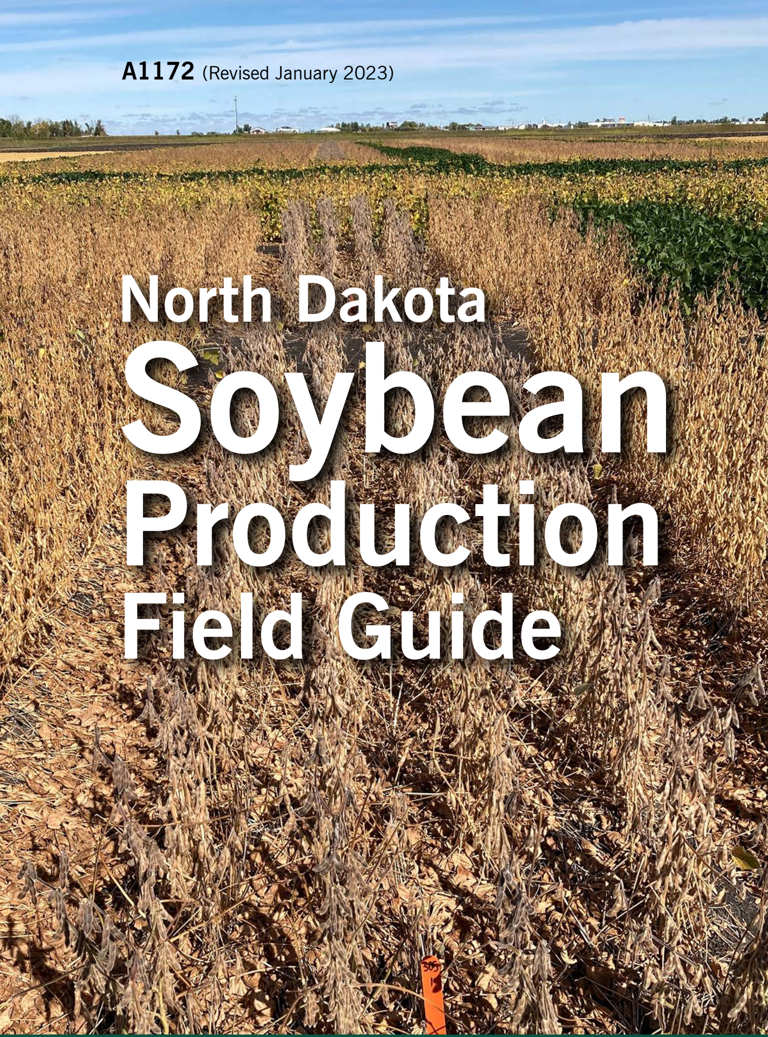
A1172 (Revised January 2023)

North Dakota Soybean Production Field Guide



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Published in cooperation with and support from

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Introduction

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Changing weather conditions with varied rainfall amounts and stored soil water require soybean [*Glycine max* (L.) Merr.] growers to make careful decisions regarding crop rotations, tillage system, fertility management, variety selection, plant establishment, weed control strategies, water management, and disease and insect management. Based on the average North Dakota state soybean yield from 1942 through 2022, the annual trend line indicated that 0.33 bushel per acre yield increase per year can be expected (Source ND NASS).

This field guide has been developed to help you make soybean production management decisions. However, detailed and extensive information on any one area is not provided because of limited space. Complete discussions on topics including variety performance, soil fertility, weed, disease and insect management are available in other Extension publications as listed on the back pages.

The pesticide use suggestions in this guide are based on federal label clearances and on some state labels in North Dakota. Also, suggestions are based on research information collected in North Dakota State University experiments or trials in other states. All pesticides listed had a federal or state label at the time of publication of this guide. Check all pesticide labels at the time of use for the most current label registration, and follow all instructions.

Plant Growth Stages and Development

Soybean plant development is characterized by two distinct growth phases. The first is the vegetative (V) stages that cover growth from emergence to flowering. The reproductive (R) stages cover growth from flowering through maturation.

Plant stages are determined by classifying leaf, flower, pod and seed development. Staging also requires node identification. A node is the part of the stem where a leaf is (or has been) attached.

A leaf is considered fully developed when the leaf at the node directly above it (the next younger leaf) has expanded enough so that the two lateral edges on each of the leaflets partially have unrolled and are no longer touching.

Vegetative stages (V)

Stage	Description
VE	**Emergence** – Cotyledons above the soil surface
VC	**Cotyledon** – Unifoliolate leaves unrolled sufficiently so that the leaf edges are not touching
V1	**First-node** – Fully developed leaves at unifoliolate node
V(n)	**nth-node** – The “n” represents the number of nodes on the main stem with fully developed leaves beginning with the unifoliolate leaves

From *Fehr and Caviness*[1].

The soybean is a dicotyledonous plant that has epigeal emergence, meaning that during germination, the cotyledons (seed halves) are pulled through the soil surface (VE stage) by an elongating hypocotyl (Figure 1). The soil-penetrating structure, breaking through the soil surface, is the hypocotyl arch.

Once cotyledons have emerged, opened and turned green, they supply the new seedling with stored energy while capturing a small amount of light energy. The growing point is between the two cotyledons, and because it is above the ground, it could be killed by a

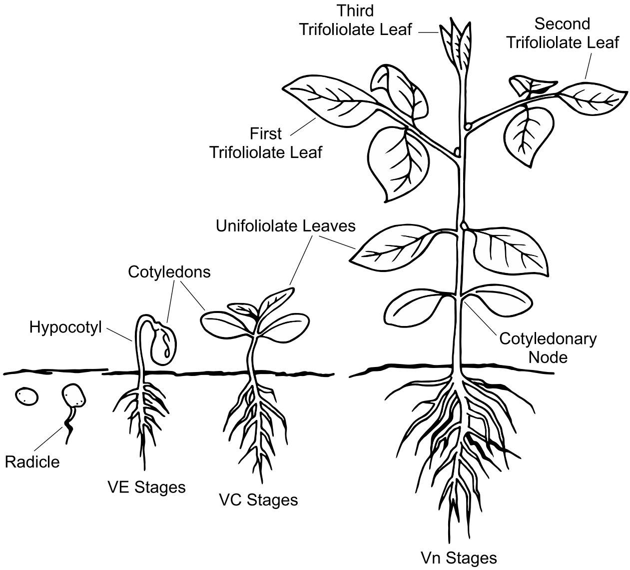

Figure 1. Soybean emergence.

spring frost or physical damage. This is in contrast with corn, wheat, field pea or lentil, in which the growing point is below the surface during the early development stages.

The first true vegetative leaves formed are the unifoliolate leaves. These two single leaves form directly opposite one another above the cotyledonary node (VC

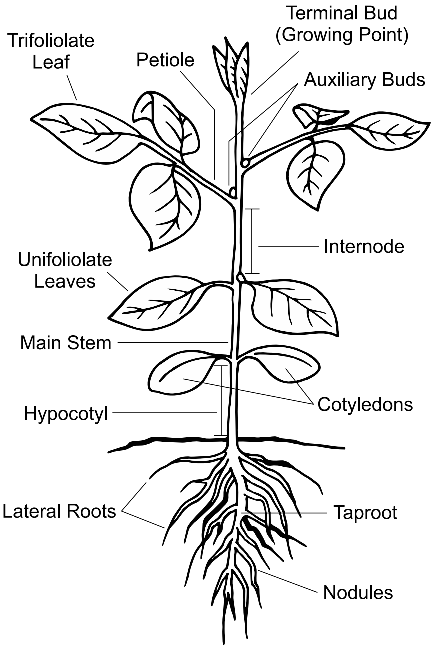

Figure 2. The soybean plant in V2 stage of development.

stage). All other leaves are trifoliolates and consist of three leaflets (V1 to Vn stages) and have an alternate arrangement on the stem (Figure 2).

Reproductive stages (R)

Stage	Description
R1	**Beginning bloom** – One open flower at any node on the main stem
R2	**Full bloom** – Open flower at one of the two uppermost nodes on the main stem with a fully developed leaf
R3	**Beginning pod** – Pod 3/16 inch long at one of the four uppermost nodes on the main stem with a fully developed leaf
R4	**Full pod** – Pod 3/4 inch long at one of the four uppermost nodes on the main stem with a fully developed leaf
R5	**Beginning seed** – Seed 1/8 inch long in a pod at one of the four uppermost nodes on the main stem with a fully developed leaf
R6	**Full seed** – Pod containing a green seed that fills the pod cavity at one of the four uppermost nodes on the main stem with a fully developed leaf
R7	**Beginning maturity** – One normal pod on the main stem that has reached its mature pod color
R8	**Full maturity** – Ninety-five percent of the pods have reached their mature pod color. Five to 10 days of drying weather are required after R8 for the soybean moisture levels to be reduced to less than 15 percent.

From *Fehr and Caviness*[1].

Number of days between stages.

Stages	Average days Fehr	Range in days Fehr
Planting to VE	10	5-15
VE to VC	5	3-10
VC to V1	5	3-10
V1 to V2	5	3-10
V2 to V3	5	3-10
V3 to V4	5	3-8
V4 to V5	5	3-8
beyond V5	3	2-5
R1 to R2	3	0-7
R2 to R3	10	5-15
R3 to R4	9	5-15
R4 to R5	9	4-26
R5 to R6	15	11-20
R6 to R7	18	9-30
R7 to R8	9	7-18

From *Fehr and Caviness*[1].

[1]Fehr, W.R., and C.E. Caviness. 1977. Stages of soybean development. Spec. Rep. 80. Iowa State Univ. Coop. Ext. Serv., Ames.

Number of days between stages (0.0-0.5 relative maturity).

Stages	Average days Carrington	Range in days Carrington
Planting to VE	18	11-26
VE to V1	13	11-15
V1 to V3	10	8-12
V3-R1	13	8-16
R1 to R3	16	12-20
R3 to R5	11	6-14
R5 to R7	36	32-44
R7 to R8	6	5-10

From *Endres et al.* Carrington Research Extension Center Annual Reports.

Extremes in growing conditions, such as temperature, rainfall and soils, can alter the development of soybean greatly. Many post-applied herbicides are labeled for application at certain soybean growth stages. To avoid herbicide injury (some herbicides), we highly recommend you identify development by growth stage and not use plant height, planting dates or row closure as a basis for application timing.

Additional information on soybean growth and development can be found in the NDSU Extension publication A1174, "Soybean Growth and Management Quick Guide."

Variety Selection and Adaptation

Soybean variety selection should be based on maturity and seed yield and quality. If needed, based on previous field history, varieties should be selected based on iron-deficiency chlorosis tolerance, soybean cyst nematode rating, Phytophthora and white mold tolerance, and lodging resistance. Comparative maturity and yield of public and private soybean varieties can be obtained from a current copy of NDSU Extension publication A843, "North Dakota Soybean Variety Trial Results and Selection Guide."

Later-maturing varieties tend to yield more than early maturing varieties when evaluated at the same location. After determining a suitable maturity, comparing yields of varieties that are of similar maturity is important. Although late maturity increases yield potential, later-maturing varieties have more risk than earlier-maturing varieties because an early fall frost may kill a late-maturing variety before the beans have completely filled in the pods, which impacts yield and quality. When soybean is planted mid-May to end of May, a 0.1 (one-tenth) later maturing variety may provide an increase in yield potential of 0.7 bushel per acre. When planting is delayed into June, changing to an earlier maturing variety is suggested.

Soybean Maturity

Soybean respond to day length (the increase of the night length) and heat units, so the actual calendar date a variety will mature is highly influenced by latitude; each variety has a narrow range of north-to-south adaptation. A model predicting when a variety will be mature is available at the North Dakota Agricultural Weather Network (https://ndawn.ndsu.nodak.edu/soybean-growing-degree-days.html). It will predict the soybean maturity date based on the selected maturity group, planting date and nearest weather station.

Soybean yield and quality are affected if a season-ending freeze occurs before a variety reaches physiological maturity. Dates of maturity are listed in the annual NDSU performance tables and provide a guide to predict physiologically mature. Usually harvest can commence seven to 14 days after the soybean crop is physiologically mature.

Varieties of maturity groups 00 (double zero), 0 (zero) and 1 are suitable for North Dakota. Maturity group 00 is very early and primarily is grown in the northern Red River Valley and the north-central area of North Dakota. Maturity group 0 is adapted to most North Dakota counties, while maturity group 1 is primarily suitable for southeastern North Dakota. These maturity groups are further subdivided. For example, a 0.1 maturity group is an early group 0 variety and a 0.9 is a late-maturity group 0 variety.

The best way to select a high-yielding variety is to use data averaged across several locations and years. Averaging across several years' data will identify a variety that likely will yield well across different weather conditions.

Phytophthora

Phytophthora root rot caused by the soilborne-fungus *Phytophthora sojae* is one of the most important disease problems of soybean in North Dakota. Phytophthora root rot tends to be more of a problem in the Red River Valley (RRV) and on poorly drained, heavy-textured soils, but the disease can cause significant stand reduction and yield loss in other areas when conditions are favorable for disease development. Management tools available to reduce Phytophthora root rot include selection of a resistant variety, use of a fungicide seed treatment, tile drainage and crop rotation.

Most varieties have Phytophthora root rot-resistance genes, and each gene confers resistance to a different race (or races) of *Phytophthora*. For example, a gene that may confer resistance to Race 3 may not confer resistance to Race 4, and vice versa.

Phytophthora sojae is a variable pathogen, and many races of the pathogen exist in North Dakota. No specific resistance gene guarantees control of the pathogen. Consequently, monitoring your fields for Phytophthora root rot every year is important. If the disease is widespread, the pathogen may have overcome the gene being used, and the gene may not be effective in future plantings.

Similarly, continually rotating effective genes is very important. Lack of a resistance gene or crop rotation can speed the development of new races. In some North Dakota fields, the pathogen already has become resistant to multiple genes. Fungicide seed treatments with activity against Phytophthora may help prevent early infection.

However, seed treatments do not provide season-long control, and over time the pathogen can become resistant to them. Consequently, fungicide seed treatments and resistance genes should be rotated. The most effective strategy would include the use of effective fungicide seed treatments, planting varieties with genetic resistance, water management (surface and subsurface drainage) and crop rotation.

Iron-deficiency Chlorosis

Iron-deficiency chlorosis (IDC) is a major problem primarily in the eastern part of North Dakota and is caused by iron being less available in soil with a pH greater than 7 and the presence of soil carbonates. Iron-chlorosis symptoms are most common during the two- to seven-trifoliolate leaf stages.

Plants tend to recover and start to turn green again during the flowering and pod-filling stages. However, IDC during the early vegetative stages can reduce yield severely. Details on IDC are available in the NDSU Extension publication SF1164, "Soybean Soil fertility".

For fields with historic IDC problems, select an IDC-tolerant variety of suitable maturity that is high yielding. Data on genetic differences for IDC tolerance is available in publication A-843, "North Dakota Soybean Variety Trial Results and Selection Guide."

Soybean Cyst Nematode

The soybean cyst nematode (SCN), *Heterodera glycines*, is a small parasitic roundworm that attacks the roots of soybean plants. Nematodes often are undetected because above-ground symptoms are uncommon until a 15% to 30% yield loss has occurred.

Soybean cyst nematode has been confirmed in many soybean-growing counties in North Dakota. Growers are strongly urged to test their soils for SCN eggs. If a positive sample for SCN is found, growers should begin managing SCN actively.

Crop rotation and resistance are the most important management tools against this disease. Two sources of resistance to SCN — PI88788 and Peking — can be found in varieties suitable for North Dakota. These sources are effective in the vast majority of the soybean fields in the state. However, the level of resistance in each variety is variable, so selecting the most resistant variety possible and monitoring the field for SCN is important. Due to the difference is resistance level between varieties, also rotate tolerant varieties in the same field.

For SCN management, a rotation out of soybean for two to three years is beneficial. Dry edible beans are susceptible to SCN and should not be used as a rotation crop for managing SCN. Nematode protectant seed treatments also are available and may help manage SCN; however, they are not a substitute for resistance and rotation.

Specialty Soybean

Food Soybean

Some soybean varieties have been developed for human consumption and have special food-processing characteristics. Tofu is a white curd that primarily is consumed in Asian countries. Special varieties have been developed that are high in protein and make smooth-textured tofu. These high-protein tofu types are lower yielding than the regular varieties that are sold to the elevator.

Natto is another human food product made from soybean. Natto is a fermented product made from whole soybean that is cooked. Natto varieties are very small seeded and tend to yield even less than the specialty varieties developed for the tofu market.

Growers should consult university publications on soybean variety performance to determine how much less these specialty varieties yield, compared with oilseed soybean. Based on the lower yield, a higher price per bushel needs to be obtained to economically justify growing these specialty soybean types. A contract should be arranged prior to growing these special types so that a market will be available.

Oil Modified

Soybean varieties with modified oil content are commercially available. Different fatty acid compositions modify the type of oil the soybean plant produces in the seed. Low saturated fats are desirable because this type of oil is better for human health.

High oleic, low palmitic, low stearic and low linolenic acid content are all genetic modifications that produce more healthful oil for human consumption. There is no indication that these modifications reduce yield. However, yield of specific varieties with modified oil content should be evaluated to determine whether high yield has been incorporated with the modified oil content. These specialty varieties should be marketed as identity-preserved (IP).

Seedbed Preparation

Soybean can be grown on a wide range of soil types under various cultural and tillage practices. Preparation of a firm seedbed with uniform soil moisture is important for optimum stand establishment.

Soybean are successfully grown using conservation tillage including direct seeding into previous crop residue and no-till. Special planters or drills may be required to handle surface residue in no-till and some reduced-tillage systems.

Soybean, like other legume crops, has difficulty emerging through compacted layers and surface crusts. Soybean is very susceptible to elevated salt levels in the soil and waterlogged conditions.

Planting Date

Soybean is susceptible to frost and prolonged exposure to near-freezing conditions in the spring and fall. Plant soybean after the soil has warmed to 50 F and air temperatures are favorable.

Soybean generally should not be planted earlier than five days before the average last killing frost or projected last frost date for a season. This provides less than a 50% chance of frost killing the soybean plant. Early in the season in a no-till or minimum-till situation, the residue tends to retard heat transfer from the soil to the air, which creates a potential for more frost damage to the young soybean plant.

Very early planting in cool, wet soil may result in low germination, increased incidence of seedling diseases and poor stands. Planting dates during the first half of May are favorable for highest yields when there is a favorable weather outlook with reduced risk of frost injury.

Planting early in the season allows the use of full-season varieties, which typically yield more than shorter-season varieties. Recent research indicates that if conditions are right during the planting season, waiting to plant may reduce the yield potential by 0.3 bushel per acre per day delay.

Data from NDSU date-of-planting studies indicated that late plantings had lower seed yields, poorer seed quality, lower oil content, shorter plant height and pods set closer to the ground, compared with optimum planting dates. Yield increased 8% with first week of May or earlier planting dates when averaged across nine NDSU trials conducted in south- and east-central North Dakota.

Some early maturing varieties have had acceptable yields when weather factors such as hail, late spring frost, or floods necessitate late planting or replanting.

In western North Dakota, with generally lower rainfall and drier conditions in August, an earlier-maturing variety has the advantage of utilizing water earlier in the season, maturing early and reducing the negative effect of droughty conditions during the end of the growing season.

Soybean stands with poor emergence often are replanted without considering the yield-compensating ability of the plants in the initial stand. The yield of an initial planting at less than full stand must be compared to the yield of the replanted crop to determine whether replanting is justified.

Replanting costs include seed, tillage, replanting and labor. The yield of a replanted crop must be sufficiently greater than the yield of the initial planting to cover the expenses associated with replanting. The risk of fall freeze damage to the replanted crop must be considered when deciding the maturity of the variety selected for replanting.

Planting Rate and Depth

Soybean yields generally do not vary significantly among a wide range of plant populations. In general, an established plant population of approximately 150,000 plants per acre is desirable regardless of row spacing. Averaged across 44 NDSU trials, planting rates of 150,000 to 175,000 pure live seeds (PLS) per acre increased yield by 6%, compared with planting rates of 100,000 to 130,000 PLS/acre. In an evaluation of data from 37 NDSU field trials across row spacings, the planting rate to realize optimum yield occurred with 180,000 and about 140,000 PLS per acre in eastern and western North Dakota, respectively (NDSU Extension publication A1961, "Soybean Response to Planting Rates and Row Spacings in North Dakota").

These research-based guidelines can be used initially in a field, and then planting rates and plant populations adjusted over time based on soil productivity, soybean variety and other management factors.

Slightly higher planting rates than normal may be advantageous with late planting dates or in no-till, where soil temperatures generally are lower. However, high planting rates may cause yields to decrease in low-rainfall environments because of drought stress, and in a good rainfall year, high planting populations may lodge more than low populations.

Low plant populations reduce lodging but contribute to low pod set and excessive branching. An extremely low seed number per foot of row may result in erratic stands due to a lack of seedling energy necessary to break the soil surface. This may be critical in solid-seeded stands in conventional-till soils prone to crusting.

To ensure planting enough soybean seed, the planting rate should be based on a seed count. You will need to know the following to calculate the rate:

1. Desired established plant population
2. Average percent of live seeds that do not develop into an established plant
3. Germination value of your seed
4. Number of seeds per pound of seed

Seeds per pound range from 2,200 to 3,400, with an average of 3,000 seeds per pound.

The following is an example for calculating planting rate:

1. Desired established plant population is 150,000 plants per acre
2. Normal stand loss is 10%
3. Seed germination is 95%
4. Soybean seed has a seed count of 3,000 seeds per pound, or 180,000 seeds per bushel

The planting rate (PR), expressed as the number of seeds per acre can be calculated from the following equation: PR = D*[100/(M1)]*[100/(100-M2)], where D is the desired plant density per acre 150,000, M1 (germination percent = 95%) and M2 (average percent stand loss on the farm = 10%).

PR = 150,000*[100/(95)]*[100/(100-10)]
= 175,450 seeds per acre

175,450 seeds ÷ 3,000 seeds per pound = 58.5 pounds/acre (lb/a) of soybean seed needs to be planted.

Plan to cover seed 1 to 1½ inches deep and place the seed in moist soil. Planting deeper than 2 inches or in a soil that crusts may result in reduced plant emergence and stand.

Row Spacing

Midwest research demonstrates that higher yields of soybean can be obtained in rows less than 30-inch spacing if stands are well-established and weeds are controlled adequately. NDSU research indicates that 14- to 22-inch row soybean out-yield wider-spaced (28- to 30-inch) soybean by an average of 4% when averaged across 24 trials.

The advantages of narrow-row soybean are: increased yield, reduced soil erosion, increased harvesting efficiency, and early crop canopy closure to help conserve soil moisture and suppress weeds. Planting in wider rows provides the opportunity to use row-crop planters, permits cultivation for weed control and may reduce the risk of white mold (sclerotinia).

Publication A1961, "Soybean Response to Planting Rates and Row Spacings in North Dakota" indicates:

- Across North Dakota or by regions, narrow rows (less than 15 inches) consistently provided greatest soybean yield.
- In eastern North Dakota, the combination of narrow rows (12 to 14 inches) and planting rates of about 170,000 PLS per acre provided optimum yield.
- In western North Dakota, the combination of narrow rows (7 to 10 inches) and planting rates of about 150,000 PLS per acre provided optimum yield.

Planting Guide

To determine the number of seeds per acre planted, add seed to your planter or drill and operate it on a firm soil surface so seed is visible on the surface. Operate it for a short distance close to your normal operating speed. Then go back and count the number of seeds dropped in 1 linear foot of planter row.

Make several counts and determine an average. Refer to one of the following charts to see that you are planting the number of seeds to reach your target plant population as can be calculated with the formula in the earlier section.

Soybean seeds per linear foot of row (seed count of 2,500 seeds per pound).

Approx. pounds live seed per acre	Seeds per acre	Seeds per foot of row with row spacing (inches) of:			
		6	12	22	30
40	100,000	1.2	2.3	4.2	5.7
50	125,000	1.4	2.7	5.3	7.2
60	150,000	1.7	3.4	6.3	8.6
70	175,000	2.0	4.0	7.4	10.0
80	200,000	2.3	4.6	8.4	11.5

Soybean seeds per linear foot of row (seed count of 3,000 seeds per pound).

Approx. pounds live seed per acre	Seeds per acre	Seeds per foot of row with row spacing (inches) of:			
		6	12	22	30
40	120,000	1.4	2.8	5.0	6.9
50	150,000	1.7	3.5	6.3	8.7
60	180,000	2.1	4.2	7.5	10.4
70	210,000	2.5	4.9	8.8	12.1
80	240,000	2.8	5.6	10.0	13.8

Air Seeder Calibration

Calibrating an air seeder usually is done by following the directions listed in the operators manual. It usually will tell you to hand turn the seed metering system a number of turns for a predetermined area. This often is listed for 1/10 or ¼ acre.

Then the metered seed needs to be weighed on a scale. Sometimes these scales are provided with the air seeder. The weights need to be multiplied by 10 for 1/10 acre or multiplied by 4 for ¼ acre, and then adjustments can be made based on the seeding rate calculated in the previous section.

Another method for calibrating an air seeder requires collecting seed from the seed openers. Probably the easiest method is to place a tarp under the openers, collect seed over an area or distance (1/10 acre) and weigh the pounds of seed collected.

First, determine the pounds of seed to plant as calculated in the planting rate section of this publication. Then (1) determine the circumference (ft.) of the seed meter drive wheel on your seeder using the following formula:

$$\text{Circumference (ft.)} = \frac{\text{diameter in inches x 3.14}}{\text{12 inches per foot}}$$

(2) Determine the drive wheel revolutions required to equal 1/10 acre. Use the following chart to calculate this number, which is based on the width of your air seeder.

Travel distance to equal 1/10 acre.

Drill width (ft.)	Distance (ft.)
16	272
20	218
24	181
28	156
32	136
36	121
40	109
44	99
48	91

(3) Next, calculate the metering wheel revolutions to cover this distance:

$$\text{Metering wheel revolutions} = \frac{\text{distance to cover 1/10 acre (ft.)}}{\text{Circumference of drive wheel (ft.)}}$$

(4) Place seed in the air seeder bin and start the air delivery system. Manually turn the metering wheel the number of revolutions that were calculated to cover 1/10 acre.

(5) Weigh the seed collected on the tarp and multiply times 10. This number should equal the pounds of seed you want to plant.

Drill calibration is becoming extremely important so you can be sure you are planting the correct amount of seed. If the amount of seed determined with either method is not equal to the amount of seed you desire, make an adjustment to the feed rate and recheck your seeder. This method also works for determining the pounds of fertilizer to be applied.

Cover Crops and Soybean Production

There is an increased interest in protecting the soil from wind and water erosion. Some producers are seeding a cover crop after their small grain or canola, prior to planting soybean in the spring.

A common cover crop is winter rye. Rye can overwinter and start regrowth in the spring. If it is a wet spring, the rye will be able to utilize some of the extra moisture and dry out the soil. Rye can be chemically terminated before planting soybean, or the soybean can be planted into the green rye, and the rye can be terminated after soybean seeding.

In a dry year, it is important to kill the rye, preferably two weeks before planting, to conserve moisture. Green planting in a dryer environment can lead to a reduction is soybean yield. More information about rye can be obtained in the extension publication A2010, "Growing rye as a cover crop in North Dakota."

Some producers are interested in establishing a cover crop after soybean harvest. It is possible to drill winter rye after harvest if there is enough growing season left. The other option is to fly on rye seed once the lower canopy in the soybean starts to turn yellow. It is important to have some rain after broadcasting the seed, as seed on top of the soil will not germinate without adequate moisture.

Summary Plant Establishment Factors

NDSU research on various plant establishment management factors has been conducted in numerous field studies. The improved management options in column A are compared with traditional management options in column B and the average percent benefit was calculated. The number of trials is indicated in the last column.

NDSU Research Summary of Soybean Plant Establishment Factors.

Factor	Option A	A Yield > B (%)	Option B	NDSU trials
Tillage system	Reduced till	4	Conventional till	37
Previous crop	Wheat	5	Soybean	6
Variety maturity group	0.1 later maturity	1.5-2	Normal maturity	4
Planting date	< early May	8	mid May	9
Planting rate (pure live seeds[1] per acre)	150-175,000	6	100-130,000	44
Row spacing (inches)	14-21	4	28-30	24
Seed fungicide	Yes	6	No	29
Seed inoculation with soybean history	Yes	2	No	16
P application at planting time	Broadcast	0.5	Band (away from seed)	7
Timing of initial weed control	At planting	5	Early POST (2- to 4-inch weeds)	8

[1]Seeding rate was compensated for the germination percent.
(Seeding rate / germination rate)*100.

Soybean Soil Fertility

Dave Franzen, Extension Soil Science Specialist

Nitrogen

Nodulation

Soybean is a legume and receives N through the symbiotic relationship with the N-fixing bacteria species *Bradyrhizobium japonicum*. Carbohydrates and minerals are supplied to the bacteria by the plant, and the bacteria transform nitrogen gas from the atmosphere into ammonium-N for use by the plant. Soybean infection by N-fixing bacteria and symbiotic N fixation is a complex process between the bacteria and the plant. The right species of N-fixing bacteria must be present in the soil, either through inoculation of the seed or the seed zone at planting. Soybean is perfectly capable of attracting bacteria to the roots when N is required, and there is no need to apply supplemental "signaling" agents.

If soybean will be planted in a field for the first time, seed inoculation with *Bradyrhizobium japonicum* (soybean inoculum) is necessary. There are several inoculums types that can be used: peat-based, liquid-based or granular. Double inoculation is encouraged, using a granular inoculant and either a peat or a liquid.

If a field has been seeded to soybeans previously and nodulation was effective, inoculation is not necessary, but neither would it hurt soybean yield. Nitrogen fertilizer is not required by soybean if adequate inoculation is present. Higher soil nitrate levels in soils increase the severity of iron deficiency chlorosis (IDC) in soils where IDC supporting conditions prevail.

Phosphorus

North Dakota soils are typically low in phosphorus (P). The soil test supported by NDSU recommendations is the Olsen sodium bicarbonate extraction method. North Dakota soybean P research within the past decade indicates an unlikely economic benefit to added P if the soil test is greater than 7 ppm. Rate of P is related to soil test from 7 ppm and below, and not to expected yield.

Phosphorus and potassium recommendation (broadcast application) for soybean based on soil test.

Olsen Soil Test Phosphorus, ppm				
VL 0-3	**L 4-7**	**M 8-11**	**H 12-15**	**VH 16+**
------ lbs/acre P_2O_5 ------				
52	26	0	0	0

Soil Test Potassium, ppm					
VL/VL 0-40	**L/L 41-80**	**M/M 81-120**	**H/M 121-150**	**VH-H 151-200**	**VH/VH 201+**
-------- lbs/acre K_2O --------					
90/90[1]	60/90	60/60	30/60	0/60	0/0

[1]Use first number for the rate of K_2O in soils with smectite:illite ratio less than 3.5; use the second number for the rate of K_2O in soils with smectite:illite ratio greater than 3.5.

Potassium

Potassium requirements for soybean are lower than they are for corn. However, in a corn and soybean rotation, fertilizing for higher nutrient levels is important. Although the critical soil level for K using the 1-N ammonium acetate extraction method is only 100 ppm for soybean, the critical level for K in corn is closer to 200 ppm. Therefore, adding K to replace what the soybean crop may remove will make fertilizing corn more efficient. In dry seasons, soybean has shown K deficiency symptoms even when soil test K is greater than 100 ppm. The recommendations for K fertilization of soybean based on soil test.

In-season application of foliar sprays of N, P and K

Foliar fertilizer for soybeans is not an effective or economic production strategy and should be avoided unless a severe nutrient deficiency is found in-season.

Sulfur

Sulfur deficiency is not commonly seen in soybean. It is most possible on sandy, low-organic-matter soils after heavy spring rains. Sulfate and thiosulfate sources are far superior to elemental S fertilizers of any kind. Sulfur is a spring fertilizer, and fall application is discouraged.

Iron

There are great amounts of iron (Fe) in North Dakota soils, but in eastern North Dakota, where rainfall is higher and calcium carbonate is abundant at the surface in many soils, soybean have a hard time obtaining it. Iron deficiency symptoms are commonly seen and yield reduction is almost always a result of the condition.

The best strategy for managing IDC is use of tolerant cultivars. NDSU IDC ratings can be found in the annually updated NDSU Extension publication "North Dakota Soybean Variety Trial Results and Selection Guide."

Iron foliar sprays are not effective in correcting a deficiency. The best application to reduce IDC is ortho-ortho-EDDHA Fe chelate applied with water in-furrow at seeding. The chelate ortho-ortho-EDDHA succeeds in delivering Fe to the plant root early in the season, but after conveying its original Fe, it also has the ability to return to the soil solution, capture additional Fe and deliver it to the plant root with the soil water stream (Goos and Lovas, unpublished data, 2012). The amount of ortho-ortho EDDHA in relation to ortho-para EDDHA is very important in an iron chelate product. Both forms can be in a product, although the form effective in reducing IDC is only the ortho-ortho-EDDHA. Recent research at NDSU has shown that the response of soybeans to EDDHA fertilizer is directly proportional to the percentage of ortho-ortho EDDHA Fe in the product. The chemical structures of ortho-ortho-and ortho-para-EDDHA are shown in Figure 3.

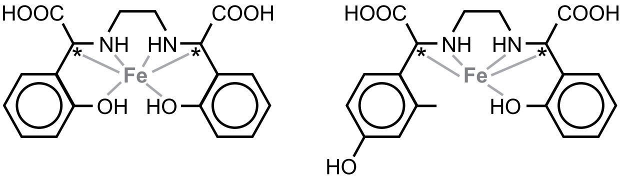

Figure 3. Ortho-ortho EDDHA (left); ortho-para EDDHA (right).

Effective strategies to reduce IDC in fields with surface pH greater than 7:

1. Screen fields through past history of IDC or with soil testing to choose fields with lower carbonates near the soil surface and with soluble salts with EC less than 2 mmohs/cm.
2. Choose soybean cultivars with high IDC tolerance from NDSU soybean variety trial data.
3. Seed a companion crop of oats, barley, or spring wheat at the time of seeding, particularly if soil nitrate-N in greater than 80 pounds N per acre.
4. Use a high ortho-ortho-EDDHA, or similarly effective iron fertilizer, in-furrow at seeding at recommended rates.
5. If possible, choose herbicides with low phytotoxicity to soybean. However, controlling weeds is very important and weed control has priority over safety if weed population is high.

Other nutrients

Soybean plant deficiencies of zinc, manganese, boron, molybdenum, nickel, chloride or copper have not been observed in North Dakota. There is no need to apply these nutrients on North Dakota soybean fields.

Salt tolerance

Soybean is one of the most sensitive crops to salt-affected soils. The relationship of relative yield and soil salt levels measured by electrical conductivity (EC) in North Dakota research is shown in Figure 4. Relative tolerance of soybean cultivars to soil EC is roughly related to cultivar IDC tolerance.

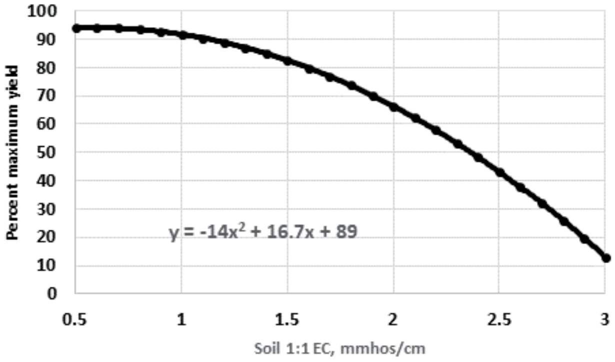

Figure 4. Relationship of salinity (1:1 soil: water EC) and relative soybean yield.

Details on identifying and managing saline soils for soybean and other crop production are available in the NDSU Extension publication “Managing Saline Soils in North Dakota.”

For more details on soybean plant nutrition, see NDSU Extension publication SF1164, “Soybean Soil Fertility.”

Irrigation and Water Use

Tom Scherer, Extension Agricultural Engineer

There are about 70,000 acres of irrigated soybeans in North Dakota, mostly on sandy loam to loamy sand soils. Soybeans are a little more drought tolerant than corn but respond well to irrigation. Irrigated and dryland soybean yield trials are annually conducted at the Carrington Research Extension Center and the Oakes Irrigation Research site. Results averaged from 10 years show a seed yield differential between dryland and irrigated Roundup Ready soybean varieties of 13.0 bushels per acre at Carrington and 21.0 bushels per acre at Oakes. Over those 10 years, the dryland yield deviation was about 15 bushels per acre and the irrigated about 7.5 bushels per acre.

With available soil water throughout the growing season, 15 to 19 inches of water will be utilized by soybean plants, depending on the variety and growing season weather. With good management, irrigation can supplement rain to provide optimum soil water conditions throughout the growing season. For those years with extended dry periods during the growing season that cause water stress, each additional inch of water provided by irrigation will result in an increase 2 to 5 bushels of yield per acre. Most years, irrigation from mid-July through August will have the greatest effect on yield.

Soybean Rooting Depth and Water Use

Soybeans are shallow rooted. Typically, roots grow laterally 8 to 12 inches and downward to a depth of 3 feet or more. Root distribution is concentrated near the soil surface. About 90% of the roots will be found in the top 2 feet, which is considered the effective rooting depth for irrigation purposes. During the course of a growing season, about 10% of the water used by the soybeans will be drawn from the soil below 2 feet.

Daily soybean evapotranspiration (ET) or water use depends on the day length, variety, stage of growth, local weather conditions, available soil water, disease pressure and soil fertility. The frequency and amount of irrigation depends on the growth stage (which determines the daily crop water use), the water-holding capacity of the soil in the root zone and the prevailing weather conditions.

Average soybean water use rates will increase from about 0.05 inch per day soon after emergence to more than 0.27 inch per day during pod development (Figure 5). The soybean water use amount includes the evaporation from the soil surrounding the plants. Water use is presented as a depth measurement because of the assumption that the soybean root mass will remove soil water from under every square foot of soil surface in the field.

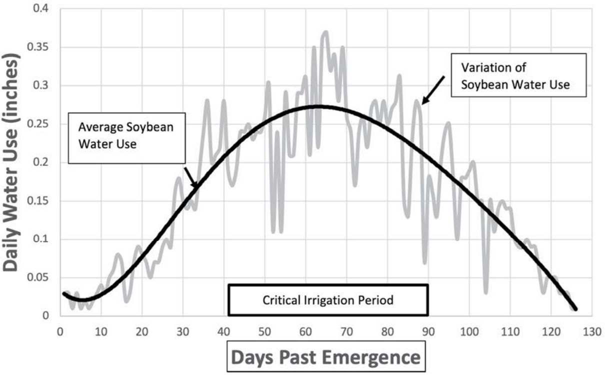

Figure 5. Average and seasonal variation of daily water use rates (in inches) for soybean.

Water-holding Capacities of Soil

The depth and water-holding capacity of the soil have a great influence on when and how often irrigation is required. Soil texture determines the amount of available water in the root zone, although other factors such as organic matter and soil compaction will modify these numbers. Note that the greater the water-holding capacity of the soil in the root zone, the less frequent the irrigation applications should be. The values shown in the Table are a good starting point, but more field specific water holding capacities can be obtained by using the Natural Resources Conservation Service's (NRCS) online Websoil Survey (*https://websoilsurvey.nrcs.usda.gov/app/HomePage.htm*).

Approximate available soil water-holding capacities for various soil textural classifications.

	Available Water	
Soil Texture	**Inches/Inch**	**Inches/Foot**
Coarse sand and gravel	0.02 to 0.06	0.2 to 0.7
Sand	0.04 to 0.09	0.5 to 1.1
Loamy sand	0.06 to 0.12	0.7 to 1.4
Sandy loam	0.11 to 0.15	1.3 to 1.8
Find sandy loam	0.14 to 0.18	1.7 to 2.2
Loam and silt loam	0.17 to 0.23	2.0 to 2.8
Clay loam and silty clay loam	0.14 to 0.21	1.7 to 2.5
Silty clay and clay	0.13 to 0.18	1.6 to 2.2

Knowing the soil texture and water-holding capacity of the dominant soil type in a field and using that information to make irrigation decisions is important. However, if different soil types are in the same field, irrigation scheduling should be adjusted based on the most drought-prone soil type.

Irrigation Water Management

Having a soil profile that is near field capacity at planting, which occurs naturally with normal fall and spring rainfall, together with some winter snowmelt, is highly desirable. Stored soil water lower in the root zone serves as a supplement during high water-use periods.

Soybeans planted on shallow soils (8 to 12 inches of top soil) underlain by coarse sand and gravel will have a reduced root zone. That means less soil water is stored and available to the plants. Sometimes, this requires applying less per irrigation (0.75 inch) more frequently, compared with deeper soils with greater total water-holding capacity.

During the period prior to flowering (R1 growth stage) and the period after the majority of the seeds are mature (R7), soybeans are relatively drought-tolerant. They can withstand 50% to 60% soil water depletion without a significant impact on yields. However, during the flowering and pod-development period, soil water levels in the root zone should not be depleted more than 50% (preferably 40%) to achieve maximum yields.

The first irrigation should be applied when the soil water is between 50% and 60% depleted after emergence. With normal rainfall, this should be when the soybeans are near flowering (late June to early July). After flowering, irrigate before the soil water profile reaches 50% depletion.

Most center pivots should be set to apply from 0.75 to 1 inch of water per revolution, which may require 2½ to 3½ days. During periods of high temperatures and wind, monitoring the soil water profile frequently is critical because keeping up with the soybean water use may be difficult.

Some tips for good irrigation management of soybeans:

- Soybeans are unique in that leaf-rolling is a visual indicator of water stress because the underside of the leaf is a lighter green than the upper surface. Usually, water stress will first occur in areas of the field with shallow topsoil.

- White mold (sclerotinia) risk increases with irrigated soybean. During flowering, an extended period with wet soil surface and crop canopy may require use of foliar fungicides to suppress disease infection and development.
- Irrigations can be terminated when at least 80% of the pods show yellowing and are mostly ripe. Another indicator is when 50% of the leaves have turned yellow.

Irrigation Scheduling

Soil water levels in the root zone are the criteria used to determine when to start and stop irrigations. Managing irrigations around rain events can sometimes be challenging. Using soil moisture sensors or the Checkbook method is important.

Several soil water monitoring methods and/or instruments are available to estimate the soil water level at a particular time and location in the field. The "soil feel" method is the most widely used. It involves using a soil probe to obtain a soil sample from specific depths in the root zone, and the amount of soil water is estimated by squeezing the soil in the palm of your hand. Accuracy of the soil feel method improves with experience.

Soil water also can be measured using tensiometers, soil water blocks and other devices. When these are used, a measurement site typically will have two sensors, one at 9 to 12 inches and one at 18 to 24 inches below the soil surface. The soil water level is estimated by reading a gauge on the device or with a portable meter.

These devices only indicate the soil water status at the installation location, so a large field may require soil water sensors at several sites.

Measuring soil water for irrigation scheduling requires a high level of dedication by the irrigation manager during the growing season. Informed irrigation decisions require reading soil water measurements two or three times per week. Measurements must be taken at several locations in the field and the readings recorded. Lately, companies now offer soil water measuring devices that can be accessed remotely, often with a smart phone app. Also, many companies offer field monitoring services based on remote sensing, either by satellite, drones or planes.

Another form of irrigation scheduling requires daily soybean water-use estimates. This method, sometimes called the "crop water use replacement method," is based on obtaining daily estimates of soybean water use and measuring rainfall amounts. Irrigations are scheduled to replace the amount of soil water used by the soybeans minus the amount of rain received since the last irrigation. Estimations of average water use for soybeans based on maximum daily temperature are shown in the table.

During the growing season, better soybean water use estimates can be obtained from the North Dakota Agricultural Weather Network (NDAWN) website: *https://ndawn.ndsu.nodak.edu/crop-water-use.html*. These estimates a calculated using the weather data from each weather station. Select the station closest to your field location.

The best choice of tools for irrigation scheduling is a combination of in-field soil water measurement and a

Average soybean water use based on maximum daily air temperature and week after emergence (inches per day).

Maximum Air Temperature (°F)	Week After Emergence															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
From 50 to 59	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.08	0.08	0.07	0.07	0.06	0.05	0.04
From 60 to 69	0.02	0.03	0.05	0.07	0.09	0.11	0.12	0.13	0.13	0.13	0.13	0.12	0.11	0.10	0.08	0.06
From 70 to 79	0.03	0.05	0.07	0.09	0.12	0.15	0.17	0.19	0.18	0.18	0.17	0.17	0.16	0.14	0.11	0.08
From 80 to 89	0.04	0.06	0.09	0.11	0.15	0.19	0.22	0.24	0.23	0.23	0.22	0.21	0.20	0.18	0.14	0.10
Greater than 90	0.05	0.07	0.11	0.15	0.19	0.23	0.27	0.29	0.29	0.29	0.27	0.26	0.25	0.22	0.17	0.13
		↑ 3rd Trifoliolate				↑ Flower				↑ Upper Pod Fill			↑ Leaf Drop			

recorded daily soil water accounting procedure called the “checkbook” method. Three different checkbook tools are available at *www.ndsu.edu/agriculture/ag-hub/ag-topics/crop-production/irrigation-tiling-drainage/irrigation-scheduling*.

The checkbook method has been used successfully for many years in Minnesota and North Dakota. The checkbook method is based on daily soybean water use and the soil water-holding capacity. Along with rainfall measurement, these parameters help predict the time and amount of water needed to replenish the root zone to maintain proper soil water levels. One advantage of the checkbook method is that you don’t need to be in the field to fill in the numbers, and it allows you to “look ahead” to determine when the next irrigation may be needed. Modern weather prediction of possible rain events also helps.

Soybean Weed Control

Joseph Ikley, Extension Weed Specialist

The weed control suggestions in this production guide are based on the assumption that all herbicides mentioned will have a registered label with the Environmental Protection Agency as of November 1, 2022.

Instructions for the registered uses of herbicides are given on container labels. Read and follow label instructions carefully. **Use pesticides only as labeled.**

Herbicide labels also can be found on the web at *www.cdms.net/Label-Database*.

It is important to manage weeds. Rule #1 control weeds **before 2 to 4 inches tall** to avoid yield loss. As an example, see table below.

North Dakota soybean yield loss from weeds removed at different intervals.

Weed height when weeds were removed	Soybean stage	Soybean yield (bu/acre)
Weed free	-	44.3
2 to 4 inches	VC (cotyledon) to V1	42.1
6 to 8 inches	V2 to V4	40.8
>10 inches	V3 to R2	36.4
Weedy check	-	22.7

Soybean fall or spring preplant herbicides.

	Rate/A	Before Planting
2,4-D amine[1]	0.5 lb ai	15 days
	1 lb ai	1 month
2,4-D ester[1]	0.5 lb ae	7 days
	1 lb ae	1 month
E-99	1 lb ae	15 days
Weedone 650	1 lb ae	15 days
Aim EC	2 fl oz	0
Affinity / thifensulfuron and tribenuron[1] All formulations	Label rates	14 days
Banvel / dicamba[1]	4 fl oz	120 days
	1 pt	120 days
	>24 fl oz	180 days
Elevore	1 fl oz	14 days
Express / tribenuron[1] All formulations	Label rates	1.5 months
Harmony / thifensulfuron[1] All formulations	Label rates	0
Liberty 280 / generic[1]	29 to 36 fl oz	0
Gramoxone / generic[1] - **RUP**	Label rates	0
Pre-Pare	0.3 oz	9 months
Rage D-Tech	9 to 16 fl oz	7 days
	17 to 24 fl oz	14 days
	25 to 32 fl oz	1 month
Pre-Pare	0.3 oz	9 months
Roundup / generic[1]	0.75 to 3 lb ae	0
Sequence	2.5 to 3.5 pt	0
Sharpen	1 to 2 fl oz	0-2 months
Spartan	3 to 8 fl oz	0
Spartan Advance	16 to 36 fl oz	0
Spartan Charge	3 to 8.5 fl oz	0
Valor EZ[2]	2 to 3 oz	0

[1]or generic brand equivalent
[2]Valor EZ = refer to label for rates >3 oz/A.

Soybean herbicides, rates, weeds controlled, when to apply and remarks.

Soil-applied Herbicides

Herbicide	Product per acre (ai/acre)	Weeds	When to Apply	Remarks
Prowl **Prowl H2O** (pendimethalin)	**2.4 to 3.6 pt EC** **2.1 to 3 pt ACS** (1 to 1.5 lb)	Annual grass and some broadleaf weeds.	PPI. Fall or spring.	Adjust rate for soil type. Do not apply PRE. Poor control of weeds with large seeds, including wild oat and wild mustard.
Sonalan **Sonalan 10G** (ethalfluralin)	**1.5 to 3 pt** **5.5 to 11.5 10G** (0.55 to 1.15 lb)			
Treflan / generic trifluralin	**1 to 2 pt** (0.5 to 1 lb)			

Valor SX **Valor EZ** (flumioxazin)	**2 to 3 oz WDG** **2 to 3 fl oz SC** (1 to 1.5 oz)	Small-seeded broadleaf weeds.	EPP, Shallow PPI, and PRE.	PRE requires precipitation for herbicide activation. Refer to label for tank-mix options, application information, and restriction. Commercial mixtures available: **Afforia** = flumioxazin + thifensulfuron + tribenuron **Authority Assist** = sulfentrazone + imazethapyr **Authority Edge** = sulfentrazone + pyroxasulfone **Authority Elite** = sulfentrazone + S-metolachlor **Authority First** = sulfentrazone + cloransulam **Authority MTZ** = sulfentrazone + metribuzin **Authority Supreme** = sulfentrazone + pyroxasulfone **BroadAxe XC** = sulfentrazone + S-metolachlor **Fierce EZ** = flumioxazin + pyroxasulfone **Fierce MTZ** = flumioxazin+pyroxasulfone+metribuzin **Kyber** = flumioxazin+pyroxasulfone+metribuzin **Sonic** = sulfentrazone + cloransulam **Surveil** = flumioxazin + cloransulam **Zone Defense** = sulfentrazone + flumioxazin.
Spartan (sulfentrazone)	**4.5 to 12 fl oz F** (2.25 to 6 oz)			
Metribuzin	Soil pH >7.5 = 0.25 lb ai Soil pH <7.5 = 0.25 to 0.38 lb ai			May injure certain soybean varieties. Commercial mixtures available: **Boundary** = metribuzin + S-metolachlor.
Sharpen (saflufenacil)	**1 to 1.5 fl oz SC** (0.36 to 0.54 oz)	Broadleaf weeds including winter annuals.		PRE requires precipitation for herbicide activation. Apply with MSO adjuvant at 1 to 1.5 pt/a for burndown control of emerged broadleaf weeds. Planting interval is dependent on soil texture and OM. Sharpen at 1.5 fl oz and Verdict at 7.5 fl oz require a 14 day plantback interval. Refer to label for tank-mix options.
Verdict (saflufenacil & dimethenamid)	**5 to 7.5 fl oz EC** (0.36 to 0.54 oz & 0.2 to 0.29 lb)			

Herbicide	Product per acre (ai/acre)	Weeds	When to Apply	Remarks
Dual / II / Magnum (S / metolachlor)	**1 to 2 pt EC** (0.95 to 1.9 lb)	Annual grasses and some broadleaf weeds.	EPP, Shallow PPI, PRE and EPOST. POST PHI: Dual = 75 days.	Requires precipitation for soil activation. Multiple rain events increase activation of pyroxsulfone. Provides 3 to 4 weeks residual weed control after activation. Adjust rate for soil type. Shallow PPI gives more consistent weed control than PRE. Use highest rates for greater and more consistent weed control. Warrant: Do not PPI. Application with other PRE or EPOST herbicides and stress environment after application may increase risk of soybean injury. Refer to labels for tank-mix options. Commercial mixtures available: **Authority Elite** = S-metolachlor + sulfentrazone **Boundary** = S-metolachlor + metribuzin **BroadAxe XC** = S-metolachlor + sulfentrazone **Fierce** = pyroxasulfone + flumioxazin **Zidua Pro** = pyroxasulfone + saflufenacil + imazethapyr.
Outlook / generic dimethenamid	**10 to 24 fl oz EC** (0.47 to 1.125 lb)			
Warrant (acetochlor - microencapsulated)	**1.25 to 2 qt ME** (0.94 to 1.5 lb)			
Anthem Maxx (pyroxasulfone & fluthiacet)	**2 to 5.5 fl oz SC** (1 to 2.87 oz & 0.03 to 0.087 oz)			
Zidua SC (pyroxasulfone)	**1.75 to 5.75 fl oz SC** (0.91 to 3 oz)			
Perpetuo (pyroxasulfone & flumiclorac pentyl)	**6 to 10 fl oz SC** (1.28 to 2.14 & 0.28 to 0.43 oz)		EPP or PRE. Post Up to V6 soybean.	Apply with PO or MSO at 1 to 2 pt/a. Certain tank mixes require use of NIS in place of oil. Follow tank mix partner recommendation. AMS or UAN can be added to tank mix to enhance weed control. Refer to label for tank-mix options and rotation restrictions. Do not apply more than 8 fl oz/a on coarse soils.

POST-Applied Herbicides in Soybean

Herbicide	Product per acre (ai/acre)	Weeds	When to Apply	Remarks
Warrant (acetochlor - microencapsulated)	**1.25 to 2 qt ME** (0.94 to 1.5 lb)	PRE control of grass and broadleaf weeds.	POST. Soybean: After emergence until R2.	Rainfall required for PRE activation. Does not control emerged weeds. Provides residual weed control after activation. No adjuvant required.
Basagran 5L / generic bentazon + MSO adjuvant	**0.4 to 1.6 pt SL / 0.5 to 2 pt applied 1 to 4 times.** (0.25 to 1 lb)	Some broadleaf weeds.	POST. Soybean: After emergence. Broadleaf weeds: Small.	Non-residual, contact herbicide requiring >15 gpa and full sunlight. Add MSO adjuvant at 1 to 1.5 pt/a. Maximum bentazon amount per season is 2 lb/a.
Cadet (fluthiacet)	**0.4 to 0.9 fl oz EC** (0.045 to 0.1 oz)	Some small broadleaf weeds including pigweed species.	POST. Soybean: 1 to 2 trifoliolates. Weeds: Small.	Contact herbicides requiring small weed size, >15 gpa, NIS or oil adjuvant at 1 to 2 pt/a, and full sunlight. May cause speckling on soybean leaves. Cadet may improve lambsquarters control. Apply Cobra with oil adjuvant at 1 to 2 pt/a. Refer to label for crop response, adjuvant type and rate, and tank-mix options.
Cobra (lactofen)	**8 to 12.5 fl oz EC** (2 to 3.2 oz)			
Resource (flumiclorac)	**2 to 8 fl oz EC** (0.215 to 1.72 oz)			
Ultra Blazer (acifluorfen)	**0.5 to 1.5 pt EC** (0.125 to 0.375 lb)			

Herbicide	Product per acre (ai/acre)	Weeds	When to Apply	Remarks
Flexstar / generic fomesafen + oil adjuvant	**0.75 pt EC** (0.176 lb)	Many small broadleaf weeds. Poor buckwheat, lambsquarters and hairy nightshade control.	POST Soybean: Prior to flowering. Weeds: Small. Do not use as a rescue treatment. Contact herbicide requiring small weed size.	Apply at >15 gpa, oil adjuvant at 1 to 2 pt/a, and full sunlight. MSO at 1 to 2 pt/a + AMS at 8.5 lbs/100 gal water will increase weed control and risk of crop injury. Apply at 1 pt/a in ND east of I-29 and south of I-94. Apply at 0.75 pt/a in ND east of Hwy 281 and in the following counties west of Hwy 281: Benson, Bottineau, Burleigh, Dickey, Eddy, Emmons, Foster, Grant, Kidder, LaMoure, Logan, McHenry, McIntosh, McLean, Mercer, Morton, Oliver, Pierce, Renville, Rolette, Sheridan, Sioux, Stutsman, Towner, Ward, and Wells. West of Hwy 281: - Do not apply to soil with OM >4%. - Do not apply after June 20. Refer to product label and ND SLN label for crop rotation restrictions and other restrictions.
FirstRate (cloransulam)	**0.3 oz WDG** (0.25 oz)	Large-seeded broadleaf weeds.	POST. Soybean: Up to full flower stage (R2). Weeds: Small.	Add oil adjuvant at 1 to 2 pt/a + 28% UAN at 2.5% v/v. Refer to label for weed size, and tank-mix options.
Harmony / generic thifensulfuron	**0.083 (1/12) oz DF** **0.125 (1/8) oz SG** (0.062 oz)	Mustard, pigweed, and lambsquarters.	POST. Soybean: 1st trifoliate until 60 days PHI.	Add oil additive at 1 to 2 pt/a + 28% UAN or AMS. Refer to label for tank-mix options.

Herbicide	Product per acre (ai/acre)	Weeds	When to Apply	Remarks
Pursuit (imazethapyr)	**2 to 3 fl oz SL** (0.5 to 0.75 oz)	Annual broadleaf weeds. Poor lambsquarters, ragweed, buckwheat and biennial wormwood control.	POST. Soybean: **Prior to flowering.** Weeds: Small and actively growing.	Add oil adjuvant at 1 to 2 pt/a + 28% UAN at 2.5% v/v. MSO adjuvants enhance weed control more than petroleum oil or NIS adjuvants. Refer to label for weed size and application information. Beyond Xtra has less soil residual carryover than Pursuit.
Beyond Xtra (imazamox)	**4 to 5 fl oz SL** (0.5 to 0.625 oz)			
Varisto (bentazon & imazamox)	**11 to 27 fl oz SL** (0.34 to 0.84 lb + 0.26 to 0.64 oz)	Small annual grass and broadleaf weeds and suppression of Canada thistle.	Allow a 30 day PHI.	Add MSO adjuvants at 1.25 to 1.5 pt/a and AMS at 8.5 lb/100 gal. Apply 11 fl oz to pre-bolt canola.
Assure II **Targa** (quizalofop)	**4 to 12 fl oz EC** (0.44 to 1.32 oz)	Annual grasses and quackgrass.	Soybean: Prior to pod set. Grass weeds: Refer to grass control table.	Add oil adjuvant at 1 gal/100 gal water but not less than 1.25 pt/a. Use highest rate of Assure II for yellow foxtail control. Grass control is reduced by tank mixtures or close interval application of POST broadleaf control herbicides. Antagonism generally can be avoided by applying a higher rate of grass herbicide or apply the grass control herbicide 1 or more days before or 7 days after the broadleaf control herbicide. Do not cultivate prior to 5 days before or 7 days after application. Refer to label for tank-mix options.
Fusilade DX (fluazifop)	**5 to 12 fl oz EC** (1.25 to 3 oz)			
Poast (sethoxydim)	**0.5 to 1.5 pt EC** (0.1 to 0.3 lb)	Annual grasses.	Soybean: All stages. Grass weeds: Refer to grass control table.	
Select Max 1EC **Select 2EC** **Shadow 3EC** (clethodim)	**9 to 16 fl oz EC** **4 to 8 fl oz EC** **2.66 to 5.33 EC** (1 to 2 oz)	Annual grasses and quackgrass.		

Grass Control with POST Herbicides

	Foxtail, green and yellow		Corn, volunteer		Quackgrass		Wheat, barley, and oat		Proso millet, wild	
	inches	fl oz/a	inches	fl oz/a	inches	fl oz/a	inches	fl oz/a	inches	fl oz/a
Assure II/Targa	2 to 4	7 to 8	6 to 30	5 to 8	6 to 10	12	2 to 6	7 to 8	2 to 6	5 to 8
Fusilade DX	2 to 4	10 to 12	12 to 24	4 to 6	6 to 10	12	2 to 6	8	4 to 8	6
Poast	2 to 4	1 pt	1 to 20	1 pt	6 to 8	2 pt	1 to 4	1 pt	4 to 6	0.5 pt
Select Max 1EC	2 to 4	9 to 12	4 to 24	9 to 12	4 to 12	12	2 to 6	9	2 to 6	9
Select 2EC	2 to 4	4 to 6	4 to 24	6	4 to 12	8	2 to 6	6	2 to 6	4 to 6
Shadow 3EC	2 to 4	2.66-5.33	4 to 24	2.66-5.33	4 to 12	5.3-10.6	2 to 6	4 to 5.33	2 to 6	4 to 5.33

Preharvest Application

Herbicide	Product per acre (ai/acre)	Weeds	When to Apply	Remarks
Glyphosate	Up to 1.5 lb ae **See Remarks.**	Preharvest weed control - broadcast or spot application.	Prior to harvest. Apply when soybean seed pods are a mature brown color, >75% leaf drop, and <30% seed moisture. PHI:Glyph. = 7 days Dicamba = 7 days. Aim = 3 days Paraquat =15 days Sharpen = 3 days	Add NIS plus AMS fertilizer at 8.5 lb/100 gal. **Do not apply on soybean grown for seed because reduced germination/vigor may occur.**
Banvel / generic dicamba + MSO adjuvant	**Up to 32 floz 4SL + 1 qt/a** (1 lb)			**Do not apply on soybean grown for seed because reduced germination/vigor may occur.** Add oil adjuvant at 1 to 2 pt/a.
Aim + MSO adjuvant (carfentrazone)	**1 to 6 oz SL + 1 qt/a** (0.256 to 1.5 oz)	Desiccant.		Contact herbicides require >15 gpa and full sunlight. Apply at >10/>5 gpa for ground/aerial application. Apply paraquat with NIS at 2 qt/100 gal water. Sharpen requires up to 10 days for optimum desiccation. Apply dicamba, Aim, and Sharpen with AMS at 8.5 lb/100 gal water or UAN at 2.5 gal/100 gal water. **Do not apply Sharpen on soybean grown for seed because reduced germination/vigor may occur.**
Paraquat + NIS **RUP**	**8 to 16 fl oz 2SL** **5.4 to 10.7 floz 3SL** (0.13 to 0.25 lb)			
Sharpen + MSO adjuvant (saflufenacil)	**1 to 2 fl oz SC + 1 to 2 pt/a** (0.36 to 0.72 oz)			
Defol 5 (Sodium chlorate)	**4 to 4.8 Qt** (5 to 6 lb)		Preharvest. 7 to 10 days prior to harvest.	Add NIS at 0.25% v/v or MSO/PO at 1 %v/v. Apply in minimum 5 GPA aerially or 20 GPA on the ground.

LibertyLink, LLGT27, E3, Xtendflex Soybean

Herbicide	Product per acre (ai/acre)	Weeds	When to Apply	Remarks
Liberty 280, Interline (glufosinate)	**32 to 43 fl oz SL** (0.58 to 0.72 lb) **Maximum total** = 87 fl oz	Annual grass and broadleaf weeds including ALS and glyphosate resistant weeds.	POST. Soybean: Emergence to pre- bloom. Weeds: Up to 3 inches tall.	**Apply only to LibertyLink soybean varieties or soybean varieties containing glufosinate-resistance genes.** Non-selective, contact, non-residual herbicide requiring thorough coverage. Apply a PRE foundation treatment prior to Liberty POST. Add AMS at 3 lb/a - do not use AMS replacement or water conditioner adjuvants. Can be applied with a registered grass herbicide. Refer to label for tank-mix options and restrictions. Most active in hot and sunny conditions. Controls weeds resistant to other herbicides.
Cheetah (glufosinate)	**29 to 43 fl oz SL** (0.53 to 0.72 lb) **Maximum total** = 87 fl oz			
Intermoc (glufosinate & S-metolachlor)	**64 fl oz SL** (0.535 & 1.25 lb)			Premix that contains S-metolachlor for residual weed control.

Roundup Ready/STS (sulfonylurea-tolerant) Soybean

Herbicide	Product per acre (ai/acre)	Weeds	When to Apply	Remarks
Harmony / generic thifensulfuron	**0.33 oz DF** **0.5 oz SG** (0.25 oz)	Annual broadleaf weeds including wild buckwheat, lambsquarters, mustard species, and volunteer RR canola.	POST. RR/STS soybean: 1st fully expanded trifoliolate to 60 days PHI.	**Apply only to RR/STS soybean varieties.** Apply with glyphosate at 0.38 to 1.125 lb ae/a. Add NIS at 1 qt/100 gal water. Apply with AMS fertilizer at 8.5 lb/100 gal. Refer to label for weeds controlled and application information.

Roundup Ready and Roundup Ready 2 Yield Soybean

Herbicide	Product per acre (ai/acre)	Weeds	When to Apply	Remarks
Glyphosate	**Maximum single application =** 1.5 lb ae **Maximum in-crop** = 2.25 lb ae **See Remarks.**	Annual and perennial grass and broadleaf weeds.	POST. Soybean: Emergence through R2 of full flowering. Allow a 14 day PHI.	**Apply only to RR / RR 2 Yield soybean varieties. Cannot plant harvested patented soybean seed.** Add AMS fertilizer at 8.5 lb/100 gal. Multiple applications may be necessary for weed flushes. Refer to label for weeds controlled, application information, and tank-mix options with residual herbicides and restrictions.

Roundup Xtend, Xtendflex Soybean

Herbicide	Product per acre (ai/acre)	Weeds	When to Apply	Remarks
Engenia 5 SL (dicamba) **RUP** Only certified applicators may purchase and apply. 	**Single application rate in-crop:** **12.8 5SL** (0.5 lb ae) **Maximum total in-crop:** 1 lb ae **Maximum total per year** 2 lb ae **Do not apply less than 0.5 lb ae/a for any application.**	Annual and perennial broadleaf weeds.	EPP, At Planting, PRE and POST. Soybean: Emergence to pre-bloom. No later than June 30. Weeds: Less than 4 inches tall.	**Apply only to RU Xtend or Xtendflex soybean varieties.** Drift and off-site movement may cause injury or death to susceptible plants and crops. For all application information and restrictions refer to: *www.xtendimaxapplicationrequirements.com* *www.engeniaherbicide.com/tank-mix.html* *www.syngenta-us.com/herbicides/tavium-tank-mixes* • Do not deviate in use from label or web sites (above). • Dicamba or auxin-specific training is required. • Apply with approved nozzles and adjuvants. • Apply with minimum 15 gpa. • Do not add any product containing ammonium. • Must add approved pH buffer agent or Vapor Reduction Agent (see product labels). • Do not apply before/during temperature inversion. • Only apply 1 hour after sunrise until 2 hours before sunset. • Do not apply when wind speed is <3 or >10 mph. • Maintain a 240 foot downwind buffer. • Maintain a 110 foot downwind buffer when using a qualified hooded sprayer. • Do not spray when adjacent sensitive crops are downwind.
XtendiMax 2.9SL (dicamba) **RUP** Only certified applicators may purchase and apply. 	**Single application rate in-crop:** **22 fl oz 2.9SL** (0.5 lb ae) **Maximum total in-crop:** 1 lb ae **Maximum total per year** 2 lb ae **Do not apply less than 0.5 lb ae/a for any application.**		EPP, At Planting, PRE and POST. Soybean: Emergence through R1. No later than June 30. Weeds: Less than 4 inches tall.	

Herbicide	Product per acre (ai/acre)	Weeds	When to Apply	Remarks
Tavium 3.38 SL (dicamba & S-metolachlor) **RUP** Only certified applicators may purchase and apply. 	**56.5 fl oz CS** (0.5 lb & 1 lb)	Annual and perennial broadleaf weeds. Residual control of grass and small-seeded broadleaf weeds.	EPP, At Planting, PRE and POST. Soybean: Emergence to V4. No later than June 30. Weeds: Less than 4 inches tall.	**Apply only to RU Xtend or Xtendflex soybean varieties.** Drift and off-site movement may cause injury or death to susceptible plants and crops. For all application information and restrictions refer to: www.xtendimaxapplicationrequirements.com www.engeniaherbicide.com/tank-mix.html www.syngenta-us.com/herbicides/tavium-tank-mixes • Do not deviate in use from label or web sites (above). • Dicamba or auxin-specific training is required. • Apply with approved nozzles and adjuvants. • Apply with minimum 15 gpa. • Do not add any product containing ammonium. • Must add approved pH buffer agent or Vapor Reduction Agent (see product labels). • Do not apply before/during temperature inversion. • Only apply 1 hour after sunrise until 2 hours before sunset. • Do not apply when wind speed is <3 or >10 mph. • Maintain a 240 foot downwind buffer. • Maintain a 110 foot downwind buffer when using a qualified hooded sprayer. • Do not spray when adjacent sensitive crops are downwind.

Some reasons why off-site movement of dicamba can occur:

1. Non- tolerant soybean plants can show phytotoxic symptoms from dicamba at rates as low as 0.0004 oz ae per acre (0.028 gram per hectare). Very small amounts of dicamba from contaminated sprayers, particle drift, and volatility can cause injury symptoms on soybean. Extremely high soybean sensitivity to dicamba influences all other discussion points.

2. Dicamba rate used in DT soybean is 8 oz ae/a compared to 0.5 to 2 oz ae/a used in wheat and corn. The higher dicamba rate applied in DT soybean applied during late June and early July can result in very high release of dicamba into the environment, which could be a source for particle drift and volatility.

3. Higher temperatures occur in late June and early July. The vapor pressure of dicamba significantly increases as temperature increases.

4. Dicamba is normally applied in May and early June in wheat and corn. Dicamba in DT soybean allows application prior to R1 stage. Later applications are more prone to dicamba drift because temperatures are higher, which allows greater dicamba volatility while soybeans are more advanced in growth to intercept dicamba, express injury symptoms, and possibly reduce yield.

5. Dicamba drift is more likely to cause yield loss the closer to and including reproductive stage. Summer solstice (June 21) is the reproductive trigger in soybean.

6. Precipitation normally decreases after late June. Dicamba is highly water soluble and rain events after application can “wash” dicamba off plant leaves into the soil to trap dicamba and reduce off-target movement.

NDSU Weed Science recommends no dicamba applications after June 20. See #3-6 above.

- This allows for PRE and Early POST applications.
- This supports the residual PRE concept for effective weed management and encourages timely applications.
- Soybeans are photoperiod sensitive: the reproductive phase begins after the longest day of the year (June 21). Off-target drift of dicamba is more likely to injure non-tolerant soybean yield when it enters the reproductive phase.
- Most off-target dicamba drift complaints result from postemergence applications. Postemergence applications have the greatest potential to contact and injure susceptible vegetation. Spraying conditions may be favorable after June 20 but average temperatures are higher, which exponentially increase the potential for dicamba volatilization. Soybean plants will be larger to intercept more herbicide.

Enlist Soybean

Herbicide	Product per acre (ai/acre)	Weeds	When to Apply	Remarks
Enlist One 3.8 SL (2,4-D Choline)	**2.0 pt SL** (0.95 lb ae)	Annual and perennial broadleaf weeds.	EPP, At Planting, PRE and POST. Soybean: Emergence through R1.	**Apply only to Enlist soybean varieties.** Drift and off-site movement may cause injury or death to susceptible plants and crops. For all application information and restrictions refer to: *www.enlist.com/en/approved-tank-mixes.html* • Do not deviate in use from label or web site (above). • Apply with approved nozzles and adjuvants. • Do not apply before/during temperature inversion. • Do not apply when wind speed is <3 or >15 mph. • Maintain a 30 foot buffer.
Enlist Duo 3.3 SL (2,4-D Choline & glyphosate)	**4.75 pt SL** (0.95 lb ae & 1 lb ae)	Annual and perennial grass and broadleaf weeds.		

Only glyphosate formulations that have been approved for use over the top of “Enlist” or “glyphosate-tolerant” soybeans can be used on Enlist soybeans. Enlist “E3” soybean varieties are also tolerant to glufosinate. Apply only glufosinate formulations that have been approved for use over the top of “Enlist” or “glufosinate-tolerant” soybeans.

Enlist One can have tank-mix compatibility issues with potassium (K) salts of glyphosate and AMS that is not fully dissolved in the spray tank. These issues can be avoided by following the correct tank-mixing procedure and allowing plenty of time for recirculation before adding the next product.

Enlist One can antagonize Group 1 (ACC-ase-inhibiting) herbicides in tank-mixes. It is recommended to increase the rate of the group 1 herbicide by at least one-third over the planned rate in order to overcome antagonism.

Weed Management in Roundup Ready, Liberty Link, Xtendflex, Enlist E3 Soybean

NDSU recommends using herbicides with different modes of action and different weed control management practices in herbicide- tolerant soybean production to delay development of resistant weeds.

Control weeds *before* 2 to 4 inches tall to avoid yield loss.

Remove weeds early, especially when grass weed populations are high. Some data from the Midwest indicate that soybean yield may not be reduced by delaying herbicide application until weeds are up to 6 inches tall. However, data from the northern Plains show that, especially under dry conditions, soybean yield loss will occur if weeds become greater than 4 inches tall prior to herbicide application.

Three Systems of Weed Control in RR Soybean

1. PRE followed by POST: **All PRE herbicides require rain for incorporation.**

   Tables lists many registered PRE soybean herbicides that can be used in herbicide-resistant soybean. PRE herbicides at 2/3 to the full labeled rate may give 60 to 99% control of some grass and broadleaf weeds, will reduce weed infestations emerging with soybean, will allow more flexibility in application of POST herbicides and will help protect yield from early season weed competition.

2. Roundup/generic glyphosate + POST broadleaf herbicide (different mode of action):

   Several herbicides listed in the following table will improve control of weeds not controlled by Roundup/glyphosate. Roundup/glyphosate has no soil residual and will not control weeds emerging after application. Roundup/glyphosate may not control some weed species or biotypes. Many POST herbicides listed will give residual weed control. Follow label directions for tank-mix and application information.

3. Roundup/generic glyphosate (EPOST = 2- to 4-inch-tall weeds) followed by Roundup/glyphosate (POST = 14 to 21 days later):

   This program will increase the risk of weed resistance unless other strategies are used in rotational crops.

The following table shows herbicides to apply in tank-mix or sequentially with Roundup/glyphosate in RR soybean for control of weeds not controlled by Roundup/glyphosate. Weed ratings are control without Roundup/glyphosate. Refer to the label for tank-mix and specific application information. Residual weed control listed in the table refers to control of subsequent flushes of weeds after herbicide application.

Roundup Ready Soybean —
Herbicides to apply in tank-mix or sequentially with glyphosate for control of weeds not controlled by glyphosate.

Herbicide	**Rate per acre**	**Buckwheat**	**Canola, Vol. RR**	**Horseweed (Marestail)[1]**	**Kochia**	**Lambsquarters**	**Nightshade species**	**Pigweed, Redroot**	**Prickly lettuce**	**Ragweed, Common**	**Smartweed, Annual**	**Waterhemp / Palmer**
		Weed Control Ratings [a,b]										
Glyphosate (4.5 lb ae)+ AMS + HSOC	32-105 fl oz	F-E	N	P-E	P-E	E	E	E	E	P-E	E	P-E
+ **2,4-D e**	+ 1 pt	F-E	P-E	G-E	P-E	E	E	E	E	E	E	P-E
+ **2,4-D e** + **Express**	+ 1 pt + 0.3 oz	F-E	G-E	P-E	P-E	E	E	E	E	P-E	E	P-E
+ **2,4-D e** + **Metribuzin**	+ 1 pt + 0.33 lb	G-E	G-E	G-E	F-E	E	G-E	E	E	E	E	F-E
+ **Afforia**	2.5-3.75 oz WDG	G-E	G-E	F-G	P-G	G-E	G-E	G-E	F-E	P	F	G
+ **Verdict**	+ 5 fl oz	G-E	P-G	G-E	G-E	E	G-E	E	G-E	G-E	E	E
+ **Verdict** + **Metribuzin**	+ 5 fl oz + 0.33 lb	E	G-E	E	E	E	E	E	E	E	E	E
+ **Verdict** + **Zidua SC**	+ 5 floz + 3.25 fl oz	E	G-E	G-E	G-E	E	E	E	E	G-E	E	G-E
Paraquat + NIS adjuvant	3 pt 2SL + 1-2 pt	F	-	F-G	G-E	P-E	G-E	E	F-G	G-E	E	G-E
+ **Verdict** + **Metribuzin** + **oil adj.**	+ 5 fl oz + 0.33	G-E	E	G-E	G-E	E	G-E	E	G-E	E	E	G-E
+ **2,4-D e+Verdict +Metrib** + **oil adj.**	+ 5 oz + 0.33 lb	E	E	E	E	E	E	E	E	E	E	E

Herbicide	Rate per acre	Buckwheat	Canola, Vol. RR	Horseweed (Marestail)[1]	Kochia	Lambsquarters	Nightshade species	Pigweed, Redroot	Prickly lettuce	Ragweed, Common	Smartweed, Annual	Waterhemp / Palmer
		Weed Control Ratings [a,b] — *without glyphosate*										
Afforia	2.5-3.75 oz WDG	G-E	G-E	F-G	P-G	G-E	G-E	G-E	F-E	P	F	G
Anthem Maxx	2-5.5 oz WDG	F-E	P-F	-	F-E	F-E	F-E	G-E	-	P	F-E	G-E
Authority Assist	6-9 fl oz	P-G	G-E	F	F-E	G-E	F-E	F-E	E	N	G-E	F-E
Authority Elite	20-32 fl oz	P-G	P	F	G-E	G-E	G-E	G-E	P	N	G-E	G-E
Authority First	4-8 oz WDG	P-G	E	P-G	F-E	G-E	F-E	E	P	N	G-E	F-E
Authority MTZ	12-15* oz	F-G	E	F	F-E	G-E	G-E	G-E	G-E	P-F	G-E	F-E
Authority Supreme	6-11.5 fl oz	P-F	P	P-F	F-E	G-E	F-E	G-E	P	N	G-E	G-E
Boundary	1.6*-2.4** pt	F-G	E	F	F-G	G	P	G-E	G-E	P-F	G	G-E
BroadAxe XC	20-32 fl oz	P-G	P-F	F	G-E	G-E	G-E	G-E	P	N	G-E	G-E
Fierce	3 oz WDG	P-F	G-E	F-G	F-E	F-G	F-E	G-E	F-G	F-G	F-G	G-E
Fierce MTZ/Kyber	1-1.5 pt	F-G	G-E	F-G	F-E	G-E	G-E	G-E	G-E	F-G	F-G	G-E
FirstRate	0.3-0.75 WDG	N	E	P-E	N	P-F	N	P-F	-	G-E	G-E	N
Metribuzin[1]	0.33-0.5 lb DF	F-G	E	F	F-G	P-G	P	G-E	G-E	P-F	G	F-G
Prowl (PPI)	See label	N	N	N	P	F-G	N	E	N	N	N-P	F-G
Panther Pro	12* fl oz	F-G	E	F-G	F-G	F-E	G-E	E	G-E	P-F	G	G
Perpetuo	6-10 fl oz	F-E	P-F	-	F	F-E	F-E	G-E	-	P-F	F-E	G-E
Pursuit	2 fl oz	F-G	G-E	N	N	P	P-E	E	-	N	G	N

Herbicide	Rate per acre	Buckwheat	Canola, Vol. RR	Horseweed (Marestail)[1]	Kochia	Lambsquarters	Nightshade species	Pigweed, Redroot	Prickly lettuce	Ragweed, Common	Smartweed, Annual	Waterhemp / Palmer
		Weed Control Ratings [a,b] **— *without glyphosate***										
Sharpen	1 fl oz	P-F	G-E	P-F	P	F	P	F-P	P	P	P	P-F
Sonalan (PPI)	See label	P	N	N	P	F-G	N	E	N	N	N-P	F-G
Sonic	4-8 oz WDG	F-G	E	P-G	F-E	G-E	F-E	E	P	N	G-E	F-E
Spartan	4.5-9 fl oz	F-G	P	F	F-E	G-E	F-E	F-E	P	N	G-E	F-E
Surveil	2.1-4.2 oz WDG	P	E	-	P-G	G-E	E	E	-	F-E	G-E	F-E
Treflan (PPI)	See label	N	N	N	P	F-G	N	E	N	N	N-P	F-G
Valor EZ	2-3 oz SC/WDG	P-F	F-E	F-G	F-G	F-E	G-E	G-E	F-E	P-F	F	G
Verdict	5 fl oz	P-F	G-E	P-F	P	F-G	F	G	G-E	P-F	F	F-G
Zidua SC	2.5 - 5.75 fl oz	F-E	P-F	-	F	F-E	F-E	G-E	-	P-F	F-E	G-E
Zidua Pro	4.5 fl oz	F-E	P-F	-	F-E	F-E	F-E	G-E	-	F-G	F-E	G-E

[a]E = Excellent (90-99%), G = Good (80-90%), F = Fair (65-80%), P = Poor (40-65%), N = None.

[b]Includes resistant populations.

[1]Ratings for PRE herbicides are for horseweed plants prior to their emergence (spring-emerging populations).

Control of Volunteer Glyphosate Resistant (GR) Crops

PRE Control of volunteer GR canola:

>90% PRE = Acuron/Flexi, Authority Assist (7-9 fl oz), Authority First/MTZ/Elite/BroadAxe XC (20-26 fl oz = 75-85%), Balance Flexx, Fierce, FirstRate, Instigate, Realm Q (POST), Resolve Q, Sharpen (2-3 fl oz), Sonic, SureStart (2 pt), Surveil, Verdict.

<70% PRE = Anthem, Authority Assist (6 fl oz), Authority MTZ, Boundary, Metribuzin, Sharpen (1 fl oz), SureStart II (1.5-2 pt), Spartan, Valor, Zidua.

POST Control of volunteer GR canola:

>90% POST = Most ALS herbicides. SureStart II (1.5-2 pt), Teammate (3-leaf).

<70% POST = Aim, Cadet, Basagran >6-leaf, Cobra, Harmony1, Realm Q, Resolve Q, Sharpen >bolting, Talinor, Ultra Blazer >3-leaf.

	Rate per acre	Canola - Pre	Canola - 3-leaf	Canola - 6-leaf	Canola - begin bolt	Canola - begin flower	Corn - 10-18 inches	Corn - 18-24 inches	Corn - 24-40 inches	Soybean - V2-V3	Soybean - V4-V6
POST Grass Herbicides[1]											
Assure II[1] / Fusilade DX	3 - 5 fl oz	N	N	N	N	N	E	E	G-E	N	N
Select[1]	3 - 6 fl oz	N	N	N	N	N	G-E	P-G	P-F	N	N
Select Max	6 - 9 fl oz	N	N	N	N	N	G-E	P-F	P	N	N
Broadleaf Herbicides											
Armezon / Impact + atrazine	0.5 floz+0.38 lb ai	E	E	E	F	P	N	N	N	P	P
atrazine[1] + oil adjuvant	0.38 lb ai	E	G-E	P	N	N	N	N	N	E	P
	0.5 lb ai	E	G-E	G	P	P	N	N	N	E	F
Bromoxynil & MCPA[1]	0.8 pt	-	E	F-G	-	-	N	N	N	E	E
Callisto + atrazine (3/8 lb ai)	3 fl oz	E	E	E	E	E	N	N	N	P	P
Capreno + atrazine (3/8 lb ai)	3 fl oz	-	E	G-E	-	-	N	N	N	G	G
Curtail[1]	0.25 - 0.5 pt	-	G-E	F-G	-	-	N	N	N	F-G	P-F
Dicamba	4 - 12 fl oz	N-P	P	P	P	P	N	N	N	E	E
Express[1]	0.167 oz DF/0.25 oz SG	-	E	G-E	F-G	F	P	P	P	P	P

Extreme[1]	1.5 pt	E	E	G-E	P	P	F-G	F	P	N	N
FirstRate / Sonic	0.2 - 0.3 oz	E	E	F-E	P-F	F	-	-	-	N	N
Flexstar + MSO	0.38 - 0.75 pt	-	E	E	E	E	N	N	N	N	N
Harmony	0.33 oz DF / 0.5 oz SG	-	E	G-E	P	P	N	N	N	N	N
Hornet	1 - 2 oz	P-F	G-E	F-E	-	-	N	N	N	E	F
Huskie / Complete / FX	11-15/13.7/13.5-18 fl oz	-	E	E	E	E	N	N	N	G	G
Laudis + atrazine (3/8 lb ai)	3 fl oz	-	E	E	E	F	N	N	N	G	G
Liberty + AMS	32 - 43 fl oz	N	E	G-E	P-F	P	N	N	N	G	F-G
MCPA[1]	1 pt	P	E	E	G-E	G	N	N	N	G	F
Permit	1.5 oz	E	E	E	-	-	N	N	N	E	G
Pursuit[1] + MSO	2 fl oz	G-E	E	G-E	P	P	G	F	P	N	N
Beyond Xtra + MSO	1 - 2 fl oz	-	E	G-E	P-F	P	P-F	P	N-P	N	N
	4 fl oz	-	E	E	G	F	G-E	F	P	N	N
Status	2.5 oz	N	F	P	N	N	N	N	N	E	G-E
	4 oz	N	G	F	P	P	N	N	N	E	E
Stinger[1] + oil adjuvant	1 - 2 fl oz	N	N	N	N	N	N	N	N	F-G	F
	3 - 4 fl oz	N	N	N	N	N	N	N	N	E	G-E
Varisto + MSO	11 -16 fl oz	-	E	E	G	F	P-F	P	N-P	N	N
	21 fl oz	-	E	E	E	E	G-E	F	P	N	N
UpBeet + MSO[2]	0.5 to 1 oz	-	G	N-P	N	N	P-F	N-P	N-P	F	N-P
WideMatch*	0.13 - 0.25 pt	N	P	P	N	N	N	N	N	F-E	P-G
Wolverine Advanced	1.7 pt	-	E	E	E	E	E	E	E	G	G
2,4-D[1]	0.5 pt	N	G	P	N	N	N	P	P	P	P
	1 pt	N	E	E	G-E	P	N	P	P	-	-

[1]Or generic equivalent.
[2]Two applications at 10 to 14 days interval.

Weed control ratings in this section are based on the following scale:

E = Excellent = 90 to 99% control
G = Good = 80 to 90% control
F = Fair = 65 to 80% control
P = Poor = 40 to 65% control
N = None = No control
"-" = insufficient information

Herbicide Comments

Soybean is a poor competitor with weeds when cool soil temperatures cause slow germination and growth, but soybean does compete effectively in warm soils when germination and growth are rapid. Soybean production requires good cultural practices. Prepare the seedbed prior to planting to kill germinating weeds.

Management practices such as thorough seedbed preparation, adequate soil fertility, the choice of a well adapted variety and the use of good-quality seed all contribute to conditions of good competition with weeds. A rotary hoe or harrow may be used to control weeds after planting but before the soybean emerge or after emergence when soybean are in the one- to two-trifoliolate leaf stage. A rotary hoe or harrow helps activate PRE herbicides under dry conditions and increase weed control.

The rotary hoe is an effective and economical weed control method when a field is not trashy, lumpy or wet, and when weeds are emerging. Cultivation is most effective when soybean are slightly wilted during the warm part of the day because the crop is less susceptible to breakage and weeds will desiccate quickly.

Poast (sethoxydim) plus petroleum oil adjuvant or applied POST controls annual grasses. **Assure II** (quizalofop), **clethodim, Fusilade DX** (fluazifop P), **Fusion** (fluazifop-P & fenoxaprop-P) plus petroleum oil adjuvant or **Select Max** (clethodim) applied POST controls annual grasses and quackgrass. Methylated seed oils (MSO) have performed equally to petroleum-based oil additives. Refer to the Select Max label for adjuvant information.

Re-treat quackgrass when regrowth is 4 to 8 inches tall. Poast only suppresses quackgrass. Most broadleaf herbicides tank-mixed with POST grass herbicides often will reduce grass control, compared with the grass herbicide applied alone. Reduced grass control can be avoided by applying the grass herbicide at least one day before or seven days after application of a broadleaf herbicide.

Assure II may provide excellent green foxtail control but less yellow foxtail control. Lower yellow foxtail control may result from applying Assure II at reduced rates, with broadleaf herbicides, or to large or stressed plants. The addition of fertilizer may enhance yellow foxtail control and control of stressed grasses.

Clethodim is an ACCase mode of action herbicide, similar to Assure II, Fusilade and Poast. However, in NDSU research, clethodim controls many grasses documented resistant to other ACCase herbicides and is antagonized less by tank-mixes with broadleaf herbicides. We recommend that clethodim be used in rotation with herbicides of different modes of action and in a resistant weed management program.

Several generic brands of clethodim are available, but not all formulations are identical to the original Select formulation. Select, Clethodim, Trigger and Volunteer are the same, but Arrow, Prism, Section and Select Max all have different formulations. Select Max is a 1 lb/gal formulation, contains activating adjuvants in the formulation, and allows the use of NIS, PO or MSO, depending on the tank-mix partner.

Basagran (bentazon) at 0.5 to 1 qt/a applied POST controls many annual broadleaf weeds and suppresses Canada thistle. NDSU research has shown greater broadleaf weed control, especially in kochia, lambsquarters, redroot pigweed and wild buckwheat, by applying Basagran as split treatments twice each at 1 pt/a, three times each at 0.67 pt/a or four times each at 0.5 pt/a, compared with one application at 2 pt/a. Make applications seven to 10 days apart, depending on the weed growth rate, growing conditions, size of weeds at application, degree of weed control from the first application and sequential flushes. The first application must be made to small weeds (1 inch).

For Canada thistle control, apply Basagran at 1 qt/a when plants are 8 inches tall to bud stage and make a second application at 1 qt/a seven to 10 days later.

Basagran is safe to soybean at all stages. The total maximum seasonal use rate is 4 pt/a, so the rate of the micro-rate can be increased if weeds are large at application or if sequential applications are delayed due to rain or wind.

Weed control from Basagran applied one to four times. NDSU data.

Basagran +	Rate	Common lambsquarters	Kochia	Redroot pigweed
	(pt/a)	--- percent control ---		
Petroleum oil at 1 qt/a	2 pt x 1 application	8	38	51
	1 pt x 2	31	64	90
	0.67 pt x 3	34	79	95
	0.5 pt x 4	76	98	99
MSO at 1.5 pt/a	2 pt x 1 application	5	86	92
	1 pt x 2	76	98	95
	0.67 pt x 3	79	98	98
	0.5 pt x 4	99	99	99

Basagran commonly is combined with fertilizer micronutrients that may cause incompatibility problems resulting in zinc precipitation. Chelated zinc materials (which are black) have greater incompatibility problems than unchelated material (clear). Recommendations to prevent precipitation are to fill the sprayer with water, add Basagran and thoroughly agitate, then add zinc fertilizer material.

Flexstar (fomesafen + adjuvants) applied POST controls many small broadleaf weeds. Apply with NIS at 0.25 to 0.5% v/v or oil adjuvant at 0.5 to 1% v/v. Oil adjuvant increase weed control but also increase the risk of soybean injury. NDSU research has shown good to excellent kochia control when Flexstar is applied at high spray volumes (greater than 17 gpa) with oil adjuvants (especially MSO type) at labeled rates and to kochia less than 2 inches tall.

Soybean injury may result when Flexstar is tank-mixed with EC formulation herbicides that act as an additional oil adjuvant. The activity of fomesafen and the risk of crop injury increase as temperature and humidity increase. A maximum of 0.75 pt/a is allowed in most of North Dakota, while 1 pt/a is allowed through the Midwest. The reduced fomesafen rate reduces carryover and crop rotation restrictions.

Flexstar is labeled on soybean and Reflex is labeled on dry bean. Flexstar contains adjuvants lacking in the Reflex formulation. Reflex may give less consistent weed control than Flexstar and will require better management strategies to achieve adequate weed control. See the label or crop rotation restriction section for additional information.

Acetochlor, dimethenamid, metolachlor or S-metolachlor and pyroxasulfone applied PPI or PRE control annual grass and some broadleaf weeds and do not control wild oat. Apply the higher rate on clay soils high in organic matter. Soybean has good tolerance, and incorporation improves consistency of weed control.

Metribuzin controls some annual broadleaf weeds, including wild mustard. Adjust the rate according to the soil type, pH and percentage of organic matter. Some soybean varieties are susceptible to metribuzin; consult seed companies for a list of susceptible varieties. Soybean injury can be reduced by using herbicide combinations with lower rates of metribuzin.

Pursuit (imazethapyr) applied POST controls or suppresses many broadleaf weeds, except ALS-resistant weeds. Pursuit has controlled marshelder, Russian thistle, common cocklebur, sunflower, smartweed and lanceleaf sage in NDSU field trials. Pursuit may not control Venice mallow, horseweed, wild buckwheat, lambsquarters and common ragweed. POST application may not provide adequate soil residual to control subsequent flushes of nightshade due to plant foliage intercepting most of the spray.

However, even a small amount of Pursuit may give a reduction in number and intensity of flushes of other weeds. Pursuit is enhanced greatest by MSO (1.5 pt/a) and basic pH blend (1% v/v) adjuvants. UAN fertilizer (a solution of urea and ammonium nitrate in water) improves weed control, especially lambsquarters.

Crop injury may result if Pursuit or thifensulfuron is applied sequentially or tank-mixed together. In sequential application, the first herbicide reduces the ability of soybean to metabolize the second herbicide. Weeds not controlled by the first herbicide may not be controlled after the second herbicide is applied.

This is particularly important for lambsquarters. Weeds that escape control from the first herbicide may be larger than labeled size by the time soybean can be treated safely with the second herbicide. Delay cultivation for 14 days after application to avoid reduction in weed control.

Tank-mixtures of Pursuit with Assure II, clethodim or Fusilade DX may result in reduced grass control. Reduced grass control can be avoided by applying the POST grass herbicide one or more days prior to or seven days after Pursuit.

Python (flumetsulam) applied PPI or PRE will control many annual small-seeded broadleaf weeds in soybean. Python does not control large-seeded broadleaf weeds such as common and giant ragweed and common cocklebur. Python requires soil water for optimum weed control. Python also is strongly affected by soil pH. High soil pH increases herbicide activity and the speed of herbicide degradation but also increases the risk of crop injury.

Excellent broad-spectrum weed control may occur when applied on soils with a pH above 7.5, when significant precipitation occurs after application, when rates are based on soil texture and organic matter content, and under light to moderate weed infestations. Some stunting may occur under poor growing conditions on soils with a pH greater than 8.

Beyond Xtra (imazamox) applied POST controls nearly all annual grass and broadleaf weeds in soybean except wild buckwheat, lambsquarters, common and giant ragweed, Venice mallow, horseweed, biennial wormwood and ALS-resistant weeds. In NDSU field trails, Beyond Xtra has controlled marshelder, Russian thistle and lanceleaf sage less than 1 inch tall. Soil residue of Beyond Xtra will not control late-germinating weeds or weed flushes later in the growing season after rain events. Beyond Xtra has greater grass and broadleaf weed control, provides improved lambsquarters control and has less carryover and crop rotation restrictions that Pursuit.

Apply Beyond Xtra with a basic pH blend adjuvant at 1% v/v or MSO-type adjuvants at 1.25 pt/a. Alternatively, apply with NIS at 0.125 to 0.25% v/v or oil concentrate at 0.5% v/v plus 28% UAN liquid fertilizer at 4% v/v. The use of 28% UAN improves control of some weeds such as lambsquarters. MSO-type oil additives should be used when weeds are large and/or stressed.

MSO or basic pH blend adjuvants enhance weed control more than NIS or some petroleum oil additives with or without 28% UAN. However, Beyond Xtra applied with MSO + UAN may result in crop injury at temperatures greater than 88 F and relative humidity greater than 80%.

Refer to the label and paragraph on Pursuit and Beyond Xtra for information and restrictions when applying Beyond Xtra before or after thifensulfuron or tank-mixing with thifensulfuron or other POST grass herbicides. Crop rotation restrictions are less with Beyond Xtra than Pursuit.

However, like Pursuit, Beyond Xtra carryover is affected by soil pH. As the soil pH increases, rate of Beyond Xtra degradation increases. At a soil pH less than 6.5, the rate of breakdown is slow and injury to sugarbeet and other sensitive crops may occur if planted before the allowed time interval. See the label or information on crop rotation restrictions.

Sonalan (ethalfluralin), **trifluralin** or **Prowl/H20** (pendimethalin) applied PPI controls most annual grasses and some small-seeded broadleaf weeds but provides no wild mustard, common cocklebur and sunflower control. Requirements for proper timing and depth of incorporation differ for each herbicide. Adjust the rate according to the soil type.

Trifluralin must be incorporated in the top 2 to 3 inches of soil within 24 hours of application. Trifluralin incorporation may be delayed up to two days if applied to a cool, dry soil. Incorporation of Sonalan 10G can delayed three to five days after application. Herbicides can be applied with most soil PPI herbicides labeled in soybean. Sonalan has less soil residue than trifluralin or Prowl and may be more active at comparable rates.

Spartan (sulfentrazone) applied shallow PPI or PRE controls most annual small-seeded broadleaf weeds and may control wild buckwheat, marshelder, wild mustard, common ragweed, hairy nightshade, Venice mallow and foxtail partially but provides no perennial weed control. The rate must be adjusted for soil texture, soil pH and organic matter content. Apply 3 to 6 fl oz/a for coarse and medium-textured soils and 4 to 8 fl oz/a for fine-textured soils. Herbicide solubility, activity and phytotoxicity increase as the soil pH increases. The user must read and follow the label for rate information to ensure adequate weed control.

Spartan provides excellent burndown weed control and may be applied up to 30 days prior to planting, but use the higher rate in the appropriate rate range. Spartan can be tank-mixed with most PPI/PRE herbicides registered in soybean.

NDSU research has shown that consistent control of susceptible broadleaf weeds and suppression of foxtail and marginally susceptible broadleaf weeds depends on at least 0.5 to 0.75 inch of rainfall shortly after application and before weeds emerge. Spartan will leave a residue in the soil for more than one year. Refer to the label for crop rotation restrictions.

Harmony (thifensulfuron) has activity on wild mustard, lambsquarters, pigweed species, annual smartweed and wild buckwheat. Apply with NIS at 0.125 to 0.25% v/v or oil adjuvants at 0.5% v/v plus liquid fertilizer at 4% v/v. Do not apply with oil adjuvants when tank-mixing with any other herbicide or severe crop injury may occur. See the label or Pursuit paragraph for precautions when tank-mixing with Pursuit and other herbicides.

Thifensulfuron as spray drift or sprayer contamination may cause severe injury to susceptible crops such as sugarbeet and sunflower. Thoroughly clean the sprayer to prevent contamination of subsequent spray mixtures and injury to susceptible crops. Follow the label for improved cleanout procedure.

Valor (flumioxazin) applied EPP or PRE controls most small-seeded broadleaf weeds and may suppress foxtail, common and giant ragweed, annual smartweed, Russian thistle and wild buckwheat. Valor does not control perennial weeds. Apply from 14 days prior to planting to just before soybean emergence.

Valor can be applied with glyphosate in early burndown programs in soybean. Valor requires a minimum of 0.25 inch of rain for activation and requires a bioassay prior to planting sensitive crops. Refer to the label for weeds controlled, rates and crop rotation restrictions.

Soybean Herbicide Injury/Symptomology

Acetanilide (Warrant, Dual, etc)

Leaf stunting, puckering and the "draw string" effect on the central vein or leaf midrib.

DNA (Trifluralin, Sonalan, Prowl)

Excessive rates with stress conditions may cause pruned roots and swollen or cracked hypocotyls.

Plant growth regulators

Leaf puckering, along with stem and branch twisting and epinasty. Leaf strapping, cupping and parallel veins may be prevalent at lower exposure rates.

ALS inhibitors

Misapplication, drift or carryover of some ALS herbicides not registered on soybean may stunt soybean plants and cause yellow or chlorotic blotches on leaves. Labeled herbicides such as Beyond Xtra and Pursuit may intensify the symptoms of iron chlorosis. Tank-mixes of Harmony GT with Pursuit or Beyond Xtra are not recommended due to severe soybean stunting and leaf burn.

Contact – soil applied (Authority and Valor)

Authority: Some soybean varieties are susceptible to injury. See your seed dealer for a list. Symptoms are stunting and yellowing of soybean leaves. Valor may cause localized speckling from a "splash effect" after a rain storm. Speckling may occur only on bare soil where no crop residue exists.

Contact – POST (Aim, Blazer, Cobra, Flexstar)

Aim, Blazer and Flexstar may show localized speckling of soybean leaves. More serious injury may result if Aim is applied in wet or dewy conditions. Injury from Cobra may vary from speckling to severe leaf burn. New soybean growth after contact herbicide application is unaffected.

Contact – POST (Basagran)

Yellow chlorotic mottling in small patches on leaves. Areas of leaf burn may occur under stress conditions or hot temperatures. Injury is cosmetic and new growth is unaffected.

Triazine

Symptoms of atrazine carryover from high rates and high soil pH may be visible as leaf burn and desiccation from the bottom leaves progressing up the plant and from leaf tips inward. Symptoms from metribuzin may be similar to atrazine where high rates are used.

Glyphosate (conventional soybean)

Symptoms from drift are expressed early on new growth as stunting and leaf yellowing. Symptoms will progress to older plant tissue. Plants may remain stunted and affected plant tissue may die seven to 14 days after exposure, depending on the herbicide concentration and growing conditions.

Insect Management in Soybean

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Producers should scout soybean fields on a regular basis to minimize insect pest damage and adopt integrated pest management (IPM) strategies, such as the use of economic thresholds and combining various control methods when available.

Prior to the first detection of soybean aphid in the U.S. in 2000, soybean grown in the north-central U.S. rarely was damaged by insects. Soybean was considered a low-risk crop when grown in rotation with corn or wheat. However, soybean aphid has become a chronic major insect pest of soybean, and insecticide use has increased dramatically.

Other insect pests that occasionally infest soybean include spider mites, bean leaf beetles, seedcorn maggots, potato leafhoppers, cutworms, armyworms, various foliage-feeding caterpillars and grasshoppers. Significant progress in soybean pest management has been made and will continue into the future to aid successful soybean production.

A growing-season calendar shows the major soybean insect pest problems and the time of occurrence in North Dakota (Figure 6).

For **insecticides** registered in soybean, please consult the soybean section of the latest version of the NDSU

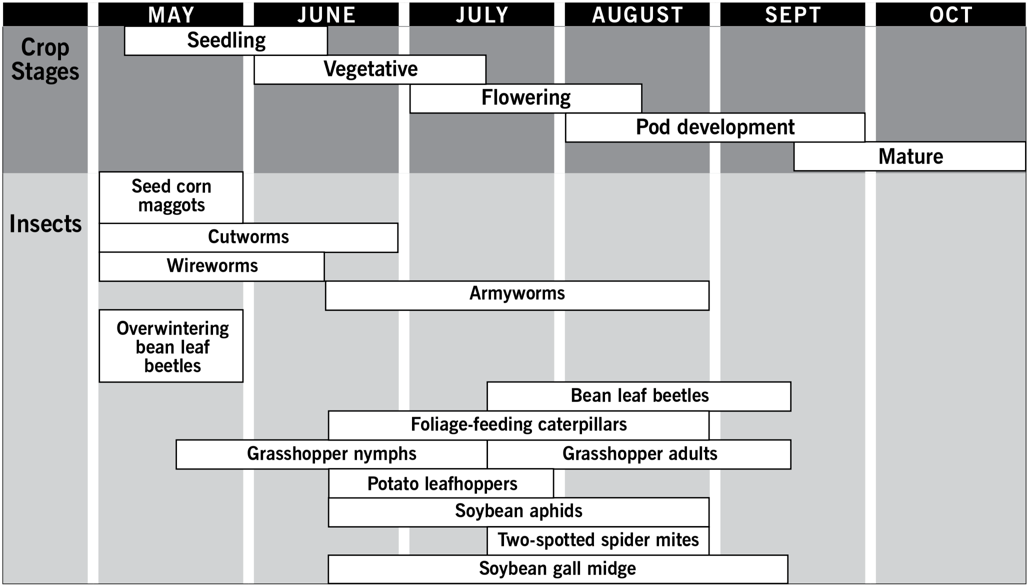

Figure 6. A growing-season calendar indicating the time of occurrence of soybean insect pests.

Extension E1143, "North Dakota Field Crop Insect Management Guide" (*www.ndsu.edu/agriculture/ag-hub/publications/north-dakota-field-crop-insect-management-guide*).

Estimating Defoliation Damage

In soybean, field scouting to assess insect populations is based on the number of insects per foot of row, insects per plant, sweep net sampling or the level of defoliation.

Insects per foot of row are determined by shaking plants over the inter-row space, on which a strip of cloth has been laid. Count the total number of insect pests per foot of row that fall on the cloth.

The percent of defoliation is determined by estimating the amount of leaf tissue loss based on visual inspection of randomly selected plants. Examples provided (Figure 7) are guidelines for estimating loss for individual leaflets. Actual defoliation estimates made for pest management decisions are based on estimated leaf area lost from the entire plant.

The growth stage of the soybean plant is important when making pest management decisions. Under most conditions, moderate defoliation early in the season has little effect on final bean yield. As plants reach the flowering and pod-filling stages, defoliation poses a greater threat to yield.

- From vegetative to pre-bloom stages, the soybean plant can sustain a 30% leaf loss.

- From flowering to pod-set (reproductive), the plant can tolerate only a 20% defoliation level.
- If pod feeding insects are present in large populations and pod clipping is occurring, treat aggressively when pod injury reaches 10%.

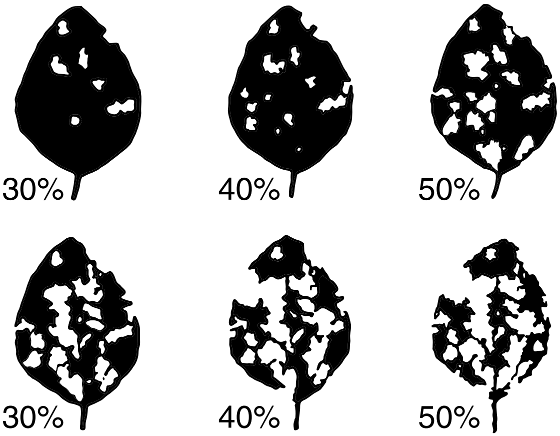

Figure 7. Soybean defoliation levels.

Armyworms [Lepidoptera: Noctuidae: *Pseudaletia unipuncta* (Haworth)]

Armyworms are greenish-brown with longitudinal stripes. Full-grown larvae are smooth, striped and almost hairless. Armyworms feed for three to four weeks. When full grown, larvae are 1½ to 2 inches long.

Armyworm larvae have six growth stages, or instars. The final instar lasts about 10 days, and they consume large amounts of plant material during that time.

Armyworms are inactive during the day, resting under plant trash, and clumps of grass or lodged plants. They feed at night or on cloudy days, crawling up on plants and consuming foliage. Due to their habit of feeding at night, armyworms may go undetected until significant damage has occurred.

Armyworms do not overwinter in the region. Moths migrate from southern states in late spring and early summer. This helps explain the sporadic infestations that occur. When moths arrive, they prefer to lay their eggs in moist, shady areas, usually where grasses have lodged. Infestations that develop within soybean fields are often due to grassy weed problems.

Armyworms are more of a problem in small grains and corn. Damage to soybean can occur when the armyworms' usual host plants become exhausted due to feeding or dry conditions. When their food is depleted in the hatching site, the armyworms may move in large numbers or "armies," eating and destroying plants or crops in their path.

Threshold

Control of armyworms is recommended when 25% to 30% of the foliage is destroyed or if significant injury to pods is evident. Most often in soybean, infestations are due to migrating armyworms. Under these circumstances, treatment of a couple of swaths ahead of the migrating armyworms to establish a barrier strip and prevent further migration and injury, may be all that is needed.

Bean Leaf Beetle [Coleoptera: Chrysomelidae: *Cerotoma trifurcata* (Förster)]

This beetle can vary from yellow to reddish brown and may have three to four black spots with a black border on the wing covers. Adults emerge from overwintering and move into bean fields as the seedlings emerge. The white larvae develop in the soil, feeding on the roots and nodules. New adults emerging from mid-July to August feed on foliage and pods.

Feeding injury to leaves appears as small round holes between the leaf veins. Late-season feeding on the foliage and pods by the new adults that emerge in August can be more important than early season feeding, especially if viruses are present. This may increase the risk of virus transmission and cause secondary fungal and bacterial infections (rotting and discoloration). Bean leaf beetles are the vector of bean pod mottle virus.

Threshold

Bean leaf beetle populations have been increasing in North Dakota over the past years. It is now found in southeast, east central and north central areas of North Dakota. A sweep net can be used to determine if bean leaf beetles are present. Treatment is recommended when **three to seven beetles per sweep** are found. Treatment thresholds based on defoliation are 30% defoliation during early vegetative to pre-bloom, 20% defoliation during bloom to pod set to fill and only 10% if pod feeding or clipping is occurring.

Cutworms (Lepidoptera: Noctuidae)

Several cutworm species affect soybeans. The dingy cutworm, *Feltia jaculifera* (Guenée), overwinters as a partially grown larva and is one of the first cutworm species to cause problems during crop emergence from early to mid-May. The moth of the dingy cutworm is known to lay her eggs on sunflower heads from mid-July through September. Soybean and other crops following sunflower in rotation are at greatest risk of injury by this cutworm.

Other cutworms — the redbacked, *Euxoa ochrogaster* (Guenée) and the darksided, *Euxoa messoria* (Harris) — overwinter as eggs, which hatch in mid to late-May. Eggs are laid in the fall and survive in weedy, wet and reduced-tillage areas. Feeding injury by these cutworms normally occurs in late-May to mid-June.

Most damage by cutworms occurs when soybean plants are in the early stage of development. Damage consists of young plants being chewed off slightly below or at ground level. Some climbing cutworms feed on foliage causing defoliation. Cutworms feed primarily at night. When checking soybean fields for cutworms during the day, dig down into the soil an inch or two around recently damaged plants; there you can find the gray to brown larvae.

Threshold

Economic thresholds for cutworm treatment decisions are not well-established. Treatment guidelines used include when one cutworm (larva) or more is found per 3 feet of row and larvae are small (less than ¾ inch long). Another guideline is when 20% of plants are cut or when gaps of 1 foot or more exist in the plant row. When making a final decision, consider if surviving soybeans are able to compensate for early stand reductions because of the plant's long growth period and branching ability.

Foliage-feeding Caterpillars (Lepidoptera)

- **Green Cloverworm, Cabbage Looper, Velvetbean Caterpillar, Thistle Caterpillar and Alfalfa Webworm:** Populations of these foliage-feeding caterpillars (larvae) are considered occasional insect pests in North Dakota. To sample for larvae (caterpillars), use a drop cloth or vertical beat sheet placed between two rows of plants. Dislodge the larvae from the plants and count them on the cloth or collection tray to arrive at an estimate of the number per row feet. Treatments also can be based on the average defoliation (see *Estimating Defoliation Damage* section near the beginning of Insect chapter).

- **Green cloverworm [Erebidae: *Hypena scabra* (Fabricius)]:** These larvae are green with two narrow white stripes down the side. When mature, larvae are 1¼ inches long, and have only three pairs of fleshy prolegs on the abdomen, plus the pair on the back tip. When moving, larvae arch the middle of the body, or "loop." Young larvae scrape leaf tissue, creating a transparent skin or "window" on the leaf surface. Older cloverworms eat holes in the leaves.

- **Cabbage looper [Noctuidae: *Trichoplusia ni* (Hübner)]:** These larvae are light to dark green with lighter-colored stripes along the side and on the top, running the length of the body. When mature, larvae are 1½ inches long, and have only two pairs of fleshy prolegs on the abdomen, plus the pair on the back tip. When moving, the larvae also arch the middle of the body or "loop." These larvae feed on leaves on the interior and lower portion of the plant. As defoliation occurs, larvae feed higher in the plant. Feeding injury is similar to the cloverworm.
- **Velvetbean caterpillar (Noctuidae: *Anticarsia gemmatalis* Hübner):** This insect does not overwinter in the region. Instead, moths migrate from southern locations. Larvae have dark lines bordered by lighter-colored, narrower lines running the length of the body. The background color ranges from a pale yellow-green to brown or black. Velvetbean caterpillars have four pairs of fleshy prolegs to distinguish them from the cloverworm and the looper. Young larvae feed on the underside of leaves in the upper portion of the plant. Older larvae consume the entire leaf, except for the leaf veins..
- **Thistle caterpillar [Nymphalidae: *Vanessa cardui* (Linnaeus)]:** This insect is the larva of the butterfly known as the painted lady. This butterfly does not overwinter in the region but migrates from

southern locations each spring. These caterpillars are brown to black, with yellow stripes along each side of the body. They are covered with spiny scoli (fleshy structures) that give the caterpillar a prickly appearance. Full-grown larvae are about 1½ inches long. Larvae feed on the leaves, webbing them together at the feeding site.

- **Alfalfa webworm [Crambidae: *Loxostege cereralis* (Zeller)]:** Larvae are 1 inch long when fully grown, and greenish to nearly black, with a light stripe that runs down the middle of the back. They have three dark spots, each with hairs, on the side of each segment. Larvae feed for about three-plus weeks. Infestations are characterized by light webbing over the leaves. Beneath the web is where the larvae feed, consuming the leaves. These larvae move very rapidly, forward or backward, when disturbed.

Threshold

Control of these foliage-feeding caterpillars normally is not warranted until greater than 30% of the foliage is destroyed prior to bloom, or when 20% of the foliage is destroyed after bloom, pod set or fill has been reached. This usually requires an average infestation of four to eight larvae per row foot.

Grasshoppers (Orthoptera: Acrididae)

In the northern Great Plains, grasshopper egg hatch normally begins in late April to early May. Most grasshoppers emerge from eggs deposited in uncultivated ground. Soybean growers should expect to find grasshoppers feeding first along bean field margins adjacent to non-crop sites, where the nymphs are hatching. Later infestations may develop when grasshopper adults migrate from harvested small grain fields. Grasshoppers will feed on leaves and pods, chewing holes in them. Soybean fields often become sites for significant egg laying from migrating grasshopper adults.

Threshold

The threatening rating is considered the action threshold for grasshoppers. **Grasshopper control is advised whenever 50 or more small nymphs per square yard can be found in adjacent, non-crop areas, or when 30 or more nymphs per square yard can be found in the field. When 20 or more adults per square yard are found in field margins or eight to 14 adults per square yard are occurring in the crop, treatment would be justified.** Because estimating the number of grasshoppers per square yard is difficult when population densities are high, pest managers can use a 15-inch sweep net and count grasshoppers collected from four 180-degree sweeps and use that value as an estimate for the number of adult (or nymph) grasshoppers per square yard.

	Nymphs (young grasshoppers) per square yard		Adults per square yard	
Rating	**Margin**	**Field**	**Margin**	**Field**
Light	25-35	15-23	10-20	3-7
Threatening (action threshold)	50-75	30-45	21-40	8-14
Severe	100-150	60-90	41-80	15-28
Very severe	200+	120	80+	28+

Many of the grasshopper infestations in soybean will be heaviest on field margins. Treating these areas early in the season during outbreaks may lessen the total number of grasshoppers successfully entering a field.

Soybean is most sensitive to defoliation during pod and seed development (growth stages R4 to R6). During this time, plants can tolerate up to only 20% defoliation.

Of greater concern is direct feeding damage to pods and seeds. Grasshoppers are able to chew directly through the pod walls and damage seed. If grasshoppers injure more than 10% of the pods, a prompt insecticide application is recommended.

■ Potato Leafhopper [Hemiptera: Cicadellidae: *Empoasca fabae* (Harris)]

The adult is about 1/8 inch long, pale green and wedge-shaped. Adults are very active, jumping or flying when disturbed. Nymphs are wingless. Adults and nymphs run backward or sideways rapidly when disturbed.

Nymphs feed on the underside of the leaf, usually completing their growth on the leaves near where they hatched. Potato leafhoppers migrate into North Dakota from southeastern U.S. When large numbers of adults may appear early in the season, frequent scouting is necessary.

Soybean with moderate to dense pubescence, or plant hairs, are tolerant to leafhopper infestations. The short plant hairs form a barrier that discourages leafhoppers from feeding and laying eggs on plant tissue. When feeding does occur, damage by leafhoppers is referred to as "hopper burn." Foliage becomes dwarfed, crinkled and curled. Small triangular brown areas appear at the tips of leaves, gradually spreading around the entire leaf margin. Potential damage to soybean by potato leafhopper is not fully understood. Damage is more likely when drier growing conditions occur.

Threshold

The threshold for spray decisions is an average of five leafhoppers per plant in the vegetative stages, and nine leafhoppers per plant in early bloom stages.

Soybean Aphid [Hemiptera: Aphididae: *Aphis glycines* (Matsumura)]

Soybean aphid was first detected in North Dakota in 2001 and has become a major insect pest.

Foliar insecticides are the primary management tactic for aphid control. However, multiple years of research have shown that natural enemies, including predators (lady beetles) and parasitic wasps, often can keep soybean aphids below the economic threshold in non-outbreak years. Another nonchemical management tactic that shows promise for controlling soybean aphid is the use of genetically based aphid-resistant soybean varieties.

Soybean aphid is small, about 1/8 inch, lime green with black cornicles ("tail-pipes") and a pale-colored cauda (tail projection). Nymphs (or young) are smaller yet.

Aphids have piercing-sucking mouthparts and feed on plant sap. When infestations are large, infested leaves are wilted or curled. Aphids excrete honeydew, a sweet substance that accumulates on surfaces of lower leaves and promotes the growth of sooty mold.

Soybean aphids colonize tender leaves and branches from early vegetative through reproductive plant stages. Later, as vegetative plant growth slows, the aphids slow their reproductive rate, move down to the middle and lower part of the plant, and feed on the undersides of leaves. Toward the end of the season, the colonies again begin to increase in number rapidly. These increases are followed by a migration to the overwintering host, buckthorn. Soybean aphids overwinter as eggs near the buds of buckthorn.

Threshold

The guidelines for making soybean aphid treatment decisions include:

- Begin scouting soybean fields at the V3 to V4 stage to determine if soybean aphids are present in fields. No treatment is recommended at this time and is discouraged so that insecticides do not reduce the presence of predators and parasitic wasps.
- The critical growth stages for making most soybean aphid treatment decisions are the late-vegetative to early reproductive stages (Vn to R3). Assessing aphid populations at these times is critical.
- **The economic threshold from R1 (first flower) through R5 (beginning seed) is an average of 250 aphids per plant and when populations are increasing actively in 80% of the field.** At R6 (full seed), no insecticide treatment is recommended. Research trials throughout the north central states have not demonstrated a yield benefit for soybean aphid management at the R6 and later maturing stages.

Soybean Aphid Resistance to Pyrethroid Insecticides

Soybean aphid with pyrethroid resistance was first documented in North Dakota in 2017. Reported failures of pyrethroid insecticides for control of soybean aphids were widespread and occurred primarily in the eastern counties of North Dakota. The source of our pyrethroid-resistant soybean aphids in North Dakota could be from migrating resistant soybean aphids that flew into North Dakota from neighboring states or from overwintering resistant soybean aphids. For pest management, growers should assume that most of our soybean aphid populations in eastern North Dakota are resistant to pyrethroids, and use other insecticide groups for aphid control.

To reduce development of insecticide resistance in soybean aphids, Extension entomologists recommend:

- Scout fields regularly and start in mid-June.
- Use the economic threshold to aid in decision-making, prevent unnecessary insecticide applications and conserve natural enemies.
- Rotate the mode of action (or insecticide class) if more than one application is necessary in a season.
- Do not use the same mode of action (or insecticide class) repeatedly year after year.
- Avoid using the lowest rate of insecticide on the label. Use high rates to prevent the development of insecticide resistance.
- Do not use premix insecticides containing two insecticides of the same or two different modes of action, because premixes have lower amounts of

active ingredient per insecticide could promote the development of insecticide resistance.

For more information, please consult the NDSU Extension publication "Management of Insecticide-resistant Soybean Aphids E1878" (*www.ndsu.edu/agriculture/ag-hub/publications/management-insecticide-resistant-soybean-aphids*).

Seedcorn Maggot [Diptera: Anthomyiidae: *Delia platura* (Meigen)]

Seedcorn maggots attack soybean seed, preventing sprouting or weakening the seedlings. The tiny, yellowish-white maggot is found burrowing in the seed, the emerging stem or the cotyledon leaves. Damage to the seedlings results in a condition called "snakeheads," or plants without cotyledon leaves.

Adult flies emerge in the spring when soil temperatures reach 50 F. They deposit eggs in soil with abundant organic matter and decaying crop residue, or on the seed or seedling. Injury from seedcorn maggots is usually most severe during wet, cold springs and in fields with high organic matter soils. When cool, wet conditions occur during planting, the slow germination and emergence of the seedling extends the period of time it is vulnerable to the maggot's feeding.

Threshold

When conditions are wet and cool, or when planting into high crop residue conditions, insecticide seed treatments provide the best defense against maggot injury.

Two-spotted Spider Mites (Acari: Tetranychidae: *Tetranychus urticae* Koch)

Adult spider mites are tiny (less than 0.2 inch) and greenish white to orange red, with two dorsal spots and four pairs of legs. Nymphs are smaller than adults and have three to four pairs of legs. Magnification is often necessary to see mites.

Host plants for spider mites include soybean, dry bean, alfalfa, corn, vegetables, ornamentals and trees. Mites overwinter as eggs on vegetation. The life cycle of spider mites can be completed in only five to 14 days, with the fastest development rates occurring above 91 F.

Each female lives for 30 days and produces about 300 eggs during her lifetime. In hot, dry weather, natural fungal diseases of mites are slowed and populations can increase from a few individuals to millions within a few generations. Mites thrive on the stressed plants that are nutrient-rich.

Leaf injury symptoms appear as stippling first and then progress to yellowing, browning or bronzing as feeding injury increases, and eventually leaf drop. Feeding injury causes water loss from the plant and reduces the photosynthetic ability of the plant. In severe cases, premature leaf senescence and pod shattering, and even plant death can occur.

When severe mite infestations occur during late vegetative and early reproductive growth, a 40 to 60% yield loss between treated and untreated soybean has been demonstrated in other Midwest states. Be sure to scout during full pod (R4) through beginning seed

(R5) stages because these crop stages are the most important contributors to soybean yield. Spider mites can cause yield reduction as long as green pods are present.

When scouting for spider mites, look on the underside of leaves and lower foliage at the field edges first for tiny mites and fine spiderlike webbing. A quick sampling procedure to determine whether mites are present is to hold a piece of white paper below leaves, then tap them to dislodge the mites. The mites appear as tiny dust specks; however, they will move slowly after being knocked off the leaf. Dislodged predatory mites will move faster than the two-spotted spider mite.

Another sampling measure involves pulling up plants and examining the underside of the leaves from the bottom of the plants upward. When spider mites need to move due to diminishing food supply, they climb to the top of plants and are dispersed by the wind through "ballooning," so they can spread quickly within a field or to adjacent fields.

Infestations typically are first noted near field edges and fields near alfalfa (a preferred host). Products labeled for mite control often do not give adequate control and the population of mites may rebound quickly to pretreatment levels or higher. When rain and humidity are present, natural infections of fungal pathogens can reduce mite populations.

Conditions that are good for the development of the pathogen are temperatures lower than 85 F, with at least 90% relative humidity for 12 to 24 hours. Mites usually become a problem when hot, dry weather occurs. When a production area has low rainfall, the region can become a “hot spot” for mite injury and a source of mites migrating to neighboring areas.

Threshold

Deciding whether to treat is difficult. No specific threshold has been developed for two-spotted spider mite in soybean. Sample plants at least 100 feet into the field. Walk in a “U” pattern and sample two plants per location at 20 different locations. Assess mite damage using the following scale from University of Minnesota Extension:

0 - No spider mites or injury observed

1 - Minor stippling on lower leaves; no premature yellowing observed

2 - Stippling common on lower leaves; small areas or scattered plants with yellowing

3 - Heavy stippling on lower leaves, with some stippling progressing into middle canopy; mites present in the middle canopy, with scattered colonies in upper canopy; lower-leaf yellowing common; small areas with lower leaf loss may occur **(spray threshold)**

4 - Lower leaf yellowing readily apparent; leaf drop common; stippling, webbing and mites common in the middle canopy; mites and minor stippling present in the upper canopy **(economic loss)**

5 - Lower leaf loss common; yellowing or browning moving up plant into the middle canopy; stippling and distortion of upper leaves common; mites present in high levels in the middle and lower canopy

If spider mites are above threshold when significant pod or seed fill remains, an organophosphate insecticide (Dimethoate) is recommended versus a pyrethroid insecticide. Pyrethroids (Asana, Baythroid, Mustang Max, Warrior) tend to flare (increase) mite populations seven to 10 days after application. Reasons for an increase in mite populations include: disruption of the natural enemies that control spider mites (predatory mites, thrips); increased movement of mites out of fields and increased reproductive rates of female mites. The only pyrethroid insecticide that will control spider mites is bifenthrin (Bifenture, Tundra, Brigade, other bifenthrin generics). Other insecticide/miticides registered for use in soybean include Agri-Mek SC (abamectin) and Zeal SC (etoxazole).

Early detection facilitates timely and effective rescue treatments. Current insecticides for soybean provide short-term protection, about seven days residue for mites and do not kill mite eggs. Fields will need to be re-monitored continually for resurging populations. If multiple applications are needed for spider mite control, be sure to rotate to a different mode of action with each subsequent application to prevent resistance.

The efficacy of an insecticide can be improved significantly with sufficient coverage (greater than 18 gallons per acre of water) and application at high pressure to penetrate foliage. Insecticides labeled for mite control have a 18-day (bifenthrin) to 28-day (abamectin) preharvest interval. Consequently, if infested fields still have green seeds but seeds are filling, accepting some yield loss from mites and not treating may be better than treating and being unable to harvest. Check product labels for current preharvest intervals and other use restrictions and plan accordingly.

IPM for Soybean Aphids and Spider Mites

When scouting soybean fields, consider all insect pests (soybean aphid and spider mites) that are present and their population levels. If the heat and drought stress continue, the risk for spider mites increases and the risk for soybean aphids is reduced (increased mortality and decreased reproductive rate due to hot temperatures greater than 90 F). If heavy rains occur, mite and aphid populations can both collapse.

Mite infestations often are concentrated early in field edges, and spot treatment can be feasible and more economical. However, under dry conditions, mites will quickly spread throughout the field, and spot treatments are not effective in controlling mites and unlikely to prevent the infestation from spreading. Early detection facilitates timely and effective rescue treatments.

■ Wireworms (Coleoptera: Elateridae)

Wireworms are most likely to be problems when soybean follows pasture, CRP or grassland. Infestations often are found in coarse-textured soils (sandy loam) where moisture is abundant, perhaps in low spots of fields.

Thresholds

Estimating wireworm infestations is difficult and labor intensive. Two methods are used by pest managers:

- **Soil Sampling:** Sample 20, well-spaced, 1-square-foot sites to a depth of 4 to 6 inches for every 40 acres being planted. If an average of **one wireworm per square foot** is found, insecticide treatment would be justified.

- **Solar Bait Trap:** In September, establish bait trap stations for two to three weeks before freeze-up. Place bait stations randomly through the field, but represent all areas of the field. You should have 10 to 12 stations per 40-acre field. Place 1 cup of wheat and 1 cup of shelled corn in a 4- to 6-inch-deep hole. Cover grain with soil and then an 18-inch-square piece of clear plastic. Dig up the grain after two weeks in the field. If an average of **one or more wireworm larvae is found per station**, treatment would be justified.

Seed Treatment: Insecticide seed treatments or at-plant soil insecticides should be applied for managing wireworms in soybean.

■ Soybean gall midge (Diptera:Cecidomyiidae: *Resseliella maxima* Gagné)

Two gall midge flies are associated with soybean: the soybean gall midge, *Resseliella maxima* Gagné, and the white-mold gall midge, *Karshomyia caulicola* (Coquillett). The soybean gall midge is a new economic insect pest of soybean, which first was reported causing yield losses in Nebraska, Iowa and South Dakota in 2018. In 2022, the first infestation of soybean gall midge in North Dakota was possibly detected in Sargent County. However, DNA confirmation of the collected midge larvae are still pending. In contrast, the white mold gall midge in a non-pest and larvae only feed on the white mold of soybean. For more information, see the NDSU Extension publication E2006, “Soybean Gall Midge and White-mold Gall Midge in Soybean.”

Consult the **IPM Crop Survey** website for yearly soybean insect pest maps: *www.ndsu.edu/agriculture/ag-hub/ag-topics/crop-production/diseases-insects-and-weeds/integrated-pest-management/soybeans-ipm*

Identification

Gall midges are in the fly family Cecidomyiidae and are similar in appearance, and requires close microscopic examination of the terminal abdominal segments of larvae or DNA testing to confirm its species identification.

Soybean gall midge – Young larvae (first and second instars) are white and smaller, whereas the mature third instar larvae are orange to reddish orange and about 1/12 inch in length. Larvae of soybean gall midge feed on plant liquids by excreting enzymes that digest the plant tissues, sometimes causing galls.

Adults are light to dark brown, small, about 1/8 inch in body length, and mosquito-like flies with an orange abdomen. Their characteristic markings are the white and black banding on the antennae and legs, and mottled wings.

Life Cycle – Soybean gall midge likely has two generations per year in northern states. The larva overwinters inside of a larval cocoon in the soil. Larvae pupate during the spring. The first generation of soybean gall midge adults emerge from mid-June through early July in Minnesota. Adults only live three to five days, and do not feed on soybeans. Females lay their eggs in crevices or cracks on the soybean stem. Once eggs hatch, larvae begin feeding under the epidermis of the soybean stem and pass through three instars.

Numerous larvae sometimes can be found in one soybean stem. Larvae drop off the plant to the soil to form larval cocoons and then pupate. The cycle repeats for the second generation until the fall, when larvae will overwinter as cocoons in the soil.

Crop Damage – Soybean gall midge feeds beneath the epidermis near the base of the stem of soybeans. Sometimes the base of the stem is necrotic (dark), swollen, deformed and gall-like. Soybean stems heavily infested by soybean gall midge are stunted, wilted, lodged or dead. Significant yield losses have been recorded in states with severe infestations and are most common at the field edges. Although current research shows soybean is the preferred host of soybean gall midge, additional hosts are dry bean, lima bean, clover and rarely alfalfa.

Scouting – Adults are not readily observable in the field due to their cryptic appearance, small size and short life span. Larval-infested stems are easier to find near the field edges of soybean fields or in newly planted soybean fields that are close to last year's infested fields, and during the R2 (full bloom) to R8 (maturity) growth stages of soybean.

Scout by walking a transect in the first four rows near the field edge, and focus in areas where dense vegetation occurs along the field edge. Examine 10 consecutive plants at 10 sampling sites per field (total of 100 plants per field). Sampling sites should be spaced more than 50 feet apart.

At each sampling site, examine plants for the presence of necrosis and brown or dark discoloration at the base and lower portion of each stem. If necrosis is observed, pull up the soybean plant and peel back the outermost layer of the stem (epidermis) on the necrotic area to look for small white or orange larvae.

Growers are encouraged to scout for soybean gall midge. Additional scouting will help further detect this economic insect pest of soybean and determine its infestation levels in North Dakota.

What to Do if You Find Suspect Soybean Gall Midge in North Dakota

If you happen to find white or orange larvae in the stems of soybean plants, you need to confirm whether it is the soybean gall midge or white-mold gall midge. Collect more than 10 larvae and place them in alcohol vials, or collect two to three plants with larvae and place them in a plastic bag. Notify and send collected samples to the Extension agent in your county or to NDSU Extension Entomology for further identification.

Integrated Pest Management (IPM) of Soybean Gall Midge

Because the soybean gall midge is a newly discovered insect pest, entomologists have been studying different IPM strategies. Studies on planting dates, host plant resistance, crop rotation, tillage and insecticide control for this pest are being conducted in states with economic populations. For more information, see the websites on soybean gall midge that summarizes the IPM research:

- Soybean Gall Midge, Soybean Research and Information Network
  https://soybeanresearchinfo.com/soybean-pest/soybean-gall-midge/

- Midwest Soybean Gall Midge Discussion Series, University of Minnesota Extension
  https://extension.umn.edu/courses-and-events/midwest-soybean-gall-midge-discussion-series
- Soybean Gall Midge Alert Network, University of Nebraska Extension
  https://soybeangallmidge.org/

Disease Management and Identification

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Many diseases of soybean in the North Dakota may affect yield and quality of the crop. Accurate identification of the problem is the first step in managing these diseases. Once identified, specific management techniques to address the problem may benefit soybean growers.

The information in this chapter is designed to aid in identification, prevention and management of soybean diseases. Pictures can be found in the picture section of this publication. Below are general recommendations for managing soybean diseases.

- **Use high-quality seed.** Certified seed will minimize the introduction of soybean pathogens. Avoid using seed produced on fields with diseases that can be seed-borne.
- **Use crop rotation.** Soybean diseases, especially root and stem diseases and soybean cyst nematodes, often increase when soybean crops are grown in close rotations. Lengthening rotations to three or four years between soybean crops allows natural processes to reduce pathogen populations. Some

crops, especially other broadleaf crops, may be infected by some pathogens that attack soybean. Have diseases accurately identified so sound decisions can be made on the use of rotation crops.

- **Scout fields for disease.** Record the incidence of disease; such information can be used to make good decisions on management practices.
- **Strengthen the soybean plant.** Use good management practices to promote the growth of soybean plants. Provide adequate soil fertility, avoid soil compaction, enhance drainage, control weeds and insects, and avoid herbicide damage.

For more information:

- **"Soybean Disease Diagnostic Series":** Pocket guide designed specifically to help growers identify soybean diseases, NDSU Extension publication PP1867.
- **North Dakota Pest Management App:** Multi-function app containing information on labeled pesticides (updated annually), diagnostic images and interactive tools for many crops grown in our region, available for Android and Apple devices.
- **"North Dakota Field Crop Plant Disease Management Guide":** Booklet containing information on all labeled pesticides (updated annually) for crops grown in our state. NDSU Extension publication PP622.
- **The SCN Coalition:** Resource center for soybean cyst nematode management, including videos, downloadable materials, state-specific information, available at *www.thescncoalition.com*.

- **Soybean Research and Information Network:** Resource center for soybean disease information in the north-central U.S., maintained by the checkoff-funded North Central Soybean Research Program, available at *www.soybeanresearchinfo.com*
- **Crop Protection Network:** Resource center containing information on many diseases of several crops developed by university plant pathologists across the U.S. and Canada, available at *https://cropprotectionnetwork.org/*

Below Ground

In general, the most significant diseases in our region, such as root rots and the soybean cyst nematode, are found underground.

■ Soybean Cyst Nematode

The soybean cyst nematode (SCN), *Heterodera glycines*, is the most important pathogen of soybean in the U.S. This nematode is a microscopic roundworm that infects soybean roots. Extensive losses occur throughout infested areas. Losses greater than 50% have been measured in infested fields in North Dakota.

Nematodes, like other soilborne pathogens, easily spread from field to field by equipment contaminated with infested soil, wind-blown soil, overland flooding or birds carrying it. In addition, SCN can be carried in soil "peds," small clumps of soil sometimes found associated with soybean seed.

In 2003, SCN was confirmed in North Dakota (Richland County). SCN has been confirmed in many North Dakota and northern Minnesota counties and is expected to continue to spread.

Symptoms

Infection by SCN often will not result in obvious above-ground symptoms unless plants are stressed or the nematode densities are high. Above-ground symptoms include stunting and yellowing or unthrifty plants. The roots can appear dark and decayed, and they have few, if any, N_2-fixing nodules.

A diagnostic characteristic is the presence of white to yellowish lemon shaped female nematode cysts (about 1 millimeter in diameter) on the roots. These can be observed if the plant is removed from the soil carefully with a shovel and the soil is gently washed or shaken off the roots.

The severity of the symptoms is directly related to the amount of SCN in the soil. Warm, dry growing seasons tend to increase severity of the above-ground symptoms, while cool, wet years tend to decrease severity. Losses from SCN are usually much greater during droughts. Severity also tends to be higher in sandy soils than heavy-textured soils, and in soils with a higher pH.

Management

Effective management of SCN is accomplished by actively managing SCN using multiple management tools.

Maintain Fields Free of SCN

In fields where SCN has not yet been confirmed, reducing the likelihood of introduction is critical. In areas where SCN has been confirmed, limiting its spread to new areas in the field or neighboring fields can reduce the chance of widespread yield loss in the future.

Reduce the likelihood of spread to new fields by cleaning any equipment that was used in an infested area. Reduce the potential spread of SCN from infested fields to adjacent clean fields through reduced-tillage operations and practices that limit wind erosion and movement of soil.

Identify SCN
Management begins by confirming the presence of *H. glycines* in the field. Visual confirmation of SCN white females (lemon-shaped cysts) on soybean roots in the mid- to late growing season can serve as confirmation of SCN. However, these are hard to identify without experience.

Take the Test – Beat the Best
The most effective method to identify SCN in fields is to soil-sample and test your fields for SCN. Soil sampling should concentrate on the top 6 to 8 inches of the soil and close to plant roots.

The most effective sampling strategy varies by situation. In fields where SCN has not been confirmed, sampling should concentrate on areas of the field where the nematode may have been introduced, such as field entrances, shelter belts and previously flooded areas. In fields where SCN sampling is being done to monitor egg levels, gridded sampling may be most effective. Sampling can be done in the fall or spring.

Growers can sample the soils in their fields and send the samples to public (for example, the NDSU diagnostic laboratory in Fargo, ND) or private laboratories where egg counts can be determined. Soil test results are used to determine if a field is infested, if an extended rotation is necessary or if a resistant variety should be used.

If SCN is confirmed, active management should begin. SCN reproduces quickly and to very high egg levels in this northern soybean-growing area; thus, once a field is infested, growing susceptible varieties may increase egg levels very quickly. Thus, management should begin immediately.

Crop Rotation
Crop rotation is an effective method to reduce egg densities in soil. Rotation to nonhost crops for one year commonly reduces populations, but two or three will increase the effectiveness of rotation. Many factors affect the reduction in egg densities, and the results in each field will vary. Data from North Dakota indicates that in heavily infested fields following rotations to nonhost crops for four to five years, egg densities in some fields were still high.

Nonhost crops include corn, sugarbeet, alfalfa, potato, small grains and sunflower. Dry edible bean, certain lupines and crambe are hosts of SCN. Consult a list of susceptible crops before growing specialty crops or cover crops in SCN-infested fields. Weed control is important because SCN will reproduce on a wide range of weeds.

Resistant Varieties
Resistant soybean varieties are an effective tool to manage SCN. Most varieties have the same source of genetic resistance (PI88788). Effectiveness of PI88788

in varieties will vary, with some varieties being more resistant than others.

For severe infestations of SCN, selecting a variety with robust resistance, if known, is important. Long-term rotation strategies that also include soybean varieties with an additional source of resistance (such as Peking resistance) are likely to be most effective and help slow nematode adaptation to the genetic resistance.

Seed Treatments
Seed treatments may provide another tool to help manage SCN, but do not take the place of genetic resistance or crop rotation. Nematicide seed treatments for SCN became widely available in the late 2010s, and new products continue to be labeled. At the time of this printing, more than a half-dozen nematicide seed treatments are available. They range from biologicals to resistance inducers, fungicides and nematicides. Consequently, effectiveness among them likely varies and may be influenced by many in-field factors. Consult the most up-to-date efficacy information when considering a seed treatment for SCN.

■ Phytophthora Root Rot

Phytophthora root rot is a major disease of soybean, especially in areas where soybean has been cultivated for many years. The disease is caused by the fungal-like pathogen *Phytophthora sojae*. Yield losses can be substantial, and entire fields have been destroyed by the disease.

The disease is common in the Red River Valley. The pathogen survives in soil as spores called oospores, which are produced in infected plants. When the soil water content is high, the spores germinate and infect the roots. Infection and disease development can occur at any stage of plant development.

Disease is most common in heavy, compacted clay soils and fields that have been saturated with water or flooded. Drenching rains, especially near the time of planting, favor disease development. Reduced tillage, especially no till, is reported to increase damage.

The pathogen does not infect other crops grown in this region. Only three *Lupinis* spp. and soybean are natural hosts. Many pathotypes (similar to races) of *P. sojae* overcome many resistance genes, and as more acreage is cropped to soybean and more resistance genes are deployed, we expect that the pathotype frequency will change.

Symptoms
Symptoms include seed rot and pre and postemergence damping off and wilting of young plants. These are common in flooded soils and often are misidentified as water damage. On older plants, leaves may become yellow and plants will wilt, with wilted leaves remaining on the plant. The lateral and tap roots are destroyed. A brown discoloration often appears on the lower portion of the stem near the soil. Disease is usually patchy in the field, often occurring in low or flooded areas.

Management
Planting resistant varieties is an important method to manage Phytophthora root rot. However, no available resistance gene can manage all the pathotypes (races) of *Phytophthora* found in our region. We recommend that growers choose a resistance gene and then monitor

the field for Phytophthora root rot. If the disease is significant in the field, select a variety with a different resistance gene the next time the field is planted. Many varieties also have tolerance and partial resistance to Phytophthora root rot. This type of resistance can be effective against all pathotypes. These varieties may not lose yield under low to moderate disease pressure but can be damaged severely under high disease pressure.

Crop rotation is not generally an effective method to reduce disease because the oospores are long-lived in soil. Reducing saturated soil conditions – for instance utilizing subsurface (tile) drainage – is a method to reduce Phytophthora root rot in the field.

Fungicide seed treatments will help protect plants from infection for the first few weeks after planting. Metalaxyl and mefenoxam have efficacy against Phytophthora and have been used for many years in our region. Recently, additional efficacious fungicide seed treatments, such as ethaboxam and oxathiapiprolin, have become available. Ethaboxam and oxathiapiprolin have different modes of action than metalaxyl and mefenoxam. Rotation of chemical products with different modes of action will help prevent the development of fungicide resistance.

Rhizoctonia Damping-off and Root Rot

The fungus *Rhizoctonia solani* causes pre and postemergence damping-off and root rot of young and adult plants. When soil populations of *Rhizoctonia* are high and soil is warm and moist for the first month after planting, pre- and postemergence damping-off can reduce stands by 50% or greater. Generally, *Rhizoctonia* causes most damage in the seedling and early vegetative stages of plant growth, but damage has also been observed on older plants. The pathogen survives in the soil and is common in this region.

Symptoms

Seed decay and brown to reddish lesions on seedling stems and roots just below the soil line are symptoms. These lesions may girdle stems and kill the plant. On older plants, the pathogen causes a reddish-brown cortical root rot, which may extend into the base of the stem. Plants may appear unthrifty or may die. Root rot can greatly reduce nodulation.

Damage from *Rhizoctonia solani* commonly is observed in areas with a long history of soybean production with close rotations or during weather conditions not favorable for seed germination and rapid growth of seedlings. Various anastomosis groups (AG) of *R. solani* exist, some of which are semi-host specific. AG 2-2, AG-4 and AG-5 are most common on soybean, but AG-3 occasionally is found. AG 2-2 can be highly pathogenic on soybeans, especially at high temperatures. AG-4 and AG 2-2 are also common on sugarbeet. AG-3, generally found on potato, is weakly pathogenic on soybean.

Crop rotation practices may impact the amount of *R. solani* in the field, and therefore, affect the severity of the disease. Disease severity appears greater in plants showing iron deficiency chlorosis.

Management

Crop rotation to non-susceptible hosts such as small grain will reduce populations of *Rhizoctonia* in the soil. Avoid close rotations with sugarbeet if you have evidence of *Rhizoctonia* in the field. Close rotations with dry bean also may increase incidence of disease.

Some seed treatments and good seedbed preparation can reduce damping-off. Cultivating soil to hill up around stems promotes lateral root growth and may lessen the effect of root rot on older plants.

Fusarium Root Rot

Fusarium root rot caused by a complex of *Fusarium* species can cause damping-off of seedlings and root rot on older plants. Infected seedlings can result in poor stands, late emergence or stunted plants.

Fusarium root rot often has been observed in association with stressed plants, such as in drought conditions or with herbicide damage. However, high populations of the pathogen in the soil may result in disease development under good growing conditions.

The pathogen may interact with other pathogens such as *Rhizoctonia* or the soybean cyst nematode to cause disease. Disease severity may be greater in plants showing iron deficiency chlorosis.

Symptoms

Infected seedling roots will show reddish or dark brown discoloration and decay. The disease at this stage may be misdiagnosed as Rhizoctonia root rot because symptoms are similar. Symptoms on older plants consist of reddish-brown lesions on roots. In advanced stages of the disease, the cortex decays, the roots are black and fissures develop in the dead surface tissues of the tap root, and the tap root may be rotted. Few nitrogen-fixing nodules may be on the roots.

Plants may appear stunted or unthrifty, and the leaves may be yellowing while the veins remain green for a short time. The leaves eventually become completely yellow, then die from the edges inward and fall from the petioles.

Management
Use high-quality seed, plant in warm, well-drained soils, reduce soil compaction and provide good fertility. Crop rotation can lower populations of the pathogen in the soil. Fungicide seed treatments may reduce damping-off by *Fusarium*. Most varieties appear to be susceptible to Fusarium root rot.

Damage to seedlings often occurs during weather conditions not conducive to rapid seed germination and plant emergence. Ridging soil around the base of the plants can promote root growth and reduce damage to root rot in older plants.

Sudden Death Syndrome

Sudden death syndrome (SDS), caused by the fungal pathogen, *Fusarium virguliforme*, is a severe disease of soybean that is expanding in North Dakota. At the time of printing, the disease has only been confirmed in Richland and Cavalier Counties in ND, but likely occurs in other areas. Yield losses from SDS can be severe when symptoms develop during early flowering.

Symptoms
The disease usually first appears in patches in fields, which expand in subsequent years. SDS symptoms are generally first noticed on the leaves at or just after pod-fill stages begin. Initial symptoms appear as scattered

circular to irregular-shaped interveinal yellow spots that produce a mottled appearance to the leaves. The yellow tissue then dies and turns brown. The upper leaves are the first to defoliate, leaving petioles. Complete defoliation can occur when the disease is severe. Flower and pod abortion can occur. Plants showing severe leaf symptoms commonly have decay of roots and plants can easily be pulled from the ground. In favorable environments, a bluish fungal growth may be observed on surface of roots.

Notably, foliar symptoms of SDS are very similar to those caused by brown stem rot, and careful examination of the stem symptoms is needed to differentiate the two diseases. We recommend cutting the lower stem longitudinally to help differentiate SDS from brown stem rot. Commonly, SDS will have a healthy (white) pith, whereas the pith will turn brown in plants suffering from brown stem rot.

Disease development is associated with wet conditions early in the growth of soybean plants, and warm temperatures and heavy rainfalls during and after flowering. Severity of the diseases is often linked to the presence of soybean cyst nematode.

Management

Selection of a soybean variety with reduced susceptibility to SDS may be prudent, if available. A few fungicide seed treatments are available and can be an effective tool for reducing yield loss to SDS. Consult the latest efficacy information when considering a fungicide seed treatment. If SCN is present in fields with SDS, management of the nematode may help reduce SDS severity.

Dry edible bean is a host of the SDS pathogen; infected dry edible bean plants express only the root rot symptoms, and do not express the classic foliar SDS symptoms.

Because SDS is favored by high water content in the soil, practices that encourage drainage (including subsurface drainage) will help minimize disease development. Reducing soil compaction can reduce severity of SDS.

Above-ground Diseases

White Mold (Sclerotinia stem rot)

White mold of soybean is a common disease caused by the fungus *Sclerotinia sclerotiorum*. It can cause significant yield reductions, particularly when soybean is planted in infested soil, the plant canopy is dense and prolonged periods of cool and wet weather occur. The disease rarely is severe when hot and dry periods persist in July and August.

Sclerotinia overwinters as sclerotia in soil and can survive for many years. When sclerotia are near the soil surface, they can germinate to form small mushrooms called apothecia. Airborne ascospores are released from the apothecia, and the infection process begins when ascospores begin to digest/infect flower tissue. This commonly occurs after the plant canopy has closed, which creates a favorable microclimate of cooler and wetter plants. Once the infection is established, the pathogen easily spreads into healthy green tissue.

Symptoms
Symptoms are commonly first observed as a cottony, white mycelial (fungus threads) growth on stems, leaves or pods. Lesions develop on main stems and lateral branches, and eventually may appear bleached and sometimes shredded from advanced decay. Sclerotia, which resemble the size and color of rat/mouse fecal matter, form in and on diseased tissue. Seeds in diseased pods may be shriveled and infected by the fungus or replaced by sclerotia. When a field with white mold is harvested, the seed is usually contaminated with sclerotia.

The pathogen has an extensive host range of more than 370 plant species and causes diseases on many crops such as sunflower, dry bean, canola, alfalfa, buckwheat, lupine, mustard, potato, Jerusalem artichoke, safflower, lentil, flax, field pea and many vegetables. Many common broadleaf weeds such as marsh elder, lambsquarters, pigweed, Canada thistle and wild mustard also are hosts.

Management
Many management tools are available for white mold control, including crop rotation, planting less susceptible varieties, avoiding planting on soils heavily infested with *Sclerotinia*, reducing the planting rate, wider row spacing and timely fungicide application. However, when the environment highly favors white mold development (cool temperatures and frequent, prolonged rains) the disease still may cause problems even if multiple tools are used.

Soybean fields should be monitored for disease incidence. Check the seed hopper at harvest for the presence of sclerotia. As the disease begins to increase in a field, the rotation time to non-susceptible crops such as small grains and corn should be increased.

Crop rotation will reduce populations of sclerotia in soil but will not eliminate the pathogen. Careful consideration should be given to avoid rotating with crops that are particularly sensitive, such as sunflower, dry edible bean and canola.

Although common soybean varieties adapted for this region are susceptible to white mold, some varieties are less susceptible than others. For example, short-maturity varieties typically are less impacted by white mold. Information on variety susceptibility may be available from seed companies.

Do not use seed from a white mold-infected crop. Seed quality could be low, and sclerotia may be introduced into the field along with the seed. Also, maintain good control of broadleaf weeds because they can be hosts of Sclerotinia and can make the microclimate more favorable for white mold. When growing a susceptible crop under irrigation, avoid practices that favor a dense canopy and free water on the plant during flowering because these will create ideal conditions for disease development.

Many fungicides are labeled for management of white mold on soybean. In favorable environments, fungicides may reduce disease. Efficacy varies, so consulting fungicide efficacy data before selecting a fungicide is important.

Optimization of the fungicide application will greatly impact efficacy, and several factors should be considered, including timing and droplet size. The pathogen needs senescing flowers to begin the infection process and lesion development takes time, so applications prior to R1 or after R3 often miss the critical window when plants are most sensitive to economically important infections. Environment has a strong influence on infection and disease development, with cool temperatures and frequent rainfall during bloom, and saturated soil conditions prior to bloom, being most favorable. Microclimate also strongly influences infection, and canopy closure and factors that influence it are very important in determining the risk of infection and optimal application timing. Droplet size is a very important consideration for optimal application, and research shows that droplets maximizing fungicide coverage vary according to canopy closure; with smaller droplets being most effective prior to canopy closure and larger droplets being more effective at canopy closure.

Septoria Brown Spot

Septoria brown spot, caused by *Septoria glycines*, is a common leaf disease that may develop throughout the season. How frequently economic loss occurs in North Dakota and Minnesota is unclear, but in most of the Midwest, little evidence is available to suggest that Septoria brown spot causes much yield loss, except under the most extreme circumstances.

Symptoms

The disease first appears as pinpoint brown spots on the leaves on the lower leaves of the plants. These spots may remain small or enlarge up to 3/16 inch, becoming irregular and angular and reddish brown to dark brown with age.

Severely diseased leaves turn yellow and fall off, with defoliation beginning lower on the stem and progressing up the plant. Brown, irregularly shaped spots may develop on the stems, petioles and pods.

Septoria brown spot development is favored by warm, humid weather. Hot, dry conditions will arrest disease development, but it may resume if conditions become wet. Rainy weather is especially favorable because *Septoria* spreads by splash-dispersed spores. Disease development also is favored in areas with poor drainage. The brown spot fungus survives on soybean crop residue and may be seed-borne.

Management

Active management of this disease in most years is unnecessary, and management techniques utilized for other diseases (for example, crop rotation) likely are sufficient. Fungicides are available, but disease pressure warranting their use in our area is unlikely.

Additionally, bacterial blight is more common in some areas than brown spot (especially in the early part of the season) and the symptoms of both pathogens can be confused. Correct identification of the pathogen is essential.

Bacterial Blight

Bacterial blight is a common foliar disease in North Dakota, but it is unlikely to cause significant yield loss. Bacterial blight (caused by *Pseudomonas syringae* pv. *glycinea*) favors cool, humid weather.

The bacteria blight pathogen can be seed-borne and can survive on soybean crop residue. Bacteria readily enter wounds in the leaf, and rapid spread may occur following late-spring or early summer rain storms, hail or cultivation when the plants are wet.

Symptoms
The disease typically begins in the upper half of the plant as small, greasy green, angular, water soaked spots that later turn yellow and reddish brown. The spots are surrounded by a narrow yellow border. As the spots coalesce, portions of the leaf tissue fall out, and the leaves become torn and ragged.

Infected young leaves may be distorted and stunted. Severely diseased leaves may drop off. Occasionally, large black spots may develop on stems, petioles and pods. Seeds in infected pods may become slimy. Hot, dry weather will slow or stop the development of bacterial blight.

Management
Do not use seed from a diseased field. Use crop rotation. Do not cultivate when the plants are wet. Some varieties are less susceptible. Because bacterial blight is caused by a *bacterial* pathogen, fungicides are not useful for control.

Downy Mildew

Downy mildew, caused by *Peronospora manshurica*, develops primarily in years with extended periods of cool, humid weather. Yield loss rarely has been reported, but localized outbreaks in northern North

Dakota counties were thought to have reduced yield by up to 5% to 10% in some fields in the 2020s.

Symptoms

Symptoms include yellow-green to yellow spots on the upper leaf surface and a purplish or grayish downy fungal growth on the lower leaf surface, opposite the yellow-green patches on the upper leaf surface. The yellow spots turn brown later in the season.

Pod infection may result in seeds that are dull white, cracked or covered with a white crust of overwintering oospores. If these white or encrusted seeds are planted, a small percentage of the emerging seedlings may be infected systemically with the downy mildew fungus, resulting in stunted plants. Leaves of systemically infected plants will have areas of green-yellow tissues along the main veins and the leaf edges will be curled downward.

Management

Use crop rotation. Use a seed treatment if planting seed from an infected field or seed that has a white crust on it. Few fungicides are labeled for downy mildew and little efficacy data exists.

Frogeye Leaf Spot

Frogeye leaf spot, caused by the fungal pathogen *Cercospora sojina*, was first identified in North Dakota in 2020. The implications for yield loss in North Dakota are unclear, but the disease causes significant yield loss in the central corn/soybean belt and mid-southern states.

Symptoms
Frogeye leaf spot is commonly observed on leaves as small, dark water-soaked spots that develop into small circular to irregular lesions (approximately 1/4 inch or less). Lesions will develop a narrow purple-red ring surrounding a tan to gray center. During high humidity, a fuzzy gray mold (mycelium) may be visible in the centers of the lesions on the underside of the leaf.

Management
Crop rotation, tillage that encourages residue decomposition, genetic resistance if available, and disease-free seed may all contribute to disease prevention or management. Foliar fungicides are commonly used in states where frogeye leaf spot is yield limiting. However, the pathogen is prone to develop resistance to fungicides, making rotation (or mixtures) of fungicide mode of action imperative. In 2020, 23% (of over 300) of the pathogen isolates collected throughout 12 southeastern North Dakota counties, were resistant to FRAC 11 (i.e., QoI or strobilurin) fungicides. Should fungicides be needed, multiple modes of action should be used.

Pod and Stem Blight

This disease, caused by *Diaporthe sojae* and *D. longicolla*, is common in southern and central Minnesota but thought to be somewhat less so in North Dakota and northwestern Minnesota.

Symptoms
Symptoms include rows of raised black fruiting bodies that develop on the stem, and a random pattern of

raised fruiting bodies that develop on the pods. Infected stems often are killed. Infected seeds are shriveled and cracked and may be covered with white fungal growth.

The pod and stem blight fungus survives on infected soybean crop refuse and can be seed-borne. It favors wet weather and crop injury as the crop nears maturity. If infected seeds are planted, plants may die on emergence.

Management
Use crop rotation. Plant high-quality seed that is nearly free of the pod and stem blight pathogen or use a seed treatment. Harvest promptly at maturity. Maintain adequate K levels in the soil.

■ Stem Canker

Stem canker is relatively common in southern Minnesota, but how frequently it occurs in North Dakota is unclear. Stem canker is caused by two different pathogens, *Diaporthe caulivora* and *D. aspalathi*. Between the two pathogens, only *D. caulivora* has been reported in North Dakota at the time of printing.

Symptoms
Early symptoms of stem canker are reddish-brown lesions that appear at the base of the leaf petiole or branches. Lesions may develop into sunken dark brown cankers with small black raised structures on the surface (perithecia). Plant parts above the lesion may die. Stem canker favors wet weather, and symptoms may be most likely observed beginning in mid-July following wet springs.

Management
Resistant varieties (if available) and crop rotation may be useful to mitigate stem canker where it has been a problem.

■ Brown Stem Rot

Brown stem rot (BSR) occurs in North Dakota is capable of causing yield loss in our region. BSR is more likely to be severe in the presence of SCN. Infection occurs through the roots and develops slowly until pods are filling.

Symptoms
Symptoms usually do not appear until late in the season. The most obvious symptoms develop inside the lower stem. When the stem is split open with a knife, the pith (central tissues) is brown. The internal browning may extend several inches above the soil or over most of the stem.

Leaf symptoms, which develop sporadically, consist of a yellowing followed by browning of tissues between the main veins. The veins remain green. The foliar symptoms (when they occur) are similar to those caused by sudden death syndrome.

The best time to assess for brown stem rot is the R5 to R6 stage, when seeds are beginning to develop in pods at the four uppermost nodes. Any time that a field suddenly turns brown late in the season, rather than yellow green, the lower stems should be split and examined for brown stem rot.

The brown stem rot fungus survives several years in soybean crop residue. The disease develops during cool or moderate temperatures. The greatest damage occurs when cool and wet weather occurs during the early reproductive stage and is followed by hot and dry weather.

Management
Resistant varieties may be available. Use crop rotation, planting nonhost crops for three years. Manage SCN. Small grain and corn are not hosts.

Charcoal Rot

Charcoal rot occurs in North Dakota and northwestern Minnesota. Charcoal rot is caused by the fungal pathogen *Macrophomina phaseolina*. The pathogen has a very large host range, which includes corn, dry edible bean and sunflower.

Yield losses are most likely when plants are under water stress midway to late in the season. Hence, drought, high temperatures and sandy soils favor charcoal rot.

In 2017 and 2018, severe outbreaks of charcoal rot occurred in localized areas of eastern North Dakota. Yield losses to the most severely infected fields in 2018 likely exceeded 50%. Yield losses to charcoal rot in North Dakota can occur, particularly in warm and dry growing seasons.

Symptoms
Charcoal rot often is observed first as a general loss of vigor in small, drought-prone, areas in a soybean field. Plants in those areas may begin yellowing and appear

to be maturing up to three or four weeks ahead of green areas in the field. Plants surrounding those areas begin pre-maturely senesce soon after, giving the misleading appearance of the disease “spreading.”

Symptoms include a light gray to silver discoloration at the base of the stem. If the epidermis is scraped off at the base of the stem, charcoal-colored microsclerotia are visible. Microsclerotia are very small, and may appear as tiny black specs or as if the stem were covered in charcoal dust. The pathogen survives as microsclerotia.

Management
Crop rotation and planting nonhost crops are important management tools. If irrigating, keep soil water content reasonably high at the end of the season.

■ Virus Diseases

Virus diseases occur but have not been a serious problem in North Dakota.

The two most common viruses that have been found in North Dakota are soybean mosaic virus (SMV) and bean pod mottle virus (BPMV). Numerous other viruses are known in soybean. The identification and confirmation of a virus disease requires special techniques. Identifying a virus based on symptoms is very difficult.

Virus symptoms vary greatly but may consist of stunting, fewer pods, leaf mosaic (light and dark green areas), puckering, blistering, distortion, chlorosis or necrosis. Plants can be infected without showing symptoms. Seed mottling can occur, which is detrimental to the quality of food beans.

The severity of disease and the effect on yield is greatly affected by the plant stage at infection, the environmental conditions and the susceptibility of the variety. Yield losses can be substantial under heavy disease pressure. Seed can transmit SMV and the virus is vectored by aphids (*Aphis glycines*). The vector of BPMV is the bean leaf beetle (*Cerotoma trifurcata*).

Hail Damage

Hans Kandel and **Greg Endres**, Extension Agronomists

Research has been conducted to accurately predict the effects of hail damage on soybean yield. Results from these studies are used by hail insurance companies to assess yield losses and consequent adjustment payment made to clients.

Yield loss predictions are based on two factors: a) the growth stage at the time of damage and b) the degree of plant damage. Plant damage is classified as leaf defoliation, stand reduction, stem damage and pod damage.

Stand reduction is a measure of the number of plants killed as a result of the hail event. The pre-storm plant population is compared with the remaining stand seven to 10 days after the storm to determine the yield loss due to stand reduction.

To determine the pre-storm population, count the original number of plants (live plants and remnants of plants) in 10 feet of row. Repeat this step several times throughout the field to get a representative sample. Now convert the average stand per 10 feet of row to plants per acre, using the following formula:

$$\frac{\textbf{(Average number of plants in 10 foot row)}}{\textbf{(Row spacing in inches)}} \times \textbf{52,250} = \textbf{number of plants per acre}$$

Using the same procedure, determine the remaining live plant population.

(Stand before the storm – Stand after the storm) = Stand loss in plants.

$$\frac{\text{(Stand loss in plants)}}{\text{(Stand before the storm/100)}} = \text{percent stand loss.}$$

Percent yield loss of soybean as affected by the amount of stand reduction (all stand counts x 1,000 plants/acre) between VC and R1.

Original stand (x 1,000)	Remaining stand (x 1,000)												
	130	120	110	100	90	80	70	60	50	40	30	20	10
	% yield loss[1]												
180[a]	2	2	3	5	6	9	12	16	22	30	40	55	74
170[a]	1	2	3	4	6	9	12	16	22	30	40	55	74
160[b]	1	2	3	4	6	8	12	16	22	30	40	55	74
150	1	2	3	4	6	8	11	16	22	29	40	54	74
140	1	1	2	4	5	8	11	15	21	29	40	54	74
130	0	1	2	3	5	7	10	15	21	29	40	54	74
120	–	0	1	2	4	7	10	14	20	28	39	54	73
110	–	–	0	1	3	6	9	13	19	28	38	53	73
100	–	–	–	0	2	4	8	12	18	27	38	53	73
90	–	–	–	–	0	3	6	11	17	25	36	52	72
80	–	–	–	–	–	0	4	8	15	23	35	50	72
70	–	–	–	–	–	–	0	5	11	20	32	49	71

Source: Soybean loss adjustment standards handbook, Federal Crop Insurance Corporation, 2021.

[1]Yield loss also will depend on the growth stage of the crop.

[a] if remaining stand is 150 or 140,000, loss is 1%.

[b] if remaining stand 140,000, loss is 1%.

Defoliation is measured as a percentage of the leaf area destroyed. Leaf tissue that is green and still attached to the plant will continue to produce photosynthate and is *not* considered destroyed leaf area. Research has shown that leaf loss during vegetative stages has little effect on yield. Defoliation loss is measured only in the reproductive stages for indeterminate varieties.

Percent yield loss of indeterminant soybean varieties as affected by degree of defoliation.

	Defoliation (% leaf area destroyed)									
Stage	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
	- - - - - - - - - - - - - - % yield loss - - - - - - - - - - - - - -									
R1-2	0	1	2	4	6	10	15	21	29	38
R3	1	3	6	11	17	24	33	43	55	68
R4	1	3	7	12	18	26	36	47	59	73
R5	1	3	7	12	19	28	38	49	63	77
R6	1	3	5	9	14	19	25	33	41	50

These tables are intended only to provide general guidelines to soybean yield losses due to hail injury. The percentage of nodes cut off or broken were not included.

Even though early season soybean defoliation appears to be very devastating, research has shown that soybean plants can recover and yield well under good growing conditions. The pod-setting and pod-fill periods are very susceptible to severe injury. Hail adjusters usually will defer final yield loss determinations until later in the season.

These percent yield loss tables and guides are being revised and updated continually as research becomes available. Specific loss predictions should be left to trained hail adjusters.

Frost Damage

Soybean plants may be damaged by frost at 32 F or lower temperatures. Temperatures of 28 F for several hours can completely kill soybean plants (stems and leaves).

During the early seedling stage (VE to VC), soybean has some tolerance to temperatures of 29 to 30 F for short periods. If the seedlings have been somewhat hardened off by cool temperatures for several days, then temperatures as cool as 28 F can be tolerated for a short duration.

The unifoliolate leaf stage is slightly more frost-tolerant than the first or second trifoliolate leaf stages. Once true leaves emerge, soybean plants become more susceptible to freezing temperatures below 32 F.

Late-season Frost Damage

Yield loss with frost occurs through the R6 stage with greatest lost at the R5 stage. The number of beans per plant and reduced bean size contribute to overall yield loss.

Soybean seed on frost-damaged plants many mature and change color as early as or even earlier than non-frosted soybean plants. The leaves tend to remain on the frost-damaged soybean plants. Seed moisture may be slightly higher and seed size usually is reduced as the soybean seed dries and shrinks.

A frost will not hurt soybean yields if the soybean growth stage is beyond R7. A frost between R6 and R7 may or may not affect yield, depending on the temperature and duration of the freeze. Beans that are still green and soft will shrivel.

Stalks rapidly turn dark green to brown and will not recover. Beans in pods that have turned yellow will mature normally. Some green beans will turn yellow after 30 to 40 days of storage.

Growers and researchers through the years have tried to use color keys such as yellow soybean leaves, yellow pods and brown pods to estimate soybean maturity and safety from frost. Generally, these methods did not work because of differences in varieties regarding symptoms of maturity. However, studies do show that "yellow" pods sprinkled with brown are the best clue of physiological maturity.

Open pods and check the shrinking of beans and look for separation of beans from the white membrane inside the pod. This indicates the soybean plants are physiological mature and fairly safe from frost injury. Pods do not all mature evenly.

Researchers have noted that if one or two pods on any of the upper four nodes have turned brown and other pods are light yellow to tan, the soybean plants are fairly tolerant to a killing frost. In the event of a leaf-killing frost when pods are still light green or yellow, wait until the pods are mature in color before combining. The most significant effect of an early frost on soybean may be in the reduction in their value as a future source of seed.

Estimating Soybean Yields

Soybean yield estimates are most accurate within three weeks of maturity but are still only estimates. Assume 2.3 beans per pod.

- Determine the number of feet of row needed to make 1/1,000 of an acre (Table on page 136).
- In the determined area, count the number of plants in 10 different randomly selected sample areas. Calculate the average.

  Avg. = ______________ = A (plants/acre)
- Count the number of pods per plant on 10 randomly selected sample areas. Calculate the average.

  Avg. = ______________ = B (pods/plant)
- Calculate pods/acre by multiplying plant population by pods/plant.

  A X B = ______________ = C (pods/acre)
- Calculate seeds/acre by multiplying pods per acre by an estimate of 2.3 seeds/pod.

  2.3 X C = ____________ = D (seeds/acre)
- Calculate pounds/acre by dividing seeds/acre by an estimate of 3,000 seeds/pound.

  D ÷ 3,000 = __________ = E (lbs/acre)
- Estimate yield by dividing pounds/acre by 60 pounds/bu.

  E ÷ 60 = ______________ = Yield (bushels/acre)

Row length equal to 1/1,000 acre

Row width (inches)	Length of a single row equal to 1/1,000 of an acre
6	87' 1"
7	74' 8"
8	65' 4"
10	52' 3"
15	34' 10"
20	26' 2"
28	18' 8"
30	17' 5"
32	16' 4"
36	14' 6"
38	13' 9"
40	13' 1"

Harvesting Soybean

Rob Proulx,
Extension Agricultural Technology Systems Specialist

Field studies in soybean harvesting have shown that a 10% or higher harvest loss is not uncommon. However, studies also have shown that harvest loss can be reduced to 3% or less. To keep losses low, you must know where harvest losses occur, how to measure loss, what is a reasonable level of loss, and the equipment adjustments and operating practices that will help reduce losses.

Harvest Losses

Soybean plants should be harvested when their seed moisture content reaches 13% on the first dry down (Figure 8). If soybeans are ready for harvest and

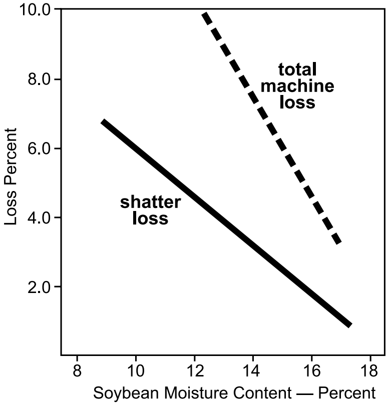

Figure 8. Shatter and machine loss related to moisture content at harvest.

subjected to alternating periods of wet and dry weather, preharvest (shatter) loss can be high. Preharvest loss, defined as soybeans that have dropped to the ground prior to harvest, is influenced by the time of harvest and can be reduced by harvesting early.

Machine loss consists of gathering losses (header losses), threshing loss, and separation loss. Gathering losses may account for more than 80% of the total loss in soybean harvesting. Gathering losses include all losses occurring at the header, which are caused by actions of the cutter bar, reel, and auger/draper belt, as well as soybeans left on uncut stubble.

Gathering losses may be categorized as follows:

- **Shatter loss:** shelled soybeans and detached pods that are shattered from stalks by the header and fall to the ground
- **Stubble loss:** soybeans in pods remaining on stubble
- **Loose stalk loss:** soybeans in pods attached to stalks that were cut, but fell to the ground and did not run through the combine
- **Lodged stalk loss:** soybeans in pods attached to uncut stalks now lying on the soil

Threshing and Separation Settings

Soybean is an easy crop to thresh, separate, and clean. Soybean seeds are easy to remove from the pod and their size and shape make them easy to clean. Nonetheless, small errors in adjustment can cause serious harvest losses.

Follow the settings recommended in your operator's manual for rotor/cylinder speed, concave spacing, airflow settings, and shoe settings. Then, operate the combine in the field and check for losses. Typically, only minor adjustments will be necessary in the field.

Rotor/cylinder speed must be fast enough to thresh soybeans from their pods, but be sure to use the slowest speed necessary for adequate threshing. Excessive rotor/cylinder speed is usually the primary cause of cracked soybeans.

Gathering Equipment

Several combine developments have improved the soybean-gathering efficiency beyond that of a conventional platform featuring a rigid cutter bar and auger conveyor. These include the integral flexible floating cutter bar, the row-crop head, pickup finger reels, pickup guards, narrow-pitch knives (1½ vs. 3 inches), combination pickup finger/air reels, and draper belts (found on draper headers). These components provide significant reductions in gathering loss.

The flexible-floating cutter bar can better follow soil slopes and cut shorter stubble, reducing stubble loss.

Pickup guards ride on the soil surface and slide under lodged soybean stalks so they are cut and directed into the combine header, while pickup reels help lift lodged stalks so the cutter bar can slide under and retrieve them.

A combination finger/air reel helps push cut stalks and pods back into the conveying auger/belt and the feeder housing. This reduces loose stalk loss and the buildup of soybean pods and seeds on the cutter bar, which reduces shatter loss.

Shatter loss is also reduced by narrow-pitch knives, which reduce side-to-side plant movements during cutting. Draper headers may also reduce shatter loss relative to an auger-style header due to their gentler handling of cut stalks, especially under dry conditions when soybean pods are most prone to shattering.

Gathering Equipment Adjustments

Reel speed and position are extremely important to reduce soybean loss. Reels with pickup fingers will cause the least disturbance to the standing plants and, when positioned correctly, will place cut plants to convey smoothly along the header's auger or draper belt and into the feeder housing.

Proper reel speed is 25 to 50% faster than forward travel speed. Faster reel speeds will rip bean pods off stalks and result in increased shatter loss. The axis of the reel should be positioned 8 to 12 inches ahead of the cutter bar.

Ground speeds of no greater than 3 miles per hour are generally recommended. If harvesting at greater speeds, look out for stubble loss, long stubble, uneven cutting heights, and shatter losses due to knife stripping. These are all indications that the ground speed is too fast.

Always operate the cutter bar as close to the ground as possible. A floating flexible cutter bar with automatic header height control is essential for minimizing harvest losses.

Harvesting Quality Seed

Cylinder (or rotor) speed has a direct effect on soybean damage (Figure 9) and has a greater effect on seed damage than does cylinder-concave clearance. Operate the rotor/cylinder no faster than necessary to remove soybeans from their pods. Keep in mind that soybeans tend to dry noticeably throughout the day. Correspondingly slowing the rotor/cylinder speed is an important practice for maintaining seed quality.

Rotor/cylinder speed may be more important for conventional combines than rotary machines, as research conducted at the University of Illinois in the late 1970s found that rotary combines produced significantly fewer splits than conventional cylinder

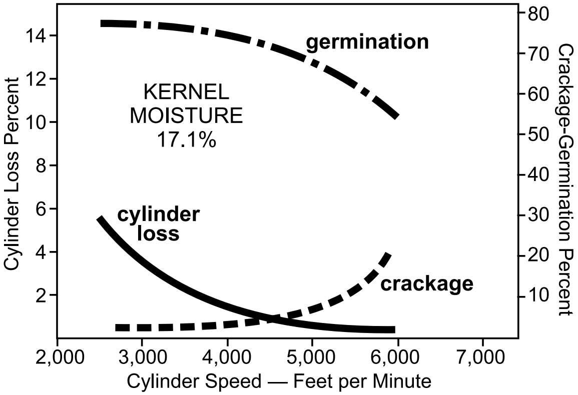

Figure 9. Relationship of cylinder speed to cylinder loss, germination and soybean crackage.

concave-type machines (although either machine type could readily produce high-quality soybean with the proper settings). Nonetheless, if cylinder or rotor speeds are too fast, damaged soybean will result.

Pre-harvest and Harvest Weed Management

U.S. soybean export customers typically demand soybean shipments with no more than 1% foreign material, which includes weed seed. Minimizing the amount of weed seed coming into the combine will improve harvested seed quality and benefit your overall weed management. Consider mowing or hand-weeding any heavily weedy areas prior to harvest (e.g., field edges, drowned-out areas). Alternatively, consider harvesting such areas last, then segregating the harvested grain in storage. Check the University of Minnesota Extension for resources on soybean seed quality and the management of foreign material throughout the soybean production cycle.

Measuring Harvest Loss

Identifying where harvest losses are occurring is important so you can take measures to eliminate or minimize the loss. The various components of soybean harvest loss are determined by making several seed counts inside a measured area.

The best way to delineate the measured area is to use a 1-foot by 1-foot square made from the building material of your choice (e.g., wood, PVC, a heavy piece of wire, etc.). You will use this square in the field to make seed counts.

Refer to Figure 10 and record your seed counts in the Loss Table.

The procedure to use in the field is:

1. Operate the combine in the field and stop. Back up the combine about 20 feet.
2. Determine the number of areas you will count across the cutting width of the combine, with at least one area every 10 feet.
3. Using the 1-foot-square frame, count all beans in the frame as you move the frame across all of your sampling areas.
   a. Count beans in the uncut area to determine the *preharvest loss* (location 1). Enter the total soybean count from all sampling areas, and the number of sampling areas, into row B of the Loss Table.
   b. Count beans behind the combine to find the *total crop loss* (location 2). Enter the total soybean count from all sampling areas, and the number of sampling areas, into row A of the Loss Table.
4. Calculate the average number of beans per sampling area. To do this, divide your total bean counts (Steps 3a, 3b) by the number of sampling areas along the cutting width of the combine (Step 2).
5. Divide values calculated in Step 4 by four, as approximately four soybeans per square foot equals one bushel per acre. If you are harvesting larger than average soybeans, then three soybeans per square foot would equal one bushel per acre.

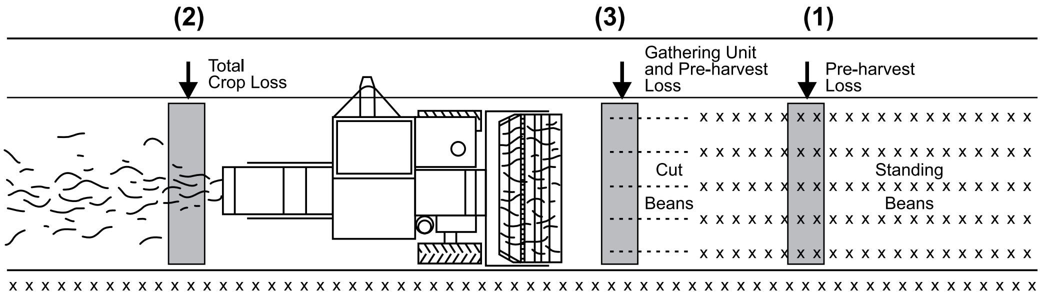

Figure 10. Areas for seed loss counts when estimating soybean harvest losses.

6. Calculate *machine loss* due to combine operation (Loss Table, row C) by subtracting the *preharvest loss* from the *total crop loss*.

7. Estimate your percent harvest loss by dividing your estimated *machine loss* (Step 6) by the estimated crop yield for the field you are harvesting. For example, if machine loss is 1.2 bu/acre in a field estimated to yield 35 bu/acre:

$$\text{percent loss} = \frac{1.2 \text{ bu/acre}}{35 \text{ bu/acre}} \times 100 = 3.4\%$$

   If the machine loss is greater than 3% of crop yield, you may need to do further investigation into the source of loss.

8. The four components of *gathering losses* are measured between the combine header and the unharvested crop (Figure 10, location 3). Again, take measurements across the entire width of the header. Enter total counts and the number of sampled areas into the appropriate Loss Table columns.

   a. Determine *shatter loss* by counting all loose beans and beans in loose pods on the ground.

   b. Determine *loose stalk loss* by counting all beans on loose stalks that were cut and are now lying on the ground.

   c. Determine *lodged stalk loss* by counting all beans on stalks still attached to the ground and lying flat. Pickup guards on the cutter bar may reduce this loss considerably.

   d. Determine *stubble loss* by counting all beans in pods still attached to the stubble.

9. Estimate the bu/acre loss for each component in Steps 8a-d. Sum these values, then subtract the *preharvest loss*. The resulting value is the total *gathering losses*.

10. Finally, subtract the *gathering losses* from the *machine loss* to give you the *threshing and separation losses*.

Once you've determined the gathering losses and threshing and separation losses, you may now determine which components of your combine are most in need of adjustment.

Loss Table

	Total soybean count (no.)	Sampling areas (no. frames)	Avg. soybeans per frame (no.)	Bushel per acre
A. Total crop loss	÷	=	÷ 4 =	
B. Preharvest losses	÷	=	÷ 4 =	
C. Machine loss (A–B)	—	—	—	
D. Gathering unit losses (a+b+c+d – B)	—	—	—	
a. shatter loss	÷	=	÷ 4 =	
b. loose stalk loss	÷	=	÷ 4 =	
c. lodged stalk loss	÷	=	÷ 4 =	
d. stubble loss	÷	=	÷ 4 =	
E. Threshing and separation losses (C–D)	—	—	—	

Soybean Drying, Handling and Storage

Kenneth Hellevang, Extension Engineer

Soybean usually is traded on a 13% moisture basis, so harvesting and selling soybean as close to 13% moisture (wet basis) as possible is to the farmer's advantage. Soybeans that are wetter than 13% moisture likely will mold under warm conditions, and buyers usually apply shrink factors and drying charges when wet beans are delivered.

On the other hand, soybeans that are drier than 11% moisture are more likely to split during harvesting and handling, and yield loss occurs due to the low seed moisture.

If the temperature of the stored beans is kept below about 60 F, soybeans usually can be held for at least six months at 13% moisture without mold problems. For storage under warmer temperatures or for storage times longer than six months, however, the recommended moisture content is 11%.

Oil quality also may be affected during storage at summer temperatures. One study showed that 12% moisture soybeans stored at 70 F had excessive oil quality loss in less than four months. During summer storage, soybeans need to be kept as cool as possible and at about 11% moisture to maintain storage quality.

Storage Management for 11% to 13% Moisture Soybean

Soybeans that are harvested at 11% to 13% moisture can be placed directly into ordinary storage bins equipped with simple aeration systems (perforated ducts or pads and relatively small fans). The suggested winter storage temperature for grains and oilseeds in the upper Midwest is 20 to 30 F.

Because soybean usually is harvested at temperatures well above 30 F, cooling the beans by operating aeration fans during cool weather is necessary. Rather than waiting until outdoor temperatures drop to 20 to 30 F before cooling stored beans, you should cool them in 10- to 20-degree stages as average temperatures drop in the fall.

For example, the soybean crop is harvested at 55 F, when average outdoor temperatures drop to 40 F run the fans long enough to cool all the beans in the bin to 40 F. Then shut the fan off for a few weeks and repeat the cycle when the average outdoor temperatures fall to about 25 F.

The airflow provided by aeration fans usually is expressed as cubic feet of air per minute per bushel of beans, or cfm/bu. You can estimate the amount of fan operation time required to cool an entire bin of beans by dividing 15 by the airflow in cfm/bu.

For example, many on-farm storage bins have an airflow of about 0.2 cfm/bu, so the cooling time would be 15 divided by 0.2, or 75 hours, which is about three days.

You can use this formula to estimate cooling time, but you should measure the temperature of the beans at several different points in the bin to make sure that cooling is complete.

When you are operating aeration fans to cool soybeans that are 11% to 13% moisture, you don't need to worry too much about relative humidity. Soybeans near the point where air enters the bin will rewet some during very humid weather and dry during dry weather. The average relative humidity during the fan operation is what determines bean moisture content. If fans are operated no longer than necessary to cool the bin, the overall moisture change will be small.

If you are concerned about operating the fan during weather that is too humid or too dry, you can install controls that will operate the fan only during weather conditions that do not cause drying or rewetting. Keep in mind that these types of controls will limit the time that the fan operates, and cooling the entire bin will take more days than cooling it would without the controls.

Once soybeans have been cooled to 20 to 30 F, check the beans every two to three weeks during winter months to make sure that the temperature is stable and that no mold, insect, and crusting problems are developing. If you find problems, or if the temperature of soybeans has moved above or below the desired range, operate the aeration fan during 20 to 30 F weather to run a temperature front through the bin.

If you need to hold the soybeans into spring and summer, increase your frequency of checking the bins to every two weeks. Cover aeration fans to limit air blowing into the bin and warming the beans. Unless a problem develops, operating the aeration fans is not necessary. If you aerate during spring or summer to remove solar heat gain on the south wall or top of the bin, do so during the coolest weather available. The goal is to keep the temperature under 40 degrees as long as possible and as cool as possible during the summer.

When spoilage problems develop in stored soybeans, they often start in pockets of accumulated fines (small pieces of broken seeds, weed seeds, and stem material) and foreign material. This material is difficult to aerate and often is wetter and more susceptible to mold growth than are whole seeds.

Try to keep fines and foreign material out of the bin by setting combines for maximum cleaning or by running beans through a grain cleaner on the way into the bin. Other options are coring bins (removing some beans through the center unloading sump) after the bin is full, using a distributor to attempt to distribute the fines and material, or frequently moving spouts during bin filling.

Soybean Handling

Bean are subject to splitting during handling, so handle soybeans gently. Belt conveyors, bucket elevators and drag or mass conveyors provide the gentlest handling. But normal grain augers can be used if they are operated slowly and full, and pneumatic or air-type conveyors can be used if the air-to-grain ratio is set properly and if lines are laid out with a minimum number of very gradual curves.

Avoid long drop heights in soybean handling to limit the potential for damage by frequently adjusting the position of conveyors or by using bean ladders or other devices that break long drops into a series of shorter drops. One handler of food-grade soybeans recommends 10 feet as the maximum height for any single drop.

Artificial Drying

In most years, fall weather conditions in the upper Midwest will dry soybean to 11% to 13% moisture in the field. But in some years, weather conditions prevent soybean from drying to 13% moisture, and sometimes growers harvest at moistures greater than 13% to avoid the harvest losses that can occur at lower moisture contents.

Soybean can be harvested without too much damage up to about 18% moisture. If soybean is harvested at a moisture content above 13%, artificial drying is necessary.

Not much published research is available on soybean drying. Most drying recommendations are based on limited experience or are extrapolated from corn drying recommendations. In most cases, dryers that were designed for corn can be adapted for use with soybean.

Natural-air Drying

Using unheated air to dry soybean usually works well, but it is a slow process (four to six weeks, depending on initial moisture, airflow, and weather). Bins used for natural-air drying should have fully perforated floors and large drying fans.

Fan power requirements depend on desired airflow and depth of beans. For example, delivery of 1 cfm/bu (cubic feet of air per minute per bushel of beans in the bin) through a 20-foot depth of soybean would require about 1 hp (horsepower) per 1,000 bushels of beans in the bin, while delivery of 1.5 cfm/bu through 20 feet of soybeans would take about 1.8 hp per 1,000 bu. An airflow rate of 1 cfm/bu through a bean depth of 26 feet also would require about 1.8 hp per 1,000 bu.

Management of natural-air soybean dryers is similar to that for natural-air corn dryers, except that soybean moisture values need to be about 2 to 3 percentage points lower than those recommended for corn.

Higher airflow rates are needed because fewer days are available for drying in the fall and outdoor temperatures are cooler. Use at least 1 to 1.25 cfm/bu to dry soybeans that are 16% moisture or less, 1.25 to 1.5 cfm/bu for 17% moisture beans and 1.5 cfm/bu for 18% moisture beans. Estimated drying times using average October temperatures are shown in the table.

Estimated drying times, days, assuming October conditions of 47 F and 65% relative humidity.

Moisture Content	Cfm/bu	Drying Time (days)
18%	1.5	40
17%	1.25	45
16%	1.0	50
16%	1.5	35

Low-temperature Drying

Early in the fall, especially in years with warm, dry weather, drying soybean to less than 13% moisture with no supplemental heat is possible. However, later in the fall, or in years with cool, damp weather, soybean might not dry to 13%, and adding a small amount of supplemental heat to the air in natural-air dryers might be helpful. Do not heat the air more than 3 to 5 degrees F, though, or you will over dry the beans.

Some alternatives to adding supplemental heat to natural-air drying bins include:

- Turn off the fan when outdoor temperatures average below about 40 F in the fall, keep beans cold during winter and resume drying when average temperatures climb above 40 F in the spring. Drying times and required airflow rates in the spring are similar to drying beans during October. Drying moisture contents greater than 15% is discouraged unless the airflow rate exceeds 1 cfm/bu.
- Install bigger fans so you can finish drying earlier in the fall when the weather is better.
- Use manual or automatic controls to turn off the fan during periods of high humidity. Fan control will increase the number of days required for drying, but it will result in drier beans.

High-temperature Drying

Many kinds of gas-fired corn dryers can be used to dry soybean, but beans can be damaged and you run the risk of dryer fires. Soybean splits easily if the beans are dried too fast or are handled roughly. Set the drying air temperature according to the manufacturer's recommendation and monitor bean quality.

Column-type dryers often can be operated at about 120 F without causing too much soybean damage, although some trial and error might be required to set dryers properly. Examine beans leaving the dryer carefully and reduce the temperature if you're getting too many splits.

Research has shown that exposing beans to relative humidities of less than 40% can cause excessive splitting. For every 20 degrees F that you heat air, you cut its relative humidity approximately in half, so you don't need very much heat to produce relative humidities less than 40%.

If the soybeans will be saved for seed, keep drying temperatures under 110 F to avoid killing the embryo. Food-grade soybeans normally cannot be dried in a high-temperature dryer that includes adding heat.

Don't forget that crops dried in gas-fired dryers must be cooled within a day or so to remove dryer heat. This can be done in the dryer or in aerated storage bins. Stored soybean should be aerated again later in the fall to cool them to 20 to 30 F for winter storage.

Immature, Frosted or Green Beans

In years when frost kills soybean plants before the seeds are fully mature, make sure you remove as much chaff and green plant material as possible before binning the beans. Beans that are nearly mature may continue to change color if exposed to sunshine while continuing to dry in the field. Small percentages of immature beans can be stored without significant molding if blended with dry soybeans, but concentrations of green soybeans and chaff can lead to heating and spoilage in storage.

Reconditioning Overly Dry Soybean

In years with exceptionally warm, dry falls, soybean sometimes is harvested at moisture contents well under 13% moisture. Although adding water to increase soybean moisture is illegal, given enough time and a high enough airflow per bushel, increasing the moisture content of soybean is possible by aerating the soybeans with humid air. But here are some practical concerns and limitations:

- The process is quite slow, even with the high airflow per bushel (0.75 to 1 cfm/bu) available on bins equipped for drying. It will be similar to the speed of drying.
- Fan control is critical, and some beans could end up too wet for safe storage.
- You may end up with layers of wet beans and dry beans unless you can find some way to mix them in the bin or while unloading the bin.
- Swelling that accompanies rewetting will increase stress on bin walls and can damage the bin wall. Periodically unloading some beans from the center of the bin has been reported to reduce the bin wall pressure.

The table of equilibrium moisture values shows the moisture content that soybeans would reach if exposed to different combinations of temperature and relative humidity for long periods of time. If you continuously aerated a bin of soybeans, they would tend to lose moisture during periods of low humidity and gain moisture during periods of high humidity.

To recondition beans to 13% moisture during normal fall temperatures of 30 to 60 F, you would need to control the fan so that it operates during weather that has an average relative humidity of 65 to 70%. The table indicates that soybean moisture increases sharply as relative humidity increases, which means that rewetting a layer of beans to a moisture content that is too high for safe storage is quite easy.

Table. Equilibrium moisture values (% wet basis) for soybean.

Temperature (F)	Relative Humidity (%)				
	50	**60**	**70**	**80**	**90**
32	10.0	11.8	13.7	16.2	19.8
40	9.8	11.5	13.5	16.0	19.6
50	9.5	11.2	13.2	15.7	19.4
60	9.2	11.0	13.0	15.4	19.1
70	8.9	10.7	12.7	15.2	18.9
80	8.6	10.4	12.5	15.0	18.7

During reconditioning, the moisture content of the beans of the whole bin does not change at once. A rewetting zone develops and moves slowly through the bin in the direction the airflow is moving. This is similar to the way a drying zone moves through a drying bin.

In most cases, not enough high-humidity hours are available in the fall to move a rewetting zone all the way through the bin. And in many cases, depending on how the fan is controlled, the parts of the bin that have been rewetted may be too wet for safe storage. Your best option is to mix the wet layers with the dry layers to reduce the spoilage risk and avoid drying charges for the wet layers when the soybeans are sold.

Mixing can be accomplished to a limited extent by emptying the bin and moving the soybeans through a grain-handling system. The most effective way to mix the beans, though, would be to use an in-bin stirring system.

If the initial moisture content of soybeans is 10% or less, controlling the fan so that it only runs when relative humidity of the air reaching the soybeans is greater than about 55% should result in rewetting. If you use a single humidistat to turn the fan on anytime humidity is greater than 55%, average humidity during the hours the fan operates should be well above 55%, and the beans are likely to rewet to at least 13%. Because humidity is almost always higher at night than it is during the day, an alternative to a humidistat would be a timer set to run the fan only during nighttime hours.

Approaches to prevent excessive rewetting include:

- Reducing the humidity setting on the humidistat that controls the fan so the fan runs during drier conditions
- Adding a second humidistat that stops the fan when relative humidity reaches very high levels
- Installing a microprocessor-based controller that monitors temperature and humidity and only runs the fan when air conditions will bring the crop to the desired moisture content (for either drying or rewetting)

The disadvantage of the last two approaches is that the fan doesn't run as many hours as it would with a single humidistat control and less total moisture would be added. Reconditioning time depends primarily on airflow per bushel and weather conditions. It is fastest when airflow per bushel is high and the air is warm and humid.

Reconditioning will be the most successful in a bin equipped as a drying bin - one that has a fully perforated floor and a fan that can deliver at least 0.75 cfm/bu. Even with this airflow, you probably would need at least a month of fan operation to move a rewetting front all the way through the bin. And keep in mind that you cannot run the fan continuously because in a typical fall, continuous fan operation would result in drying rather than rewetting.

To increase chances of success in using airflow to recondition soybean:

- Use a bin equipped with a fully perforated floor and a fan that can deliver at least 0.75 cfm/bu.
- If it is available, use a bin equipped with stirring equipment. If stirring equipment is not available, consider transferring the soybeans to another bin to mix the wet and dry layers.
- Use timers, humidistats, programmable controllers or some other type of automatic control to limit fan operation to weather conditions that will cause rewetting.
- Keep reconditioned beans cool (20 to 30 F is the suggested winter-storage temperature) to reduce chances of spoilage.
- Watch carefully for signs of moldy soybeans and excessive stress on the bin.

Food or High-value Soybean

More care is required with high-value soybean primarily to minimize the amount of cracked skins and beans. The optimum moisture content for harvest is about 13% to 15%. At moisture contents below about 11%, you have more split soybeans, germination is reduced due to more damage during harvest and handling, field loss will be greater and less weight is available to market below 13% moisture.

To minimize damage during handling, belt conveyors are preferred to augers. If augers are used, they should be operated at a slow speed and be kept full. Pneumatic conveyors can be used if the proper air-to-grain ratio is maintained, gentle curves are used in the conveying tubes and a low conveying velocity is used. Drop heights should be minimized, so bean ladders are recommended in bins or other locations where the beans may fall during conveying.

Cold soybeans are more susceptible to damage during handling. Use care in drying soybeans because much of the damage that occurs during handling is due to stresses created during drying.

Damage during drying occurs when the relative humidity of the drying air is below about 40%. Generally, the drying air in a high-temperature dryer should not be heated more than 20 degrees F to minimize the potential for damage to the seed coat.

One study showed that with a 100 F drying temperature, 10 to 60% of the skins were cracked and 5 to 20% of the beans were cracked. Another study showed about 15% of the seed coats cracked with the drying air at 40% relative humidity, and 30% of the seed coats cracked with a 30% relative humidity.

Under the authority of the U.S. Grain Standards Act (USGSA), USDA established the soybean standards to help in the marketing of soybeans. The standard Soybeans of other colors (see U.S.

Soybean grades table) has been used for many years for determining soybean quality. USDA has received requests (2022) from representatives of U.S. soybean producers and grain traders to remove SBOC, as a grade-determining factor for describing the quality for soybeans (e.g., U.S. No 1 Yellow soybeans, U.S. No. 2 Yellow Soybeans, etc.). After a comment period, a change may be made. Please consult the most up-to-date information on this topic.

U.S. Standards for Soybean Grades and Grade Requirements

	Grades U.S. Nos.			
Grading Factors	**1**	**2**	**3**	**4**
	Minimum pound limits			
Test weight (lb/bu)	56.0	54.0	52.0	49.0
Damaged Kernels	**Maximum % limits**			
Heat (part of total)	0.2	0.5	1.0	3.0
Total	2	3	5	8
Foreign Material	1	2	3	5
Splits	10	20	30	40
Soybean of Other Colors[1]	1	2	5	10
Other Materials	**Maximum count limits**			
Animal filth	9	9	9	9
Castor beans	1	1	1	1
Crotalaria seeds	2	2	2	2
Glass	0	0	0	0
Stones[2]	3	3	3	3
Unknown foreign substance	3	3	3	3
Total[3]	10	10	10	10

U.S. Sample grade is soybean that:

(a) Does not meet the requirements for U.S. Nos. 1, 2, 3 or 4; or

(b) Have a musty, sour or commercially objectionable foreign odor (except garlic odor); or

(c) Are heating or otherwise of distinctly low quality.

[1] Disregard for mixed soybeans.

[2] In addition to the maximum count limit, stones must not exceed 0.1% of the sample weight.

[3] Includes any combination of animal filth, castor beans, crotalaria seeds, glass, stones and unknown foreign substances. The weight of stones is not applicable for total other material.

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Resource Publications

North Dakota State University

- "North Dakota Soybean Variety Trial Results and Selection Guide" (current year) (A843)
- "Soybean Growth and Management Quick Guide" (A1174)
- "Soybean Response to Planting Rates and Row Spacings in North Dakota" (A1961)
- "North Dakota Weed Control Guide" (current year) (W253)
- "North Dakota Field Crop Plant Disease Management Guide" (current year) (PP622)
- "Soybean Disease Diagnostic Series" (PP1867)
- "North Dakota Field Crop Insect Management Guide" (E1143)
- "Soybean Aphid, Aphis glycines, Management in North Dakota" (E1232)
- "Management of Insecticide-resistant Soybean Aphids" (E1878)
- "Soybean Gall Midge and White-mold Gall Midge in Soybean" (E2006)
- "Soybean Soil Fertility" (SF1164)
- "Crop Rotations for Increased Productivity" (EB48)
- "Managing Saline Soils in North Dakota" (SF1087)
- "Growing rye as a cover crop in North Dakota" (A2010)

Useful Soybean Websites

Soybean Production Management

NDSU Extension
www.ndsu.edu/agriculture/extension

NDSU Extension publications
www.ag.ndsu.edu/publications/crops/browse-by-crop/soybeans

NDSU Research Extension Centers
https://www.ndsu.edu/agriculture/ag-hub/research-extension-centers-recs

NDSU Crop and Pest Report
https://www.ndsu.edu/agriculture/ag-hub/ag-topics/crop-production/crop-pest-report

NDSU Weed Science
www.ndsu.edu/weeds

NDSU Insect Updates for North Dakota
www.ag.ndsu.edu/extensionentomology

NDSU Foundation Seedstocks
www.ag.ndsu.edu/fss

North Dakota Crop Improvement and Seed Association
www.ndcropimprovement.com

Commodity Groups and Organizations

American Soybean Association
soygrowers.com

Minnesota Soybean
mnsoybean.org

North Dakota Soybean Council
ndsoybean.org

North Dakota Soybean Growers Association
https://ndsoygrowers.com/

Northern Crops Institute
www.northern-crops.com

United Soybean Board
unitedsoybean.org

SOYBEAN – GENERAL

Nodules on soybean roots
(Courtesy D. Berglund)

Iron chlorosis deficiency
(Courtesy D. Berglund)

Soybean flowers
(Courtesy D. Berglund)

Soybean pod 10 mm long
(Courtesy D. Berglund)

Bean development stages
(Courtesy D. Berglund)

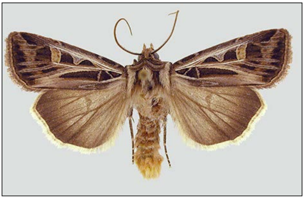
Harvest loss: four beans per square foot is 1 bu/a
(Courtesy D. Berglund)

Armyworm adult
(Courtesy G. Fauske, NDSU)

Armyworm larva
(Courtesy R. Smith, Auburn University, Bugwood.org)

Bean leaf beetle adult
(N. Wright, Florida Department of Agriculture & Consumer Services, Bugwood.org)

Bean leaf beetle defoliation
(Courtesy J. Halvorson, NDSU)



Dingy cutworm adult
(Courtesy G. Fauske, NDSU)

Dingy cutworm larva
(Courtesy J. Gavloski, Manitoba Agriculture, Food and Rural Initiatives)

Redbacked cutworm adult
(Courtesy G. Fauske, NDSU)

Redbacked cutworm larvae
(Courtesy J.Gavloski Manitoba Agriculture, Food and Rural Initiatives)

Darksided cutworm adult
(Courtesy G. Fauske, NDSU)

Green cloverworm adult
(Courtesy J. Gavloski, Manitoba Agriculture, Food and Rural Initiatives)

Green cloverworm larvae
(Courtesy J. Gavloski, Manitoba Agriculture, Food and Rural Initiatives)

Green cloverworm pupae
(Courtesy J. Gavloski, Manitoba Agriculture, Food and Rural Initiatives)

SOYBEAN – INSECTS

Painted lady butterfly
(Courtesy W. Ciesla, Forest Health Management International, Bugwood.org)

Thistle caterpillar
(Courtesy J. Knodel, NDSU)

Alfalfa webworm adult
(Courtesy W. Cranshaw, Colorado State University, Bugwood.org)

Alfalfa webworm larva
(Courtesy J. Knodel, NDSU)

Grasshopper adult
(Courtesy P. Beauzay, NDSU)

Grasshopper nymph
(Courtesy G. Fauske, NDSU).

SOYBEAN – INSECTS

Potato leafhopper adult
(Courtesy S. Brown, University of Georgia, Bugwood.org)

Potato leafhopper nymph
(Courtesy S. Brown, University of Georgia, Bugwood.org)

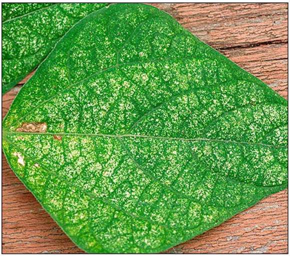
Soybean aphids (adults, nymphs, and white casted skins) on underside of leaf
(Courtesy P. Beauzay, NDSU)

Close-up of soybean aphid alate
(Courtesy P. Beauzay, NDSU)

Seedcorn maggot adult
(Courtesy Pest and Diseases Image Library, Bugwood.org)

Seedcorn maggot larva
(Courtesy W. Cranshaw, Colorado State University, Bugwood.org)

Close-up of two-spotted spider mite
(Courtesy D. Cappaert, Michigan State University, Bugwood.org)



Stippling injury from two-spotted spider mites
(Courtesy W. Cranshaw, Colorado State University, Bugwood.org)

Webbing from two-spotted spider mites
(Courtesy D. Cappaert, Michigan State University, Bugwood.org)

Click beetles (adult wireworm)
(Courtesy S. Brown, University of Georgia, Bugwood.org)

Wireworm
(Courtesy M. Boetel, NDSU)

Soybean gall midge adults
(Courtesy M. L. Helton, Iowa State University)

Soybean gall midge necrotic stem base
(Courtesy V. Calles Torrez, NDSU)

Soybean gall midge larvae
(Courtesy V. Calles Torrez, NDSU)

Phytophthora root rot
(Courtesy H.A. Lamey)

White mold
(Courtesy S. Markell)

Soybean cyst nematode
(Courtesy S. Markell)

Rhizoctonia root rot
(Courtesy B.D. Nelson)

Fusarium root rot
(Courtesy B.D. Nelson)

Sudden death syndrome
(Courtesy B.D. Nelson)

SOYBEAN – DISEASES

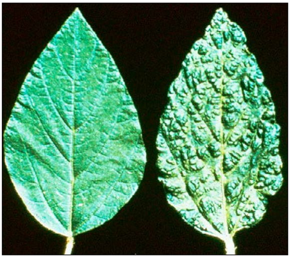
Bacterial blight
(Courtesy S. Markell)

Septoria brown spot
(Courtesy D. Malvick)

Downy mildew on upper leaf
(Courtesy S. Markell)

Pod and stem blight
(Courtesy D. Malvick)

Brown stem rot
(Courtesy C. Grau)



Leaf puckering from virus
(Courtesy Illinois Ag. Exp. St.)

Seed mottling from virus
(Courtesy H. J. Johnson)

Leaf distortion from virus
(Courtesy M.C. Shurtleff)

Frogeye leaf spot
(Courtesy S. Markell)

Frogeye leaf spot underside leaf
(Courtesy S. Markell)

Charcoal rot
(Courtesy B. D. Nelson)

Stem canker
(Courtesy D. Malvick)

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1.7M-1-23; 2M-9-24