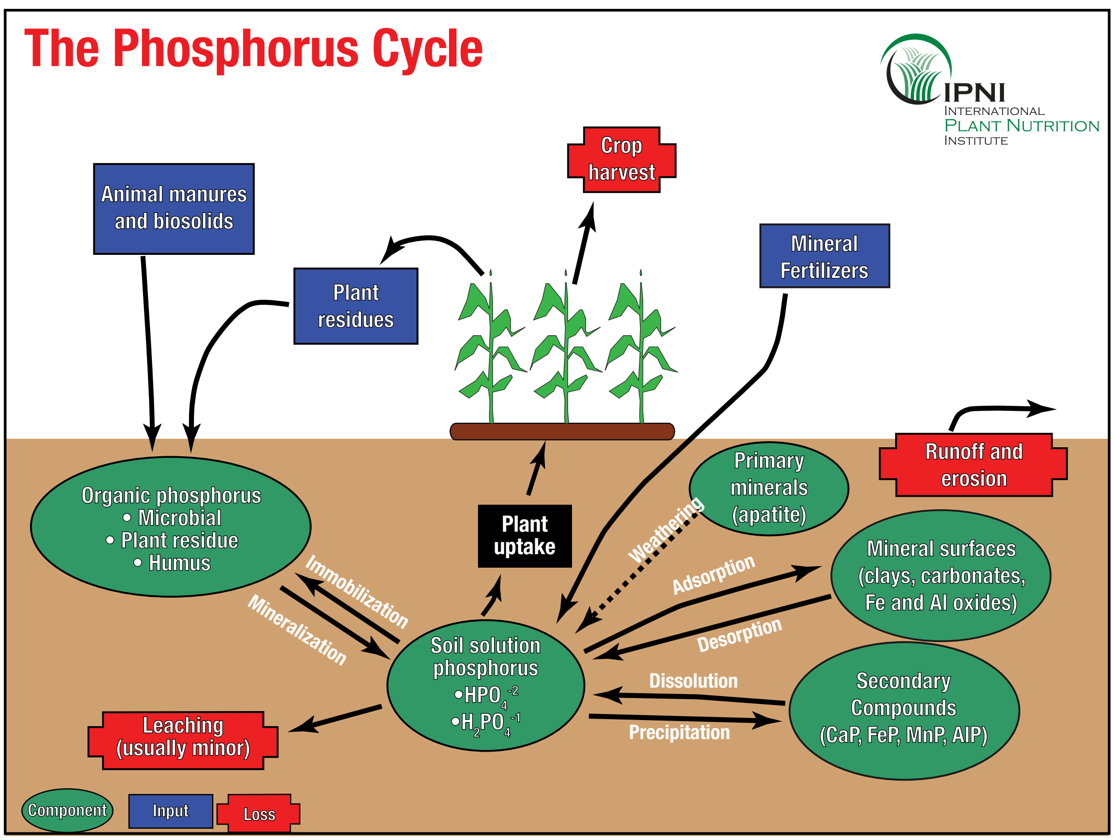
If manure is applied, the recommendation should be adjusted based on the amount of P contained in the manure. If an analysis of the manure is available, assume 90% of total P is available. If an analysis is not available, calculate P from data in Table 7.9.

Figure 7.5. P-deficient Corn

Deficiency symptoms appear as leaf "purpling" along leaf edges and slow and stunted growth. Symptoms most often appear early in the season, especially in low areas with high water tables.

(Photo courtesy of Howard J. Woodard, South Dakota State University)

Figure 7.6. The phosphorus cycle



(Courtesy of International Plant Nutrition Institute)

Table 7.8. Equations used to calculate P recommendation

Bray-1 P & Mehlich III

$FPR = (0.7 - 0.035 \times STP) \times RYG$

Olson P

$FPR = (0.7 - 0.044 \times STP) \times RYG$

Where:

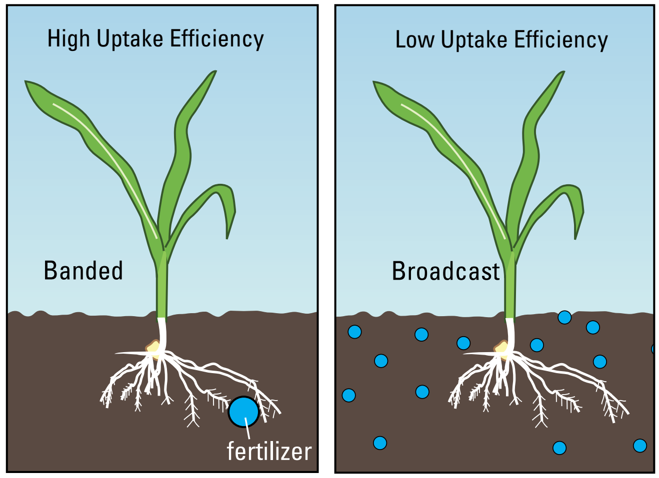
FPR = Fertilizer P Rate (lbs P_2O_5/A)

STP = Soil Test P Value (ppm)

RYG = Realistic Yield Goal (Bu/A)

(Gerwing and Gelderman 2005)

Figure 7.7. Band vs. broadcast P application



(Illustrations courtesy of Colorado State University)

Phosphorus in the Environment

Off-site movement of P generally occurs with runoff and erosion because P is strongly attached to soil. The transport of P from production fields to streams and lakes can result in algal blooms. Transport is minimized by adopting conservation tillage and other management practices designed to reduce or contain runoff and erosion. Concentrations of P in runoff waters can be reduced by minimizing the exposure of manure and fertilizer to runoff water (Table 7.10). Adopting these and other management practices has the potential to improve the quality of surface water.

Table 7.10. Phosphorus management techniques to improve water quality

- Place P sources below soil surface:
  - incorporate
  - inject
  - band apply
- Divide large variable fields into small management units – fertilize according to crop need and soil test.
- Maintain a buffer between "fertilized" and surface water or drainage.
- Consider developing and maintaining "grassed" or "wooded" buffers or filter strips in fields near surface waters or drainages.
- Avoid application of manure on frozen or snow-covered ground.
- Maintain surface residue levels above 30% to reduce erosion and runoff.

Table 7.9. *Estimated phosphorus content of manure

Type of Livestock	P_2O_5 Liquid (Lbs/1,000 gal.)	P_2O_5 Solid (Lbs/ton)
Swine		
Farrowing	12	6
Nursery	19	8
Grow-Finish (deep pit or solid)	42	9
Grow-Finish (wet/dry feeder)	44	-
Grow-Finish (earthen pit)	22	-
Breeding-Gestation	25	7
Farrow-Finish	24	8
Farrow-Feeder	18	7
Dairy		
Cow	15	3
Heifer	14	3
Calf	14	3
Veal calf	22	3
Herd	15	4
Beef		
Beef cows	16	4
Feeder calves	18	4
Finishing cattle	18	7
Poultry		
Broilers	40	53
Pullets	35	35
Layers	52	51
Tom turkeys	40	50
Hen turkeys	38	50
Ducks	15	21

(Adapted from Lorimor and Powers 2004)

* These values vary drastically depending on feeding and manure storage and handling practices and are not likely representative of actual nutrient content of the manure. Use only for planning purposes. These values should not be used in place of a regular manure analysis.

Potassium

Potassium-deficiency symptoms appear as leaf yellowing and burning that begins at the tip of older leaves (fig. 7.8). Commonly, these symptoms are observed in sandy soils with low organic matter and in fields that were previously harvested for silage. About 0.27 lbs. of K_2O are removed by each bushel of corn grain, while K_2O removed with silage averages about 7.3 lbs./ton. Silage's high potassium (K) removal occurs 1) because K levels in plant material are nearly three times greater those that found in grain and 2) because K is soluble and can be washed out of dead leaves (so when the entire live plant is harvested, most K is removed from the field). Based on these estimates, a 150 bu/acre corn crop removes 40.5 lbs. of K_2O with the grain.

Most agricultural soils in South Dakota have relatively high K levels. However, in some situations there may be a positive response to K fertilizer applied as starter or broadcast. In South Dakota, K fertilizer recommendations are based on the amount of K extracted from a 0-to-6-inch soil sample using the equations in Table 7.11.

If manure is applied, K fertilizer may not be needed (manure contains high amounts of K). K fertilizer can be applied in contact with the seed in small amounts. However, seed germination can be reduced from salt damage if the N plus K_2O in the fertilizer exceeds 10 lbs./acre.

Figure 7.8. Potassium-deficient corn

Potassium-deficiency symptoms appear as burning of leaf edges.
(Photo courtesy of University of Georgia–Athens)

Table 7.11. Calculating a K recommendation

Corn for Grain

$$FKR = (1.1660 - 0.0073 \times STK) \times RYG$$

Corn for Silage

$$FKR = (9.50 - 0.06 \times STK) \times RYG$$

Where:
FKR = Fertilizer K Rate (lbs K_2O/A)
STK = Soil Test K Value (ppm)
RYG = Realistic Yield Goal (Bu/A)
A minimum of 60 lbs K_2O/A is recommended.
(Gerwing & Gelderman 2005)

Secondary and Micronutrients

In most situations, the secondary nutrients (Ca, Mg, S) and micronutrients (B, Zn, Fe, Cu Mo, Mn) do not limit yields in South Dakota. Zinc (Zn) deficiencies can be observed in coarse-textured soils, eroded soils, organic soils, or soils with high levels of P. Seasonal climate conditions may also affect Zn availability, as Zn-deficiency symptoms are often observed in cool, wet soils. Corn suffering from Zn deficiency can be seen in fig. 7.9.

Iron (Fe) deficiencies may be observed in leveled or eroded sites when calcareous subsoils have been exposed and pH levels are above 7. Fe-deficiency symptoms in corn are observed as yellowing with interveinal striping of younger leaves (fig. 7.10). Correcting for Fe deficiency can be difficult; the best approach is to incorporate manure or biosolids in problem areas.

Micronutrient deficiencies usually result from environmental conditions and may be temporary or have little effect on yield. If micronutrient deficiencies

Figure 7.9. Zinc deficiency in corn

Zinc-deficiency symptoms are shown on the youngest leaves and appear as feathering and striping.
(Photo courtesy of University of Georgia)

Figure 7.10. Iron deficiency in corn

Iron deficiency appears first in youngest leaves.
(Photo courtesy of University of Georgia)

are suspected, soil testing is recommended. Recommendations for Zn and Fe can be found in Table 17.12.

Considerations for No-Till

No-tillage can result in slower early season growth. Starter fertilizer applied with or near the seed can be used to enhance early season growth. If N or K is applied with the seed, the total amount added should not exceed 10 lbs. of N + K_2O. If possible, N fertilizer should be subsurface band applied. In no-tillage systems, it is recommended that the N rate be increased 30 lbs./acre. Broadcasting urea onto residue-covered fields in the fall can result in a substantial amount of N loss. To increase N-use efficiency, it is recommended that the N be spring-applied.

Table 7.12. Zinc and iron recommendations

Zinc soil test interpretation (ppm)	Zinc recommendations (lb/acre[1])
0.0–0.25 Very low	10
0.26–0.50 Low	10
0.51–0.75 Medium	5
0.76–1.00 High	0
1.01+ Very high	0

[1]Based on inorganic products as source of zinc, such as zinc sulfate.

Iron soil test ppm	Interpretation	Iron recommendations lb/acre
0–2.5	Low	0.15
2.6–4.5	Medium	0.15
>4.5	High	0

(Gerwing and Gelderman 2005)

Additional Information and References

Clay, D.E., C.G. Carlson, K. Brix Davis, J. Oolman, and B. Berg. 1997. Soil sampling strategies for estimating residual nitrogen. J. Production Agriculture. 10: 446-51.

Clay, D.E., N. Kitchen, C.G. Carlson, J.C. Kleinjan and W.A. Tjentland. 2002. Collecting representative soil samples for N and P fertilizer recommendations. Crop Management. http://www.plantmanagementnetwork.org/cm/.

Gelderman, R., Gerwing J. and K. Reitsma. 2005. Recommended soil sampling methods for South Dakota. FS935. South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Department of Agriculture. Brookings, SD. http://agbiopubs.sdstate.edu.

Gerwing, J. and R. Gelderman. 2005. Fertilizer recommendations guide. EC750. South Dakota State University, South Dakota Cooperative Extension Service, United States Department of Agriculture. Brookings, SD. http://agbiopubs.sdstate.edu/articles/EC750.pdf.

Lorimor, J. and W. Powers. 2004. Manure characteristics–manure management systems series. Midwest Plan Service – 18, Sec. 1, 2nd ed. Ames, IA.

Reitsma, K.D., R.H. Gelderman, P. Skiles, K. Alverson, J. Hemenway, H.J. Woodard, T.E. Schumacher, D.D. Malo and D.E. Clay. 2008. Nitrogen Best Management Practices for Corn in South Dakota. FS941. South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Department of Agriculture. Brookings, SD. http://agbiopubs.sdstate.edu.

Rehm, G., G. Randall, J. Lamb, and R. Eliason. 2006. Fertilizing corn in Minnesota. FO-3790-C. U. of Minn. Ext. Service, St. Paul, MN. http://www.soils.umn.edu.

Clay, D.E., and K.D. Reitsma. 2009. "Soil fertility." Pp. 39-48. In Clay, D.E., K.D. Reitsma, and S.A, Clay (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 8
Corn Insect Pests

Historically, the major corn insect pests have been corn rootworms (northern and western), European corn borer, and black cutworm. *Bt*-corn hybrids are effective against most of these pests. However, *Bt*-corn hybrids are not effective against corn leaf aphid, corn root aphid, sap beetles, corn rootworm adults, grasshoppers, white grubs, wireworms, seed corn beetle, and seed corn maggots. These insect pests can reduce corn yields. This chapter discusses the management and biology of important corn insect pests commonly observed in South Dakota.

Corn Rootworms (*Diabrotica barberi* and *Diabrotica virgifera virgifera*)

Pest highlights

- Two major species occur in South Dakota: northern corn rootworm and western corn rootworm.
- *Bt*-corn hybrids with the *Bt*-rootworm gene are effective against corn rootworm larvae.
- Crop rotation is an effective tactic in managing corn rootworms.
- Corn rootworms are currently the most damaging insect pests of continuous corn in South Dakota.

Rootworm description

Adult northern corn rootworm beetles are approximately ¼-inch long and greenish to yellowish in color, while western corn rootworm beetles are yellow with black longitudinal markings on their wings (fig. 8.1). Larvae of both species are white with a brown head and grow to a size of ⅝ inch (fig. 8.2). Both the larvae and the adults have chewing mouthparts.

Figure 8.1. Adult beetles of northern corn rootworm (top) and western corn rootworm (bottom)

(Photo courtesy of Mike Catangui, South Dakota State University)

Figure 8.2. Larvae and pupae of corn rootworms

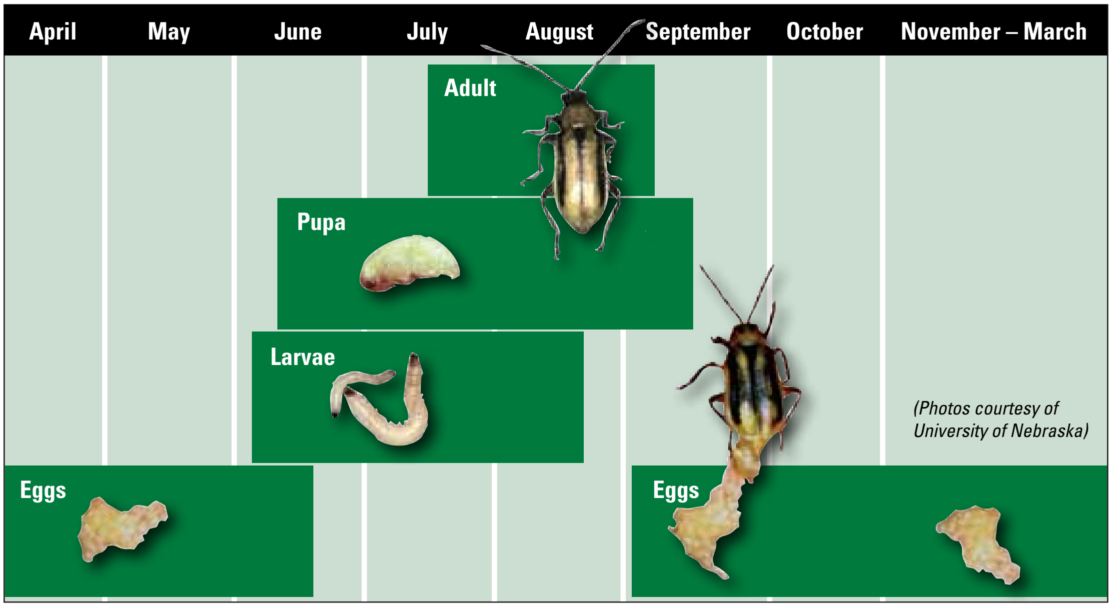
(Photo courtesy of Mike Catangui, South Dakota State University)

Rootworm biology

Rootworm larvae feed on corn roots and cannot normally survive on roots of other crops such as soybean, wheat, sunflower, and alfalfa. This feature makes crop rotation an excellent control approach. Because the most common alternative hosts for rootworm larvae are green, yellow, and giant foxtail, the control of these weed pests is important for limiting future rootworm infestations.

Rootworm eggs are laid in the soil from late summer until the female rootworm beetle adults are killed

Figure 8.3. Life cycle of the western corn rootworm in South Dakota



by the first killing frost (fig. 8.3). In South Dakota, rootworm eggs are primarily laid in cornfields, where they overwinter in the soil. Fields where corn was the previous crop will most likely have rootworm eggs waiting for the new corn crop. Eggs hatch as soon as corn roots start growing. Most injuries by rootworm larvae occur in June and July (a period of active root growth). Larvae transform into pupae in mid-July, and adult rootworm beetles emerge from the soil starting from late July through August. Adult beetles feed on corn pollen, silk, and on the leaves of corn, soybeans, sunflowers, and garden flowers.

In the larval stage, root feeding reduces water and nutrient intake (fig. 8.4) and can result in lodging (fig. 8.5). Lodged corn is difficult to harvest, decreasing harvest efficiency. Yield losses can be minimized by using *Bt*-corn hybrids, granular and liquid insecticides, and seed treatments.

Management: *Bt*-corn hybrids

Genetically engineered corn hybrids with YieldGard® Rootworm, YieldGard® Plus, YieldGard® VT Triple, Herculex® RW, Herculex® XTRA, and Agrisure® RW genes are resistant to feeding by rootworm larvae (Table 8.1). These *Bt*-corn hybrids produce proteins toxic to rootworm larvae. To prevent the development of insect resistance to *Bt*-corn, growers must seed at least 20% of a field with non-*Bt*-corn hybrids, thus creating a refuge area.

Figure 8.4. Root pruning caused by rootworm larvae on corn

(Photo courtesy of Mike Catangui, South Dakota State University)

Figure 8.5. Lodging, or "goosenecking," of corn plants as a result of rootworm injuries

(Photo courtesy of Mike Catangui, South Dakota State University)

Table 8.1. *Bt*-corn genes that confer resistance to corn against insects			
***Bt* gene trademark**	***Bt* proteins**	**Company**	**Target insects**
Agrisure® RW	Modified Cry3A	Syngenta Seeds	corn rootworm larvae
Herculex® RW	Cry34Ab1+Cry35Ab1	Dow AgroSciences and Pioneer Hi-Bred	corn rootworm larvae
YieldGard® Rootworm	Cry3Bb1	Monsanto Company	corn rootworm larvae
YieldGard® VT Root-worm	Cry3Bb1	Monsanto Company	corn rootworm larvae
Agrisure® CB	Cry1Ab	Syngenta Seeds	corn borer larvae
Herculex® I	Cry1F	Dow AgroSciences and Pioneer Hi-Bred	corn borer, black cut-worm, and western bean cutworm larvae
YieldGard® Corn Borer	Cry1Ab	Monsanto Company	corn borer larvae
Agrisure® CB/RW	Cry1Ab+Modified Cry 3A	Syngenta Seeds	corn borer and corn rootworm larvae
Herculex® XTRA	Cry1F+Cry34Ab1+Cry35Ab1	Dow AgroSciences and Pioneer Hi-Bred	corn borer, black cutworm, western bean cutworm, and corn rootworm larvae
YieldGard® Plus	Cry1Ab+Cry3Bb1	Monsanto Company	corn borer and corn rootworm larvae
YieldGard® VT Triple	Cry1Ab+Cry3Bb1	Monsanto Company	corn borer and corn rootworm larvae
More information about *Bt* genes is available at the following: Agrisure - http://www.agrisuretraits.com Herculex® - http://www.dowagro.com/herculex/ YieldGard® - http://www.yieldgardvt.com			

Rootworm seed treatments

Insecticidal seed treatments available to corn growers are clothianidin (Poncho®), imidacloprid (Gaucho®, Prescribe®), or thiamethoxam (Cruiser®). These systemic insecticide seed treatments are applied to seed before bagging and sale.

Rootworm insecticides

Granular or liquid rootworm insecticides are applied in-furrow or very close to the seed furrow during planting. Many different insecticides can be used for rootworm larval control. Information about these control agents is available at the SDSU Extension Entomology Web site (http://plantsci.sdstate.edu/ent).

Scouting and economic threshold

Corn ears during the R1 to R2 (silking to blister) stages may be scouted for adult beetles to predict the potential for rootworm infestation the following season. In continuous corn, an average of 3 beetles per 10 ears examined is considered the economic threshold for control treatment. More rootworm scouting information can be found at http://entomology.unl.edu/pmguides/crwlarv.htm.

European Corn Borer (*Ostrinia nubilalis*)

Pest highlights

- South Dakota has both the univoltine (1 generation) and bivoltine (2 generation) ecotypes.
- *Bt*-corn hybrids with the *Bt*-corn borer gene are effective against this pest.
- Univoltine corn borers can be more damaging and harder to manage than bivoltine corn borers.
- Yield loss can range from 2 to 6% per larva per plant.

Corn borer description

A fully grown corn borer larva is about 1-inch long. It has a dark brown head and its body is light tan with brown spots (fig. 8.6). The adult moth is triangular in shape, yellowish in color with wavy markings on wings, and 1/2-inch long (fig. 8.7). Male moths are darker in color than female moths.

Figure 8.6. European corn borer larva

(Photo courtesy of Jon Kieckhefer, South Dakota State University)

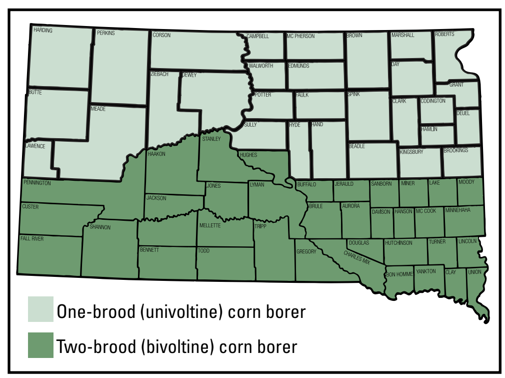
Figure 8.7. European corn borer moths

(Photo courtesy of Mike Catangui, South Dakota State University)

Corn borer biology

Corn borers have 4 stages of development: egg, larva, pupa, and adult. These stages cummulatively represent 1 generation. Larvae have 5 instars (larval stages) that increase in size as the larva develops. At the fifth instar stage, a larva prepares to pupate and become an adult. Corn borers are characterized by their number of generations within a season. In the northern environment, there is generally only 1 generation (univoltine); but in central areas of the Corn Belt, 2 generations can be produced each season (bivoltine). In southern areas of the United States, 3 generations are possible (multivoltine).

Figure 8.8. Predicted distribution of univoltine and bivoltine corn borers in South Dakota



Univoltine corn borers (1 generation per year)

The univoltine corn borer occurs in the northern counties of South Dakota (fig. 8.8). Univoltine corn borer moths start flying in mid-June. Peak populations occur in mid-July. Moths lay eggs mainly on the underside of leaves of pre-tasseling (V18) to tasseling (VT) corn. Eggs hatch within a week, and the newly hatched larvae first feed on the leaf collars and then migrate to the tassels to feed on pollen.

The univoltine larvae stay on the corn plants from June through harvest and overwinter in stalk residues left on the field. They transform into pupae and moths in the following spring.

Bivoltine corn borer (2 generations per year)

In the southern portion of the state, corn borers can have 2 generations (fig. 8.8). These moths start flying in mid-May and the adult moths lay eggs on the underside of the leaves when corn is between the V6 to V9 growth stages. Newly hatched larvae first feed in the whorl, causing a “shot-holing” type injury that is visible when leaves unfurl (fig. 8.9). Second- and third-instar larvae feed on the leaf surface and midribs, causing a “window paning” type injury. Fourth-instar larvae tunnel into the stalk, molt into a fifth-instar larvae after 10 days, then transform into pupae after about the same amount of time. Tunnels in the stalk produced by the larvae are very injurious because they interfere with water and nutrient transport.

Adult moths emerge from the stalk after 8 days. These second-generation moths lay eggs on the underside of leaves, leaf collars, and ear husks at tasseling (VT) and silking (R1) corn. Eggs hatch into second-generation corn borer larvae that burrow into the stalks and ear shanks and feed on developing seeds. Fully grown (fifth-instar) larvae overwinter on stalks and stover left on the field. The winter survival potential of larvae increases with the amount of residue remaining in the field.

In transition zones, flight paths of univoltine and bivoltine corn borers converge, and both can exist in the same field. This phenomenon has been observed along the northern border of Minnehaha County and along the southern borders of Lake and Moody counties. More information about both corn borer moth flight-monitoring data and corn borer biology can be found at the SDSU Extension Entomology Web site (http://plantsci.sdstate.edu/ent/).

Figure 8.9. Shot-hole symptoms of corn borer infestations

(Photo courtesy of Mike Catangui, South Dakota State University)

Table 8.2. Estimated yield loss per corn borer larva at specific corn growth stages	
Growth stage	**% Yield loss/larva/plant**
V10 (mid-whorl)	5.9
V16 (green tassel)	5.0
R1 (pollen shed)	4.0
R2 (blister)	3.1
R4 (dough)	2.4
(After North Central Regional Extension publication No. 327)	

Corn borer injuries to corn

Corn borer injury can result in stalk breakage, reduction in water and nutrient transport, secondary infection with stalk rot fungi, and yield loss. Injuries to ears can result in ear drop, reduced grain quality, and secondary infection with mycotoxin-producing fungi. Leaf feeding by early instar larvae causes shot-hole and window-paning type injuries that are usually not serious enough to reduce photosynthesis. However, these leaf injury symptoms serve as indicators of the presence of corn borers. The timing of larval infestation affects final yield (Table 8.2). In general, the univoltine corn borer is more injurious to corn than the bivoltine corn borer because larvae of the former stay in the plants the entire season. In bivoltine corn borer, the first-generation larvae are generally more injurious than the second generation because they occur during the plant stage that is more sensitive to stress.

Corn borer management

Bt-corn hybrids with YieldGard® Corn Borer, YieldGard® Plus, YieldGard® VT Triple, Herculex® I, Herculex® XTRA, Agrisure® CB, and Agrisure® CB/RW genes produce *Bt* proteins in their leaves, stalks, and ears that are toxic to the corn borer larvae. *Bt*-corn hybrids have performed very well during corn borer outbreaks. However, the severity of corn borer infestations fluctuates from year to year.

The decision to deploy *Bt*-corn hybrids is made before planting. Therefore, techniques are needed to reduce the economic risk associated with treatment and variety choice decisions.

Bt-corn may be most suitable for planting in areas where the univoltine corn borer occurs (fig. 8.8). This pest is less predictable than the bivoltine corn borer. In bivoltine regions, corn borer outbreaks often decline to levels below economic thresholds in the year after an outbreak. However, the risk of corn borers may be sufficient to warrant regular planting of *Bt*-corn hybrids if corn follows corn in the rotation. For more information on risk, check the annual corn borer moth flights at the SDSU Extension Entomology Web site (http://plantsci.sdstate.edu/ent/). To prevent the development of insect resistance to *Bt*-corn, growers must plant at least 20% of their corn acres with non-*Bt*-corn hybrids. Information on refuge requirements and insect resistance management can be found at http://www.pioneer.com/CMRoot/Pioneer/biotech/irm/irmbroch.pdf and at http://www.monsanto.com/monsanto/ag_products/pdf/stewardship/2008_YieldGard®_irmguide.pdf.

Corn borer scouting and insecticides.

Insecticide treatments can be effective against corn borers. South Dakota State University research indicates that insecticide is an effective control if applied at the right time and rate. Corn properly treated with insecticides often produces yields similar to *Bt* hybrids. Scouting is critical to maximize the effectiveness of insecticides (Table 8.3).

Western Bean Cutworm (*Striacosta albicosta*)

Pest highlights

- Western bean cutworm larvae feed on the developing seeds in the corn ears late in the season.
- *Bt*-corn hybrids that have Herculex® I and Herculex® XTRA genes are resistant to this pest.
- *Bt*-corn hybrids with the YieldGard® Corn Borer, YieldGard® Plus, YieldGard® VT Triple, Agrisure® CB, and Agrisure® CB/RW genes are not effective against this pest.
- This pest can reduce yields up to 40%.
- Injured ears may be susceptible to mycotoxin-producing fungi.

Cutworm description

The western bean cutworm larva is about 1¼-inch long when fully grown and has an orange-brown head, black dorsal shield behind the head, and a brownish body with gray markings (figs. 8.10 and 8.11). The adult moth is about ¾-inch long, brown in color, and has a distinct white band on the leading edge of its forewings (fig. 8.12).

Cutworm biology

In South Dakota, western bean cutworm moths start flying in early July and reach peak numbers during the third or fourth week of July, when corn is between the VT (tasseling) and R1 (silking) stages. The moths lay eggs on the upper surface of the leaves in the upper canopy. The eggs hatch within a week and the first-instar larvae begin migrating toward the developing ears near egg sites. Larvae usually go through 5 instars, or stages. The third- through fifth-instar larvae feed on developing kernels for approximately 1 month (fig. 8.11), then migrate to the soil where they prepare for overwintering. Once in the soil, the larvae construct earthen cells 5 to 10 inches belowground in which to overwinter.

Western bean cutworm injuries to corn

Several cutworm larvae can feed simultaneously on a single ear. Early studies in Colorado indicate that direct feeding on the developing ears can result in up to 40% loss in grain yield. Injured ears may also be susceptible to infection with mycotoxin-producing fungi (fig. 8.11).

Table 8.3. Corn borer scouting, timing, and additional information

Look for egg masses, newly hatched larvae, and signs of injury on leaves:

- V8-V14 (mid- to late-whorl) for 1st-generation bivoltine corn borer
- V16-R1 (green tassel through pollen shed) for univoltine corn borer
- R1-R2 (silking through blister) for 2nd-generation bivoltine corn borer

Details for calculating economic thresholds and a list of labeled insecticides for corn borers can be found at the SDSU Extension Entomology Web site (http://plantsci.sdstate.edu/ent/).

Figure 8.10. Western bean cutworm larva

(Photo courtesy of Mike Catangui, South Dakota State University)

Figure 8.11. Western bean cutworm injury

(Photo courtesy of Mike Catangui, South Dakota State University)

Figure 8.12. Western bean cutworm moth

(Photo courtesy of Mike Catangui, South Dakota State University)

Western bean cutworm management

Bt-corn hybrids with Herculex® I and Herculex® X-TRA genes produce the Cry1F protein that provides resistance to western bean cutworm larvae. However, *Bt*-corn hybrids with YieldGard® Corn Borer, YieldGard® Plus, YieldGard® VT Triple, Agrisure® CB, and Agrisure® CB/RW genes do not provide resistance to western bean cutworm larvae.

Western cutworm scouting and insecticides

Scouting for western bean cutworms should start at the V16 (green tassel) stage and continue through the R3 (milk) stage. Eggs and newly hatched larvae are usually found in the silks or leaves in the upper canopy. Because the timing of spray application is very important (the insecticide must be applied before the larvae enter the ears), scouting must also be timed accordingly. At least 100 plants (10 plants from 10 locations on the field) per 40-acre field must be inspected to accurately gauge the infestation level. Both the center and borders of the cornfield must be inspected. This pest should be controlled if 8% of the plants have eggs or newly hatched larvae. For insecticides to be effective, the insecticide must be applied before the larvae enter the ears. Information on different insecticides is available at the SDSU Extension Entomology Web site (http://plantsci.sdstate.edu/ent/).

Black Cutworm (*Agrotis ipsilon*)

Pest highlights

- Black cutworm larvae feed on corn seedlings early in the season.
- Only Herculex® I and Herculex® XTRA *Bt*-corn hybrids are effective against this pest.
- If the seedlings are cut below the growing point, significant stand loss can result.
- Black cutworms do not overwinter in South Dakota. Moths migrate into the state in early spring and are attracted to wet and weedy fields.

Figure 8.13. Black cutworm larvae, pupa, and cut seedling

(Photo courtesy of Mike Catangui, South Dakota State University)

Figure 8.14. Missing corn seedlings due to black cutworm injury

(Photo courtesy of Mike Catangui, South Dakota State University)

Black cutworm description

A full-grown larva is about 1½-inches long, dark brown to black, and "greasy" in appearance (fig. 8.13). Under the microscope or hand lens, the skin of the larva has a rough, pebbly texture. The pupa is brown and about ¾-inch long (fig. 8.13).

Black cutworm biology

Moths start migrating into South Dakota from southern states in early April. Southerly winds influence the transport, distribution, and severity of black cutworm infestations. Eggs are deposited on weeds and crop residues before corn is planted. Black cutworm larvae initially feed on weeds, then move to corn seedlings in May through early June. Corn seedlings can be cut underground, below the growing point, resulting in extensive seedling stand loss (fig. 8.14).

Black cutworm management

Only *Bt*-corn hybrids with Herculex® I and Herculex® X-TRA are considered resistant to black cutworm larvae. Seed treatments of clothianidin or thiamethoxam provide protection from cutworm damage.

Black cutworm scouting and insecticides

Scouting for black cutworm larvae should start at the VE (germination and emergence) stage and continue on through V4 (fourth leaf). Insecticide treatment is recommended if 5% (1 in 20) of the seedlings show signs of cutting or leaf feeding and if the larvae are less than 1-inch long. Information on different insecticides is available at the SDSU Extension Entomology Web site (http://plantsci.sdstate.edu/ent/).

Sap Beetles (*Glischrochilus quadrisignatus, Carpophilus lugubris, Carpophilus dimidiatus*)

Pest highlights

- Both the larval and adult stages feed on corn ears.
- Infested ears may become susceptible to infection with mycotoxin-producing fungi.
- Three species of sap beetles commonly infest corn in South Dakota.
- Adults can overwinter in soil, crop residues, and unharvested ears.

Sap beetles description

The picnic beetle (*G. quadrisignatus*) is $^1/_3$-inch long and shiny black with 4 yellowish markings on its wings (fig. 8.15). The dusky sap beetle (*C. lugubris*) is dull brown and $^1/_{16}$-inch long (fig. 8.16). The corn sap beetle (*C. dimidiatus*) is $^1/_8$-inch long and reddish brown. Larvae are whitish or pinkish and measure ¼-inch long (fig. 8.17).

Sap beetles biology

Sap beetles can overwinter in South Dakota under crop residues and in unharvested corn ears. Adults become active in the spring and presumably start feeding on crop residues and the sap of trees, laying eggs near food sources. There are 3 larval instars, and sap beetles develop from egg to adult in about a month. Several overlapping generations per growing season are possible.

Sap beetle adults appear to be attracted to corn pollen during tasseling and silking in August and follow corn leaf aphid infestations. Eggs may be laid directly on the developing corn ears, with larvae and adults feeding on developing kernels (figs. 8.15 and 8.17). Direct feeding by sap beetles does not appear to reduce yield, but injured ears may become susceptible to mycotoxin-producing fungi later in the season (fig. 8.18).

Sap beetle management

Most insecticides labeled for major corn insect pests are also labeled for use against sap beetles. Economic thresholds have not been determined. *Bt*-corn hybrids currently available are completely ineffective against sap beetles.

Corn Root Aphid (*Aphis maidiradicis*)

Pest highlights

- Corn root aphids overwinter as eggs in the nests of cornfield ants.
- Ants "farm" the aphids for their honeydew.
- The aphids feed on the sap of corn seedlings, using syringe-like mouthparts.
- Infested seedlings appear yellowish and stunted.

Figure 8.15. A picnic (sap) beetle on a corn ear

(Photo courtesy of Jon Kieckhefer, South Dakota State University)

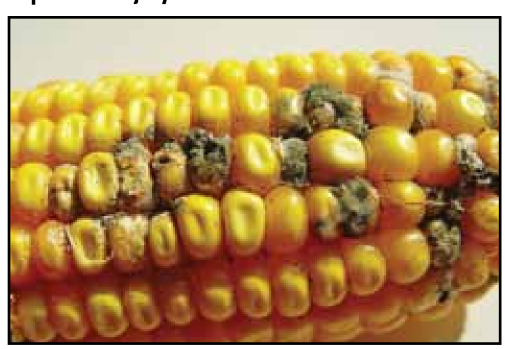
Figure 8.16. Dusky sap beetles

(Photo courtesy of Mike Catangui, South Dakota State University)

Figure 8.17. Sap beetle larvae on a corn ear

(Photo courtesy of Mike Catangui, South Dakota State University)

Figure 8.18. Fungal infection on a corn ear after sap beetle injury



(Photo courtesy of Mike Catangui, South Dakota State University)

Corn root aphid description

Corn root aphids are plump, yellow-green to blue-green insects, about 1/16-inch long when fully grown (fig. 8.19). They have syringe-like mouthparts to withdraw sap from the roots. Corn root aphids are usually found underground, clustered around the roots of corn plants. Individual aphids can either be winged or wingless, with the former usually darker in color than the latter. Stunted and yellowish corn seedlings, along with the presence of numerous cornfield ants and ant nests, may be signs of corn root aphid infestations (fig. 8.20).

Figure 8.19. Corn root aphid adults and nymphs

(Photo courtesy of Heinrichs et al.)

Corn root aphid biology

Corn root aphids spend much of their time underground, feeding on the sap of corn roots. The honeydew that aphids excrete is used by cornfield ants as food. There is a symbiotic relationship between the ants and aphids. Aphids supply food to the ants, while the ants protect and transport the aphids. Although the corn root aphid is capable of forming wings, its dispersion is aided by cornfield ants. Corn root aphids overwinter as eggs that are cared for by cornfield ants in their nests. These eggs hatch in the spring and are carried by ants to the roots of acceptable available plants such as smartweed, wheat, and corn. Aphids can also be carried by the ants from weeds to corn later in the season. Like most aphid species, corn root aphids multiply very fast and complete their life cycles from nymphs to adults within a week. Winged aphids may be produced when a colony becomes overcrowded. High numbers of aphids withdrawing sap from the roots of corn seedlings may result in the stunting and yellowing of corn leaves (fig. 8.20).

Figure 8.20. Suspected area (due to numerous ant nests present and corn injury symptoms) of corn root aphid infestation

(Photo courtesy of Roger Barrick, South Dakota State University)

Corn root aphid management

There are currently no economic thresholds or insecticides available for use against corn root aphids on corn in South Dakota.

Corn Leaf Aphid (*Rhopalosiphum maidis*)

Pest highlights

- Corn leaf aphids mainly infest the whorl, tassel, and developing ears.
- Heavy infestations may reduce photosynthesis, pollination, and ear development.
- Maize dwarf mosaic virus can be transmitted by corn leaf aphids.
- Honeydew produced by the aphids may attract other pests, such as molds and sap beetles.

Figure 8.21. Corn leaf aphid adults and nymphs

(Photo courtesy of Jon Kieckhefer, South Dakota State University)

Corn leaf aphid description

Bluish-green wingless and winged corn leaf aphids range in size from 1/16 to 1/8 inch (fig. 8.21); both wingless and winged forms may be present. Corn leaf aphids can usually be found in the whorl, tassel, developing ears, and upper leaves. Heavily infested plants may appear “messy” or “sticky” (fig. 8.22).

Corn leaf aphid biology

Corn leaf aphids do not overwinter in South Dakota, because they are killed by frost. Winged adults arrive in June from warmer climates. Once on the corn plants, the aphids multiply very quickly by giving birth to live aphids. Initially the corn whorls are infested, but as the season progresses the infestation spreads to the emerging tassels, silking ears, and upper leaves. The entire plant potentially can be covered with corn leaf aphids. Like any other aphid species, corn leaf aphids have syringe-like mouthparts that they use for withdrawing sap. Partially digested sap is continuously excreted as honeydew. Winged aphids can migrate into nearby cornfields. Corn leaf aphids can reduce yields by directly interfering with pollination and by causing plant stress during the reproductive stages from VT to silking.

Figure 8.22. Corn leaf aphids on tassel and leaf

(Photo courtesy of Mike Catangui, South Dakota State University)

Corn leaf aphid management

Management decision-making tools are available for the corn leaf aphid. Information for scouting and estimating economic thresholds is available at http://plantsci.sdstate.edu/ent/.

Additional Information and References

Catangui, M. A. 2000. European corn borer in South Dakota. South Dakota State University, Brookings, SD. http://plantsci.sdstate.edu/ent/ecb/ecb_mgmt_SD.htm.

Catangui, M. A. 2003. Transgenic Bacillus thuringiensis corn hybrid performance against univoltine ecotype European corn borer (Lepidoptera: Crambidae) in South Dakota. Jour. of Econ. Entomology. 96: 957–68.

Catangui, M. A. and R. K. Berg. 2002. Comparison of Bacillus thuringiensis corn hybrids and insecticide-treated isolines exposed to bivoltine European corn borer (Lepidoptera: Crambidae) in South Dakota. Jour. of Econ. Entomology. 95: 155–66.

Catangui, M. A. and R. K. Berg. 2006. Western bean cutworm, Striacosta albicosta (Smith) (Lepidoptera: Noctuidae), as a potential pest of transgenic Cry 1Ab Bacillus thuringiensis corn hybrids in South Dakota. Environmental Entomology. 35: 1439–52.

Heinrichs, E. A., J. E. Foster, and M. E. Rice. 2006. Maize insect pests in North America. In: E. B. Radcliffe and W. D. Hutchison [eds.], Radcliffe's IPM World Textbook. University of Minnesota, St. Paul, MN. http://ipmworld.umn.edu.

North Central Regional Extension Publication No. 327. 1998. European corn borer: ecology and management. Iowa State University, Ames, IA.

Steffey, K. L., M. E. Rice, J. All, D. A. Andow, M. E. Gray, and J. W. Van Duyn (eds.). 1999. Handbook of Corn Insects. Entomological Society of America, Lanham, MD.

Catangui, M.A., B.W. Fuller, and B.W. French. 2009. "Corn insect pests." Pp. 49–58. In Clay, D.E., K.D. Reitsma, and S.A, Clay (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 9
Corn Diseases in South Dakota

Corn diseases can be separated into 1) seed and seedling diseases, 2) root-infecting nematodes, 3) leaf diseases, 4) rusts, 5) stalk rots, and 6) ear and grain molds. Yield losses can result from diseases directly reducing yields or from harvestability, spoilage, or marketing and/or use issues associated with mycotoxin contamination. See Table 9.1 for corn disease management information.

Attention to optimal seed quality, hybrid selection, seed treatments, weed and insect control, crop rotation, soil fertility, irrigation, and prompt harvest can reduce disease impacts. This chapter discusses aspects of recognizing and managing South Dakota corn diseases.

Seed and Seedling Diseases

The major seed and seedling diseases of corn in South Dakota are seed rot, damping-off, and seedling blights. Fungi that are found naturally in soil cause these diseases. Losses from seed and seedling diseases can be severe, especially in years when soils remain cool and wet after planting. Poorly drained

Table 9.2. Managing seed and seedling diseases

➤ **Fungicide seed treatments**
- Captan (not effective against *Pythium*)
- Fludioxonil (not effective against *Pythium*)
- Metalaxyl
- Mefanoxam

➤ **Cultural practices**
- Avoid planting when soil temp <50°F.
- Place seed at appropriate depth.
- Use quality seed treated with fungicide.
- Manage crop residue.
- Avoid conditions that compact soil.
- Consider drainage, if feasible.

Table 9.1. Corn disease management

Preplant considerations
- Know the disease history of fields and select hybrids resistant to the most common diseases.
- Always choose high-quality seed that has been treated with fungicide.
- Use seed treatment fungicides that address known disease risks.
- Avoid planting when soil is cold and wet.
- Avoid situations that favor soil compaction.
- Manage crop residue to avoid clumps or areas of heavy mulch.
- Plant seed at populations recommended for the selected hybrid.
- Regularly rotate to crops other than corn.
- Avoid nutrient deficiencies. Potassium nutrition is most critical.

In-season considerations
- Periodically scout for diseases to identify problems for future management decisions.
- Control grassy weeds in and around fields to destroy sites where pathogens and pathogen carriers can survive.
- Control insects that may act to transmit diseases from plant to plant.
- Apply an effective fungicide to susceptible hybrids when conditions favor disease and scouting indicates a threat.

Grain storage and use
- If grain is to be stored for more than 6 months, maintain grain moisture content at or below 13%.
- To reduce spoilage potential, sanitize bins before filling.
- If ear or kernel diseases are observed, test grain for mycotoxins before feeding.

soils or areas with heavy residue cover often have more disease problems than do well-drained soils.

Poor, sparse, or irregular stands and wilting and damping-off of young seedlings are typical symptoms of seed and seedling diseases. Poor-quality seed (low test weight) can lead to poor vigor and increased disease problems. Control for seedling diseases includes broad-spectrum seed treatments and various cultural practices that reduce seedling stress (Table 9.2).

Table 9.3. Nematodes parasitic to corn

- *Pratylenchus* (lesion)
- *Xiphinema* (dagger)
- *Hoplolaimus* (lance)
- *Longidorus* (needle)
- *Trichodorus* and *Paratrichodorus* (stubby-root)
- *Tylenchorhynchus* (stunt)

Nematodes

Nematodes are microscopic roundworms commonly found in soil. Some species are beneficial, while others are detrimental to crops. Nematodes that feed on corn roots reduce the root mass and allow entry of fungi that cause root diseases. Corn yield losses can result from *Pratylenchus* infestations in South Dakota. To date, other nematode species have been inconsequential in South Dakota corn production. It is not economically feasible to use nematicides for the control of corn nematodes, unless a soil analysis reveals exceptionally high populations. See Table 9.3 for a list of nematodes that are parasitic to corn.

➤ Symptoms of corn nematodes:
- Stunted plants and uneven plant height along rows.
- Uneven population.
- Yellow (chlorotic) plants.
- Poor ear fill.

➤ Managing corn nematodes:
- Soil analysis to determine population of a detrimental nematode.
- Contact your local Extension educator or the SDSU Nematode Testing Service for assistance.

Fungal Leaf Diseases

Substantial yield losses can result from leaf diseases. Leaf diseases increase the susceptibility of the plant to stalk rots that can lead to ear rots, lodging, and poor grain quality. Yield reductions are related to hybrid susceptibility, the presence of inoculum, weather conditions, and the timing of the infection. In addition, excessive crop residue on the soil surface can increase leaf diseases. Gray leaf spot and anthracnose were mere curiosities until the wide-scale adoption of no-till systems.

Residue-borne diseases can be managed by selecting resistant hybrids, by burying surface residue with tillage, and by crop rotation. Any disease can be managed more effectively by recognizing incidence and practices that favor disease development (Table 9.4).

Table 9.4. Common South Dakota leaf diseases and symptoms

Northern Corn Leaf Blight
(Exserohilum turcicum, aka *Helminthosporium turcicum)*
Symptoms: Long, narrow, cigar-shaped, tan lesions (fig. 9.5).

Gray Leaf Spot
(Cercospora zeae-maydis)
Symptoms: Small, boxy, elongated, water-soaked lesions (fig. 9.6).

Eyespot
(Aureobasidium zeae, aka *Kabatiella zeae).*
Symptoms: Small, light-colored, circular lesions (1/8") (fig. 9.7).

Anthracnose
(Colletotrichum graminicola)
Symptoms: Large (~½" long), oval/elliptical, brown lesions (fig. 9.8).

Favorable conditions
- Warm, wet conditions; high humidity.
- Extended rainy periods.
- Heavy morning dew.
- Plants stressed by weather or poor fertility.
- Anthracnose is associated with potassium deficiency.

Management/control measures
- Tillage to reduce residue.
- Crop rotation.
- Resistant hybrids.
- Fungicides when conditions favor disease.

Northern corn leaf blight (NCLB)

Many modern hybrids have low resistance to northern corn leaf blight. This pathogen survives the winter on corn residue. Viable spores infect the leaves of the following corn crop, producing cigar-shaped lesions that can become quite large (fig. 9.1).

Gray leaf spot (GLS)

Gray leaf spot (GLS) survives on corn residue and is a serious problem in reduced-till and no-till irrigated fields. Symptoms of GLS are elongated, angular lesions that may grow together to form large dead areas on leaves (fig. 9.2). Significant yield reductions can result from heavy infestations.

Eyespot

Eyespot is a problem in continuous corn and reduced-tillage systems because the pathogen survives on corn residue. In rare cases, yield loss may be significant due to barren ears and reduced plant vigor. Symptoms of eyespot are small, light-colored, circular lesions (fig. 9.3). Light to moderate infections typically result in little to no yield loss, but symptoms can be striking. Eyespot may increase susceptibility to stalk, ear, and grain rots. Resistant hybrids are the best defense against this disease.

Anthracnose

Anthracnose is a leaf spot or blight that may develop into a stalk rot. Symptoms are large (~½" long) oval/elliptical brown lesions (fig. 9.4). The pathogen that causes anthracnose survives on corn residue. Potassium deficiency and continuous corn systems elevate the risk for this disease. Residue management and selecting resistant hybrids are the best options for control.

Figure 9.1. Northern corn leaf blight

(Photo courtesy of Martin Draper, USDA-CSREES)

Figure 9.2. Gray leaf spot in corn

(Photo courtesy of Martin Draper, USDA-CSREES)

Figure 9.3. Eyespot in corn

(Photo courtesy of University of Nebraska)

Figure 9.4. Anthracnose in corn

(Photo courtesy of Martin Draper, USDA-CSREES)

Fungal Leaf Diseases – Rusts

Spores of rust-causing fungi typically blow in on southerly winds. The rust that frequently occurs in South Dakota, common corn rust, is less of a yield threat than is southern corn rust. Selecting resistant hybrids is the best strategy for control.

- ➤ Disease organism
  - Common corn rust (*Puccinia sorghi*) (fig. 9.5a)
  - Southern corn rust (*Puccinia polysora*) (fig. 9.5b)
- ➤ Symptoms
  - Erupting pustules of reddish-brown spores that crack the epidermis and easily rub off.
  - Common rust sporulates on the both upper and lower leaf surfaces.
  - Southern rust sporulation is heavier on the upper leaf surface.
- ➤ Favorable conditions
  - Cool nights.
  - Dews or light rains.
- ➤ Management/control measures
  - Resistant hybrids.
  - Fungicides are only recommended to protect susceptible inbred lines.

Figure 9.5. Corn rusts

a. Common corn rust

b. Southern corn rust

(Photos courtesy of Karen Rane and Gail Ruhl, University of Maryland)

Bacterial Diseases

Bacterial diseases can be destructive if infections are severe and widespread. The selection of resistant hybrids and the use of other integrated pest management strategies is the best approach for controlling bacterial diseases. Anti-bacterial pesticides are not available for sale.

Stewart's disease

This disease (fig. 9.6) is occasionally seen in southeast South Dakota. It is spread by corn flea beetles feeding on plant leaves. Incidence and the severity of the disease is related to the winter survival of flea beetles.

Figure 9.6. Symptoms of Stewart's bacterial disease

(Photo courtesy of Martin Draper, USDA-CSREES)

Table 9.5. Organisms and symptoms of common bacterial diseases in South Dakota

Stewart's disease (*Pantoea [Erwinia] stewartii*)
Symptoms: Water-soaked margins (fig. 9.11) and flea beetle feeding.
Holcus spot (*Pseudomonas syringae*)
Symptoms: Circular tan and papery lesions 3/8 inch in diameter (fig. 9.12).
Goss's wilt (*Clavibacter michiganense*)
Symptoms: Small green to black lesions that may grow together, progressing to discolored vascular tissue with a slimy stalk rot leading to wilting (fig. 9.13).

Favorable conditions

- Warm winters may elevate populations of flea beetles that carry the disease organism (Stewart's disease).
- Heavy rainfall, especially when accompanied by high winds.

Management/control measures

- Tillage to bury crop residue.
- Crop rotations.
- Selection of resistant hybrids where appropriate.

Flea beetles are likely to overwinter if the *sum* of the average monthly temperatures for December, January, and February in degrees Fahrenheit (°F) is greater than 90. The wilt phase of this disease has not been observed in South Dakota from 1997 to 2007.

Holcus leaf spot

Leaf spot is sporadically observed in South Dakota but is not known to reduce yield or grain quality. Symptoms are tan, papery, circular lesions (3/8" diameter) (fig. 9.7) and can be mistaken for paraquat injury. The bacterium survives on corn residue, spreading by rain splash. Typically, infections follow heavy thunderstorms or irrigation. Crop rotation and residue management are recommended in situations of severe outbreak.

Goss's wilt

Goss's wilt is rare in South Dakota. It was first recognized in south-central Nebraska. The pathogen can be seed borne but is also associated with residue, making it a potential problem in continuous corn or reduced tillage systems. Most problems are observed on susceptible hybrids and inbred lines.

Goss's wilt is generally restricted to the leaf-spotting phase of the disease, sometimes called "freckles." Spots may coalesce, forming large dead areas on the leaf. In some cases the disease becomes vascular, causing the wilt phase of the disease (fig. 9.8).

Viral Diseases

While many viruses are known to infect and cause corn diseases, only wheat streak mosaic virus (WSMV) and maize dwarf mosaic virus (MDMV) are observed to varying degrees in South Dakota. Wheat streak mosaic can be severe on wheat but rarely causes measureable yield loss in corn. Nonetheless, corn may serve as a reservoir for WSMV, infecting newly planted winter wheat in the fall.

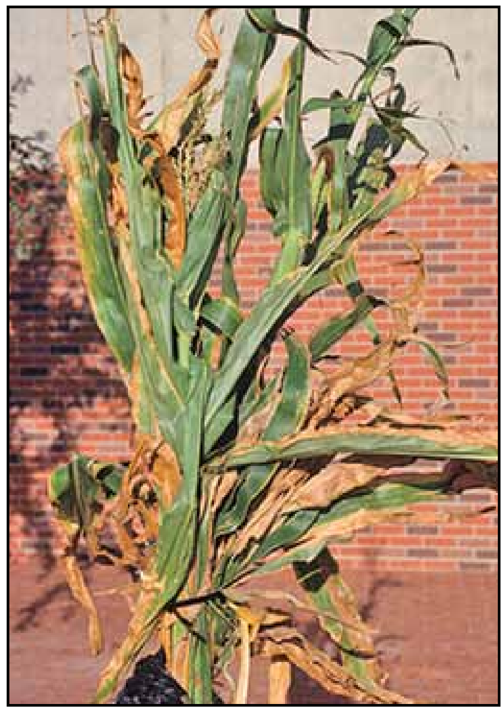
The wheat curl mite (*Aceria tosichella Keifer*) transmits WSMV and can survive on both wheat and corn. Corn serves as a host for the mite after wheat harvest, until a new crop of wheat emerges. Winter wheat adjacent to corn may be at risk from WSMV. In corn, wheat curl mites feeding in developing ears cause a kernel red streak (fig. 9.9); the streak is a response to a toxin in the saliva of the mite. Red streak is often seen during drought periods that favor wheat curl mite populations.

MDMV is transmitted by several species of aphids, especially the corn leaf aphid. Aphids overwinter in

Figure 9.7. Symptoms of Holcus leaf spot

(Photo courtesy of Martin Draper, USDA-CSREES)

Figure 9.8. Symptoms of Goss's wilt



(Photo courtesy of University of Nebraska-Lincoln)

Figure 9.9. Kernel red streak (response to toxin in saliva of wheat curl mite [*Aceria tosichella Keifer*])

(Photo courtesy of Martin Draper, USDA-CSREES)

Figure 9.10. Maize dwarf mosaic

(Photo courtesy of UC-Davis)

the southern United States and are brought to South Dakota by southerly winds and low-level jet streams.

Losses from MDMV are normally negligible in hybrid corn. MDMV can be problematic when planting is delayed or in susceptible inbred lines. Symptoms (fig. 9.10) will be more pronounced following periods with cool nighttime temperatures.

Resistant corn hybrids and wheat varieties are the best lines of defense against WSMV and MDMV, but a single hybrid cannot carry resistance genes for both diseases (Table 9.6).

Table 9.6. Organisms and symptoms of common viral diseases in South Dakota

Wheat Streak Mosaic Virus
Symptoms: Small chlorotic spots or rows of broken flecks that elongate parallel to the leaf veins.
Maize Dwarf Mosaic Virus.
Symptoms: Small chlorotic spots also oriented in rows parallel to the leaf veins (fig. 9.10).

Favorable Conditions
- Wheat Streak Mosaic – Dry weather and exposure to wheat curl mites.
- Maize Dwarf Mosaic – Cool nights, susceptible inbred lines, delayed planting, and aphid feeding.

Management/Control Measures
- Wheat Streak Mosaic – Avoid planting in wheat stubble and adjacent to wheat fields.
- Control grassy weeds and volunteer wheat.
- Resistant hybrids – No single hybrid can carry resistance for both WSM and MDM viruses.

Smuts

Smut is the most common and easily identified disease in corn. Common corn smut may occur on ears, tassels, or leaves (Table 9.7). This fungus can infect any rapidly growing tissue (fig. 9.11). Yield losses from common smut can be significant for susceptible hybrids.

Table 9.7. Characteristics of smuts found in South Dakota

Disease organism and symptoms
Common Smut (*Ustilago zeae*)
Symptoms: Silvery-white galls on ears and tassels (fig. 9.11); small to elongated pustules on leaf midrib.
Head Smut (*Sphacelotheca reiliana*)
Symptoms: Dark, "stringy" masses emerging from ear sheath or consuming tassel (rare).

Favorable conditions
- Plant injury from insects, hail, wind or field equipment.

Management/control measures
- Resistant hybrids.
- Reduce plant stress.
- Manage ear feeding insects.
- Balanced fertility.
- Fungicides are not proven to be efficacious.

Figure 9.11. Common corn smut (ear)

(Photo courtesy of Kurtis D. Reitsma, South Dakota State University)

Head smut is rare but has been reported in South Dakota. Head smut-infected ears are severely reduced in size, and the galls are not apparent. Most hybrids are tolerant to head smut.

Smut spores attached to soil particles can be blown long distances by the wind. Hot, dry conditions are favorable for transport of the spores. Wounds provide infection points for the fungus to enter the plant.

Management includes the adoption of techniques that reduce wounds (corn borers, injury to roots, stalks, and leaves), deep plowing of diseased stalks, and the use of resistant hybrids. Usually, smut-infected plants are destroyed. In Mexico, however, smut is called *nuitlacoche*, which is considered a delicacy.

Stalk Rots

Stalk rots are among the most common and damaging of the corn diseases (Table 9.8; figs. 9.12, 9.13, and 9.14). Yield losses result from premature plant death and lodging.

The severity of stalk rot loss can be minimized by ensuring that optimal nitrogen (N) and potassium (K) levels are present. Excessive N that is out of balance with K can cause a rapid flush of growth that does not have sufficient structural composition to ward off colonization by fungal pathogens. Plants weakened by disease, drought, and other stressors may be predisposed to stalk rots. Increased severity of stalk rot is often observed in high plant populations.

Control measures for many stalk rot diseases include burying the residue by tillage or including non-host plants in the rotation. Adoption of conservation tillage may reduce stalk rot incidence by increasing water availability and reducing plant stress in a dry environment. However, in environments that favor stalk rot, non-host years are important.

Figure 9.12. Gibberella stalk rot

(Photo courtesy of Bradley E. Ruden, South Dakota State University)

Table 9.8. Organisms and symptoms of common stalk rot diseases in South Dakota

Fungi

Gibberella stalk rot (*Gibberella zeae* aka *Fusarium graminearum*) (fig. 9.12)
Fusarium stalk rot (*Fusarium* spp.) (fig. 9.13)
Charcoal rot (*Macrophomina phaseolina*) (fig. 9.14)

Bacteria

Erwinia stalk rot (*Erwinia carotovora* ssp. *carotovora*)

Symptoms

- Decay of pith in the center of stalk while the rind remains sound.
- Lodging.

Favorable conditions

- Nutrient deficiencies.
- Deficiency or imbalance of N and/or K.
- High plant populations under stress.
- Wet spring weather followed by hot, dry conditions in the late summer.
- Erwinia stalk rot is associated with overhead irrigation systems using surface water sources.

Management/control measures

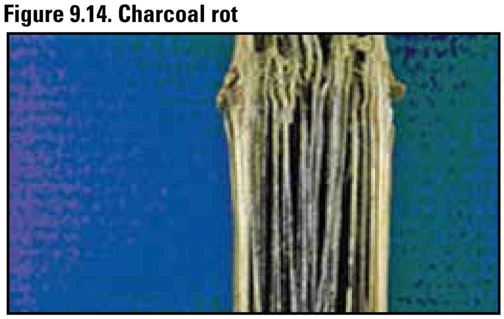
- Resistant hybrids.
- Ensure sufficient levels of N and K are in soil.

Figure 9.13. Fusarium stalk rot

Cross section of a corn stalk infected with *fusarium* stalk rot. Note the stringy appearance of the tissue in the center of the stalk.

(Photo courtesy of Bradley E. Ruden, South Dakota State University)

Figure 9.14. Charcoal rot



(Photo courtesy of Bradley E. Ruden, South Dakota State University)

Ear and Kernel Rots – Mycotoxins

Ear and grain molds can severely reduce grain quality. Spoilage or mycotoxin concentration can limit end-use or reduce profits due to dockage or rejection at the point of sale. See Table 9.9 for additional information

The most common fungi that produce mycotoxins and attack grain are *Apergillus*, *Fusarium*, and *Penicillium*. However, not all ear rot diseases produce mycotoxins (e.g., Diplodia ear rot). Crop stress from drought; ear injury (e.g., hail); or cool, wet conditions following silking (R2) favor ear molds.

If infections occur in the field, look for the characteristic cottony growth of fungal mycelium. *Aspergillus* or *Penicillium* produce powdery yellow-green or blue-green mold, respectively, between the kernels, usually at the ear tip (figs. 9.15 and 9.16). *Fusarium* produces a whitish-pink to lavender mold on kernels and/or silks (fig. 9.17). *Gibberella* generally appears as a reddish or pinkish mold growing from the tip down the ear (fig. 9.18). Diplodia ear rot appears as a white or grayish mold between the kernels and is concentrated at the base of the ear (fig. 9.19). The husks appear bleached and may stick to the ear.

Stored grain with a moisture content of greater than 13% may be subject to mycotoxin problems. Stored grain with Penicillium ear molds may have a blue discoloration of the embryo ("blue-eye" mold) or a light cover of a yellow-green mold. *Aspergillus*-infected kernels may fluoresce green under UV light.

Figure 9.15. Aspergillus ear rot (*Aspergillus* spp.)

(Photo courtesy of Gary Munkvold, Iowa State University)

Table 9.9. Ear and kernel rot characteristics commonly found in South Dakota

Disease organisms (all fungi)

Aspergillus ear rot (*Aspergillus* spp.) (fig. 9.15)
Penicillium ear rot (*Penicillium oxalicum* [Currie and Thom]) (fig. 9.16)
Fusarium kernel or ear rot (*Fusarium* spp.) (fig. 9.17)
Gibberella ear rot (*Gibberella zeae* [Schwein.]) (fig. 9.18)
Diplodia ear rot (*Diplodia maydis* [Berk.] and *D. zeae* [Schwein.] Lev.) (fig. 9.19)

Management and control

- Timely planting, adequate fertility, good weed and insect control, supplemental irrigation, and suitable plant population and hybrid selection.
- Mycotoxin concentrations can be the highest in damaged kernels. Screening to remove smaller or cracked kernels can reduce concentrations.
- Properly harvesting, drying, and storing grain can reduce risk. Stored corn with a moisture content >13% can result in mold and mycotoxin production if not handled properly. Wet corn should be dried within 24 hours of harvest. Minimize the time that wet corn is stored in trucks, combines, or bins to no more than 4 to 6 hours. Reducing grain depth, stirring devices, or batch dryers also speed the grain drying process. As grain moisture content approaches 12%, mold fungi typically become dormant.
- Clean combines, carts, augers, and bins regularly to minimize cross contamination. A chlorine cleaning solution (¾ cup bleach/gallon of water) will suppress fungi and can kill fungal growth on handling facilities if contact is sufficient in length.
- If mycotoxin contamination in grain is suspected, a subsample should be tested prior to feeding to livestock.

Figure 9.16. Penicillium ear rot

(Photo courtesy of Bill Zettler, University of Florida)

Figure 9.17. Fusarium kernel or ear rot (*Fusarium* spp.)

(Photo courtesy of Gary Munkvold, Iowa State University)

Figure 9.18. Gibberella ear rot (*Gibberella zeae* [Schwein])

(Photo courtesy of Martin Draper, USDA-CSREES)

Figure 9.19. Diplodia ear rot (*Diplodia maydis* [Berk.] and *D. zeae* [Schwein.] Lev.)

(Photos courtesy of Gary Munkvold, Iowa State University)

Mycotoxins

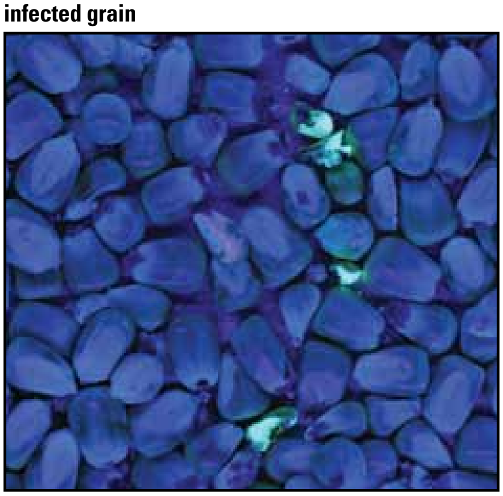
Fungi that infect cereals and grains often produce harmful metabolites that can reduce grain value. These metabolites are "mycotoxins," which means "fungus poison," and have serious effects if tainted grain is allowed to enter the food chain. During the Middle Ages, ergot-infected rye caused hallucinations. More recently, toxic concentrations of aflatoxin in corn used in pet food led to serious illness, death, and pet food recalls.

Grain is typically pre-screened for aflatoxin using a black light (UV) test (*Aspergillus*-infected grain generally glows bright green-yellow [fig. 9.20]). Although this test is quick and easy, it is not conclusive (because factors other than *Aspergillus* can cause grain to fluoresce). A definitive test in the laboratory is needed to confirm mycotoxin concentrations.

Corn suspected of containing aflatoxin or any other mycotoxin should be appropriately sampled and analyzed. The results of the analysis can provide the owner with options for disposition of the grain. Producers are advised to contact their local Extension educator or the SDSU Plant Diagnostic Clinic for more information regarding mycotoxin analysis.

Serious illness or death may occur in livestock if feeding guidelines developed by the United States Food and Drug Administration (FDA) are exceeded. FDA feeding guidelines and action levels are summarized in Table 9.10.

Figure 9.20. Black light (UV) test showing infected grain



(Photo courtesy of Bradley Ruden, South Dakota State University)

Table 9.10. Summary of U.S. Food and Drug Administration animal feeding guidelines

- ➤ Aflatoxin - produced by *Aspergillus* spp.
  - FDA animal feed guidelines – ***do not exceed:***
    - ♦ Dairy – 5 ppb.
    - ♦ Aflatoxin M1 can accumulate in lactating dairy cattle, leading to contaminated milk.
      - – FDA action level for milk – 0.5 ppb.
  - Mature breeding beef cattle, swine, and poultry – 100 ppb.
  - Finishing swine – 200 ppb.
  - Finishing beef – 300 ppb.
  - Human consumption.
    - ♦ FDA action level for all human food – 20 ppb.
- ➤ Fumonisins - produced by *Fusarium* spp.
  - FDA animal feed guidelines:
    - ♦ Horses – 5 ppm
    - ♦ Swine – 10 ppm
    - ♦ Cattle – 50 ppm
- ➤ Deoxynivalenol (DON) aka vomitoxin - produced by *Fusarium* spp.
  - FDA animal feed guidelines:
    - ♦ Cattle and chickens – 10 ppm not to exceed 50% of the diet.
  - Swine – 5 ppm not to exceed 20% of the diet.
  - All other animals – 5 ppm not to exceed 40% of the diet.
    - ♦ Can reduce weight gain and feed refusal at lower levels.
  - Human consumption.
    - ♦ FDA recommendation <1 ppm.
- ➤ Zearalenone - produced by *Fusarium* spp.
  - Zearalenone production is associated with excessive fall rainfall; highest accumulations are associated with fluctuating temperatures in the low to moderate range, particularly if high-moisture corn is harvested and stored.
  - FDA animal feed guidelines have not been developed.
    - ♦ Zearalenone has estrogenic properties and can affect livestock reproduction.
      - – Swine are the most sensitive livestock.
        - ♦ Concentrations of 1 to 5 ppm can adversely affect young gilts and breeding sows.
    - ♦ Can affect cattle and poultry.
      - – Poultry are the least sensitive.
- ➤ Ochratoxins - produced by *Penicillium* spp. ("Blue Eye")
  - Toxin is produced after harvest during improper storage. Storage of corn with moisture levels below 16% prevents accumulation of ochratoxin.
  - FDA animal feed guidelines have not been developed.
  - Major concern in swine but can also affect poultry.

Additional Information and References

Cassel, E.K., B. Campbell, M.A. Draper, and B. Epperson. 2001. Aflatoxins: hazards in grain/aflatoxicosis in livestock. FS907. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD. http://agbiopubs.sdstate.edu.

Draper, M.A. 2004. Common corn smut. FS918. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD. http://agbiopubs.sdstate.edu.

Jackson, T.A., R.M. Harveson, and A.K. Vidaver. 2007. Goss's bacterial wilt and leaf blight of corn. G1675. University of Nebraska-Lincoln Extension Service. Lincoln NE. http://www.ianrpubs.unl.edu/epublic/pages/publicationD.jsp?publicationId=679.

Larson, E. 2007. Minimizing aflatoxin in corn. Mississippi State Information Sheet 1563. http://msucares.com/pubs/infosheets/is1563.htm.

Rane, K. and G. Ruhl. Crop diseases in corn, soybean and wheat. 2007. Extension/Pathology/CropDiseases/Corn/ Purdue University, Department of Botany and Plant Pathology. West Lafayette. http://www.btny.purdue.edu/.

Ruden K. and M.A. Draper. 2007. Managing Crop Diseases with Fungicides. FS917. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD. http://agbiopubs.sdstate.edu.

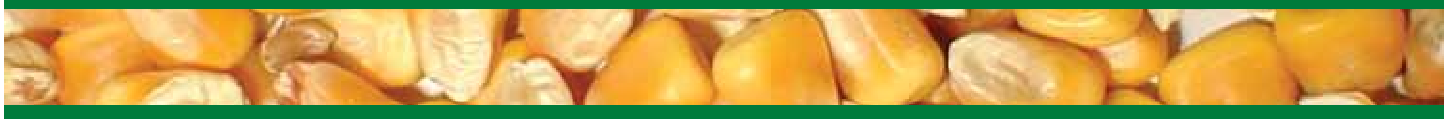
United States Department of Agriculture, Grain Inspection, Packers & Stockyards Administration. 2006. Grain fungal disease & mycotoxin reference. http://archive.gipsa.usda.gov/pubs/mycobook.pdf .

WeedSoft© Crop Growth Stage Learning Module; Corn. 2007. University of Nebraska–Lincoln. http://weedsoft.unl.edu/Publications.htm.

Draper, M.A., M. A. Langham, S.A. Clay, and B.E. Ruden. 2009. "Corn diseases in South Dakota." Pp. 59–69. In Clay, D.E., S.A, Clay, and K.D. Reitsma (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 10
Weeds and Herbicide Injury in Corn



This chapter addresses weed problems and herbicide injuries that commonly occur in South Dakota corn production. Photographs and information are provided to assist producers in managing weed pressure and to help identify herbicide injury symptoms resulting from improper application, unintentional exposure, or adverse environmental conditions.

Effective and economical weed management depends on reliable agronomic practices (Table 10.1). Uncontrolled weeds can reduce yield, harbor insects and diseases, or interfere with harvest. Weeds emerging early in the season are generally the most competitive, resulting in the greatest yield loss, whereas late-emerging weeds produce few seeds and have a lesser effect on yield. When controlling weeds, it is important to adopt management strategies that minimize the risk of producing herbicide-resistant weeds (Table 10.2). The competitiveness of a weed is dependent on its species and density (Table 10.3). Optimal control timing improves yield potential by reducing weed pressure at critical growth stages. Weed control between the V2 and V8 growth stages is more critical compared to control of weeds that emerge after V8.

Table 10.1. Best management practices for weed control

Seed selection
- Selecting hybrids well adapted for the area.
- Planting high-quality seed at optimal populations with clean equipment.

Agronomic practices
- Reliable fertility-, insect-, and disease-management practices.
- Crop rotation.
- Uniform crop stands.

Weed identification and mapping
- Scouting and mapping problem areas in fields.
- Identifying weed species, densities, and noting location changes from year to year.

Herbicide selection
- Selecting herbicides that provide optimal control of critical weed species.
- Rotating herbicides that control weeds at different sites of action.

Herbicide application
- Calibrating and maintaining application equipment to apply herbicides at optimal rates.
- Proper application timing of pre- and post-emergent herbicides with respect to both weed and crop growth stages.

Herbicide Control

Effective herbicide programs are an integral component of the entire production enterprise and should be compatible with the entire cropping system. Well-developed programs are compatible with unique soils, tillage systems, weed problems, crops, and crop use. Herbicide selections should be based on the scope and magnitude of weed problems and on the potential return

Table 10.2. Management to minimize the herbicide resistance of weeds

- Scout fields for resistant weeds.
- Rotate herbicides by
  - mode of action,
  - active ingredient.
- Use tillage or cultivation for control when weeds are excessive.

(Hager and Retsell 2008)

Table 10.3. Relative competitiveness of common South Dakota weeds
Yield loss due to weeds varies by species, weed density, and time of emergence. Weeds that emerge early tend to cause more yield loss than those that emerge after crop establishment. All weeds have the potential to cause 100% yield loss; however, some are relatively more competitive with corn than others. This table gives a relative rating of different weed species and their ability to cause a measurable (usually 5%) yield loss.

Highly competitive weeds (1 or fewer plants per foot of row result in yield loss.)			
Common cocklebur	Common sunflower	Common waterhemp	Giant ragweed
Moderately competitive weeds (5 to 10 plants needed per foot of row to result in yield loss.)			
Canada thistle	Field bindweed	Switch grass	Velvetleaf
Hedge bindweed	Horseweed	Volunteer corn	Giant foxtail
Common lambsquarters	Woolly cupgrass	Redroot pigweed	Russian thistle
Kochia	Wild proso millet		
Low competitive weeds (>10 needed per foot of row to result in yield loss.)			
Wild buckwheat	Green foxtail	Yellow foxtail	Longspine sandbur
Large crabgrass	Witchgrass	Venice mallow	Barnyardgrass

on investment. Always read and follow product label instructions before tank mixing and application. Add adjuvants at the correct rate and only if recommended on the label. Make sure the sprayer is calibrated so that proper amounts of herbicide are applied. Application at optimal crop and weed growth stages decreases the chances of crop injury and increases product effectiveness and yield potential.

Some herbicide products require incorporation for optimal performance. Herbicides are typically incorporated with some type of tillage, such as disking. A good "rule of thumb" is that a product will be incorporated about half the depth of the tillage. For example, disking at 4 inches incorporates the product 2-inches deep.

A disadvantage of herbicidal weed control is that weeds may become tolerant or resistant to a herbicide that is used continuously. Many producers have been relying on glyphosate-resistant (e.g., RoundupTM) genetics for the basis of their weed control. In 2005, over 73% of South Dakota corn acreage had a glyphosate product applied. The reliance on a single herbicide may result in unwanted and unexpected consequences, such as weed species shifts or herbicide resistance.

Herbicide-resistant weed populations can occur when a single herbicide or multiple herbicides with the same mode of action are used repeatedly over several years. In several Midwestern states, ryegrass, Johnsongrass, common waterhemp, horseweed, and common and giant ragweed have been identified as glyphosate resistant. In addition, densities of tolerant weeds (e.g., those that were never well-controlled with the herbicide) may increase.

Glyphosate-tolerant weeds in South Dakota and surrounding areas include velvetleaf, wild buckwheat, field bindweed, kochia, and Asiatic dayflower. Herbicide resistance and tolerance reduces weed control, leaves the producer with uncontrolled weeds, and may increase costs. In addition, across the United States more than 55 weed species have been documented to be resistant to several commonly used herbicides (including triazines; sulfonylureas and imidiaziliones; and 2,4-D). Resistance to these herbicides has been observed in pigweeds, kochia, and foxtails. Herbicide resistance can reduce 1) the efficacy of herbicides at high rates or 2) the efficacy of other herbicide products with a similar mode of action. The type of weeds in a field should be considered when developing a management plan. Herbicide programs in fields with a large percentage of glyphosate-tolerant plants should include alternative herbicide chemistries.

Scout and Map Fields to Identify Weed Species, Densities, and Location Changes

Effective field scouting includes identifying weed species and mapping problem areas. Maps can be drawn from scouting activities and can be used to identify species shifts and to assess weed control effectiveness. Scouting also helps determine if shifts in species or changes in control with a herbicide have occurred. This is valuable information for future weed management decisions. Information on mapping can be found in Clay et al. (1999).

Weed management options depend on tillage, corn genetics, and crop rotation. For example, mechanical control is not an option in a no-till system. For no-till corn, some important considerations include the following:

- Consider a burndown application prior to or at planting. Winter annuals such as horseweed and mustards are more difficult to control after they are >6-inches tall.
- For moderate to heavy weed infestations, consider tank mixing a soil-residual herbicide in the burndown application.
- If treating with a foliar-contact herbicide (such as glyphosate products), do not treat too early; the weeds must emerge for effective control.
- Do not apply the herbicide too late, as weeds may cause yield loss as early as the V2 stage. Large weeds are often more difficult to control than small weeds.
- Continue to scout the fields, and use a second application if needed. Some herbicides have no residual activity.
- If environmental conditions are favorable, a second weed flush can occur. Fields treated with herbicides that have residual activity are less likely to have multiple flushes.

In tilled systems, disking and cultivation can be effective weed control strategies. Rotary hoes can be effective to control small weeds in corn up to about the V2 growth stage. Keep inter-row cultivation as shallow as possible to reduce weed seed germination and soil water loss. The total amount of herbicide applied can be reduced by band applying the herbicides in-row and by relying on cultivation for inter-row weed control.

Biocontrol has not been shown to be an effective weed control strategy in corn, but biocontrol may be an option in adjacent non-cropped areas to reduce seed load. The South Dakota Department of Agriculture administers a program that provides assistance for the biocontrol of Canada thistle, leafy spurge, spotted knapweed, purple loosestrife, and musk thistle (http://www.state.sd.us/doa/das/hp-w&p.htm). Documenting the effectiveness of biocontrol efforts is important for future decisions. The success rates of biocontrol efforts are currently inconsistent. If biocontrol is ineffective, alternative control efforts are recommended.

Use Appropriate Cultural Practices

Good cultural practices can be used to reduce weed problems. For example, split or band fertilizer applications reduce weed growth. Planting when soil is warm results in rapid germination and canopy development. Planting narrow rows (e.g., 22") increases competition and canopy cover.

Cultivation is an option for curtailing weeds between rows. Rotary hoes work well for weed control between germination and emergence. In no-till systems, the importance of chemical control is increased because cultivation is not a viable option. When using Roundup (glyphosate) Ready™ seed in no-till systems, it is important to do the following:

- Consider a burndown application.
- Avoid early applications of glyphosate products (weeds must emerge for effective control).
- Avoid late applications of glyphosate products (the critical weed-free period for corn begins at V2, and early emerging weeds reduce yields).
- Continue field scouting, and use a second application if needed (the critical weed-free period ends between V6 and V8).

Sprayer Calibration and Maintenance

Applying herbicides at labeled rates is the legal obligation of the applicator. Well-maintained application equipment that applies treatments at the prescribed rate can optimize control and reduce under- or over-application. An investment of time and money for the replacement of worn or faulty parts can be minimal compared to the loss of product or crop yield. Equipment calibration is outlined in FS933, "Calibration of Pesticide Spraying Equipment" (Wilson 2006), which is available either from your county Extension educator or online at http://agbiopubs.sdstate.edu.

Anyone who applies pesticides (including herbicides) to an agricultural commodity that has a value greater than $1,000 is required to be a certified applicator (SDCL § 38-21-38). There are 2 classes of certification: private and commercial. Contact your local Extension educator or the South Dakota Department of Agriculture for more information on certification.

Certified applicators that handle and apply any pesticide are required by rule to have a written "pesticide handling and discharge response plan." A template for developing this plan is available from your local Extension educator or from the South Dakota Department of Agriculture at http://www.state.sd.us/doa/das/hp-pest.htm#handling. The plan can serve as a reference for action in the event of an emergency.

Herbicides are a regulated material and must be stored, handled, and applied in compliance with federal and state law. Some general safety suggestions are presented in Table 10.4. Questions regarding regulatory compliance should be directed to the South Dakota Department of Agriculture, Office of Agronomy Services, at (605) 773-4432.

Table 10.4. Safety tips for the transport, storage, and mixing of herbicides

Transport

- Place small containers (2.5 gal. or less) in watertight totes.
- Insure that loads do not exceed weight limits of trailers.
- Tie down tanks with load straps strong enough to secure the load.
- Avoid transportation on vehicles or trailers where the load can cause a rollover.

Storage

- Store herbicides away from sensitive areas such as wells, populated buildings, animal feed, and so on.
- Avoid storing herbicides in unheated storage over the winter – freezing may break containers or compromise the integrity of the product.
- Avoid storing or transporting near direct heat (e.g., furnaces or exhaust).
- Triple rinse containers, store in appropriate locations, and dispose as labels direct.
- Lock doors to avoid accidental opening or vandalism.

Usage

- Use secure hoses, containers, and pumps.
- Lock valves to avoid accidental opening or vandalism.
- Load and mix herbicides 150 feet from wells, lakes, or wetlands.
- Have an anti-back-siphon device when filling equipment.

Recordkeeping

The 1990 Farm Bill initiated the Pesticide Recordkeeping Program (PRP) and requires certified private applicators to keep records of all applications of federally registered restricted-use pesticides (RUP). Essentially, producers are required to record what RUP was used, and when, where, and to what crop it was applied. Instructions and recordkeeping forms are available by contacting county Extension educators, the South Dakota Department of Agriculture, or online from the USDA–Agricultural Marketing Service at http://www.ams.usda.gov/science/prb/Prbforms.htm. More information is provided in Chapter 13 ("Recordkeeping") of this publication.

Weed Identification: South Dakota Weeds of Importance

Weed control practices rely on the accurate identification of weeds. The weeds presented here (the images primarily are of seedlings and small plants) are common in many corn fields. Small weeds are controlled more easily with herbicides or tillage than larger weeds. Seedlings may be more difficult to identify than small plants. Rotation of crops, rotation of chemicals, and rotation of control methods are recommended to minimize weed problems.

Volunteer corn (*Zea mays*)

Time of emergence: Typically emerges early—before or just after planting—depending on soil temperature and moisture conditions.

Life cycle and reproduction: Annual, reproducing from seed lost during or before harvest.

Areas of infestation: Typically occurs in localized areas (fig 10.1). Can be problematic in corn monoculture systems or when a herbicide-resistant variety was planted the previous year.

Yield loss potential: Volunteer corn may cause yield losses up to 15%.

Effective management: Use techniques that minimize harvest loss discussed in Chapter 11 ("Corn Grain Harvest"). If a glyphosate-tolerant variety was planted, rotate to a broadleaf crop and use a grass herbicide or cultivate inter-row areas.

Herbicide resistance: Resistance depends on the transgenic traits of the hybrid from which the volunteers originated. Volunteers originating from hybrids resistant to glyphosate (Roundup Ready® varieties), glufosinate (LibertyLink® varieties), or sethoxydim will also be resistant to these herbicides.

Figure 10.1. Volunteer corn

(Photo courtesy of Mike Moechnig, South Dakota State University)

Woolly cupgrass (*Eriochloa villosa*)

Time of emergence: When soil temperatures are favorable, woolly cupgrass emerges before or just at planting. Germination season is short (all seedlings emerge within 2 weeks after initial emergence).

Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (fig. 10.2)**:** The cotyledon and the first true leaf are very wide. Leaves are covered in fine, soft hair (hence the name "woolly"), and one of the leaf margins generally is crinkled. This plant is often confused with foxtails but typically does not tiller as much as a foxtail plant. The seed head is a distinctive panicle with compressed rows of seed. The seeds are oval and vary in color from tan to brown to green.

Areas of infestation: Found in fertile loam to clay loam soils.

Yield loss potential: Moderately competitive, especially plants that emerge early in the season.

Effective management: Typically not controlled by pre-emergence grass herbicides in the acetanilide family, though early suppression may be seen.

Herbicide resistance: None has been reported.

Figure 10.2. Woolly cupgrass

(Photo courtesy of Weed Science Society of America. Illustration courtesy of Iowa State University)

Longspine sandbur (*Cenchrus longispinus*)

Time of emergence: Non-native warm-season grass, emerging after planting.

Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (fig. 10.3)**:** Sandbur has stems that are flattened with hairs and leaves that may be rough to the touch. The plant has a short, fringed, and hairy ligule. Seeds are enclosed in sharp, spiny, hairy burs that give the plant its name.

Areas of infestation: Found in sandy soils, though may be found in fertile loam to clay loam soils.

Yield loss potential: Yield loss is often low. Its sharp spurs make it a nuisance plant.

Effective management: Tillage is effective when sandbur is small. Competition with shading reduces growth. Chemical control is often effective.

Herbicide resistance: None has been reported.

Figure 10.3. Longspine sandbur

(Photos courtesy of California Department of Food and Agriculture)

Barnyardgrass (*Echinochloa crus-galli*)

Time of emergence: Warm-season grass, emerging late in the season after planting.

Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (fig. 10.4)**:** This warm-season grass has flattened, smooth, and branched stems without an auricle or ligule. This grass has broad leaves and typically is reddish or purple at the base of the plant. Barnyardgrass size can vary from 2-inches tall with only one tiller, to over 4-feet tall with 50+ tillers. Larger plants are found around field edges or in areas with poor canopy cover.

Areas of infestation: Found in wetter areas.

Yield loss potential: Yield loss is often low.

Effective management: Tillage is effective when plants are small. Shade under a crop canopy reduces growth. Chemical control is often effective.

Herbicide resistance: Biotypes resistant to photosynthetic inhibitors (e.g., atrazine), lipid synthesis inhibitors (e.g., sethoxydim), and other chemicals.

Figure 10.4. Barnyardgrass

(Photos courtesy of Pacific Northwest Weed Handbook)

Wild proso millet (*Panicum miliaceum*)

Time of emergence: Typically late in the season, after corn planting.

Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (fig. 10.5)**:** This warm-season grass has a round stem with a membranous ligule tipped with a fringe of hair. Seedlings look like corn but are hairy. Leaf blades are flat. Hairs may or may not be on the blade and sheath, but hairs are present at nodes. This grass can grow up to 6-feet tall. Seeds are large, shiny, and white, green striped, olive-brown, or black, and often remain on the root of seedlings, which helps in identification. Non-black seeds are usually not viable after two seasons; black seeds can remain viable for up to 4 years.

Areas of infestation: Tolerates sandy, dry soils and high temperatures.

Yield loss potential: Yield loss is moderate to high.

Effective management: Tillage is effective when plants are small. Shading by the crop canopy reduces growth. Chemical control often is effective. Sanitation of equipment is suggested to prevent spread.

Herbicide resistance: None noted at this time.

Figure 10.5. Wild proso millet

(Photos courtesy of Steve Dewey, Utah State University)

Giant foxtail (*Setaria faberi*), Yellow foxtail (*S. pumila*), and Green foxtail (*S. viridis*)

Time of emergence: Giant foxtail emerges just before or at corn planting. Yellow and green foxtails emerge toward the end of planting.

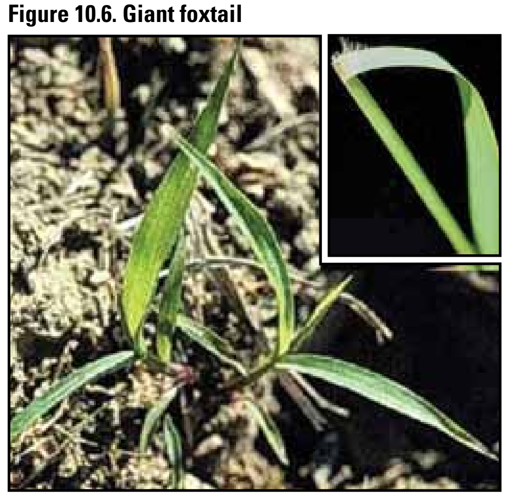
Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (figs. 10.6, 10.7)**:** Giant foxtail is infrequently found in South Dakota. Soft, short hairs are found on the leaf blade, and the plant has a hairy ligule. Plants can grow up to 7-feet tall. Yellow and green foxtails infest most eastern South Dakota fields. Yellow foxtail has long yellow hairs near the ligule, a flattened stem, and large seeds. Green foxtail has no or few hairs on the leaf blade, a round stem, and its seeds are small.

Areas of infestation: Common in several soil types and in many climates.

Yield loss potential: Depending on density, corn yield losses can approach 50%. The potential for yield loss is greater with giant foxtail compared to yellow or green foxtail at similar densities.

Figure 10.6. Giant foxtail



(Photos courtesy of Weed Science Society of America)

Effective management: Tillage, crop rotation, and post-emergence cultivation are effective control measures.

Herbicide resistance: Biotypes of these foxtails have shown resistance to a number of herbicides with different modes of action. Giant foxtail has been reported to be resistant to photosynthetic inhibitors (atrazine), ALS inhibitors (sulfonylureas and imidiazilinones), and lipid inhibitors (sethoxydim). Yellow foxtail has been reported to be resistant to ALS and photosynthetic inhibitor herbicides. Green foxtail has been reported to be resistant to dinitroanailine (trifluralin), ALS, lipid synthesis inhibitors, and photosynthetic inhibitors. Yellow foxtail is more tolerant to atrazine than are giant or green foxtail.

Large crabgrass (*Digitaria sanguinalis*)

Time of emergence: This warm-season grass emerges after corn emergence.

Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (fig. 10.8)**:** Hairs found everywhere on plant, and it has a flattened stem. Membranous ligule and seedhead finger-like spikes. This grass can grow from 6-inches to 2-feet tall.

Areas of infestation: No specific growing requirements.

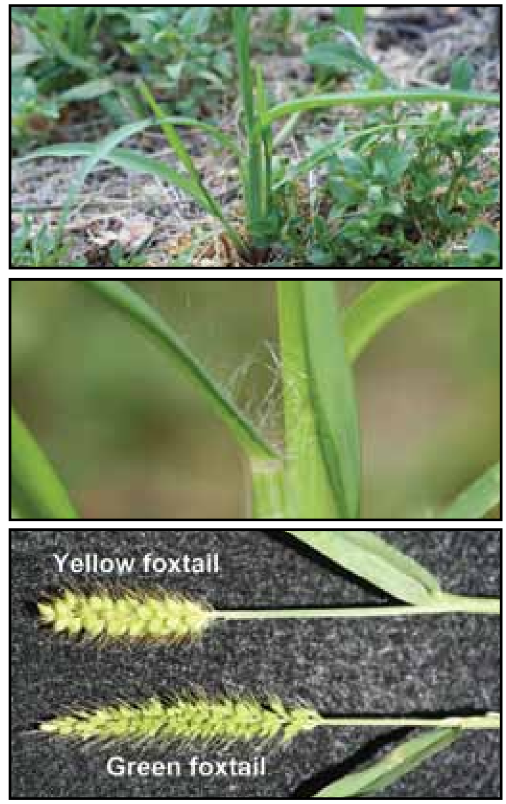
Yield loss potential: Low, even at high densities.

Effective management: Tillage, crop rotation, and post-emergence cultivation may be effective management tools.

Herbicide resistance: Herbicide resistance has been reported to lipid synthesis inhibitors (e.g., sethoxydim) in Wisconsin.

(Photo courtesy of Pacific Northwest Weed Handbook)

Figure 10.7. Yellow foxtail



(Photos courtesy of Mike Moechnig, South Dakota State University)

Figure 10.8. Large crabgrass

(Photos courtesy of Mike Moechnig, South Dakota State University)

Witchgrass (*Panicum capillare*)

Time of emergence: This warm-season grass emerges after corn emergence.

Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (fig. 10.9)**:** Witchgrass has a flat stem and long, soft hairs covering most of the plant. The ligule is a fringe of hair. Panicles are an open inflorescence, spreading, hairy, and large. When mature, the panicle can break off and tumble along the ground.

Areas of infestation: Grows well in sandy, droughty soil.

Yield loss potential: Low, even at high densities.

Effective management: Tillage, crop rotation, and post-emergence cultivation can be effective control measures.

Herbicide resistance: A biotype of witchgrass that is resistant to photosynthetic-inhibitor herbicides (e.g., atrazine) has been reported in Canada.

Figure 10.9. Witchgrass

(Photo courtesy of Weed Science Society of America)

Switchgrass (*Panicum virgatum*)

Time of emergence: This warm-season grass emerges late in the season, after corn has emerged.

Life cycle and reproduction: This perennial reproduces by rhizomes and seed, often escaping waterways or other areas. Vegetative stems are sometimes confused with witchgrass.

Distinguishing characteristics (fig. 10.10)**:** There is a V-shaped patch of hair on the upper leaf surface near the stem. Plants can grow up to 6-feet tall. Switchgrass is grown in stands for biofuel, but escaped plants can be problematic.

Areas of infestation: Switchgrass grows well in sandy or droughty soil types.

Yield loss potential: Moderate.

Effective management: Pre-emergence grass herbicides other than atrazine.

Herbicide resistance: Escaped plants can be difficult to control. Tolerant of atrazine.

Figure 10.10. Switchgrass

(Photo courtesy of Texas A&M University)

Wild buckwheat (*Polygonum convolvulus*)

Time of emergence: Typically early (before or just at corn planting). Late flushes may occur, depending on soil temperature and moisture conditions.

Life cycle and reproduction: This annual vining broadleaf reproduces from seed.

Distinguishing characteristics (fig. 10.11)**:** An ocrea (white to brown sheath) is located at the base of the leaf on the stem. This plant is often confused with the perennial field bindweed and is known as black bindweed in other regions. Triangular seeds, the ocrea, very small flowers, leaf shape, and root structure help distinguish wild buckwheat from field bindweed.

Areas of infestation: Wet areas of fields.

Yield loss potential: Yield losses can be as high as 30%. However, low densities may not reduce corn yield. The vines, which twine up corn stalks, can become tangled in harvest equipment. If mixed with corn grain, the high water content of wild buckwheat seeds may cause spoilage.

Effective management: Bromoxynil, atrazine, dicamba, clopyralid, and some sulfonylurea-type herbicides can be used for control. Tillage, crop rotation, and post-emergence cultivation may be management tools.

Herbicide resistance: No resistance reported but is difficult to control with glyphosate and 2,4-D. The tolerance to glyphosate makes wild buckwheat a problem even in glyphosate-resistant corn hybrids.

Figure 10.11. Wild buckwheat

(Photos courtesy of Mike Moechnig, South Dakota State University)

Horseweed (*Conzya canadensis*)

Time of emergence: Horseweed may overwinter as a rosette and bolt in the spring or emerge in the spring at or before planting.

Life cycle and reproduction: This winter or summer annual reproduces from seed.

Distinguishing characteristics (fig. 10.12)**:** The plant has numerous linear, hairy (although some plants have few or no hairs) leaves crowded on the stem. The flowers are very small and are generally white.

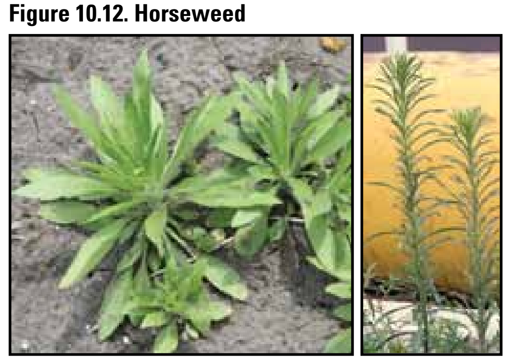
Areas of infestation: Tolerates drought conditions well.

Yield loss potential: Historically, this weed has seldom been dense enough to warrant control. However, high densities in soybean have led to >80% yield loss.

Effective management: For control of overwintering populations, auxin-type (e.g., 2,4-D) herbicides in a burndown pre-plant application have been effective. In cases where resistance biotypes are a problem, select an appropriate herbicide or tillage, crop rotation, and post-emergence cultivation.

Herbicide resistance: Biotypes resistant to photosynthetic inhibitors (atrazine), glyphosate, amino acid synthesis inhibitors (ALS inhibitors), and paraquat have been observed. Resistance to glyphosate, triazine, and paraquat has been reported in several states (i.e., Indiana and Ohio). Rotating herbicides or using other control methods is necessary to minimize the risk of developing further herbicide-resistant biotypes of horseweed.

Figure 10.12. Horseweed



(Photos courtesy of Mike Moechnig, South Dakota State University and Weed Science Society of America)

Common sunflower (***Helianthus annuus***)

Time of emergence: Common sunflower emerges at or just before planting.

Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (fig. 10.13)**:** Cotyledons are oval with toothed margins on alternating leaves. Stems become multi-branched, covered with stiff hairs as the plant matures. Has characteristic yellow flowers.

Areas of infestation: Typically occurs in drier soils.

Yield loss potential: At moderate densities, can reduce corn yields 70%.

Effective management: Many different herbicides can be used for common sunflower control. Tillage, crop rotation, and post-emergence cultivation should also be considered.

Herbicide resistance: Some biotypes of common sunflower have been reported to be resistant to amino acid synthesis inhibitor (ALS inhibitor) herbicides.

Figure 10.13. Common sunflower

(Photos courtesy of Mike Moechnig, South Dakota State University)

Common cocklebur (***Xanthium strumarium***)

Time of emergence: This weed typically emerges after planting.

Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (fig. 10.14)**:** Cotyledons of the seedling are linear, thick, and shiny green. Leaves are alternate and large with wavy margins. Seeds are in burs that stick to animal coats.

Areas of infestation: Typically occurs in wet areas.

Yield loss potential: Highly competitive with corn, causing up to 70% yield reductions at high density.

Effective management: Several herbicides are available for control of common cocklebur. Tillage, crop rotation, and post-emergence cultivation may also be effective measures for stand reduction.

Herbicide resistance: Biotypes of cocklebur have been reported to be resistant to amino acid synthesis inhibitor (ALS inhibitor) herbicides in some Midwestern states.

Figure 10.14. Common cocklebur

(Photos courtesy of Mike Moechnig, South Dakota State University)

Russian thistle (*Salsola iberica*)

Time of emergence: Typically emerges before or at planting.

Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (fig. 10.15)**:** Seedlings resemble small pine trees with threadlike leaves. Older plants become spine-like, with the leaf surface from smooth to hairy with non-showy flowers. The entire plant breaks off at the base and disperses seed as it tumbles in the wind.

Areas of infestation: A very drought- and salt-tolerant plant, it can be found in many areas.

Yield loss potential: Up to 60% corn yield reductions have been reported, depending on density.

Effective management: Pre-emergent herbicides give excellent control. Post-emergent herbicides work best on very young plants. However, little or no control is achieved after the plant becomes spiny. Prevention and cultural control should be implemented in addition to herbicide management.

Herbicide resistance: Biotypes in other states have been reported to be resistant to amino acid synthesis inhibitor (ALS inhibitor) herbicides.

Figure 10.15. Russian thistle

(Photos courtesy of Mike Moechnig, South Dakota State University)

Redroot pigweed (*Amaranthus retroflexus*)

Time of emergence: Typically emerges at or during corn planting.

Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (fig. 10.16)**:** Cotyledons are thin and linear. Leaves are lance-like with alternate arrangement. The lower surface is hairy. Stems are stout and the lower portion is reddish (hence the name "redroot"). Seeds are black, shiny, and numerous. Large plants can produce over 800,000 seeds. Plants may hybridize with other *Amaranthus* species.

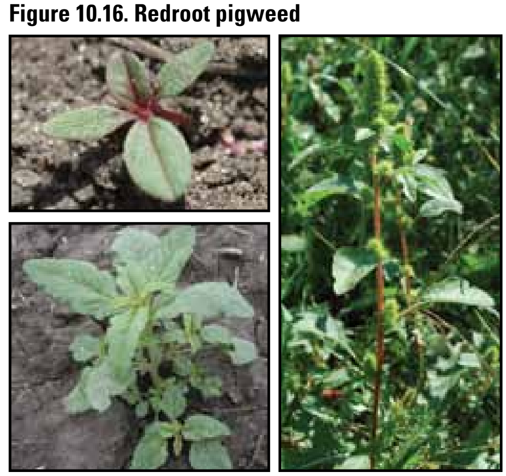
Areas of infestation: Disturbed areas, usually with high fertility.

Yield loss potential: Up to 55% corn yield reductions reported, depending on density.

Effective management: Many different herbicides can be used for redroot pigweed control, though care must be taken because some resistant biotypes have been reported in other states. An integrated program combining cultivation and appropriate herbicides should facilitate effective redroot pigweed control.

Herbicide resistance: Biotypes of redroot pigweed in other states have been shown to be resistant to triazine and amino acid synthesis inhibitor (ALS inhibitor) herbicides.

Figure 10.16. Redroot pigweed



(Photos courtesy of Mike Moechnig and Kurtis D. Reitsma, South Dakota State University)

Common waterhemp (*Amaranthus rudis*)

Time of emergence: Typically emerges late in the season after corn emergence.

Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (fig. 10.17)**:** The first true leaves of seedlings are more lance-like than the oval leaves seen on redroot pigweed. Leaf surfaces are not hairy. This species has male and female plants. The inflorescence of the female plant is more highly branched than that of the redroot pigweed. The female waterhemp has been reported to produce over 1 million shiny black seeds.

Areas of infestation: Disturbed areas with high fertility.

Yield loss potential: Up to 55% corn yield reductions reported, depending on density.

Effective management: Common waterhemp is difficult to control and is often seen after layby operations. Some resistant biotypes have been reported in other states. Prevention and cultural control should be implemented in addition to chemical management.

Herbicide resistance: Biotypes of this plant have been reported to be resistant to amino acid synthesis inhibitor (ALS inhibitor) herbicides, PS II inhibitors (not used in corn production), glyphosate, and cell-membrane disruptor (PROTOX-inhibitor) herbicides.

Figure 10.17. Common waterhemp

(Photos courtesy of Mike Moechnig and Kurtis D. Reitsma, South Dakota State University)

Common lambsquarters (*Chenopodium album*)

Time of emergence: This weed typically emerges at or just before planting.

Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (fig. 10.18)**:** Emerging plants are very small. Leaves are opposite and are covered with a mealy powder, especially on the underside. The stems are erect, may have green or red stripes, and can grow to almost 6-feet tall under certain conditions. The flowers are nonshowy and without petals.

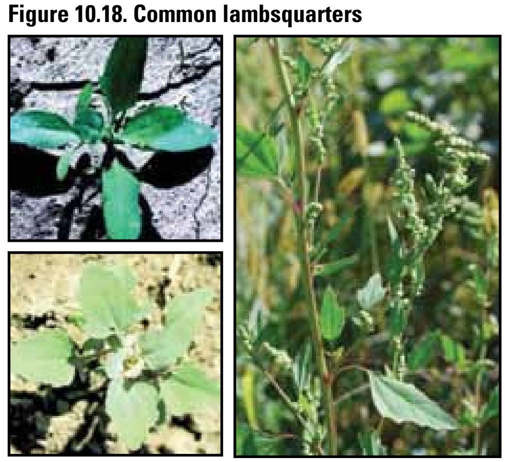
Areas of infestation: Found in disturbed sites.

Yield loss potential: Up to 40% corn yield reductions reported, depending on density.

Effective management: Pre-emergent broadleaf herbicides often give season-long control. Post-emergent herbicides work best on very young plants. This species is difficult to control if taller than 6 inches. Prevention and cultural control should be implemented in addition to herbicide application.

Herbicide resistance: Biotypes of this plant have been reported to be resistant to amino acid synthesis inhibitors (ALS inhibitors) and to photosynthesis inhibitors. Reduced sensitivity to glyphosate has been reported in some populations.

Figure 10.18. Common lambsquarters



(Photos courtesy of Mike Moechnig and Kurtis D. Reitsma, South Dakota State University)

Kochia (*Kochia scoparia*)

Time of emergence: Emerges at or before planting.

Life cycle and reproduction: Annual, reproducing from seed.

Distinguishing characteristics (fig. 10.19)**:** Seedlings can be very small—with over 1,000 present in a 1 ft^2 area. Leaf margins are fringed with hair. Leaf surfaces range from being without hairs to very hairy. Wind-blown plants will disburse seed in the fall.

Areas of infestation: Found in disturbed sites.

Yield loss potential: Yield losses of up to 40% have been reported.

Effective management: Pre-emergent broadleaf herbicides may provide season-long control. Post-emergent herbicides work best on very young plants. This species is difficult to control if taller than 6 inches. Prevention and cultural control should be implemented in addition to herbicide management.

Herbicide resistance: Some kochia biotypes are resistant to atrazine, amino acid synthesis inhibitor (ALS inhibitor) herbicides, and growth-regulator (i.e., auxin) herbicides.

Figure 10.19. Kochia

(Photos courtesy of Mike Moechnig, South Dakota State University)

Canada thistle (*Cirsium arvense*)

Time of emergence: Typically emerges before or just at planting.

Life cycle and reproduction: This perennial has deep and extensive root systems. It spreads by seeds or pieces of root transported from one location to another.

Distinguishing characteristics (fig. 10.20)**:** Leaves have crinkled edges and spiny margins, somewhat lobed and hairless. Stems may be hairy, especially when mature. Plants are diecious (males and females are distinct). Pink to purple flowers are numerous and compact at the top of the plant.

Areas of infestation: Found in disturbed sites

Yield loss potential: Up to a 40% corn yield reductions have been reported.

Effective management: Herbicides can control seedlings, but older plants should be treated with herbicides when in the bud stage or in the fall after the first frost.

Herbicide resistance: Biotypes of Canada thistle have been reported to be resistant to growth-regulator (auxin-type) herbicides.

Figure 10.20. Canada thistle

(Photos courtesy of Mike Moechnig, South Dakota State University)

Field bindweed (*Convolvulus arvensis*)

Time of emergence: Late spring to early summer.
Life cycle and reproduction: Perennial, can grow from rhizomes or seed.
Distinguishing characteristics (fig. 10.21)**:** Leaves are arrow-shaped on a twining stem. The root system can be extensive and deep rooted. Flowers are white to pink and bell or trumpet shaped.
Areas of infestation: Grows well in dry soils.
Yield loss potential: Can reduce yields 50%. Vining nature of the plant can cause problems with harvest equipment.
Effective management: Combination of herbicides and competitive crops.
Herbicide resistance: This plant is tolerant of glyphosate. Biotypes have been reported resistant to growth-regulator (auxin-type) herbicides.

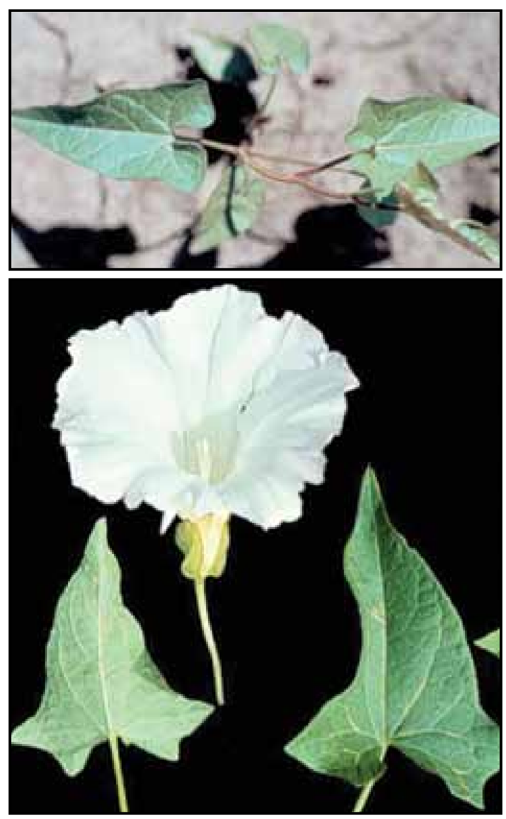
Hedge bindweed (*Calystegia sepium*)

Time of emergence: Typically emerges before or at corn planting.
Life cycle and reproduction: Perennial vining plant, reproducing from seed and rhizomes. It can be confused with field bindweed.
Distinguishing characteristics (fig. 10.22)**:** Leaves have a long petiole and have a pointed tip. The flowers are large, funnel shaped, and white to pink in color.
Areas of infestation: Found in disturbed sites.
Yield loss potential: This plant is not as aggressive as field bindweed, though the vines may cause problems during harvest.
Effective management: Prevention and cultural control should be implemented in addition to herbicide application.
Herbicide resistance: To date, herbicide resistance has not been reported.

Figure 10.21. Field bindweed

(Photos courtesy of Mike Moechnig, South Dakota State University)

Figure 10.22. Hedge bindweed



(Photos courtesy of Weed Science Society of America)

Herbicide Damage in Corn

Herbicides can cause predictable symptoms to plants. The purpose of this section is to show symptoms and discuss the mode of action of commonly used herbicides.

Growth-Regulator Herbicides

A. Phenoxy acids

Example: 2,4-D

Mode of action: Acts as a synthetic auxin, disrupting nucleic acid metabolism and protein synthesis, which ultimately leads to plant death.

Appearance of symptoms (fig. 10.23)**:** Symptoms appear within hours of application on sensitive species.

Injury symptoms	Injury cause
Rolled leaves. Fused brace roots. Stalk bending and brittleness. Missing kernels on ear.	Applied to rapidly growing corn. Applied too late in growing season.

Figure 10.23. Onion leafing due to 2,4-D

(Photo courtesy of Leon Wrage, South Dakota State University)

B. Benzoic acids

Example: dicamba (Banvel®)

Mode of action: Acts as a synthetic auxin. See 2,4-D above.

Appearance of symptoms (fig. 10.24)**:** First appearance of symptoms can come within hours after application on sensitive species.

Injury symptoms	Injury cause
Same as 2,4-D, but may occur at lower application rates than 2,4-D.	Variable hybrid sensitivity. Applied during sensitive growth stage of corn.

Figure 10.24. Root pruning due to dicamba (Banvel®)

(Photo courtesy of Leon Wrage, South Dakota State University)

Lipid Synthesis Inhibitor Herbicides

A. Cyclohexanediones

Example: sethoxydim (Poast®)

Mode of action: Inhibits the formation of lipids used for membrane development and stops growth of new tissue.

Appearance of symptoms (fig. 10.25)**:** Symptoms may first appear 2 to 4 days after treatment. The death of the plant is slow.

Injury symptoms	Injury cause
Yellowing or reddening of new leaves. Stunting of plant. Death of tissue and browning. Growing point dies.	Misapplication. Tank contamination.

Figure 10.25. Sethoxydim (Poast®) injury

(Photo courtesy of Leon Wrage, South Dakota State University)

Amino Acid Synthesis Inhibitor Herbicides

A. Amino acid derivatives

Example: glyphosate (Roundup®)

Mode of action: Amino acid synthesis inhibitor; stops synthesis of aromatic amino acids (those that contain a phenyl ring).

Appearance of symptoms (fig. 10.26)**:** Symptoms appear within 3 to 10 days after treatment. Environmental conditions that slow growth (e.g., extreme heat, cold, or drought) reduce the effects of glyphosate. May look like P deficiency, except purpling is first seen on the older leaves.

Figure 10.26. Glyphosate (Roundup®) injury to non-tolerant corn

(Photo courtesy of Leon Wrage, South Dakota State University)

Injury symptoms	Injury cause
Yellow then brown foliage. Growing point dies. Purpling of foliage.	Misapplied to non-tolerant corn. Tank contamination.

B. Phosphoric acid-type

Example: glufosinate (Liberty®)

Mode of action: Stops the synthesis of the amino acid glutamine, resulting in buildup of toxic levels of ammonia in the leaves.

Appearance of symptoms (fig. 10.27)**:** Symptoms appear within 3 to 5 days after treatment

Figure 10.27. Glufosinate (Liberty®) injury to non-tolerant corn

(Photo courtesy of Mike Moechnig, South Dakota State University)

Injury symptoms	Injury cause
Pale yellow or purple leaves. Water-soaked lesions.	Misapplied to non-tolerant corn. Applied too late in the season.

C. Sulfonylureas and imidiazalinones (ALS inhibitors)

Example: primisulfuron (Beacon®)

Mode of action: Inhibits the formation of branched-chain amino acids.

Appearance of symptoms (fig. 10.28)**:** The growing point becomes yellow within 2 to 4 days after treatment. Plant death occurs within 7 to 10 days after treatment.

Figure 10.28. Primisulfuron (Beacon®) injury to corn

Top: Bottle brush roots. Bottom: pinched ears.
(Photos courtesy of Leon Wrage, South Dakota State University)

Injury symptoms	Injury cause
Stunted plant, stunted internodes. Yellow translucent leaves. Death of growing point. Bottlebrush roots.	Hybrid sensitivity. Applied too late. Tank contamination. Applied to non-tolerant corn. Corn ears have pinched appearance.

Pigment Inhibitor Herbicides

A. Isoxazoles

Example: isoxaflutole (Balance®); mesotrione (Callisto®)

Mode of action: Inhibit enzymes in the carotenoid pigment pathway; these pigments protect chlorophyll from destruction.

Appearance of symptoms (fig. 10.29)**:** White areas on plants or albino plants appear during emergence.

Injury symptoms	Injury cause
White tissue. Poor emergence. Stunted plants. Growing point dies.	Applied on cool, wet, or sandy soils. Carryover problem.

Cell-Membrane Disruptor Herbicides

A. Bipyridiliums

Example: paraquat (Gramoxone®)

Mode of action: Destruction of cell membranes.

Appearance of symptoms (fig. 10.30)**:** Symptoms are often observed within hours. Contact herbicide symptoms primarily seen on treated leaves as speckling. Untreated and new leaves may not show symptoms.

Injury symptoms	Injury cause
Limp leaves. Water-soaked appearance (looks like frost damage). Brown tissue in water-soaked areas.	Drift. Tank contamination.

B. Aryl triazolinones (PROTOX inhibitors)

Example: carfentrazone (Aim®)

Mode of action: Inhibits the protoporphyrinogen oxidase, resulting in cell membrane destruction.

Appearance of symptoms (fig. 10.31)**:** Appearance of necrotic (dead tissue) speckling on leaves within a few days after exposure. Symptoms are most often observed during emergence or in seedling plants.

Injury symptoms	Injury cause
Yellowing or reddening of new leaves. Stunting of plant. Death of tissue and browning. Growing point dies.	Misapplication. Tank contamination.

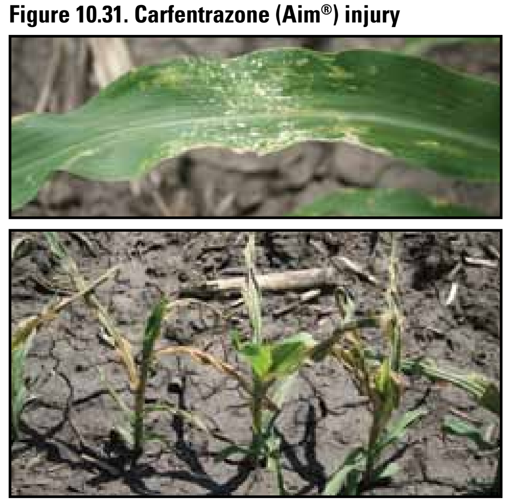
Figure 10.29. Isoxaflutole (Balance®) injury

(Photo courtesy of Iowa State University)

Figure 10.30. Paraquat (Gramoxone®) injury

(Photos courtesy of Mike Moechnig, South Dakota State University)

Figure 10.31. Carfentrazone (Aim®) injury



Corn seedlings have chlorotic to white veins (tiger stripping), and the lower leaves may droop.
(Photos courtesy of Mike Moechnig, South Dakota State University)

Photosynthetic Inhibitor Herbicides

A. Triazines

Example: atrazine (Aatrex®)

Mode of action: Stops electron flow in photosynthesis.

Appearance of symptoms (fig. 10.32)**:** Symptoms are observed within a few days. If due to soil application, older leaves show the most damage. If applied to leaves, treated leaves and outer margins of treated leaves show the most damage.

Injury symptoms	Injury cause
Yellow and brown leaves. Crop oil synergy if applied as a post emergence.	Cool wet conditions slowing corn growth.

Figure 10.32. Atrazine (Aatrex®) injury

(Photo courtesy of Iowa State University)

B. Benzonitriles

Example: bromoxynil (Buctril®)

Mode of action: Stops electron flow in photosynthesis.

Appearance of symptoms (fig. 10.33)**:** Symptoms are observed within a few hours. Contact-type herbicide-speckling of treated areas first observed.

Injury symptoms	Injury cause
Yellow and brown leaves.	Crop oil with the post-emergence application.

Figure 10.33. Bromoxynil (Buctril®) injury

(Photo courtesy of Leon Wrage, South Dakota State University)

Seedling Growth Inhibitor Herbicides

A. Dinitroanalines

Example: trifluralin (Treflan®); pendimethalin (Prowl®)

Mode of action: Inhibits the growth of roots or shoots of seedlings.

Appearance of symptoms (fig. 10.34)**:** Symptoms are apparent during or soon after plant emergence. Roots shortened with few fine root hairs.

Injury symptoms	Injury cause
Stunted plants. Roots short and thick.	Carryover. Misapplication. Over-application.

Figure 10.34. Root clubbing from pendimethalin (Prowl®)

(Photo courtesy of Leon Wrage, South Dakota State University)

Seedling Growth Inhibitor Herbicides continue on pg. 90

Seedling Growth Inhibitor Herbicides continued

B. Acetanilides

Example: metolachlor (Dual®); acetochlor (Harness®)

Mode of action: Growth inhibitor that affects roots or shoots of seedlings.

Appearance of symptoms (fig. 10.35)**:** During or soon after plant emergence. Leaves do not unfurl.

Injury symptoms	Injury cause
Poor emergence. Stunted plants. Leaf out underground before emergence.	Over-application. Cool, wet soils.

C. Thiocarbamates

Example: EPTC + safener (Eradicane®); butylate + safener (Sutan®)

Mode of action: Inhibits the growth of roots or shoots of seedlings.

Appearance of symptoms (fig. 10.36)**:** Symptoms appear during or soon after plant emergence. Leaves show buggy whipping.

Injury symptoms	Injury cause
Buggy whipping (leaf entrapment). Stunted plants.	Over-application. Cool, wet soils.

Figure 10.35. Metolachlor (Dual®) injury

(Photo courtesy of Greg Stewart and Mike Cowbrough, Ontario Ministry of Agriculture and Food)

Figure 10.36. EPTC + safener (Eradicane®) injury

(Photos courtesy of Leon Wrage, South Dakota State University)

Documenting Suspected Herbicide Drift Damage

Herbicide drift to non-target plants can result in significant economic losses. Careful attention to application techniques can help minimize drift. At some point it may be necessary to document drift. The following guidance is provided to document losses:

- Record information related to the suspected problem.
  - Date, rate, and name of herbicide used.
  - When damage occurred/was noticed.
  - When adjacent fields were sprayed.
  - The crop in neighboring fields.
  - Herbicides used in neighboring fields (if possible).
  - Wind speed, application type, and speed of travel.
  - Cultural practices in the damaged field.
- Consider all possible causes of the injury.
  - Diseases, nutrients, herbicide carryover, growing conditions, and flooding.
  - Possible tank contamination.
  - Plant samples may need to be submitted to a disease or nutrient laboratory.
- Make a map of the area.
  - Include the legal land description of the field.
- Collect quality photographs.
  - Include tops, roots, and close-ups of affected portions.
- Estimate yield losses.
  - In many situations, it is not possible to calculate yield losses until 10 to 20 days after damage.
  - Visual estimation is not reliable.
  - Compare yields in damaged and undamaged areas during or just before harvest.
- Promptly contact all parties suspected of being involved.
  - Insurance companies may need to be contacted for inspections.
  - It may be necessary to file a complaint with the South Dakota Department of Agriculture.

Additional Information and References

Clay, S.A., G.J. Lems, D.E. Clay, F. Forcella, M.M. Ellsbury, and C.G. Carlson. 1999. Sampling weed spatial variability on a field-wide scale. Weed Sci. 47:674–81.

Corn Production. 2008. Agronomy Extension, Iowa State University. http://www.agronext.iastate.edu/corn/.

Hager, A.G. and D. Retsell. 2008. Weed control for corn, soybean, and sorghum. 2008 Illinois Agricultural Pest Management Handbook. http://www.ipm.uiuc.edu/education/index.html.

Herbicide Injury Gallery. 2009. Ontario Ministry of Agriculture, Food and Rural Affairs. http://www.omafra.gov.on.ca/english/crops/facts/herbinjury_gallery/herbicidegal.htm.

Hofman, V., and J. Wilson. 2003. Choosing drift-reducing nozzles. FS919. South Dakota State University, South Dakota Cooperative Extension Service. http://agbiopubs.sdstate.edu.

Wilson, J. 2006. Calibration of pesticide spraying equipment. FS933. South Dakota State University, South Dakota Cooperative Extension Service. http://agbiopubs.sdstate.edu.

Wilson, J. 2002. Pesticide container disposal and recycling. ExEx8078. South Dakota State University, South Dakota Cooperative Extension Service. http://agbiopubs.sdstate.edu.

United States Department of Agriculture, Natural Resources Conservation Service. 2008. PLANTS Database. Washington DC. http://plants.usda.gov/.

Clay, S.A. and M.J. Moechnig. 2009. "Weeds and herbicide injury in corn." Pp. 71–92. In Clay, D.E., S.A, Clay, and K.D. Reitsma (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 11
Corn Grain Harvest

Corn (grain) harvest can begin when grain moisture drops below 30%. However, most producers will allow corn to dry in the field until grain moisture is between 18 to 25%. Harvesting corn when grain moisture levels are high can result in excessive drying costs, kernel damage, and harvest loss from improper threshing. Allowing corn to stay in the field too long can result in excess harvest loss from stalk lodging, ear drop, or kernel shattering.

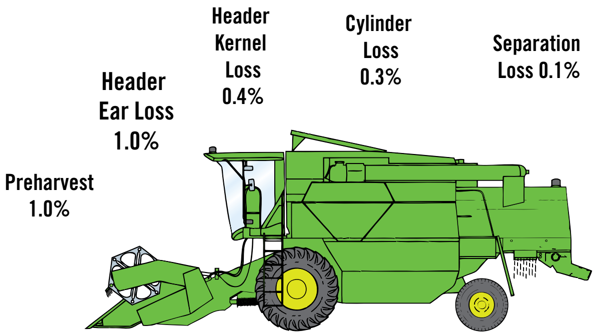
An optimal harvest depends not only on the condition of the crop but also on the proper maintenance and adjustment of harvest and grain handling and drying equipment. This chapter provides guidance for assessing harvest losses and kernel damage to determine if equipment adjustment is necessary to minimize losses.

(Photo courtesy of USDA-NRCS)

Sources of Grain Harvesting Losses

Corn (grain) lost in the field during harvest operations reduces profits and can result in weed problems (volunteer corn) in following years. The combine harvester performs a series of operations, each of which can contribute to grain losses. While it is not possible to eliminate all harvest losses, skillful operators evaluate the amount of loss, identify the source, and adjust the combine for optimal performance (fig. 11.1).

Figure 11.1. Acceptable harvest losses at optimum combine adjustment



(Source of data: Nicolai and Humberg)

Harvest losses can be classified into the following groups:

- **Preharvest loss** – Where a portion of crop loss is caused by lodging or ear drop. Incidence of disease, insects, and severe weather can increase loss severity. As the crop dries, loss potential increases. Producers should evaluate crop loss potential and mechanical drying cost when considering delaying harvesting for grain dry-down purposes.

- **Header ear loss** – Results from driving too fast, driving off the row, or operating the header too high off the ground. Losses often average 3 to 4% of the total crop yield, but losses can be reduced to 1% with proper machine operation and adjustment.

- **Header kernel loss** – Occurs at the header and is the result of ear shattering (ears make contact with gathering chains, snapping bars, stalk rolls, and feeder-house conveyor chains). Losses average about 0.6% but can be reduced to 0.4% with proper adjustments or with the replacement of excessively worn parts. Kernel loss can be reduced by proper adjustment of gathering chain and feeder house conveyor chain tension and speed. Inspect wear on snapping bars, stalk rolls, and feeder house conveyor chains, and replace if wear exceeds the tolerances stated by the manufacturer.

- **Combine cylinder or threshing loss** – The result of incomplete shelling, with some kernels remaining attached to the cob as they pass through the machine. Correct rotor or cylinder speed and concave clearance adjustment can reduce losses to 0.3% or less. Correct adjustment is achieved when cobs are not broken and kernels are removed from the cob. Excessive threshing results in low threshing losses but increases kernel damage. Worn concaves and rasp bars can also lead to threshing loss. Replace concaves and rasp bars if wear exceeds the tolerances stated by the manufacturer. When combining high moisture corn (> 20%), concave inserts are an option to avoid losses from reduced threshing.

- **Combine separation and cleaning loss** – Results from kernels passing through the combine (kernels are embedded in the stalk and husk residue and are not separated). Others pass over the sieves and out of the combine. With correct rotor speeds, sieve openings, and fan adjustments, this loss should be held to 0.1%.

Measuring Grain Combine Losses

Yield loss determinations should be made at least 300 feet from the field border. If the combine is equipped with a calibrated yield monitor, a yield observation should be made while operating at a constant speed. This yield can be used to determine percentage losses from combine operations. The total yield loss at a given point in the field can be determined by abruptly stopping the combine and disengaging the separator. Backup a short distance to allow access to the area behind the header (but ahead of the chaff discharge pattern).

To measure ear losses, mark off an area that represents 1/100 of an acre, centered over a harvested combine pass. The area should have a width equal to the width of the combine and a length that is determined by dividing 435.6 by the combine harvesting width in feet. For example, if the combine has a 6-row head (30-inch rows), then the size of 1/100 acre is calculated in the following manner:

$$6 \text{ rows} \times \left(\frac{30 \text{ in}}{\text{row}}\right) \times \left(\frac{1 \text{ ft}}{12 \text{ in}}\right) = 15 \text{ ft}$$

The length of the area for 1/100 of an acre (435.6 ft^2) is then calculated:

$$\left[\left(\frac{1 \text{ acre}}{100}\right) \times \left(\frac{43560 \text{ ft}^2}{1 \text{ acre}}\right)\right] \div 15 \text{ ft} = 29 \text{ ft}$$

Thus: 15 ft × 29 ft ≈ 0.01 acre or 435.6 ft^2

Collect all ears on the ground in this area. Each 0.75lb. ear represents one bushel per acre loss. If smaller ears are found, the equivalent number of 0.75lb. ears should be determined. For example, if three 0.5lb. ears are found, this is equivalent to two of the larger ears. When equipment is properly adjusted, ear loss should be less than one bushel per acre. If losses are excessive, determine the pre-harvest loss in an area that has not yet been harvested. This can be done by measuring a length corresponding to 1/100 of an acre ahead of the harvester, counting dropped ears in that area, and converting the result to bushels. The preharvest loss should be subtracted from ear loss measurements that have been taken behind the combine. The difference is the ear loss that is attributable to the machine.

To measure kernel loss, use a 10-square-foot (ft^2) area centered over each row. The width of the loss-measurement area should be equal to the row spacing, and the length should be 48 inches for a 30-inch row and 40 inches for a 36-inch row. A rectangular PVC pipe frame with the correct inside dimensions for row spacing is a handy tool for this procedure. Loss should be determined for each row harvested in a single pass of the combine.

Two kernels per ft^2, or 20 kernels per $10ft^2$, is equivalent to a 1-bushel per acre loss. Count the kernels found in the 10 ft^2 area over each row and calculate the average number of kernels per 10 ft^2. The average number should be less than 40 kernels per 10 ft^2, or 2 bushels per acre.

Kernel-loss measurements can be taken in a harvested area behind the combine where the machine was in steady operation. If these losses appear large (in excess of 1%), repeat the measurement in the area behind the header but ahead of the chaff pattern. The losses measured here are attributable to the header. Review header adjustments and operating parameters if kernel losses exceed 0.5 to 0.6% of the total yield. The owner's manual is the best source of guidelines for proper settings and operating parameters.

If kernel losses are large but header losses are acceptable, possible causes include the following:

- excessive air through the sieves
- sieve opening that is too small
- separator and cleaning system overload due to excessive forward speed
- worn concaves or rasp bars

Too many kernels remaining on cobs can result either from cylinder or rotor speeds that are too slow or from cylinder-concave or rotor-concave clearances that are too large.

The largest single source of loss is typically from ear loss at the gathering head. Since these losses are affected by both machine settings and operator performance, every effort should be made to

- drive accurately on the rows,
- maintain an appropriate ground speed for crop conditions,
- operate the header at an appropriate height for crop conditions,
- set and maintain gathering chains according to the operator's manual,
- check the operator's manual for proper combine maintenance and adjustment.

Adjustments to Prevent Cracked Kernels

Improper adjustments of cylinder or rotor speed and concave clearance can lead to excessive kernel damage. Initial settings should be made according to the operator's manual, with further adjustments made in the field to correct for field conditions. Inspect grain in the tank after harvesting a small portion of the field, evaluating the grain for proper threshing, broken cobs, and kernel attachment. Correct adjustment results in few or no broken cobs, with zero kernels attached to them. Shelling action that is too vigorous, however, results in excessive kernel breakage.

Adjustments for Reducing Foreign Material in Grain

The amount of foreign material (i.e., stalks, leaves, and cobs) can be reduced with correct sieve and fan adjustment. High volumes of plant residues add to the load on sieves, resulting in high amounts of foreign material in the grain and increased kernel loss. Make initial settings according to the operator's manual, and make fine adjustments, if necessary, based on observations of grain losses in the field. Grain separation losses may occur when extra stalks and leaves pass either through the rotary separator or over straw walkers, as not all kernels filter through residue before its discharge. Reducing ground speed helps to reduce kernel loss by allowing more time for kernel and residue separation.

Although combine manufacturers continue to make combine adjustments easier, operators must make proper adjustments to ensure that losses are below 5%. Time spent evaluating and optimizing harvest equipment loss efficiency can make a difference in profit margins.

Combine Safety Considerations

For anyone who operates a combine, good safety habits are important for avoiding injury or death. Combines have many moving parts that need regular adjustment and maintenance. Set aside time to properly prepare the equipment for harvest. Rushed repairs and breakdowns may lead to injuries. To minimize problems routine winter maintenance and daily servicing is recommended.

Winter maintenance includes the following:

- Cleaning the combine with a power washer.
- Checking all bearings, chains, and belts.
- Checking the auger and the condition of the straw chopper.
- Replacing or repairing broken guards shields and lights.

Daily servicing during harvesting should include the following:

- Greasing zerks.
- Filling the fuel tank.
- Checking the hydraulic oil, radiator fluid, chain tensions, rock traps, and air pressure.
- Clearing the engine compartment for debris that can cause fire.

When repairing or conducting maintenance, always be safe:

- When working on machinery, put the ignition key in your pocket (so no one can start the machinery).
- Check hydraulic leaks carefully. Never use your hand to look for hydraulic leaks, because oil under high pressure can easily be injected through the skin, resulting in serious medical problems. Use a piece of cardboard, wood, or sheet metal to detect leaks.
- Don't trust hydraulics with your life. Use the safety stops on lift cylinders when working under the header.
- Always refuel the combine after it has cooled. Fuel vapors can easily ignite on hot engine and combine parts. Refueling accidents are a major cause of combine fires.
- Keep the cab windows clean of dust. Dust on the windows reduces visibility and adds to the stress of long hours at work. A spray bottle of window cleaner and a roll of paper towels should be kept in the combine cab and used often.
- The cab's air conditioning-system filter should be cleaned or replaced on a regular basis. Dust and mold in the air or in air conditioner filters can lead to serious illness. Working conditions in the cab are important to a safe harvest.

When transporting the combine from one field to another:

- Drive the combine only while you are alert and aware of your surroundings. Hours of steady operation can put you into a trancelike state. To avoid dangerous situations, it is recommended to schedule breaks for every 3 hours,
- Move combines from field to field only during daylight. Driving combines on public roads after dark is risky. The size of a combine, coupled with its unfamiliar shape and lighting pattern, makes it a hazard on the road after dark.
- Keep your distance from other vehicles and machines. Combines need a lot of room to maneuver, and they have large blind spots. Always be aware of the location of other equipment.

When operating the combine in the field:

- Examine fields for hazards such as washouts and other surprises that can develop during the growing season. Alert other workers to those hazards.
- Don't make sudden changes in speed or turn sharply when operating on slopes; combines have a high center of gravity and rollovers can occur.
- Maintain a safe distance from ditch banks that could shear under the weight of a combine. A grassed buffer strip at the edge of all ditches can help minimize this risk.
- No one should be in the combine's grain tank or in the receiving wagon/truck while unloading, as this can result in serious injury or death.
- Shut off the engine and pocket the key before attempting to clear a residue plug. If reversing the header does not clear the plug, stop the combine as quickly as possible and pocket the key. A good rule to follow is to avoid having anyone in the cab when working on equipment.

To minimize the risk of fires:

- Attempt to keep the combine free of harvest materials. Use a leaf blower frequently, or use a pressure washer to clear the combine of dust and debris around hot surfaces. Combine fires may be caused by electrical shorts, harvest materials, refueling when combine is hot, and overheated cooling systems.
- Keep a freshly filled fire extinguisher on each combine. It should be readily accessible from the ground and should be a 10-pound, class ABC dry-chemical unit.
- Keep wiring and fuses in proper operating condition and position.

Keep a complete first-aid kit on the combine. First-aid kits, like fire extinguishers, should be kept in a safe location and be easy to reach from the ground. The kit should be equipped with supplies for treating major injuries. Pressure bandages and wraps should be in plentiful supply. Immediately use the cell phone and call for help when a major injury occurs.

Additional Information and References

Cyr, D. L. and S B. Johnson. 2002. Combines and corn picker safety. Bulletin 2343. University of Maine, Orono, Maine. http://www.cdc.gov.

Shay, C., L.V. Ellis, and W. Hires. 1993. Measuring and reducing corn harvesting losses. University of Missouri Extension Publication G1290. http://extension.missouri.edu.

Schuler, R. 1997. Corn combine losses for a good operator. Minnesota/Wisconsin Engineering Notes. University of Minnesota, St. Paul, Minn. http://www.bbe.umn.edu.

Humburg, D.S., R.E. Nicolai, and K.D. Reitsma. 2009. "Corn grain harvest." Pp. 93–98. In Clay, D.E., S.A, Clay, and K. Reitsma (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

The information in this chapter is provided for educational purposes only. Product trade names have been used for clarity. Any reference to trade names does not imply endorsement by South Dakota State University, nor is any discrimination intended against any product, manufacturer, or distributor. The reader is urged to exercise caution in making purchases or evaluating product information.

CHAPTER 12
Corn Drying and Storage

The goal for a corn drying and storage system is to maintain grain quality without impeding harvesting or shipping. This chapter describes the factors that influence grain quality, proper handling techniques, drying procedures, storage management, and safety precautions.

Grain Quality

Corn grain quality at harvest is influenced by a variety of weather conditions, harvest adjustments, and handling procedures. High-quality corn has the following characteristics:

Few fines and foreign materials.
- Clean corn dries and stores better. To remove fines and foreign material, consider installing a grain cleaner. A bypass mechanism is recommended when cleaning is not necessary.

Little physical damage and few stress cracks.
- Test incoming grain for broken corn and foreign material to evaluate harvesting and variety performance.

Very little mold and insect damage.
- Inspect stored grain periodically to determine if insect control is necessary.

Grain quality will not improve with storage, drying, or handling. Minimizing corn grain damage during storage requires that the storage system have good drying, cooling, and handling characteristics.

Drying Damage

Stress cracks are fractures inside the kernel that are not expressed on the outer seed coat. These cracks increase kernel breakage during handling and reduce milling quality. Drying techniques influence the occurrence of kernel stress cracks. Kernel stress cracks develop when corn is rapidly dried at high temperatures through the critical moisture range of 19% to 14% and is then quickly cooled. Slow drying and delayed cooling reduces cracking.

Drying Temperatures

Comparatively lower drying temperatures maintain higher grain quality (i.e., test weight, color, and brittleness). Initially, if the corn has a high moisture content, a lower drying temperature is needed to maintain grain quality. If grain quality is poor at harvest, low drying temperature becomes even more critical to prevent further reduction in quality. If cooled immediately, corn can be dried in high-speed automatic “batch” or “continuous-flow” dryers at 200 to 220°F. Corn can be dried at temperatures up to 240 to 250°F if cooling is delayed. Heated “in-bin” dryers, with or without stirrators, should be operated between 110 and 140°F. If corn drying depths exceed 4 feet without stirration, to prevent over-drying the drying air temperature should be limited to 10°F above ambient air temperature.

Handling Damage

Corn kernel damage can be minimized by properly sizing and operating handling equipment. Reducing kernel drop heights and travel velocity reduces the potential for breakage. Increased kernel breakage results from the following:

- improperly installed or operated handling equipment
- corn kernel impact at high velocities
- kernel stress cracks developed during drying and/or cooling
- very dry or cold kernels

To prevent grain damage, augers should be operated at the manufacturer-rated capacity. If incoming flow rates are variable, using bearing-supported augers can prevent kernel damage. Kernel damage also can be reduced by installing surge bins over the hopper (surge bins keep the auger full when incoming flow rates are variable).

Bucket elevators cause little kernel damage if drop heights are minimal. When drop height exceeds 40 feet, kernel damage potential increases. Installing grain decelerators every 40 feet in the down spout can reduce kernel damage.

Storage Damage

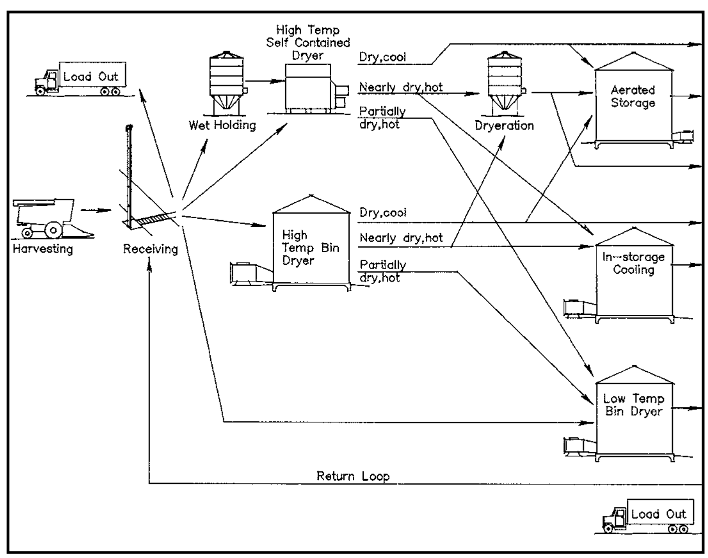
Mold and insects cause most of the damage that occurs during storage. Corn that is improperly stored or dried or is damaged is susceptible to both molds and insects. Aeration in storage facilities controls grain temperature and reduces the chance for spoilage. Pockets of fines (broken kernels, weed seeds, trash) can cause spoilage, as they restrict airflow and provide food for insects and mold. Spoilage can be reduced by removing fines with a grain cleaner and by adjusting the bin grain spreader to reduce the concentration of fines.

Grain Handling

A well-organized grain handling system reduces time and stress during a busy season and improves efficiency. Handling systems include conveyors, hoppers, pits, surge bins, spreaders, sweep augers, and cleaners. The system is designed to receive grain, move the grain from one component to another, and load grain for transportation (fig. 12.1). Factors for consideration when planning a corn handling system are as follows:

- **Performance** – completing the job in the time allowed without a loss of quality.
- **Capacity** – matching the handling system to the farm needs.
- **Convenience** – ease of handling with the labor available.
- **Cost** – balancing equipment costs with farm need and revenue.

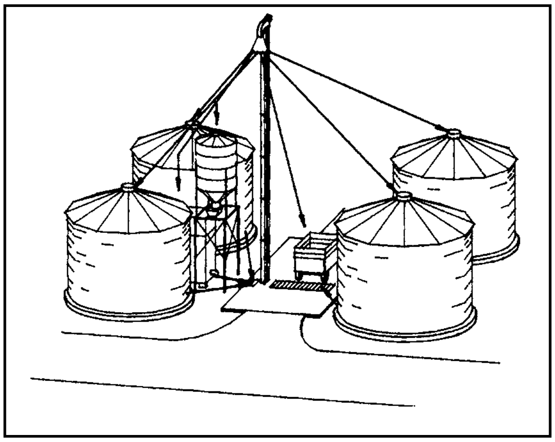
Figure 12.1. Grain center facilities and conveying processes



(Courtesy of Cloud et al. 1997)

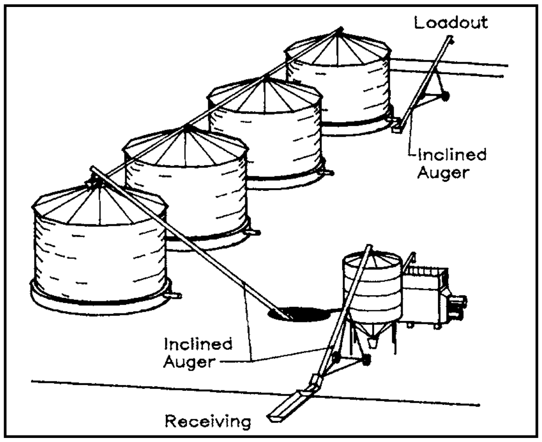
The receiving and load-out areas are often the hubs of larger handling centers, with bucket elevators used for conveyance (fig. 12.2). The handling center should be planned so that the grain can go from the elevator to any component (e.g., wet holding, dryer, storage). This

Figure 12.2. Bucket elevator system



(Courtesy of Cloud et al. 1997)

Figure 12.3. Inclined conveyor system

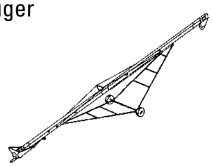
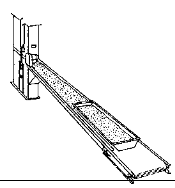
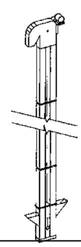
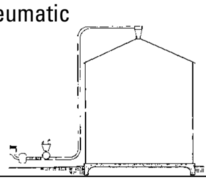


(Courtesy of Cloud et al. 1997)

type of system is convenient because it can be easily automated and requires no setup time. These systems are also able to handle both low-capacity conveying and high-capacity needs. Good planning allows the system to grow gradually from a low-investment, low-capacity system to a high-capacity system.

In smaller centers, the system may not require as much convenience and conveyance; therefore, the cost of the handling system can be reduced. Figure 12.3 depicts an auger conveying system where the grain is not returned to the central hub for load out. Table 12.1 lists and categorizes some of the more common conveyors used to move grain.

Table 12.1. Comparison of selected grain conveyors

Type of Conveyor	Horsepower Requirement	Advantages	Disadvantages
Auger 	Low to medium with dry grain; medium to high with wet grain	Simple, widely available in many sizes. Low cost. Available for horizontal, inclined, or vertical applications. Portable, wheeled, or fixed.	High torque and power required for wet grain. Medium-to-heavy wear. Noisy – if not bearing-supported. High kernel damage – if not operated at rated capacity.
Belt 	Low	Good for long distances. Low power requirement. Quiet Least handling damage. Capacity only affected by grain weight. Self-cleaning.	Limited in angle of elevation. Expensive. Belt maintenance.
Bucket 	Low	Efficient, compact. Low maintenance. Quiet High capacity for vertical lift. Reliable and adaptable to automation. Easily cleaned.	Difficult to erect and change capacity. Expensive. Grain damage high for large drop heights. Elevator head service is difficult.
Pneumatic 	High	Flexible installation. Easily cleaned. Convenient grain delivery to many locations.	High power requirement. Creates dust, usually requires separation equipment.

Drying

Wet corn either must be used or must be dried for storage. A "rule of thumb" is that corn should not be harvested until the moisture content is less than 30%. If storage is planned for 12 months or less, corn should be dried to 14% moisture content; if storage is planned for longer than 12 months, 13% moisture content is the target. The relationship between storage time, grain moisture, and storage temperature is shown in Table 12.2. At low temperatures (30 to 35°F), corn with moisture contents of 14 or 15% can be safely stored for extended periods of time. However, the risk of spoilage increases with temperature.

Table 12.2. Allowable grain storage time (in days, as influenced by grain moisture percentage and storage temperature [modified from Pohl and Durland 2002])

Temperature degrees °F	Grain moisture percentage (%)										
	14	15	16	17	18	20	22	24	26	28	30
30			847	503	323	160	95	64	47	37	31
35			634	377	242	120	71	48	35	28	23
40		879	474	282	181	90	53	36	26	21	17
50		492	265	158	101	50	30	20	15	12	10
60	576	275	149	88	57	28	17	11	8	6	5

A complete drying system includes grain-receiving equipment, a wet-holding tank, a dryer, grain-cooling equipment, and conveyance of the corn to the storage bin. A well-designed drying system should

- be safe and convenient,
- not slow harvesting and have adequate capacity,
- provide a space where wet corn can be stored prior to drying,
- have an appropriate drying and ventilation system,
- result in a minimum loss of quality,
- provide the opportunity for future expansion.

There are numerous types of grain-drying systems, but they can be characterized into 5 general categories (Table 12.3). The characteristics of each drying system are as follows:

Low-temperature and natural-air bin dryers

- Grain is dried slowly in these systems. These systems work best in low-temperature and low-humidity environments. With low-temperature dryers, air is heated to 10°F above ambient air temperature (in natural drying systems, the air is not heated). In low-temperature systems, the corn is placed in a bin that has a perforated floor, a high capacity fan, and a spreader. Airflow for southeast South Dakota should be 1.25 cfm/bu (cubic feet per minute/per bushel), and for the balance of South Dakota airflow should be at least 1 cfm/bu. As reported by Hansen (2005), natural air-drying systems take advantage of the temperature, moisture, and storage-length relationships shown in Table 12.3. Natural air-drying systems can be used to reduce energy inputs. To prevent spoilage, careful management (which may involve frequent climbs to the top of the bin to inspect the grain) is needed. These systems can be used to store grain for relatively long periods of time at 15% moisture. Details about natural-drying systems are available in Hansen (2005) and in Wilcke and Morey (1995).

High-temperature bin dryers

- In high-temperature bin dryers, a layer of corn (usually not more than 9-feet deep) is placed on the floor and the air is heated to between 120 and 180°F. Corn dries as heated air moves through the layer of grain. If temperatures are near the high end of the range, a delayed cooling cycle should be used to reduce kernel brittleness and stress cracks.

Continuous-flow bin dryers

- Continuous-flow bin dryers typically are bins with a perforated drying floor, a fan, a heater, a grain spreader, unloading equipment, and an auger for the transfer of grain to storage. Grain flow to both storage and cooling bins is usually automatically controlled. Separate wet holding bins can assure optimum drying depths.

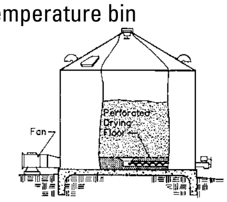
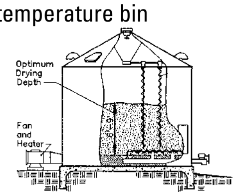
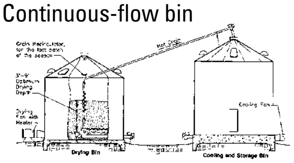
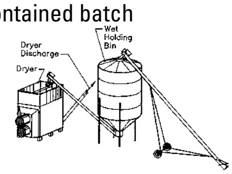
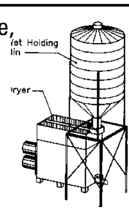
High-temperature, self-contained batch systems

- High-temperature, self-contained batch systems have all the drying equipment (filling, unloading, and controls) built into the dryer. These dryers are movable, but fuel, electricity, and corn-handling equipment are required at each site. Batch drying systems require more time compared to continuous-flow systems, as drying does not occur during filling and unloading.

High-temperature, self-contained continuous-flow dryers

- High-temperature, self-contained continuous-flow dryers are loaded and unloaded either continuously or in frequent intermittent cycles. Loading and unloading conveyors must be sized for maximum grain-drying capacity.

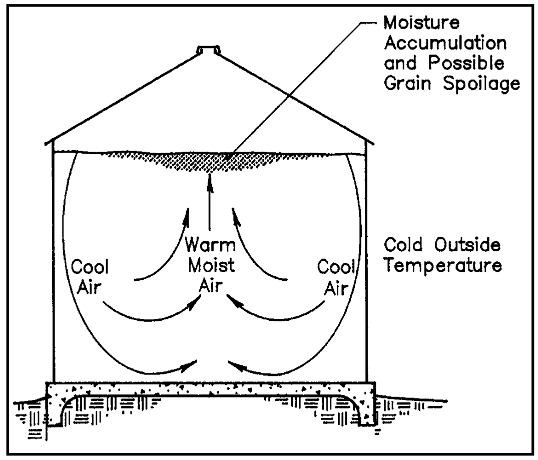
Table 12.3. Comparison of selected grain-drying systems

Type of Drying System	Relative Cost	Advantages	Disadvantages
Low-temperature bin 	Low	Very little corn handling required. Fast harvesting (i.e., not waiting for dryer). Same system used for both drying and storage.	Maximum filling moisture content is 22%. High humidity and low temperatures reduce drying rate. Works best in low-humidity regions. Requires careful management.
High-temperature bin 	Low to medium	Dryer bins can be used for storage after last drying batch. Mixing wetter and drier corn in conveying auger after drying improves storage.	Drying and storage are in separate bins. If dryer bin does not have stirring system, limit drying depth to 2.5–4 ft. More labor than other high-temperature drying.
Continuous-flow bin 	Medium	Dryer bins can be used for storage after last drying batch. Mixing wetter and drier corn in conveying auger after drying improves storage.	Drying and storage are in separate bins. Drying bin must be completely emptied every few days to prevent fines from accumulating.
High-temperature, self-contained batch 	Medium to high	Cooling cycle is built into dryer, or it can be programmed to cool in bin. System can be automatically controlled.	Drying cycle time is longer than continuous flow. Requires a separate wet-corn holding bin.
High-temperature, self-contained continuous-flow 	High	Low-capacity conveyors can be used to move dried corn to cooling or storage bins. Recovering some discharge air from lower part of dryer can save energy.	Requires a separate wet-corn holding bin.

Storage

Storage protocols should be used to maintain grain quality. During storage, grain quality does not improve and can only decrease if proper precautions are not taken. Grain temperature is the primary factor influencing spoilage. Lower storage temperatures decrease biological and insect activity, thereby increasing safe-storage periods. Whether the storage is short- or long-term, the proper selection of construction materials, sizing, and location are essential. Corn quality is generally easier to manage in small storage containers than in large storage containers. As a general rule, never have more than 1/2 of the total annual grain production in a single storage facility. A mixture of storage sizes provides the flexibility to meet changing needs. To minimize storage costs and maximize management flexibility and production and/or marketing options, the storage capacity should be large enough to meet your needs at a reasonable cost per bushel.

Figure 12.4. Pattern of moisture migration in stored grain



(Courtesy of Cloud et al. 1997)

Managing grain in storage is important to maintain grain quality after it is harvested. To maintain quality, moisture and insect activity must be controlled. Factors that can cause corn to lose quality during storage include the following:

- initial grain quality
- grain moisture content
- grain temperature
- amount and distribution of fines and foreign material
- the presence of insects

Spoilage can occur in isolated areas of the bin ("pockets") where kernel moisture is high. Pockets of high kernel moisture can result from moisture migration. For example, as outside temperatures drop during late fall and winter, corn in a bin does not cool uniformly. Corn near the bin wall cools more rapidly, causing a convection air current (fig. 12.4); the air then rises through the warm center, where air moisture content is increased. As the warm air reaches the corn surface, moisture condenses and accumulates. Moisture migration can result in spoilage and can be minimized by maintaining an even grain temperature in the bin.

An aeration system is essential for preventing temperature variation. In order to control temperature (and also reduce insect activity), an aeration system moves air through the stored corn. In South Dakota, for overwinter storage, stored corn should be uniformly cooled to below 35°F; for storage during the spring, summer, and fall, corn should and warmed to between 50 and 60°F. An airflow rate of 1 cfm/bu is adequate for most corn aeration in South Dakota. Storage systems should be routinely monitored to prevent loss from spoilage and insect damage.

Broken corn kernels and fines can increase spoilage by changing airflow patterns. Air currents from aeration fans tend to go around pockets of fines, resulting in slower cooling. Pockets of fines often develop into hot spots that result in spoiled grain. To minimize problems, 1) clean the corn with a screen cleaner before putting it in the bin and 2) use a spreader during bin loading to evenly spread the remaining fines.

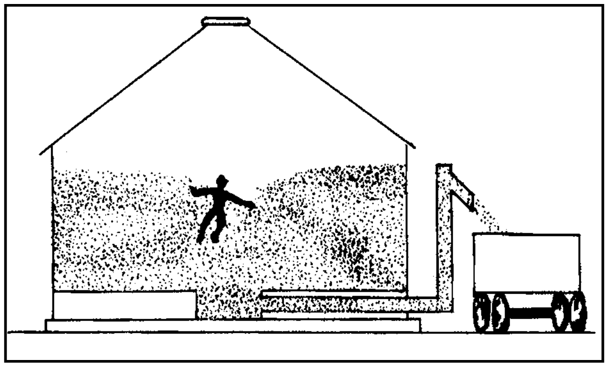
In round bins without a distributor, dried corn peaks at an angle of between 18 and 20°. Peaking allows for more bushels to be stored in the bin, but it can cause moisture-migration problems. Peaks can be reduced or removed by withdrawing a small amount of grain immediately after loading the bin.

Safety

Absolutely forbid entry into a bin or gravity-flow trailer when grain is flowing. Suffocation is a major cause of accidental death when handling corn (fig. 12.5). Always be aware of the following safety rules when working with flowing grain:

- Always lock access doors to grain storage structures.
- Lock out power to all types of grain-handling equipment.
- Always use the "buddy system" (notifying a second person [who is at your location] where you are) when unloading or loading grain.
- Never permit children to ride in grain wagons or enter grain storage areas.
- Always know where ALL family members are (especially children) at all times when grain is loaded, unloaded, moved, or otherwise handled.
- Do not enter grain bins that are being loaded or unloaded. Flowing grain can trap and suffocate you in seconds.
- Never allow children to play in grain storage equipment, whether the equipment is empty or full.
- Maintain, repair, or replace broken safety shields on open chains, belts, and power-take-off (PTO) shafts.

Figure 12.5. Flowing corn can trap you in seconds



(Courtesy of Cloud et al. 1997)

Breathing mold spores in stored corn can cause illness and may lead to chronic health problems. When working in dusty or moldy corn, wear a respirator that filters fine dust. Disposable masks or respirators with replaceable cartridges designed to filter dust ensure protection for grain handlers. Change the mask or cartridge frequently for the greatest protection. Filter masks may provide adequate protection from common agricultural molds, dusts, and chaffs; however, they will not protect the wearer from gases during and after grain bin fumigation.

Absolutely forbid entry into a grain bin during or after fumigation; wait either until the bin has been cleared or until the reentry interval stated on the product label has been satisfied. Fumigation management plans are required for anyone fumigating stored grain. More information is available from the South Dakota Department of Agriculture, Office of Agronomy Services, or online at http://www.state.sd.us/doa/das/fum_mgmt_plan.pdf.

Maintain proper and effective shields and guards on such hazardous equipment as moving belts, roller chains, pulleys, sprockets, gears, and shafts. Wear work clothing with no loose ends or strings that may catch on machinery. Make sure everyone who operates the equipment has the appropriate training and is physically, mentally, and emotionally able to operate the equipment safely.

Additional Information and References

Cloud, H.A., L.D. Van Fossen, L.F. Backer, R.C Brook, L.A, Brook, K.J. Hellevang, B.A. McKenzie, W.H. Peterson, and R.O. Pierce. 1997. Grain Drying, Handling and Storage Handbook. Midwest Plan Service, Iowa State University, Ames, Iowa. https://www.mwps.org/.

Doss, H.J. and W. McLeod. 2002. Avoid risks when working around grain handling and processing equipment. National Ag Safety Database. http://www.cdc.gov.

Hansen, R. 2002. Natural Air Grain Drying in Ohio. Crop observation and recommendation network. The Ohio State University. http://corn.osu.edu.

Hellevang, K.J. 1994. Grain drying. AE701. North Dakota Cooperative Extension Service, North Dakota State University. Fargo, ND. http://www.ag.ndsu.nodak.edu.

Pohl, S., G.R. Durland. 2002. Grain drying guidelines for a wet fall harvest. ExEx1014. South Dakota State University, South Dakota Cooperative Extension Service. http://agbiopubs.sdstate.edu.

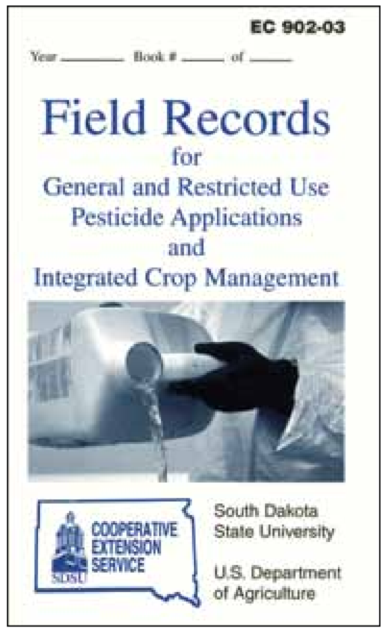
Wilcke, W., and R.V. Morey. 1995. Natural-air corn drying in the upper Midwest. University of Minnesota Extension Bulletin 6577-60. http://www.extension.umn.edu.

Nicolai., R.E. 2009. "Corn drying and storage." Pp. 99–106. In Clay, D.E., S.A, Clay, and K.D. Reitsma (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 13
Recordkeeping

Recordkeeping is an important component of all crop production systems. The time that is spent maintaining careful records can help to improve the production, profit, and overall efficiency of the production enterprise. Records provide information needed to identify successes and failures.



Records should be as detailed and complete as possible. Some basic elements of records include field location, crop type, hybrid number, genetic enhancements, soil type(s), previous crop, tillage, planting information, soil test and fertilizer/manure applications, pesticide applications, and harvest information. Scouting maps and the results of soil and manure tests should be attached or included in records. The location of problem areas within the field should be identified on the map. If available, daily or monthly weather records should be attached to the yearly record, as weather is one of the most influential yet uncontrollable variables that can impact crop yield.

Federal law requires that all private applicators keep records of applications of all restricted-use pesticides (RUP). These records have minimum requirements and must be kept for a minimum of 2 years. Restricted-use pesticides may only be purchased or applied by a certified applicator. All of these products will clearly state "restricted use" on the label. Additional information on pesticide and general field recordkeeping is available from the South Dakota Department of Agriculture (http://www.state.sd.us/doa/das/hp-pest.htm) or from local Extension educators.

Name:				
Address:				
City:	State:		Zip:	
Certification Number:		☐ Private	☐ Commercial	Exp. Date:
Field Name:				Acres:
Quarter:	Section:	Township:	Range:	
Soil Type:				

------Crop Information------	**------Soil Fertility------**	
Previous Crop:	Date of Sampling:	
Tillage:	Soil Test Results	Pre-Sidedress N Test
Residue % at Planting:	NO_3- N:	NO_3- N:
------Planting Information------	P:	
Hybrid:	K:	
Maturity: RM: GDU:	pH:	
Yield Goal:	OM:	
Planting Date:	Other:	
Planting Depth:	**------Nitrogen Credits from Previous Year------**	
Moisture at Planting:	Manure N Credit	Legume Credit
Planting Population:		
Actual Population:	***Attach Soil and Manure Test Results**	

------Fertilizer/Manure Applications------

Date	Fertilizer Grade –or– Type of Manure	------Nutrients Applied------				
		N	P_20_5	K_20	Other	Cost/Acre
	Summary totals for crop:					

------Herbicide/Insecticide/Fungicide Applications------

Date	Brand Name	EPA Registration Number (from label)	Target Pest	Amount Used	Acres Applied

------Harvest Information------

--Acres with Percent Lodging--				
0–25%	25–50%	50–75%	75–100%	Date of Harvest:
				Estimated Yield:
				Actual Yield:
--Aflatoxins--				Harvest Loss:
Black Light Test: ☐ Positive ☐ Negative				Moisture % at Harvest:
If aflatoxin is suspected, submit sample for laboratory analysis regardless of black light test results.				Date of Sale:
				Price Received:

Field map of:			
Quarter(s):	Section:	Township:	Range:
Crop Year:		Crop:	

	N ↑

Scouting notes:

Additional Information and References

Arzeno, A. 2004. Record keeping in farm management. ExEx5054. South Dakota State University, South Dakota Cooperative Extension Service, College of Agriculture and Biological Sciences. http://agbiopubs.sdstate.edu.

Deneke, D., R. Gosmire, B. Ruden, J. Wilson. 1995. Field records for general and restricted use pesticide applications and integrated crop management. EC902-03. South Dakota State University, South Dakota Cooperative Extension Service. United States Department of Agriculture. http://agbiopubs.sdstate.edu.

Recordkeeping Manual for Private Pesticide Applicators. United States Department of Agriculture, Agricultural Marketing Service – Pesticide Records Branch. http://www.ams.usda.gov/science/sdpr.htm.

South Dakota Department of Agriculture, Division of Agricultural Services, Office of Agronomy Services. Pesticide Programs – Recordkeeping Requirements. http://www.state.sd.us/doa/das/.

Wilson, J.A., K.D. Reitsma, and D.E. Clay. 2009. “Recordkeeping.” Pp. 107–10. In Clay, D.E., K.D Reitsma, and S.A, Clay (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 14
Useful Calculations: Corn Yields and Storage Requirements

Table 14.1. Distance conversion multipliers

		Unit Converting To (UT)								
		Mile (Mi)	Rod (Rd)	Yard (yd)	Foot (ft)	Inch (in)	Kilometer (Km)	Meter (m)	Centimeter (cm)	Millimeter (mm)
Unit Converting From (UF)	Mile	-	320	1,760	5,280	63,360	1.609	1,609	160,934	*
	Rod	0.003125	-	5.5	16.5	198	0.00503	5.03	502.9	*
	Yard	0.000568	0.1818	-	3	36	0.00091	0.914	91.44	914.4
	Foot	0.000189	0.0606	0.333	-	12	0.00031	0.3048	30.48	304.8
	Inch	*	0.0051	0.028	0.083	-	*	0.0254	2.54	25.4
	Kilometer	0.6214	198.84	1,093.6	3,280.8	39,370	-	1,000	100,000	*
	Meter	0.00062	0.1988	1.0936	3.28	39.370	0.001	-	100	1,000
	Centimeter	*	*	0.0109	0.0328	0.3937	*	0.01	-	10
	Millimeter	*	*	*	0.00328	0.0394	*	0.001	0.1	-

Example: To convert miles to rods, multiply the number of miles by 320.
* Values are either too large or small to be useful for conversion. If it is necessary to convert to these units, convert to a larger or smaller unit and then convert that result to the desired unit. Conversion multiplier values have been rounded but will provide accurate results in most situations.

Table 14.2. Area conversion multipliers

		Unit Converting To (UT)								
		Square Mile (Mi^2)	Acre (Ac)	Square Yard (yd^2)	Square Foot (ft^2)	Square Inch (in^2)	Square Kilometer (Km^2)	Hectare (ha)	Square Meter (m^2)	Square Centimeter (cm^2)
Unit Converting From (UF)	Square Mile	-	640	*	*	*	2.59	259	*	*
	Acre	0.0015625	-	4,840	43,560	*	0.00405	0.4047	4,047	*
	Square Yard	*	*	-	9.0	1,296	*	*	0.8361	8,361
	Square Foot	*	*	0.1111	-	144	*	*	0.0929	929
	Square Inch	*	*	*	0.0069	-	*	*	0.0006	6.4516
	Square Kilometer	0.3861	247	*	*	*	-	100	1,000,000	*
	Hectare	0.003861	2.47	*	*	*	0.01	-	10,000	*
	Square Meter	*	*	1.196	10.764	1,550	*	*	-	10,000
	Square Centimeter	*	*	*	0.00108	0.155	*	*	*	-

* Values are either too large or small to be useful for conversion. If it is necessary to convert to these units, convert to a larger or smaller unit and then convert that result to the desired unit. Conversion multiplier values have been rounded but are appropriate in most situations.

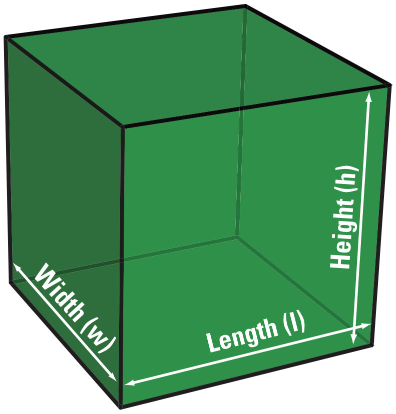
Table 14.3. Liquid volume measure conversion multipliers												
		Unit Converting To (UT)										
		Acre Inch (Ac*In)	Cubic Foot (ft^3)	Gallon (Gal.)	Quart (Qt.)	Pint (Pt.)	Cup (C)	Fluid Ounces (Fl. Oz)	Table-spoon (Tbsp)	Tea-spoon (Tsp)	Cubic Meter (m^3)	Liter (L)
Unit Converting From (UF)	Acre Inch	-	3,630	27,154	*	*	*	*	*	*	102.79	*
	Cubic Foot	0.000275	-	7.48	29.92	59.84	*	*	*	*	0.0283	28.32
	Gallon	*	0.1337	-	4	8	16	128	256	768	0.003785	3.785
	Quart	*	0.0334	0.25	-	2	4	32	64	192	0.000946	0.946
	Pint	*	0.0167	0.125	0.5	-	2	16	32	96	0.000473	0.473
	Cup	*	0.0084	0.0625	0.25	0.5	-	8	16	48	0.000237	0.236
	Fluid Ounces	*	0.0011	0.0078	0.03125	0.0625	0.125	-	2	6	0.000029	0.029
	Table-spoon	*	*	0.0039	0.01562	0.03125	0.0625	0.5	-	3	*	*
	Teaspoon	*	*	0.0013	0.00521	0.01042	0.0208	0.167	0.334	-	*	*
	Cubic Meter	*	35.31	264.17	1056.7	2113.38	4226.75	33,814	*	*	-	1000
	Liter	*	0.0353	0.2642	1.05669	2.11337	4.2268	33.814	67.628	202.884	0.001	-

* Values are either too large or small to be useful for conversion. If it is necessary to convert to these units, convert to a larger or smaller unit and then convert that result to the desired unit. Conversion multiplier values have been rounded but are appropriate in most situations.

Table 14.4. Dry volume measure conversion multipliers										
		Unit Converting To (UT)								
		Bushel (Bu)	Peck (Pk)	Dry Quart (qt-d)	Cubic Yard (yd^3)	Cubic Foot (ft^3)	Cubic Meter (m^3)	Cubic Centimeter (cc)	Liter (L)	Milliliter (mL)
Unit Converting From (UF)	Bushel	-	4	32	0.0461	1.244	0.0352	35,239	35.24	35,239
	Peck	0.25	-	8	0.0115	0.311	0.0088	8,810	8.81	8,810
	Dry Quart	0.03125	0.125	-	*	0.039	*	1,101	1.101	*
	Cubic Yard	21.7	86.785	*	-	27.0	0.7646	764,555	764.555	764,555
	Cubic Feet	0.804	3.214	25.71	0.037	-	0.0283	28,317	28.317	28,317
	Cubic Meter	28.378	113.51	908	1.308	35.315	-	1,000,000	1,000	1,000,000
	Cubic Centimeter	*	*	*	*	*	*	-	0.0001	1.0
	Liter	0.0284	0.1135	0.908	0.00131	0.0353	0.001	1,000	-	1,000
	Milliliter	*	*	*	*	*	0.000001	1.0	0.001	-

* Values are either too large or small to be useful for conversion. If it is necessary to convert to these units, convert to a larger or smaller unit and then convert that result to the desired unit. Conversion multiplier values have been rounded but are appropriate in most situations.

Figure 14.1. Perimeter, area, and volume of a square, rectangle, or cube



Square or Rectangle

Perimeter = $(l \times 2) + (w \times 2)$

Area = $l \times w$

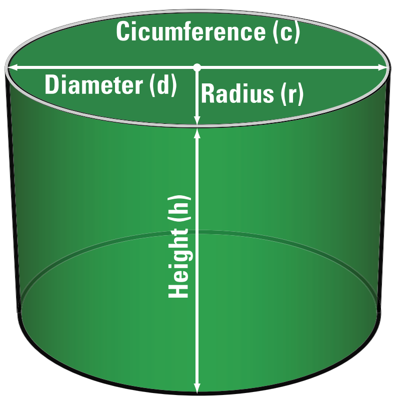
Cube or 3-Dimensional Rectangle

Perimeter = $(l \times 4) + (w \times 4) + (h \times 4)$

Surface Area = $(l \times w) \times 6$

Volume = $l \times w \times h$

Figure 14.2. Circumference, area, and volume of circles and cylinders



***Pi* (π) = 3.14159**

Area of a Circle (A)

$A = \pi \times r^2$

Circumference (c)

$c = 2 \times r \times \pi$

Volume of Cylinder (v)

$v = \pi \times r^2 \times h$

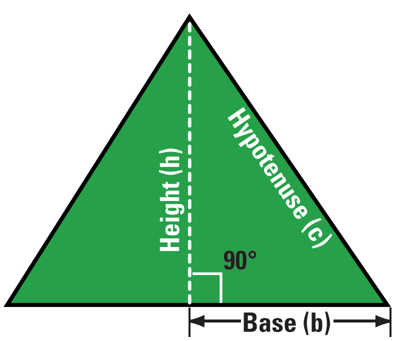
Volume of a Cone

$v = \frac{1}{3} \times r^2 \times \pi \times h$

Volume of Sphere

$v = \frac{4}{3} \times \pi \times r^2$

Figure 14.3. Measurements for triangular objects



Length of any Side of a Right Triangle

Pythagorean Theorem: $A^2 + B^2 = C^2$

Where:

A = Height (h)
B = Base (b)
C = Hypotenuse (c)

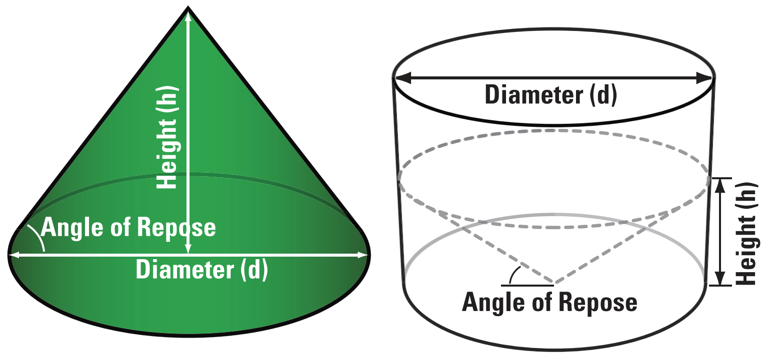
Area of a Triangle

Area = $(b \times h) \div 2$

Volume of a Pyramid (v)

$v = \left(\frac{1}{3}\right) \times ((b \times 2) \times h)$

Figure 14.4. Estimating the volume of a cone



$$v = \frac{1}{3} \times r^2 \times \pi \times h$$

Where:
- v = Volume
- r = radius
- π = Pi = 3.14159
- h = height

(Courtesy of Wilke & Wyatt 2002)

Estimating the Amount of Grain in a Pile

Corn is often piled on the ground when covered storage is not available. The amount of corn in a cone-shaped pile can be estimated by finding the volume using the equation in figure 14.4. The radius (r) of the pile is estimated by measuring the diameter (d) and dividing by two. The height of the pile can be estimated by measuring it or by finding the pile's angle of repose (AR). AR can be measured using a clinometer, or estimated using standard values provided in Table 14.5. Friction, cohesion, the shape of the grain, grain moisture, fine and foreign material content, spoilage, and the method for filling or emptying will influence AR. For dry corn, AR values range from 15 to 26 degrees (0.40 to 0.49 radians). Representative values of AR for selected crops in degrees and radians are provided in Table 14.5.

For the example below, consider a pile of corn with a diameter of 120 feet and an assumed AR of 23 degrees (Table 14.5). An estimate of the amount of grain is found using the following steps:

1) Find the radius of the pile from measured diameter (d):

$$r = \left(\frac{d}{2}\right) = \left(\frac{120\text{ ft}}{2}\right) = 60\text{ ft}$$

2) Estimate the height (h) of the pile using the AR.

$$h = (\mathit{Tan}\ \text{AR}) \times (r\text{ ft}) = (0.42) \times (60\text{ ft}) = 25.2\text{ ft}$$

3) Find the volume (v) of the cone:

$$v = \left[\frac{1}{3} \times r^2\right] \times \pi \times h = \left[\frac{1}{3} \times (60)^2\right] \times 3.14159 \times 25.2 = 95{,}001\text{ ft}^3$$

4) Convert cubic feet (ft^3) to bushel:

$$v_{bushel} = 95{,}001_{ft3} \times 0.803 = 76{,}286_{bushel}$$

The amount of corn is found by multiplying the volume in ft^3 by 0.803 (Table 14.4).

Table 14.5. Angle of repose (AR) for selected commodity grains

Crop	[1]Angle (AR°)		Tangent (tan(AR°))
	Deg.	Rad.	
Barley	28	0.49	0.53
Corn (Shelled)	23	0.40	0.42
Oats	28	0.49	0.53
Soybeans	25	0.44	0.47
Sunflowers	27	0.47	0.51
Wheat	25	0.44	0.47

(Adapted from Wilke & Wyatt 2002 and Grain Drying, Storage, and Handling Handbook, MWPS-13)

[1]Angles reported in degrees (Deg.) and radians (Rad.). To convert from degrees to radians:

$$\text{radians} = \text{degrees} \times \left(\frac{180}{\pi}\right)$$

Estimating Corn Yields

Estimates of pre-harvest yield can be helpful for planning purposes. One method for calculating a pre-harvest yield estimate is to sample a number of ears in a known area, calculate the number of kernels per ear, and convert kernels per ear to bushels per acre. Pre-harvest yield can be estimated by following the steps below:

Table 14.6. Length of row equal to 1/1000 acre at selected row spacing

Row Spacing (inches)	Length equal to 1/1000 acre
7	74 feet, 8½ inches
15	34 feet, 10 inches
22	23 feet, 8 inches
30	17 feet, 5 inches
38	13 feet – 9 inches

1) Measure the length of row required for 1/1000 acre. For fields with 30-inch row spacing, 1/1000 is equal to the area of a rectangle that is 30-inches wide and 17-feet-and-5-inches long (Table 14.6).
2) Determine the average number of kernels on a representative ear by counting the number of rows and the number of kernels in a row. IMPORTANT: Select an average-looking ear; if the largest ear is selected, yield is overestimated; if the ear is too small, yield is underestimated. Averaging the number of kernels per ear from several ears improves accuracy. Calculate the kernels per ear as shown below:

$$\frac{\text{kernels}}{\text{ear}} = \left[\left(\frac{\text{kernels}}{\text{rows}}\right)\times\left(\frac{\text{rows}}{\text{ear}}\right)\right] = \left[\left(\frac{35\text{ kernels}}{\text{rows}}\right)\times\left(\frac{16\text{ rows}}{\text{ear}}\right)\right] = \frac{560\text{ kernels}}{\text{ear}}$$

3) Count the number of plants in the length of row or sample area (SA). In the example below, 27 plants were counted in a 17-feet-5-inch row. The average number of ears per plant can be used, but in most cases it is recommended to assume 1 ear per plant.

$$\frac{\text{kernels}}{\text{SA}} = \left(\frac{\text{kernels}}{\text{ear}}\right)\times\left(\frac{\text{ear}}{\text{plant}}\right)\times\left(\frac{\text{plant}}{\text{ear}}\right) = \left(\frac{560\text{ kernels}}{\text{ear}}\right)\times\left(\frac{1\text{ ear}}{\text{plant}}\right)\times\left(\frac{27\text{ plants}}{\text{SA}}\right) = \frac{15{,}120\text{ kernels}}{\text{SA}}$$

4) An estimate of yield (bu/acre) is calculated by converting the value of kernels/sampling area (SA) to bu/acre. For this calculation it will be assumed that a bushel contains approximately 80,000 kernels.

$$\text{Yield } \frac{\text{bu}}{\text{acre}} = \left(\frac{\text{kernels}}{\text{SA}}\right)\times\left(\frac{\text{bu}}{\text{kernels}}\right) = \left(\frac{15{,}120\text{ kernels}}{0.001\text{ acre}}\right)\times\left(\frac{1\text{ bu}}{80{,}000\text{ kernels}}\right) = \frac{189\text{ bu}}{\text{acre}}$$

Estimating Yield Loss During Harvest

Measure the number of kernels in a 1ft^2 area behind the combine and convert units to bu/acre. The example below shows that if 13 kernels are collected, the yield loss is 7.1 bu/acre.

$$\text{Yield loss} = \left(\frac{13\text{ kernels}}{\text{ft}^2}\right)\left(\frac{43{,}560\text{ ft}^2}{\text{acre}}\right)\left(\frac{1\text{ bu}}{80{,}000\text{ kernels}}\right) = \frac{7.1\text{ bu}}{\text{acre}}$$

Note: This calculation assumes that a bushel of corn contains 80,000 kernels.

Estimating Test Weight (TW)

Test weight (TW) is a measure of grain quality and is defined as the amount of weight the grain must have to make one bushel. Test weight increases as grain dries because dry kernels pack together more easily than wet ones. In addition, kernels shrink as they dry, allowing for more kernels to make up a bushel. Test weight is usually measured by weighing one dry quart of corn and converting that value to pound per bushel. When calculating test weight, it is important to remember that one dry quart is not equal to one liquid quart. One dry quart is equal to 4⅔ cups, and one bushel contains 32 dry quarts. For example, what is the test weight if 1 dry quart (4⅔ cups) of corn at 15.5% moisture weighs 28 ounces?

$$\text{Test weight } \left(\frac{\text{lbs}}{\text{bu}}\right) = \left(\frac{\text{oz}}{\text{DryQt}}\right)\times\left(\frac{32\text{ DryQt}}{1\text{ bushel}}\right)\times\left(\frac{1\text{ lbs}}{16\text{ oz}}\right)$$

$$\text{Test weight } \left(\frac{\text{lbs}}{\text{bu}}\right) = \left(\frac{28\text{ oz}}{1\text{ DryQt}}\right)\times\left(\frac{32\text{ DryQt}}{1\text{ bushel}}\right)\times\left(\frac{1\text{ lbs}}{16\text{ oz}}\right) = \frac{56\text{ lbs}}{\text{bu}}$$

Grain Moisture

The grain percent moisture is defined by the following equation:

$$\% \text{ moisture} = \left(\frac{\text{water weight}}{\text{water weight - dry grain}}\right) 100\%$$

If it is assumed that 1 bushel of corn at 15.5% moisture weighs 56 pounds, then 1 bushel of corn contains 47.32 pounds of dry corn. Based on the equation

$$\frac{\text{lb}}{\text{bu}} = \left(\frac{47.32 \text{ lbs/bu}}{100 - \% \text{ moisture}}\right) \times 100$$

the weight of corn required to produce 47.32 pounds of dry matter can be calculated (Table 14.7). These values should not be confused with either test weight or how bushels of corn are actually calculated at the elevator.

Table 14.7. Corn moisture conversions relative to a standard bushel

% moisture	lb/bu	% moisture	lb/bu
11.0	53.17	21.0	59.90
12.0	53.77	22.0	60.67
13.0	54.39	23.0	61.45
14.0	55.02	24.0	62.26
15.0	55.67	25.0	63.09
15.5	56.0	26.0	63.95
16.0	56.33	27.0	64.82
17.0	57.01	28.0	65.72
18.0	57.71	29.0	66.65
19.0	58.42	30.0	67.60
20.0	59.15	31.0	68.58

(Adapted from Evans et al. 1997)

Grain Marketing

Corn yield is measured either in bushels or in standard bushels (Table 14.8). Yield monitors generally calculate yields in standard bushels (56 lbs. at 15.5% moisture), while elevators often calculate yields in bushels (56 lbs., irrespective of moisture percentage). Corn yield is classified and graded according to standards outlined in rules administered by the Grain Inspection, Packers and Stockyards Administration, an agency of the United States Department of Agriculture. Most corn grown in South Dakota is marketed as yellow dent corn and carries a grade that ranges from 1 to 6. Factors influencing grade are broken kernels and foreign material; test weight; heat damage; damaged kernels (total); stones; heating; musty, sour, or other objectionable foreign odor; and distinct low quality (Evans et al. 1997). Grain moisture is not a grading factor, but it greatly influences quality and is important in dockage schedules.

Yield estimates and trading schedules are based on the "bushel" volume unit; however, grain is usually weighed at the point of sale. Standard test weight is used to convert the weight of grain to bushels and is also an indicator of grain quality. Most grain buyers will base dockage schedules on 56 lbs/bu at 15.5% moisture, which is the weight per bushel at the maximum permitted moisture content of U.S. No. 2 corn (Evans et al. 1997).

Table 14.8. Standard test weight values at selected grain moisture content

	Grain Moisture (%)					
	20%	18%	15.5%	13%	10%	0%
Commodity	----------Weight (lbs/bu.)----------					
Corn	59.15	57.71	*56.0	54.39	52.58	47.32
Soybeans	65.25	63.65	61.78	*60.0	58.0	52.2
Wheat	64.88	63.29	61.42	[1]*60.0	57.67	51.9

[1]Standard Test Weight Value Based on 13.5% Moisture
* Standard Test Weight (Stw) Values

Table 14.9. Theoretical moisture shrink factors for drying shelled corn to various final moisture levels

Final Moisture Content (FGM) (%)	Moisture Shrink Factor (MS)(% shrink per point)
15.5	1.183
15	1.176
14	1.163
13	1.149
12	1.136
11	1.126
10	1.111
9	1.099
8	1.087
0	1.000

$$MS = (IGM - FGM) \times MSF$$

Where:
MS = Moisture Shrink (%)
IGM = Initial Grain Moisture (%)
FGM = Final Grain Moisture (%)

1. For corn with a moisture content (IGM) of 20%, determine the moisture shrinkage if dried to 15.5%.
   $5.32\% = (20\% - 15.5\%) \times 1.183$
2. For corn with a moisture content of 20%, determine the moisture shrinkage if dried to 13%.
   $8.043\% = (20\% - 13\%) \times 1.149$

(Adapted from Hicks and Cloud 1992)

Evaluating Grain Sales

Growers should seek more than one quote when selling corn because grain buyers use different discounts. Grain buyers may use a "pencil shrinkage" method to calculate the total shrink factor (TS). TS is the sum of the moisture shrink factor (MS) and handling shrink factor (HS). TS is calculated with the following equation:

$$TS = MS + HS$$

Theoretical MS for grain are shown in Table 14.9. Handling shrink varies from buyer to buyer. The actual amount of handling shrink has extreme variations (Hoffbeck 2007). The example below is provided to demonstrate how shrinkage is used to determine selling price:

Problem: A seller has 100,000 lbs of corn with 20% initial grain moisture content (IGM). To get the best price for his corn, he obtains 2 bids.

Buyer #1 quotes a price of $5.00 per dry bushel, uses a TS of 1.25, and shrinks grain to a final grain moisture content (FGM) of 14%.

Buyer #2 quotes a price of $5.05 per dry bushel, uses a TS of 1.35, and shrinks grain to an FGM of 13%.

To whom should the seller sell the corn? Both buyers assume wet corn weighs 56.0 lbs/bu. The value of the corn is found using the following equation:

$$\text{Value of Corn} = \left[\frac{(100\text{-}(TS(IGM\text{-}FGM)))}{100}\right] \times \left[\left(\frac{\text{lbs wet corn}}{\text{Lot}}\right) \times \left(\frac{1\text{ bu}}{56.0\text{ lbs}}\right)\right] \times \left[\frac{\text{price (\$)}}{\text{bu}}\right]$$

Where:

TS = Total Shrink (%) = Moisture Shrink (MS) + Handling Shrink (HS)

IGM = Initial Grain Moisture (%)

FGM = Final Grain Moisture (%)

Buyer #1:

$$\$8{,}259.00 = \left[\frac{(100\text{-}(1.25(20\%\text{-}14\%)))}{100}\right] \times \left[\left(\frac{10{,}000\text{ lbs}}{\text{Lot}}\right) \times \left(\frac{1\text{ bu}}{56.0\text{ lbs}}\right)\right] \times \left[\frac{\$5.00}{\text{bu}}\right]$$

Buyer #2:

$$\$8{,}166.00 = \left[\frac{(100\text{-}(1.35(20\%\text{-}13\%)))}{100}\right] \times \left[\left(\frac{10{,}000\text{ lbs}}{\text{Lot}}\right) \times \left(\frac{1\text{ bu}}{56.0\text{ lbs}}\right)\right] \times \left[\frac{\$5.05}{\text{bu}}\right]$$

In the example, the seller receives $93.00 more for the lot of corn from buyer #1 than buyer #2.

Why use the term shrinkage?

Our forefathers developed the way corn is bought and sold. A clear understanding of the method is needed to maximize your payments. Before large-scale weighing was available at most country elevators, corn was sold by volume (thus the bushel became the basic unit of grain commerce). The inside dimensions of a grain wagon were measured to determine the wagon's width, length, and the height of the grain in the box. A bushel (United States dry measure) equals 2150.42 cubic inches (CRC handbook). When wet corn (greater than 15.5% moisture content) was bought, it was found that as the grain dried, it lost volume (test weight increased by .25 to .5 lb/bu point); thus the term "shrinkage" was used to describe the phenomena of loss of volume when there was a loss of moisture from a load of corn. Today, while we don't measure the volume and instead make most transactions based upon weight, we still use the word shrinkage to indicate moisture loss.

Mechanical Drying Costs

Whether corn is dried on-farm or at a commercial grain terminal, there is cost associated with drying. Typical on-farm gas-fired dryers use 0.015 to 0.025 gal. propane (LP)/(bushel per moisture percentage point). If 0.02 gal. of propane is used to reduce the moisture content 1% in one bushel of corn, then the cost per bushel per percent moisture is $0.04 (assuming $2.00/gal propane cost). The cost for dry-down of a bushel of grain 1 percentage point is calculated in the following manner:

$$\frac{\$0.04}{\text{bu}} = \left(\frac{0.02\ \text{gal}}{\text{bu}} \times \frac{\text{LP}\ \$2.00}{\text{gal LP}}\right)$$

Capital costs for drying vary widely. It is not unusual for capital cost to range from $0.01 to $0.02 per bushel per percentage point. Labor adds additional cost, ranging from $0.01 to $0.02 bushel per moisture percentage point. Based on these estimates, drying costs could be around $0.08 per bushel per percent moisture. Based on these estimates, the drying cost of drying 23% moisture corn to 15.5% would be $0.60 per bushel [$0.08·(23% - 15.5%)]. Moisture shrinkage can be calculated in the following manner:

$$\left(\frac{(23\text{-}15.5) \times 1.183}{100}\right) = 8.875\%\ \text{per bushel}$$

Total shrinkage and drying costs would be $1.088/bushel ($0.60 + [0.08875 × $5.50/bu]). Propane cost varies considerably; current price estimates may be found at http://tonto.eia.doe.gov/dnav/pet/pet_pri_prop_dcu_nus_m.htm.

Bin Storage Requirements

As corn yields have increased, so has the on-farm storage of corn. Producers may store grain for livestock feed or simply to retain equity. Just like any other piece of equipment, storage bins are capital assets that depreciate and require maintenance. The right amount of storage considers production potential, but the proportion of that production stored on-farm will vary by operation. Determining bin capacity is a simple calculation of the volume of a cylinder. For example, a bin with a diameter of 30 feet and a height of 36 feet holds how much corn?

1) Calculate volume (fig. 14.2):

$$25{,}447\ \text{cubic ft} = 3.14159 \times \left(\frac{30\ \text{ft}}{2}\right)^2 \times 36\ \text{ft}$$

2) Convert cubic feet to bushel (Table 14.4):

$$v(\text{bu}) = x\ \text{ft}^3 \times \left(\frac{0.804\ \text{bu}}{1\ \text{ft}^3}\right)$$

$$20{,}000\ \text{bu} \approx 25{,}447\ \text{ft}^3 \times \left(\frac{0.804\ \text{bu}}{1\ \text{ft}^3}\right)$$

Additional Information and References

Digital Dutch, 2004. WWW Unit Converter. Digital Dutch, Amsterdam. http://www.digitaldutch.com/unitconverter/.

Evans, M.G., R.L. Nielsen, and C.B. Southard. 1997. USDA Grading Standards and Moisture Conversion Table for Corn. Purdue University Cooperative Extension Service, West Lafayette. http://www.ces.purdue.edu/extmedia/ay/ay-225.pdf.

Hicks, D.R. and H.A. Cloud. 1991, Calculating grain weight shrinkage in corn due to mechanical drying. National Corn Handbook. NCH-61. Purdue University Cooperative Extension Service, West Lafayette. http://www.ces.purdue.edu.

Hoffbeck, C. 2007. How to determine corn moisture shrink and total shrink. Field Facts 7:11. 1–2. Pioneer HiBred International.

Rankin, M. 2007. Bushels, test weight, shrink, and storage. University of Wisconsin Extension Service. http://www.uwex.edu/ces/crops/bushelstestweight.htm.

Wilcke, W. 1999. Calculating bushels. University of Minnesota Extension Service. http://www.bbe.umn.edu/extens/postharvest/bushels.pdf.

Wilcke, W. and G. Wyatt. 2002. Grain storage tips. Factors and Formulas for Crop Drying, Storage and Handling. University of Minnesota Extension Service, St. Paul. http://www.extension.umn.edu/distribution/cropsystems/M1080-FS.pdf.

Reitsma, K.D., D.E. Clay, S.A. Clay, and C.G. Carlson. 2009. "Useful calculations: corn yields and storage requirements." Pp. 111–19. In Clay, D.E., K.D Reitsma, and S.A, Clay (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 15
Corn Calendar and Troubleshooting Guide

Figure 15.1. Corn production calendar

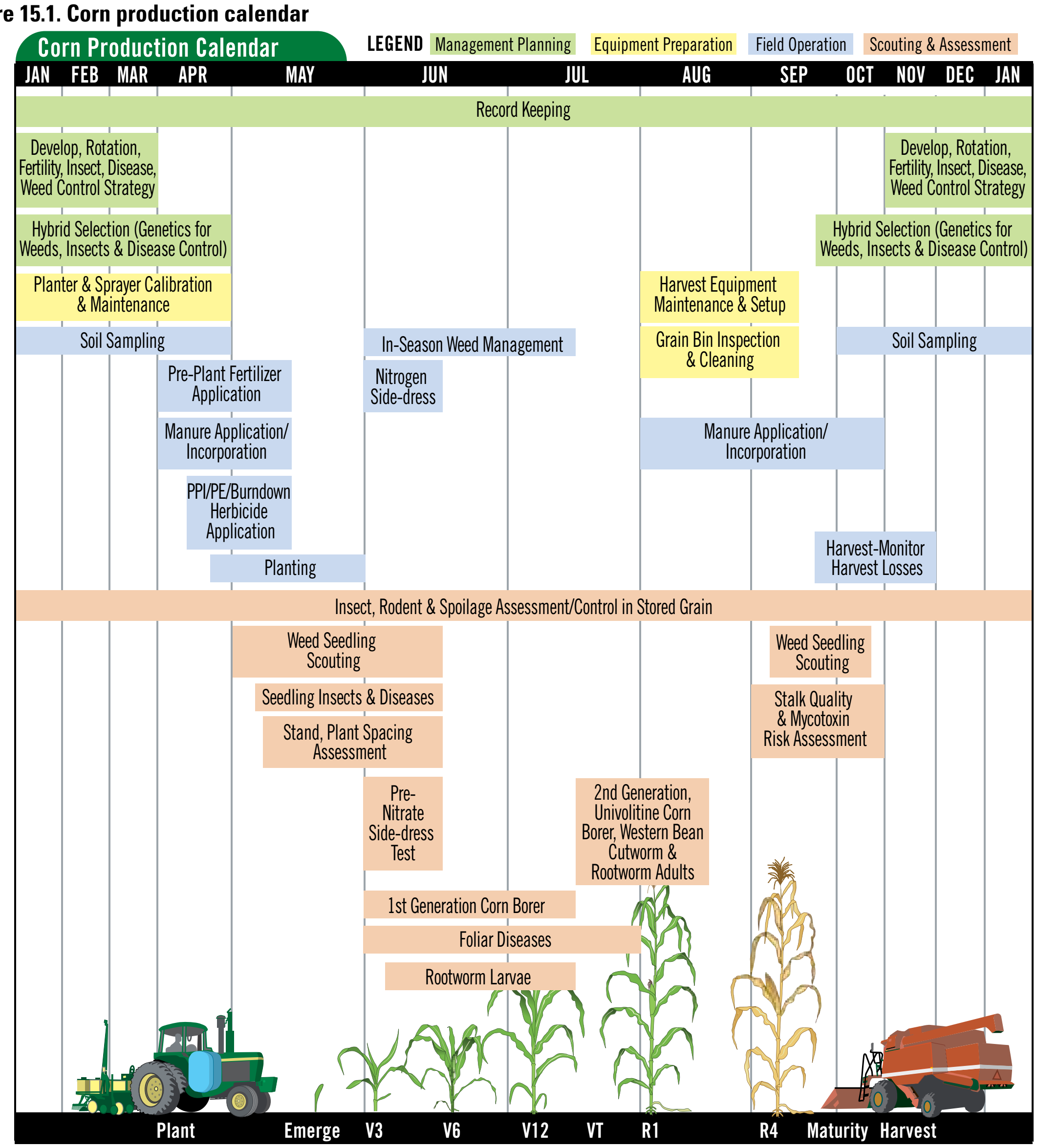
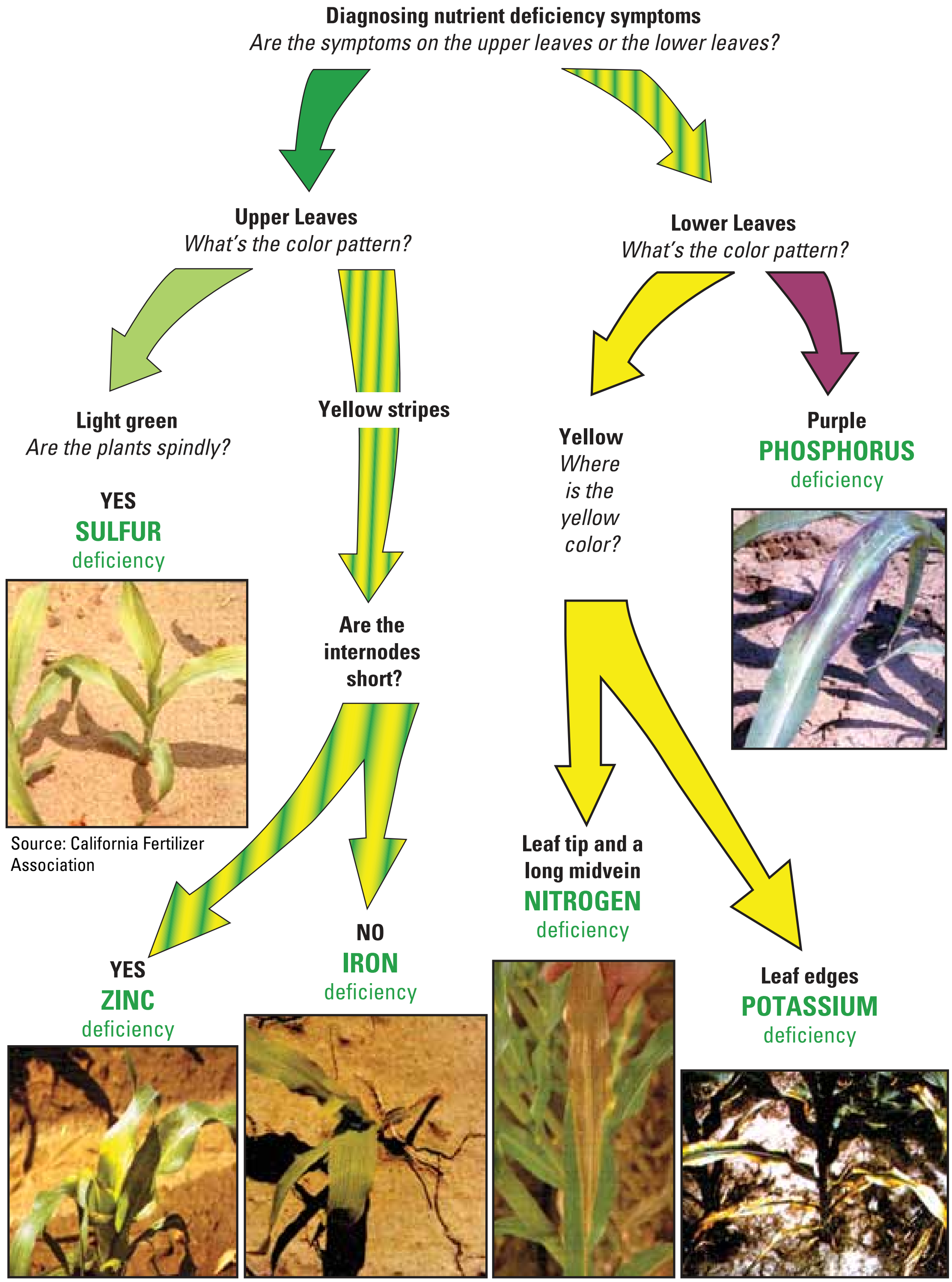


Table 15.1. Corn troubleshooting guide	
Symptoms	**Suspected problem**
Before emergence	
Corn does not emerge	
No seed was planted	Empty planter box Clogged delivery system
Seed not sprouted	No seed Fertilizer injury (too much N and K placed with seed) Too dry kernels not swelled Too cool, swelled but not sprouted
Rotted seed	Dead seed or Seed Rot
Seed eaten or dug up	Insects, birds, rodents
Emergence to V6	
Rotted seed or seedlings	Seed/seedling disease
Seedlings emerge then die	Seedling disease Waterlogged soil
Sprout with twisted leaves	Soil crust or cloddy soil Seed planted too deep Herbicide damage
Poor seedling vigor/slow growth	Low fertility Too cool or dry
Pale green-yellow color	N or S deficiency Water logged
Leaf edges yellow or dead	K deficiency
Purple or reddish color	P deficiency or roundup injury
White striping	Fe deficiency
Broad white area leaf center	Zn shortage
Leaves rolled and wilted	Water deficiency
Plants cut off at ground level	Cut worms
V6-tasseling	
Plants lean or fall over	Rootworm
Stalks break off	Corn borer
Leaves shredded	Hail injury
Silking to maturity	
Delayed silking	Population too high, or drought Shortages of N or P
Silks eaten off	Rootworm or grasshoppers
Large irregular eaten (field edges)	Grasshoppers
Kernels tunneled and eaten	Corn borer, corn sap beetles
Premature dying individual plants	Stalk rot Corn borer damage
Dying of plants in small areas	Drought Stalk rot
Barren stalks	Population too high Low fertility Silks eaten by insects Maize dwarf mosaic
Full cob only scattered kernels	Silks eaten by insects Drought
Maturity to harvest	
Stalks broken above the ear	Corn borer
Stalks broken below the ear	K deficiency Stalk rot
Ears dropped off	Corn borer
(Adapted from Aldrich et, al., 1975)	

Figure 15.2. Corn nutrient deficiency diagnostics



Source: International Plant Nutrition Institute

Additional Information and References

Aldrich, S.R., W. O. Scott, and E.R. Leng. 1975. Modern Corn Production. A&L Publications, Champaign, IL.

Reitsma, K.D., S.A. Clay, C.G. Carlson, and D.E. Clay. 2009. "Corn calendar and troubleshooting guide." Pp. 121-24. In Clay, D.E., K.D. Reitsma, and S.A, Clay (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Cooperative Extension Service, South Dakota Agricultural Experiment Station; South Dakota Corn Utilization Council; USDA-CSREES-406; South Dakota Department of Environment and Natural Resources through EPA-319; South Dakota USGS Water Resources Institute; USDA-North Central Region SARE program; Colorado Corn Growers Association; and Colorado State University.

CHAPTER 16
Websites with Related Information

Professional Organizations and Producer Groups

American Society of Agronomy	https://www.agronomy.org
National Corn Growers Association	http://www.ncga.com
Professional Soil Scientists Association of South Dakota	http://pssasd.sdstate.org
Soil and Water Conservation Society	http://www.swcs.org/
South Dakota Corn Utilization Council	http://www.sdcorn.org

Corn Energy

Corn Energy Calculator	http://www.bess.unl.edu
Corn Refiners Association	http://www.corn.org

Corn Production Information

Colorado	http://wsprod.colostate.edu/cwis435/WQ/cornbook.htm
Indiana	http://www.agry.purdue.edu/ext/corn
Iowa	http://www.agronext.iastate.edu/corn
Kansas	http://www.oznet.ksu.edu/library/crpsl2/c560.pdf
North Dakota	http://www.ag.ndsu.edu/pubs/plantsci/rowcrops/a1130-2.htm#Index
South Dakota	http://plantsci.sdstate.edu/varietytrials

Silage Information

North Dakota	http://www.ag.ndsu.edu/procrop/crn/silage.htm
Wisconsin	http://www.uwex.edu/ces/crops/uwforage/Silage.htm

Corn Production Costs and Risk Calculators

Iowa	http://www.extension.iastate.edu/agdm/crops/html/a1-20.html
South Dakota	http://econ.sdstate.edu/Extension/otherlinks.htm

Soil Fertility and Fertilizer

International Plant Nutrition Institute	http://www.ipni.net
SDSU Plant Science – Soil Testing Lab	http://plantsci.sdstate.edu/soiltest
The Fertilizer Institute	http://www.tfi.org

Global Positioning Systems, Self-Guidance Systems, and Lightbars

AGCO Corporation	http://www.agcocorp.com
CaseIH	http://www.caseih.com
Ford-New Holland	http://www.newholland.com
John Deere	http://www.deere.com
Massey Ferguson	http://www.masseyferguson.com
Raven Industries	http://www.ravenprecision.com/us

Precision Farming and Remote Sensing

Crop Circle	http://holsci.com
NTech Industries	http://www.ntechindustries.com
Site Specific Management Guidelines	http://www.ppi-far.org/ssmg
South Dakota Precision Farming	http://plantsci.sdstate.edu/precisionfarm
South Dakota View	http://sdview.sdstate.edu
Upper Midwest Aerospace Consortium	http://www.umac.org

Seed Technology

Asgrow & DEKALB	http://www.asgrowanddekalb.com
Garst Seed Company	http://www.garstseed.com
Monsanto	http://www.monsanto.com/monsanto/ag_products/default.asp
Pioneer HiBred International	http://www.pioneer.com
Syngenta	http://www.syngenta-us.com/home.aspx

South Dakota Soils Information

USDA – NRCS Soil Data Mart	http://soildatamart.nrcs.usda.gov
USDA – NRCS Web Soil Survey	http://websoilsurvey.nrcs.usda.gov/app

State and Federal Government Agencies

South Dakota Department of Agriculture	http://www.state.sd.us/doa
South Dakota Department of Environment and Natural Resources	http://www.state.sd.us/denr/denr.html
South Dakota Department of Game, Fish, and Parks	http://www.sdgfp.info
USDA – Farm Service Agency	http://www.fsa.usda.gov/FSA
USDA – National Agricultural Statistics Service	http://www.nass.usda.gov
USDA – Natural Resources Conservation Service (South Dakota)	http://www.sd.nrcs.usda.gov
USDA – Rural Development Agency (South Dakota)	http://www.rurdev.usda.gov/sd

South Dakota State University

South Dakota State University	http://www3.sdstate.edu
South Dakota Agricultural Experiment Station	http://www3.sdstate.edu/AgExperimentStation
South Dakota Cooperative Extension Service	http://www3.sdstate.edu/CooperativeExtension
South Dakota State University Extension Publications	http://agbiopubs.sdstate.edu

Clay, D.E. and K.D. Reitsma. 2009. "Websites with related information." Pp. 125–27. In Clay, D.E., K.D. Reitsma, and S.A. Clay (eds). Best Management Practices for Corn Production in South Dakota. EC929. South Dakota State University, South Dakota Cooperative Extension Service, Brookings, SD.

Support for this document was provided by South Dakota State University, South Dakota Corn Utilization Council, USDA-CSREES-406, South Dakota Department of Environment and Natural Resources through EPA-319, South Dakota USGS Water Resource Institute, Colorado Corn Growers Association, and Colorado State University.

Best Management Practices for Corn Production in South Dakota is the collective work of agricultural professionals from South Dakota State University, South Dakota Cooperative Extension Service, and Cooperative State Research, Education, and Extension Service. All content has been peer-reviewed and includes 66 informational tables and over 100 full-color illustrations.