BU-6967-S Minnesota
W-1141 North Dakota
1998

Herbicide and Nonherbicide Injury Symptoms on Spring Wheat and Barley

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Plant injury on spring wheat and barley can be caused by field equipment operations, weather-related stress, crop pests, soil nutrient problems, and other factors. Plant injury symptoms may look the same even though the cause of the injury is different. This publication will help professional agriculturists and growers distinguish between herbicide and nonherbicide injuries on spring wheat and barley.

Part I Herbicide Injury Symptoms

HERBICIDE MODE OF ACTION

Understanding herbicide mode of action is necessary to diagnose small grains for herbicide injury, prepare herbicide mixes, and plan herbicide rotations to minimize development of chemical resistance. Herbicide mode of action is the sequence of events from the time the plant absorbs the herbicide until its death. Herbicide mode of action is a process that includes 1. plant contact, 2. absorption by plants, 3. movement within the plants to the site of action without being deactivated, and 4. reaching toxic levels at the site of action. Understanding how the herbicide works helps in determining the proper method and timing of application to maximize weed control and minimize potential crop injury.

SOIL-APPLIED HERBICIDE AND PHYTOTOXICITY

Weed control with soil-applied herbicides depends on three conditions: 1. the herbicide must be in the soil solution and in contact with an actively growing plant (dormant weed seeds are not affected), 2. the herbicide must be available to the plant in adequate quantities, and 3. sufficient soil moisture must be present. Many weeds have small seeds that germinate primarily within the top two inches of the soil. For soil-applied herbicides to be effective, they must be positioned from the soil surface to two inches deep. Herbicide placement within the germinating weed zone can be accomplished by mechanical incorporation or rainfall. Soil-applied herbicides are absorbed when roots or shoots of germinating weed seedlings come in contact with the herbicide in the soil solution.

Plant roots continue to take up herbicide as long as root hairs remain in contact with the treated soil. As the roots penetrate deeper in the soil and move farther away from the treated soil, the herbicide absorption declines. If root tips of weeds grow out of the herbicide-treated soil, they are likely to survive.

Many soil-applied herbicides are absorbed by the plant shoot as it emerges through the soil. Shoot-absorbed herbicides often injure or kill plants before emergence. Volatile herbicides such as the thiocarbamates (e.g., triallate [Far-Go]) and the dinitroanilines (e.g., trifluralin [Treflan]) can penetrate the shoot as a gas.

The conditions that affect herbicide efficacy can also affect crop injury. For example, trifluralin can severely inhibit root growth of wheat if it is incorporated in the spring so deeply that the herbicide comes in contact with the developing root system. High herbicide application rates can also injure crops. In addition, excess moisture from heavy rainfall can cause herbicides to leach or concentrate in sufficient quantities in the crop germination zone to damage the crop. Physical and environmental factors that enhance rapid crop emergence and reduce the time that a plant is exposed to the treated soil will reduce the potential for crop injury.

Herbicides vary in their ability to translocate within a plant. Some soil-applied herbicides, such as trifluralin (Treflan), are not mobile within the plant. Plant injury from this type of soil-applied herbicide would be confined to the site of uptake. Other herbicides are mobile and move within the plant. For example, soil-applied atrazine is absorbed by plant roots and moves upward in the xylem (water transport system) and becomes concentrated in the leaves. Generally, plant injury symptoms associated with mobile herbicides will be most conspicuous at the location where the herbicides concentrate.

POSTEMERGENCE HERBICIDE AND PHYTOTOXICITY

Effective postemergence herbicide application is dependent on an adequate amount of the herbicide making contact with aerial plant parts. Thorough spray coverage of the plants can be achieved through proper selection of the spray tips, spray pressure, and spray volume. Flat fan nozzles are generally recommended for postemergence applications. Always read herbicide labels carefully for application details.

For most postemergence applications, the chemistry of a compound determines how it interacts with the biological and physical systems of the plant. This interaction often determines the rate and amount of the herbicide uptake. Factors such as plant size and age, water stress, air temperature, relative humidity, and herbicide additives also influence the rate and amount of herbicide uptake. Additives such as crop oil concentrates, surfactants, or liquid fertilizer solutions (e.g., 28% UAN) can enhance the performance of the herbicide. These same factors can also increase the risk of crop injury. Herbicide uptake may decrease under hot dry conditions or when applied to older, larger weeds under water stress. Environmental conditions at application can affect the rate and amount of uptake. For example, wild oat control with difenzoquat (Avenge) increases with rising temperature after treatment. These differences in herbicide uptake help to explain how weed control effectiveness and potential for crop injury can fluctuate. Rapid herbicide absorption by the plant helps ensure that the compound enters the plant and minimizes potential wash off from rain.

As with soil-applied herbicides, postemergence herbicides differ in their ability to move within a plant. Non-mobile postemergence herbicides are called contact herbicides. It is essential that contact herbicides thoroughly cover the plant. Contact herbicides include the bipyridylium, diphenylether, benzothiadiazole, and nitrile families. Other herbicides are mobile and can move from where they enter the plant to their site of chemical activity. Growth regulator herbicides such as 2,4-D, dicamba (Banvel), or clopyralid (Stinger), move up and down within the plant's transport system (phloem) to the growing points of the shoots and roots. With systemic herbicides it is most likely that crop injury will be prominent where the herbicides concentrate, in the roots and growing points.

HERBICIDE SELECTIVITY

The susceptibility or tolerance of different plants to a herbicide is called herbicide selectivity. Many plants can deactivate or metabolize a herbicide before plant injury occurs. Wheat and barley tolerate growth regulator herbicides, such as 2,4-D and MCPA, because they can metabolize these herbicides faster than broadleaf plants. The genetics of a plant also affect a plant's tolerance to a herbicide. Some cultivars of wheat are tolerant while others are susceptible to the herbicide difenzoquat (Avenge). This difference is due to specific genes within the plants.

Many plant-related factors determine herbicide selectivity. Plant age and height differences between crops and weeds can be used successfully to kill some weeds. Other factors include differences in herbicide retention, penetration, translocation, and metabolism. It is also important to remember that selectivity depends upon herbicide dosage. A herbicide applied at a high dosage may kill all the weeds, but also increases the risk of crop injury. In contrast, a low dosage is safer for the crop but may not kill any weeds.

Situations may occur in which a crop may be injured by a herbicide to which it is normally tolerant. This often occurs because environmental stresses such as hot or cold temperatures, high relative humidity, or hail decrease a plant's natural ability to reduce uptake or deactivate a herbicide. Postemergence tribenuron + thifensulfuron (Harmony Extra) injury to wheat or barley under cold and wet weather conditions is a good example of environmentally induced herbicide injury. An excessive application of a herbicide, due to misapplication, can also injure a tolerant crop by overwhelming the crop's herbicide metabolism and deactivation systems.

HERBICIDE RESISTANCE

Table 1.
Herbicide families used in wheat and barley where resistant weed biotypes have developed

Herbicide Family	Weed Biotypes
Dinitroaniline	Green foxtail
Arlyoxyphenoxypropionate	Wild Oat
Sulfonylurea	Kochia, Prickly Lettuce, Russian Thistle
Thiocarbamate	Wild Oat

Several common weed species in small grains have developed herbicide resistance. These weed species and the herbicides against which they have developed resistance are shown in **Table 1**. These resistant weed species can no longer be controlled by these herbicides.

Herbicide resistance develops through the selection of naturally occurring weed biotypes that have an inherent ability to tolerate the herbicides. The term "biotype" refers to plants within a species that have a slightly different genetic makeup from the general population. For example, "triallate resistant wild oat" is a biotype of wild oat that looks like any other wild oat plant. However, the resistant wild oat biotype can survive a herbicide rate several times higher than that needed to control susceptible biotypes. Resistance may arise due to the natural morphological or physiological characteristics of the species. It is also possible that resistance may develop in response to selection pressures due to farming practices or particular herbicide usage.

Herbicide resistance usually begins when a small number of resistant biotypes from a species survives an application from a particular herbicide. When a small grain field is sprayed with a herbicide, susceptible weeds die and resistant biotypes survive. The resistant biotype plants that mature and set seed become the source of future generations of resistant biotypes that eventually replace the susceptible weed species.

Three factors that intensify the selection process of resistant weed biotypes are herbicide efficacy, frequency of use, and duration. A highly effective herbicide acts like a screening process by removing the susceptible weeds and leaving the resistant weed biotypes. The greater the efficacy of a herbicide, the greater the selection intensity for selecting the resistant weed biotypes. This intense selection pressure allows the resistance weed biotypes to quickly establish themselves over a few growing seasons. Coupled closely with herbicide efficacy in this selection process is frequency of herbicide use. When herbicides with the same mode of action are applied over consecutive growing seasons to crops in rotation, pressure is placed on susceptible weed species and resistant weed biotypes are left. Also phytotoxicity from soil-applied herbicides that offer full season activity or from multiple applications made during the growing season can intensify the resistant weed biotype selection process. Although herbicides select for resistant biotypes, they probably do not directly cause the genetic mutation in the resistant biotypes.

Resistance mechanisms differ with herbicide families. Resistant biotypes may possess small biochemical differences from susceptible counterparts that eliminate sensitivity to specific herbicides. For example, in sulfonylurea-susceptible plants the herbicide binds to an enzyme (acetolactate synthase or ALS) that is responsible for disrupting amino acid biosynthesis **(Figure 1)**. Plants resistant to sulfonylurea herbicide have a modified ALS enzyme that prevents herbicide binding.

Regardless of how resistance develops, it is important to know the herbicide mode of action to plan weed control programs that prevent the development and spread of resistant weeds. Weed control programs should incorporate a variety of strategies that emphasize prevention. Relying solely on a single strategy or one herbicide family for managing weeds increases the likelihood that herbicide resistance will development. Guidelines using an integrated approach for managing herbicide resistant weeds follow.

STRATEGIES FOR PREVENTING AND MANAGING HERBICIDE RESISTANT WEED PROBLEMS

- Scout fields to identify weed species present.
- Use herbicides only when necessary.
- Practice herbicide rotation using herbicides with different modes of action and herbicides from different chemical families.
- Use herbicide mixtures with different modes of action.
- Control weed escapes and sanitize equipment to prevent the spread of resistant weeds.
- Integrate mechanical, cultural, and chemical weed control methods.

HERBICIDE FAMILIES

Knowledge of how herbicides kill weeds (herbicide mode of action) is helpful in selecting and applying herbicides to achieve effective weed control for a given situation. This understanding is also essential to preventing herbicide resistance. There are many herbicides available on the market, and these have several modes of action. Herbicides with similar chemical properties and activity are grouped into "families." An example of a herbicide family used in spring wheat and barley is the sulfonylureas of which tribenuron + thifensulfuron (Harmony Extra), tribenuron (Express), triasulfuron (Amber), metsulfuron (Ally), and chlorsulfuron (Glean) are members. Herbicides in the same chemical family generally have the same mode of action. Different herbicide families may or may not have the same mode of action. Therefore, understanding the herbicide's mode of action and the chemical family it belongs to will greatly aid in planning effective weed control and preventing herbicide resistance. An understanding of the different modes of action also is a helpful tool in diagnosing herbicide injury problems. The following pages describe characteristics of herbicide families commonly used in spring wheat and barley. They are grouped according to their mode of action: amino acid synthesis inhibitors, cell membrane disrupters, growth regulators, lipid inhibitors, photosynthesis inhibitors, seedling growth inhibitors, and unclassified.

Amino Acid Synthesis Inhibitors

The amino acid synthesis inhibitors include the sulfonylureas, imidazolinones, and amino acid derivatives herbicide families. Amino acid synthesis inhibitors act on a specific enzyme to prevent the production of specific amino acids, the key building blocks for normal plant growth and development **(Figure 1)**. Sulfonylurea and imidazolinone herbicides prevent the production of three essential branch-chain amino acids by inhibiting one key plant enzyme. This key plant enzyme is called acetolactate synthase (ALS) or acetohydroxy acid synthase (AHAS). The amino acid derivative herbicides inhibit the production of three essential aromatic amino acids by inhibiting another key plant enzyme, called SEPSP synthase. In general, injury symptoms are slow to develop (1 to 2 weeks) and include stunting or delayed plant growth that leads to eventual death of the plant. Herbicides in the sulfonylurea and the imidazolinone families can move in both the xylem and phloem to areas of new growth and can be taken up through plant foliage and roots. The amino acid derivative herbicides are nonselective and the site of uptake is the plant foliage. Herbicides in this family move via the phloem to all parts of the plant; these are excellent annual weed control herbicides and are active on perennial weeds as well.

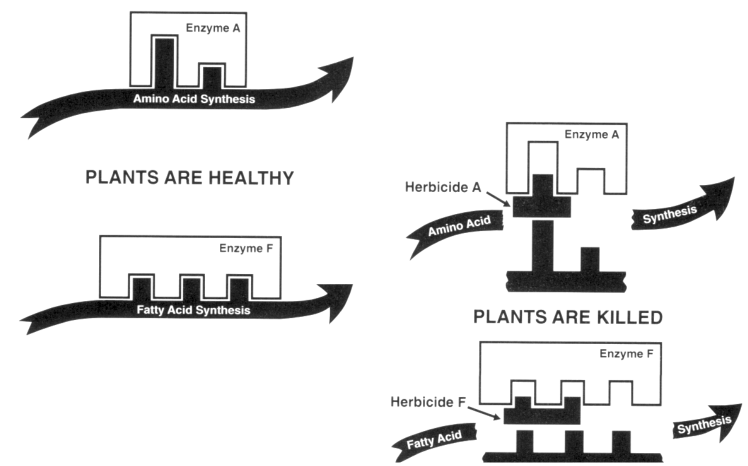


Figure 1. Enzymes function as steps in biological processes. Enzymes are also extremely specialized in their function. As a result, different enzymes are involved with the many different biological processes that occur within a plant. Some herbicides can stop specific enzymes from functioning, resulting in a disruption of specific plant processes; this often leads to the death of the plant. This herbicide-enzyme relationship is very specific and any chemical modification of the herbicide or enzyme can eliminate herbicidal activity. Reprinted with permission from Herbicide Mode of Action, J. Gunsolus and W. Curran, NCR Extension Publication 377, University of Minnesota Extension Service, St. Paul, 1996.

Photo 1

Photo 1 and 2
Imidazolinones or sulfonylureas can cause yellowing or stunting of small grain. Injury is generally temporary.

Photo 2

Imidazolinones

Imazamethabenz (Assert)

Application Timing (wheat and barley): Postemergence after 2-leaf stage but before the second node is visible. Wheat and barley have good tolerance to Assert, and injury is uncommon. Injury may occur under adverse weather conditions and high application rates.
Injury Symptoms: Slight discoloration (yellowing) of youngest leaves and delayed growth.
Site of Action: ALS inhibitor.

Sulfonylureas

Chlorsulfuron (Glean, Finesse)

Application Timing (wheat and barley): Postemergence from the 2-leaf up to the preboot stage. Spring wheat and barley have good tolerance to Glean, and crop injury is uncommon.
Injury Symptoms: Injury symptoms that could occur are: a reduction in tiller number, spike number, plant stand, and kernel weight; leaf chlorosis with yellow striations occurring on youngest leaves; stunted plants and distorted growth. Do not tank mix with malathion insecticide as crop injury may result.
See photos 1 and 2.
Site of Action: ALS inhibitor.

Metsulfuron (Ally, Finesse)

Application Timing (wheat and barley): Postemergence from the 2-leaf to the preboot stage. Spring wheat and barley have good tolerance to Ally and crop injury is uncommon.
Injury Symptoms: See injury symptoms under chlorsulfuron.
Site of Action: ALS inhibitor.

Triasulfuron (Amber)

Application Timing (wheat and barley): Preplant incorporated or preemergence; postemergence from the 2-leaf to the preboot stage. Spring wheat and barley have good tolerance to Amber, and crop injury is rare.
Injury Symptoms: See injury symptoms under chlorsulfuron.
Site of Action: ALS inhibitor.

Thifensulfuron + Tribenuron (Harmony Extra)

Application Timing (wheat and barley): Postemergence from 2-leaf stage but before the flag leaf is visible. Spring wheat and barley have good tolerance to Harmony Extra.
Injury Symptoms: See injury symptoms under chlorsulfuron.
Site of Action: ALS inhibitor.

Tribenuron (Express)

Application Timing (wheat and barley): Postemergence from 2-leaf stage, but before the flag leaf is visible.
Injury Symptoms: See injury symptoms under chlorsulfuron.
Site of Action: ALS inhibitor.

Prosulfuron (Peak)

Application Timing (wheat and barley): Postemergence from the 3-leaf stage, but before the second node is detectable in stem elongation.
Injury Symptoms: See injury symptoms under chlorsulfuron.
Site of Action: ALS inhibitor.

Amino Acid Derivatives

Glyphosate (Roundup Ultra)

Labeled Application Timing (wheat and barley): Preplant and preemergence application in reduced and no-tillage fields. Labeled as preharvest application for perennial weed control. Misapplication, off-target drift, or tank residual contamination may occur.
Injury Symptoms: Youngest leaves near the growing point slowly become chlorotic and later die. Chlorotic segments may appear in heads after exposure to very low rates. **See photos 3 and 4.**
Site of Action: EPSP synthase enzyme.

Photo 3 Roundup injury on spring wheat. Youngest leaves near growing point slowly become chlorotic and die.

Photo 4 Roundup drift injury on spring wheat.

Cell Membrane Distruptors

In spring wheat and barley, the cell membrane disrupters include only the bipyridylium herbicide family. Herbicides in this family are postemergence contact herbicides that are activated by sunlight to form active compounds that disrupt the plant cells causing disintegration of cell membranes and chloroplasts. Destruction of cell membranes results first in rapid desiccation of plant foliage (wilting), followed by necrosis, and eventual death of the plant. On bright sunny days herbicide injury symptoms can occur in one to two hours. Since bipyridyliums are contact herbicides, they are an excellent choice for burn down of annual weeds. Because of the limited translocation of this chemical within plants, underground root systems are not destroyed and perennial weeds usually regrow after their top growth has been destroyed.

Bipyridyliums

Paraquat (Gramoxone, Cyclone)

Application Timing (wheat and barley): Preplant or preemergence in reduced tillage and no-tillage fields. Not labeled for application to emerged wheat or barley. Injury may result from misapplication, off-target drift, or tank contamination. This herbicide has no soil activity.
Injury Symptoms: Mottled yellowing of leaf tissue, wilting and rapid desiccation occurring soon after direct application. Necrotic spots can appear on leaves from droplet drift. The growing point on contacted plants may emerge green even though more mature leaf tissue is dead.
Site of Action: Activated by Photosystem I (PSI).

Photo 5
Elongated rachis, twisted awns, missing spikelets, and heads not emerging from the flag leaf caused by 2,4-D applied to spring wheat before tillering.

Photo 6
Heads not emerging from the twisted flag leaf and shortened peduncles can be caused by a late application of a growth regulator herbicide.

Photo 7
Sterile florets and head tips caused by a late application of dicamba to spring wheat.

Growth Regulators

The growth regulator herbicides used in wheat and barley include the following herbicide families: phenoxy-acetic acids, benzoic acids, and the pyridines. Growth regulator herbicides interfere with numerous biological activities and protein synthesis of plants, causing a variety of plant growth abnormalities. These herbicides are selective against broadleaf weeds but are capable of injuring grass crops. Herbicides in this group move systemically in the plant by way of the phloem or xylem. The herbicides are quickly translocated to areas of new plant growth making them very effective against annual and perennial broadleaf weeds. Herbicide uptake is primarily through the leaves but root uptake is also possible. Injury symptoms are most obvious on newly developing leaves.

Phenoxy-acetic Acid

2,4-D

Application Timing (wheat and barley): Postemergence from tillering (5-leaf) to the preboot stage. Barley is considered slightly more tolerant to 2,4-D than wheat. Crop tolerance and crop injury symptoms produced are highly dependent upon crop growth stage at application. The window of safe application is slightly wider in barley than wheat (that is, damage in wheat may occur at a later seedling and earlier boot stage than with barley).

Injury Symptoms: There are two critical growth periods when injury may occur on wheat and barley with 2,4-D. These two periods are the seedling and boot stage. When 2,4-D is applied to wheat and barley before the tillering stage, rolled leaves (onion-leafing) may develop and inhibit the number of tillers produced. Additional injury symptoms that may occur at this growth stage are elongated rachis, twisted awns, and missing spikelets. Application of 2,4-D to wheat and barley after the jointing stage may result in twisted flag leaf, abnormal head emergence, and sterile spikelets. Treatments made after the soft dough stage do not result in any visual abnormalities or yield decrease. **See photos 5 and 6.**

Site of Action: Specific site(s) unknown, believed to have multiple sites of action.

MCPA

Application Timing (wheat and barley): Postemergence from 2-leaf to early boot stage. In comparison to 2,4-D, MCPA has greater crop safety and a wider window of application timing. Crop injury only occurs from high application rates or late applications.

Injury Symptoms: See Injury Symptoms under 2,4-D.

Site of Action: Specific site(s) unknown, believed to have multiple sites of action.

Benzoic Acid

Dicamba (Banvel)

Application Timing (wheat and barley): Postemergence in spring wheat before plants exceed the 5-leaf stage and in barley before the 4-leaf stage. Plant injury from dicamba can be minimized if postemergence applications are made to wheat or barley between the 2- to 4-leaf stage. Wheat is more tolerant than barley to dicamba.

Injury Symptoms: Dicamba injury in wheat and barley is similar to that caused by phenoxy-acetic acid (2,4-D). Applications of dicamba made from the jointing to the boot stage can cause stem and leaves to layover and result in floret sterility, while late tiller stage applications can cause stunting and delay heading. **See photo 7.**

Site of Action: Specific site(s) unknown, believed to have multiple sites of action.

Pyridines

Clopyralid (Stinger, Curtail)

Application Timing (spring wheat and barley): Stinger and Curtail are both postemergence herbicides labeled for wheat and barley. Stinger is applied from the 3-leaf to early boot stage. Curtail is applied from tillering to the preboot stage. Barley is more tolerant than wheat to clopyralid.
Injury Symptoms: Similar to the phenoxy-acetic acids. The premix Curtail contains 2,4-D and may produce typical phenoxy injury symptoms in small grains, therefore application and timing is more critical with Curtail than with Stinger.
Site of Action: Specific site(s) unknown, believed to have multiple sites of action.

Picloram (Tordon)

Application Timing (spring wheat and barley): Postemergence from 3- to 5-leaf stage. Picloram is labeled only at very low use rates in spring wheat and barley because of crop injury and carryover potential. Picloram is usually applied in combination with 2,4-D or MCPA.
Injury Symptoms: Similar to the phenoxy-acetic acids. **See photo 8.**
Site of Action: Specific site(s) unknown, believed to have multiple sites of action.

Photo 8

High rates of the pyridine herbicides can cause prostrate growth, yellowing, and stunting of spring wheat and barley.

Lipid Synthesis Inhibitors

Lipid synthesis inhibitors used in small grains consist of one herbicide family, the aryloxyphenoxy-propionates. Herbicides in this family inhibit the production of fatty acids within plants. Fatty acid synthesis in plants is an essential process in the development of plant lipids that are required for cell membrane integrity and normal plant growth. The lipid synthesis inhibitor herbicides prevent the activity of acetyl-CoA carboxylase enzyme, which is involved in fatty acid biosynthesis **(Figure 1)**. Broadleaf plants are tolerant to these herbicides; however, almost all perennial and annual grasses are susceptible. Herbicides in this family are taken up by foliage and are translocated via the phloem to areas of new growth. Injury symptoms are slow to occur (7 to 14 days) and first appear on new leaves emerging from the whorl of the grass plant.

Aryloxyphenoxypropionates

Diclofop (Hoelon)

Application Timing (spring wheat and barley): Hoelon can be applied to wheat postemergence before the first node (jointing) moves above ground and while wild oats are in the 1- to 3-leaf stage. It also can be applied postemergence prior to tillering in barley.
Injury Symptoms: Hoelon applied to spring wheat and barley can cause yellowing of leaf tips and blades soon after application. Wheat is more tolerant to Hoelon than barley. Suppression of shoot and root growth may also occur. Applications made after the jointing stage may result in stem pinching approximately one inch above the soil line. This can weaken the stem and make it susceptible to breakage or lodging. Environmental conditions, such as wet soils or cold temperatures below 35°F that precede or follow application, can also result in crop injury. **See photos 9 and 10.**
Site of Action: Acetyl-CoA carboxylase enzyme.

Photo 9

Photos 9 and 10
Diclofop can cause barley injury when applied at high rates and during cool temperatures. Note leaf yellowing, browning, and stunting.

Photo 10

Photo 11

Photos 11 and 12
Fenoxaprop can cause injury to barley. Note leaf yellowing and stunting.

Photo 12

Photo 13
Bromoxynil can cause small grain injury under adverse weather conditions

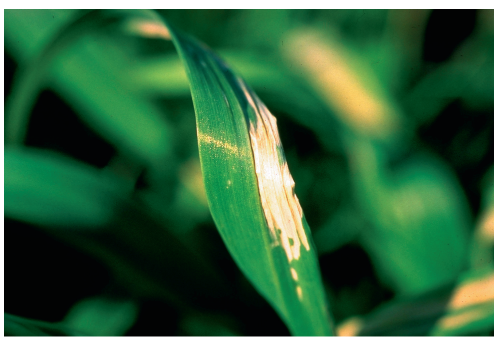


Photo 14
Bromoxynil injury to spring wheat. Note the necrotic leaf spot. Injury is temporary and small grains quickly recover.

Fenoxaprop

(Cheyenne) = fenoxaprop + MCPA ester + thifensulfuron + tribenuron
(Dakota) = fenoxaprop + MCPA ester
(Tiller) = fenoxaprop + MCPA ester + 2,4-D amine

Application Timing (spring wheat, not labeled for barley): Cheyenne, postemergence from the 3-leaf stage to the end of tillering (6-leaf stage) and before jointing; Dakota, postemergence from the 3-leaf stage to the end of tillering and before jointing; Tiller, postemergence after crop begins to tiller (3- to 4-leaf stage) until the 6-leaf stage and before jointing.

Injury Symptoms: Any of the three fenoxaprop mixtures applied to spring wheat can cause yellowing of leaf tips and blades soon after application. Suppression of shoot and root growth could occur and last through the season. Applications made after the jointing stage may result in stem pinching approximately one inch above the soil line. This can weaken the stem and make it susceptible to breakage or lodging. Temporary leaf yellowing or plant stunting also may occur if cool, wet conditions exist at the time of application. With Cheyenne, these types of plant injury may also result under prolonged cool weather (daily temperatures <50°F) or widely fluctuating temperatures just before or after treatment. **See photos 11 and 12.**

Site of Action: Acetyl-CoA carboxylase enzyme.

Photosynthetic Inhibitors

The nitrile herbicide family is the only photosynthesis inhibitor labeled for spring wheat and barley. The nitriles, Buctril and Bronate herbicides, are primarily used for control of annual broadleaf weeds in small grains. The nitrile herbicides are contact herbicides that close the photosynthetic (food producing) process in susceptible plants by binding to specific sites within the plant's chloroplasts. Injury on susceptible broadleaf weeds appears first as blistered lesions on leaves that eventually become necrotic within a 24-hour period. Since the nitriles are classified as contact herbicides, they are not translocated within the plant and good foliar coverage is essential for good weed control. There is no soil activity with the nitrile herbicides.

Benzonitriles

Bromoxynil (Buctril, Bronate, Bison, Moxy)

Application Timing (wheat and barley): Postemergence from emergence until the boot stage. Spring wheat and barley have good tolerance to Buctril.

Injury Symptoms: Injury symptoms from Buctril on small grains appears as leaf tip chlorosis, general wilting, and necrotic leaf spots. Crop injury from Buctril on small grains is uncommon, but can occur if application is made during abnormally cool temperatures or when high temperature or humidity follows application. Crop injury on small grains is short lived and recovery is generally rapid. **See photos 13 and 14.**

Site of Action: D-1-quinone-binding protein of photosynthetic electron transport.

Seedling Growth Inhibitors

The seedling growth inhibitors used in small grains include the thiocarbamate and dinitroaniline herbicide families. These herbicides interfere with development of seedlings as they emerge from the soil. They are soil-applied herbicides that require incorporation to be effective. Plants continue to take up the herbicide until after they have emerged from the soil. If plants emerge from the treated soil uninjured, they are likely to remain so. Seedling growth inhibitors are active at two sites, the developing shoot and the root. Root-inhibiting herbicides stop plant cell division, which in turn inhibits shoot elongation and lateral root formation. Uptake of these herbicides is through developing shoots and roots. Translocation of the herbicide is limited within the plant, and therefore the injury is mainly confined to the uptake areas. Shoot-inhibiting herbicides are absorbed by developing shoots and roots and are transported via the xylem and phloem to areas of new growth.

Photo 15
Far-Go injury to spring wheat. Note the uneven emergence and stunting.

Shoot Inhibitors (Thiocarbamat

Triallate (Far-Go)

Application Timing (wheat and barley): Preplant incorporated in the fall or spring; preemergence incorporated in the spring. Barley has more tolerance to Far-Go than wheat.

Injury Symptoms: Injured small grain seedlings may show reduced coleoptile length, stunting, or delayed emergence. Shoot tips may also fail to unroll from the coleoptiles giving the plant a buggy-whip appearance. Plant injury is increased when Far-Go is incorporated too deeply into the germinating zone of the small grains. Tank mixes of Far-Go + Treflan can result in increased crop injury if applied to soils that are exces sively wet and cool. **See photos 15, 16, and 17.**

Site of Action: Specific site(s) unknown; believed to have multiple sites of action.

Photo 16
Far-Go can cause shoot tips to fail to unroll from the coleoptiles, giving the plant a buggy-whip appearance.

Photo 17
Wheat leaves emerging through the side of the coleoptile caused by high application rate of Far-Go.

Root Inhibitors (Dinitroanilines)

Trifluralin (Treflan)

Application Timing (spring wheat and barley): Wheat, preplant incorporated in the fall and preemergence incorporated in the spring; barley, preplant incorporated in the fall or spring and preemergence incorporated in the spring.

Injury Symptoms: Injured small grain plants will exhibit shortened, swollen root tips giving them a "club-like" appearance; reduced lateral root growth will also be visible. Injured grass shoots are thick, short, and may appear red or purple in color. Injury is more severe if Treflan is incorporated too deeply (>1.5 inches) into the seeding zone (2 to 2.5 inches) of wheat or barley. Tank mixes of Far-Go + Treflan can result in increased crop injury if applied to soils that are excessively wet and cool. Numerous environmental factors such as high soil salinity, soil compaction, drought, heavy rainfall followed by soil crusting, or cold wet soils can stress plants, accentuating the injury effects of Treflan. **See photo 18.**

Site of Action: Tubulin protein involved in cell division.

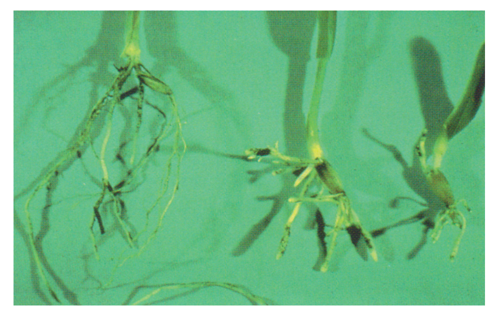


Photo 18
Trifluralin injury to wheat. Note the shortened, swollen root tips.

Unclassified

The last two small grain herbicides are categorized as unclassified because they do not have common characteristics that could be used to place them in a specific herbicide family.

Difenzoquat (Avenge)

Application Timing (spring wheat and barley): Wheat, 3- to 5-leaf wild oats (wheat is usually 5- to 6-leaf stage); barley, 3- to 5-leaf wild oats (barley is usually 2- to leaf). Barley is very tolerant to Avenge, but selectivity to hard red spring wheat is cultivar (variety) dependent.

Injury Symptoms: Common injury symptoms appear on leaf tips as chlorosis or necrotic burn spots that develop soon after application. Leaf tip burn or yellowing occurs on hard red spring wheat and barley 5 to 8 days following Avenge application. This injury symptom is temporary and disappears in about two weeks. Crop injury potential from Avenge can be heightened if temperatures exceed 85°F following application. The most common time for this injury to occur are the first three days following application. **See photos 19 and 20.**

Site of Action: Unknown and believed to have multiple sites.

Photo 19
Avenge can cause leaf burn and leaf necrosis under hot, dry conditions. vThis injury is usually temporary and disappears as new leaves emerge.

Photo 20
Avenge can only be applied to labeled varieties of spring wheat. Application of Avenge to sensitive varieties will result in severe injury or death.

Propanil (Stampede)

Application Timing (spring wheat and barley): Wheat, postemergence from the 2- to 5-leaf stage; barley, postemergence from the 2- to 4-leaf stage.

Injury Symptoms: Injury appears as leaf tip burn, leaf necrosis, and reduced plant height. Hard spring wheat and barley tolerance is influenced by crop growth stage, post-treatment temperatures, and tank mixes. Hard red spring wheat height reductions may be greater following treatment at the 5-leaf rather than the 2-leaf stage. Temperatures greater than 86°F that soon follow treatment can lead to more leaf tip burn and necrosis. Tip browning and yellowing can appear on foliage 2 to 5 days after application and will generally last about two weeks. Applications of Stampede made under adverse growing conditions can cause more severe crop injury and delay the recovery time. Crop injury to small grains may also occur if frost immediately follows an application of Stampede. **See photo 21.**

Site of Action: Multiple sites–photosynthesis, RNA synthesis, and protein synthesis.

Photo 21
Stampede causes leaf burn, yellowing, and stunting. Injury is usually temporary and will disappear as new leaves emerge (10–14 days).

Part II Nonherbicide Injury Symptoms

Good seedbed preparation coupled with accurate planting are important to ensure good stand establishment. These operations are strongly connected to the environmental conditions that follow. The lack of a firm seedbed, or poorly adjusted planting equipment, can be compounded by heavy rains that can result in poor emergence, uneven stand, and weak seedlings.

Deep Planting

Wheat and barley both have elongating coleoptile-type emergence in which the coleoptile can elongate, but not the first internode. This type of emergence limits the maximum seeding depth to about 2.5 inches for tall varieties and 2 inches for semi-dwarf varieties. The most common characteristic of planting small grains too deep is uneven emergence and stand. Examination of individual plants will show an elongated subcrown internode, but the coleoptile and the subcrown internode are limited in how far they can expand. With deep plantings, the subcrown internode may elongate up to four inches, depending on the seed size and soil conditions. When cereal grains planted too deep begin to germinate, vegetative leaves may begin to emerge through the coleoptile and expand below the soil surface. Since the vegetative leaves are not adapted to penetrate soil, they often become folded and usually will die before emerging. Crop injury from deep plantings can appear similar to injury caused by herbicides in the dinitroaniline or thiocarbamate families. Deep planting also can increase crop injury from dinitroaniline and thiocarbamate herbicides. **See photo 22.**

Soil Crusting

Soil crusting can be caused by tilling wet soils or from standing water after heavy rains. Heavy clay soils are especially subject to soil crusting. Wheat and barley seedlings can emerge through about one quarter-inch of soil crusting without too much difficulty. Deep planting of small grains can cause even a light crust to affect wheat and barley emergence. Soil crusting can create plant malformations similar to those associated with deep plantings. Some of these symptoms are uneven stand, leafing out underground, emerged shoots bent over, shoots emerging through the side of the coleoptile, and twisted and kinked leaves. Soil crusting will affect only the plant shoot; it has no effect on the roots. Crop injury from soil crusting can appear similar to injury caused by herbicides in the dinitroaniline, thiocarbamate, and benzoic acid families. **See photo 23.**

Soil Compaction

Soil compaction refers to the compression of the soil airspace and bulk into a smaller volume. The risk of compaction is greatest in fine-textured and low organic matter soils. Small grains growing in compacted soils tend to have smaller root systems that result in shorter plants. It is quite common to see wheel tracks made by heavy equipment that support fewer and smaller plants. The ultimate agronomic result of soil compaction is reduced top growth and yield. Crop injury from soil compaction can appear similar to injury caused by herbicides belonging to the dinitroaniline and thiocarbamate families. **See photo 24.**

CULTURAL PRACTICES

Photo 22
Deep-planted small grains take longer to emerge and can result in uneven stands. Elongated internodes appear in plants on the right. Plants on left show seedling growth when planted at correct depth.

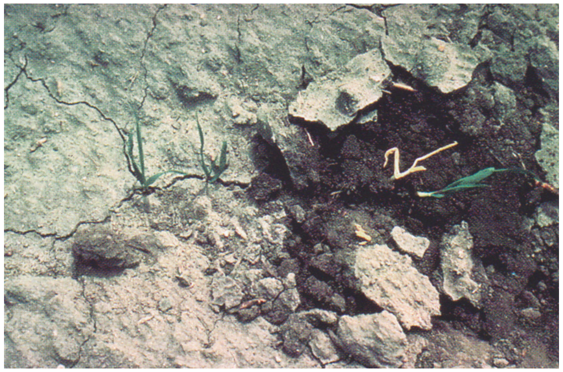


Photo 23
Soil crusting can result in delayed emergence; emerged shoots that are bent over; and twisted, kinked leaves.

Photo 24
Lighter colored areas in photo show the result of wheel track compaction made by postharvest tillage.

Photo 25
Cold, wet soils cause poor soil aeration that in turn reduces oxygen levels needed for normal root growth.

Photo 26
Under drought conditions, small grain plants suffer from cell dehydration. This results in cessation of cell division, reduced biochemical activity, and slowed photosynthesis. Plants suffering under these conditions will appear stunted and yellow or bronze in color.

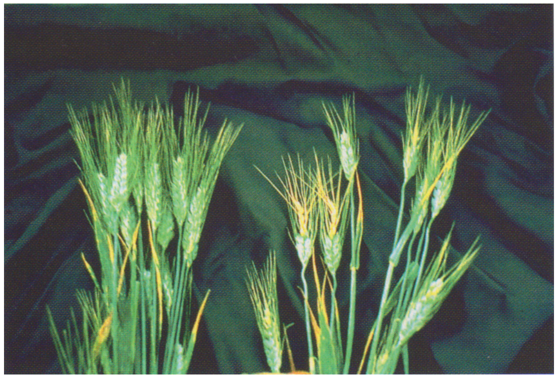


Photo 27
Hot weather that occurs during the conversion from vegetative to reproductive stages can cause small grain plants to fall behind in their ability to carry out respiration and supply materials for new growth of leaves, florets, and spikelets. High temperatures during flowering can result in head sterility.

Water

Excess Water

Excess moisture may affect wheat and barley in several ways. Small grains grown in soils that are poorly drained or have depressed areas can be prone to drowning from standing water remaining on the soil surface for several days after heavy rains. The result is poor soil aeration that reduces soil oxygen levels needed for root respiration and proper root function. In addition to soil oxygen deprivation to plant roots, nutrient uptake by roots also becomes limited. Excessive moisture keeps soil temperature low and elevates the relative humidity in the crop canopy, favoring the onset of plant diseases. Low soil temperatures slow crop growth and development and can predispose plant roots to soil-borne pathogens. Typical symptoms associated with excessively wet soils are dead or dying plants in low lying areas, uneven emergence, poor growth, and chlorotic plants. **See photo 25.**

Water Shortage

Under drought conditions, the evaporative cooling process within plants, called transpiration, decreases. Water is primarily utilized in plant transpiration. When transpiration is reduced, heat loss by wheat and barley plants slows down and leaf temperature increases. Drought stress is increased by low humidity, high temperatures, strong winds, and high light intensity. Small grain plants under drought stress will exhibit erect leaves rolled toward the midrib. The inward rolling of the leaf is due to specialized cells that have collapsed. The curled leaf helps to reduce leaf area exposed to the sun, thereby reducing leaf heating. Although this helps to protect the leaves from heat damage, it also reduces photosynthesis. Plants are usually able to take up water at night, but as soil moisture becomes limiting the leaf curling occurs earlier in the day; hence, plant productivity declines.

In severe drought cases, small grain leaves become ashen to bronze in color, hard, dry, and florets can be aborted. Drought stress after heading causes plants to wilt slightly, lose color, and ripen heads prematurely. Below ground, the root systems of drought-stressed small grain plants are limited, and these plants may appear dark blue-green in color. Barley is more tolerant to drought stress than spring wheat. Small grain crop injury from drought stress can appear similar to injury symptoms caused by herbicides from the amino acid, bipyridylium, dinitroaniline, phenoxy-carboxylic acid (2,4-D, MCPA), and thiocarbamate families and difenzoquat (Avenge). **See photo 26.**

Temperature

Heat Stress

Wheat is especially sensitive to temperatures that exceed 90°F for any significant period. Plants can be injured at seedling emergence, reproductive development, stem elongation, heading, and flowering by high temperatures. When wheat leaves are exposed to high temperatures, photosynthesis slows down and plant respiration increases. During these periods of heat stress and high respiration rates, calories are burned faster than new food is produced. The result is a loss of plant growth. Heat stress results in smaller leaves and fewer spikelets. **See photo 27.**

Frost Injury

Frost injury to wheat and barley involves the physical disruption of cell protoplasts by ice crystals that enlarge inside and between plant cells. Damage patterns in the field reflect the topographic pattern of cold air flow and where it settles. Plant parts that are the nearest to the crop canopy suffer the most damage. Leaf tips appear water-soaked and dark green, then dry out and turn brown within a few days. Shriveling and water-soaking damage can also appear at the base of the peduncle. Freezing temperature is most dangerous to wheat and barley when it coincides with tiller elongation, heading, or flowering. Frosts that occur during tiller elongation cause the collapse and death of meristematic (growing) tissues immediately above and below nodes. Such damage may lead to early tiller maturity, white heads, and new shoot formation at the crown. Flowering grain heads injured from frost may have sterile spikelets that turn white prematurely. Crop injury from frost is similar to injury produced by herbicides from the amino acid and bipyridylium families and by difenzoquat (Avenge). **See photo 28.**

Photo 28
Leaves injured by spring frost appear at first water-soaked, then dark green. These injured leaves dry out and quickly turn brown. Frost injured plants quickly recover if the growing point was not exposed to freezing temperatures.

Hail

Spring wheat and barley plants sustain random physical injury when injured by hail. Injury symptoms from hail appear as shredded leaves, lodged plants, broken heads, and kinked culms. It is common to see bleached spots on plants appearing where immature plant tissue was injured from hail stones. Hail injury can mimic injury symptoms from herbicides belonging to the phenoxy-carboxylic and benzoic acid families. **See photo 29.**

Photo 29
Hail injury occurring on small grains in the preboot stage can cause the grain head to curl up inside the sheath, resulting in twisted heads that are partially exposed and hanging down. The effects of hail injury can also be similar to injury from dicamba applied too late.

Color Banding

Color banding occurs on young grain seedlings because of temperature changes. It is commonly associated with deep planted grains. Color banding occurs when temperatures at the soil surface fluctuate widely. Newly emerged grain plants will exhibit alternate color bands of yellow and green leaf tissue that correlates with high and low temperatures. Color banding can sometimes occur when water laden or frosted leaves are quickly dried by surface heat generated by solar radiation. Emerging leaf tissues of small grains are sensitive to temperature extremes, but quickly lose their sensitivity with age. **See photo 30**.

Photo 30
Coleoptiles of small grain seedlings exposed to fluctuating temperatures at the soil line exhibit yellow and green color bands. Injury is temporary.

Sandblasting

Sandblasting injury is caused by winds impacting soil particles against plant leaves. Symptoms of sandblasting appear as small abrasions on leaves caused by blowing sand. Lesions from this injury often appear coppery in color. Severe winds can shred plants making them prone to desiccation. Sandblasting injury appears similar to injury caused by herbicides from the benzonitrile and bipyridylium families or propanil (Stampede). **See photo 31.**

Photo 31
Blowing sand from strong winds can injure small grain leaves resulting in leaf abrasions.

Common Root Rot (Fusarium & Helminthosporium spp.)

Common root rot is difficult to diagnose and often goes unnoticed. This disease enters plants through the root causing seedling blight or attacks older plants predisposed to several environmental stresses. Seedlings can be killed before or after emergence. Infected plants occur in random patches in fields and are stunted and lighter green than healthy plants. Older plants that are infected will mature early, produce few tillers, have shriveled seed or no seed, and produce heads that are bronzed, bleached, or white. Upon close examination, infected root systems will display a brown color and have fewer roots than healthy plants. Plants infected at the culm base can lodge. **See photos 32 and 33.**

Photo 32
Wheat plants attacked by common root rot turn prematurely and appear white. The heads of these grain plants are empty. Green plants in foreground are healthy.

Photo 33
Plants affected by common root rot (left) show a poorly developed root system compared to healthy plants on the right.

Septoria Leaf Blotch (Septoria spp.)

Septoria leaf blotch is particularly damaging to wheat but rarely causes significant losses in barley. Several Septoria species attack all aerial plant parts of wheat and barley throughout the growing season. Initial symptoms of this disease are chlorotic flecks that usually begin on the lowest leaves of healthy plants. Lesions appearing lens-shaped are caused by Septoria nodorum whereas lesions that show parallel borders are caused by Septoria tritici. When no leaf moisture is present, infection sites quickly dry out and develop yellow margins that later turn red brown. Older lesions will develop ashen gray centers with small black specks, which are the pycnidia. The pycnidia harbor spores that disperse with splashing raindrops spreading the disease to healthy plant tissue. These black specks are visible to the eye and serve as a good diagnostic tool. **See photo 34.**

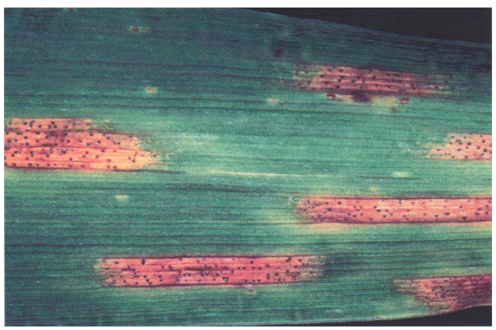


Photo 34
Lesions caused by Septoria tritici show black pycnidia in centers that can be seen without the use of a hand lens

Tan Spot (Pyrenophora trichostoma)

Spring wheat is susceptible to tan spot while barley is a poor host. Tan spot develops initially as yellow-tan flecks on both upper and lower leaf surfaces. The lesions expand into lens-shaped tan blotches with yellow borders. A characteristic of tan spot is a small, dark brown center. Lesions may coalesce and form larger ones. Injury from this disease can be confused with injuries caused by herbicides in the bipyridylium and benzonitrile families, and also difenzoquat (Avenge) and propanil (Stampede). **See photo 35.**

Photo 35
Yellow borders with small dark-brown centers are the typical symptoms of tan spot.

Aphids

Aphid populations exceeding 30 percent of stems infested can cause serious yield reductions. Although aphids can appear at different times during the growing season, they cause the most damage if they reach high numbers between tillering and the flag leaf stage. Three aphid species that are the most common in the north central small grain production area are the English grain aphid, Macrosiphum avenae (Fab.); the birdcherry oat aphid, Rhopalosiphum padi (L.); and the greenbug, Schizaphis graminum (Rond.). Aphids have piercing-sucking mouthparts that draw plant sap from leaves when feeding. Feeding injuries from high aphid populations result in slow plant growth, stunted plants, and chlorotic leaves. In addition to feeding injuries, these aphid species are capable of transmitting plant diseases such as barley yellow dwarf virus. Crop injury caused by aphids is similar in appearance to the chlorosis and stunting injury symptoms caused by herbicides belonging to the aryloxyphenoxypropionate and benzonitrile families and propanil (Stampede). **See photo 36.**

INSECT DAMAGE

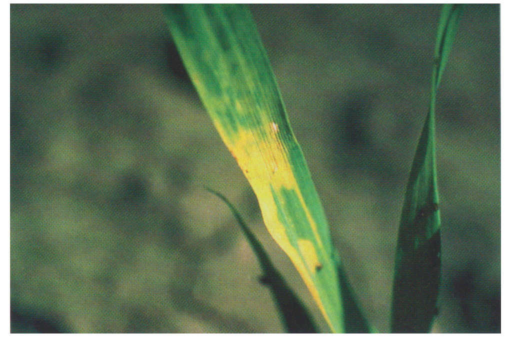


Photo 36
Leaf yellowing shown here is the result of aphids injecting their toxic saliva while feeding on leaves.

NUTRIENT DEFICIENCIES

Nutrient deficiency or toxicity stresses small grains and can appear similar to herbicide injury. Nitrogen (N), sulfur (S), iron (Fe), and copper (Cu) are the most common nutrient deficiencies that occur in spring wheat and barley. Nutrient deficiency symptoms are similar for spring wheat and barley.

Copper

Copper deficiency in spring wheat and barley occurs in high organic soils. Although copper is required in minute quantities to activate plant enzymes, the lack of the element in relation to other metal ions can affect yields. Copper deficiency symptoms in small grains develop on the youngest leaves and generally appear on younger plants instead of more mature ones. Leaves appear light green and become dry at the tips. In addition to leaf tips dying, severe copper deficiencies lead to leaves that become shriveled, twisted, and broken and eventually to the death of the plant. Roots of affected plants are stunted and are excessively branched. Copper deficiency in mature small grain plants can cause bleached heads, poor fill, and occasional partial head emergence. **See photo 37.**

Other factors causing white heads are frost injury, wheat stem maggot, head blight (scab), barley yellow dwarf virus, and common root rot disease.

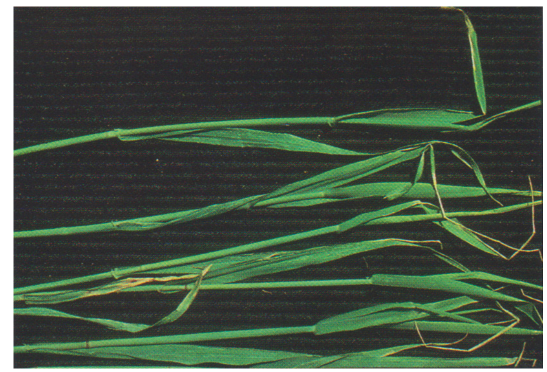


Photo 37
Copper deficiency in small grains is generally seen as a light green color in plants with leaf tips turning brown.

Photo 38
Wheat plants lacking in nitrogen first become light green, then yellow.

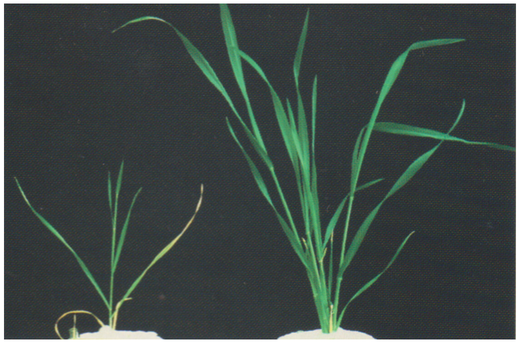


Photo 39
A laboratory demonstration shows the effects of phosphorus deficiency.

Photo 40
Wheat and barley plants without adequate phosphorus levels appear stunted, have reduced tillers and a poor root system.

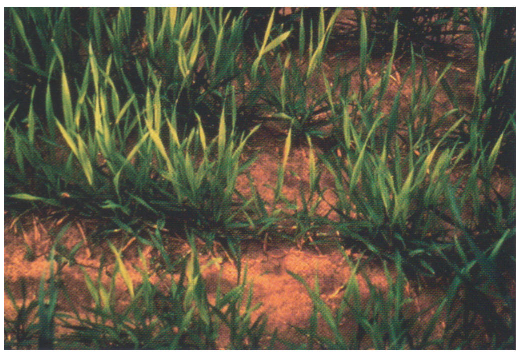


Photo 41
Yellowing of leaves is a characteristic of sulfur or nitrogen deficiency. Yellowing from nitrogen deficiency usually begins with older leaves and moves upward. Sulfur deficiency is usually more pronounced in younger leaves.

Nitrogen

Soil nitrogen can become limiting to small grains for a variety of reasons. Intensive cropping, with or without rotation, can deplete the soil nutrients starting with nitrogen. Excessive rain can leach nitrogen from sandy soils or cause denitrification, making nitrogen unavailable for plant uptake. Low levels of nitrogen in the soil can cause reduced tillering, stunting, poor kernel fill, and low grain protein. Nitrogen deficiency causes an overall yellowing of the plant with the lower leaves yellowing and dying from the leaf tips inward. Nitrogen deficiency can mimic injury symptoms caused by propanil (Stampede), imidazolinone, and sulfonylurea herbicides. **See photo 38.**

Phosphorus

Phosphorus deficiency is a common occurrence in spring wheat and barley. The common phosphorus deficiency symptom usually associated with many other crops, purple leaf discoloration, is less common with wheat and barley. The lack of vigor and poor tillering in small grains is the best indicator of phosphorus deficiency. Phosphorus deficiency symptoms are similar to injury caused by aryloxyphenoxypropionate and dinitroaniline herbicides. **See photos 39 and 40**.

Sulfur

Sulfur deficiency occurs only in sandy soils where the organic matter content is 2 percent or less. The symptom of sulfur deficiency in spring wheat and barley is an overall yellowing and stunting of the plant. It is difficult to distinguish sulfur from nitrogen deficiency. Sulfur deficiency is similar to injury caused by aryloxyphenoxypropionate, imidazolinone, and sulfonylurea herbicides.
See photo 41.

SOIL pH

Spring wheat and barley can be grown over a range of soil pH levels. However, micronutrient toxicities can occur if the soil pH is extremely low or high. Although spring wheat and barley can grow well under high soil pH, barley is more suitable for soils with a high pH and salinity.

High Soil pH

Problems associated with high pH in wheat production include decreased availability of micronutrients. The solubility of iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) decreases markedly with higher pH levels. High soil pH levels can limit the soil availability of Zn, Cu, and Mn, but generally are not a severe problem in major small grain production areas. Iron chlorotic areas in small grain fields appear in irregular patterned zones and generally occur in soils severely eroded or low in organic matter.

Viruses cause a wide range of symptoms in spring wheat and barley. The symptoms that develop will depend upon the strain of virus, crop variety, and cultural environment. Viruses in small grains are mainly transmitted by feeding aphids and mites that vector the virus. Once the virus enters the healthy plant it begins to replicate itself and moves cell to cell. Small grain virus infections can induce stunting, rosetting, mosaics, chlorotic streaking, yellowing, and necrosis. Chlorosis ranges from light green to yellow and in some instances white. Symptoms of virus infection are difficult to distinguish from the signs of malnutrition and adverse weather effects.

Barley Yellow Dwarf Virus

Barley yellow dwarf virus (BYDV) is transmitted by aphids. It is easily confused with a nutritional disorder or the effects of adverse weather. Visible symptoms are contingent upon the time of infection. Leaf discoloration in shades of yellow, red (seen on oat plants), and purple (rare) appear from the tip to the base and along the margins to the midrib. The earliest infection by BYDV is the 4- to 5-leaf stage resulting in slow growth and delayed maturity. Infected barley and wheat plants appear as a conspicuous yellow whereas infected oat plants have a reddish hue to their leaves. This disease is more pronounced during in cool weather (60–80°F) with ample sunlight. Barley yellow dwarf virus is carried by the oat birdcherry aphid and infestation coincides with large migrations of aphids. Infection sites can appear as stunted yellow single plants or as groups or clusters of yellow plants among healthy plants. This disease can be confused with aryloxyphenoxypropionate, benzonitrile, imidazolinone, and sulfonylurea herbicides. **See photos 42 and 43.**

Wheat Streak Mosaic Virus

Wheat streak mosaic virus (WSMV) occurs on spring wheat, barley, corn, rye, oats, and numerous annual and perennial wild grasses. It is the most serious on winter wheat grown in the Great Plains. The virus is vectored by the wheat curl mite (Eriophyes tulipae, [synonym] Aceria tulipae). Infection sites depend on three factors: 1) the population of the wheat curl mite; 2) proximity of virus infected grass plants, especially volunteer wheat; and 3) proper moisture levels that keep wheat actively growing where mites are maintained at high populations. Symptoms will vary according to the time of infection and the distribution of wheat curl mites. Many times, only margins of fields are infected. Infected spring wheat or barley plants are stunted, with mottled green-yellow streaked leaves. The streaks are parallel and discontinuous. Leaves and sometimes entire plants may become yellow and necrotic. Stunting and yellowing become more obvious as spring temperatures rise. The mite vector prefers to feed on the upper surface and near the margin of leaves. Mites feeding near the leaf margins causes the leaves to curl upward and toward the midvein. Crop injury from WSMV can be confused with injury symptoms of imidazolinone and sulfonylurea herbicide families. **See photo 44.**

Photo 42 Leaf discoloration in shades of red, yellow or purple that runs from leaf tip to base and from midrib to margins is typical of BYDV.

Photo 43 Aphids found on stunted and discolored plants are a good diagnostic clue of the presence of BYDV; however, this clue is not a definitive diagnosis.

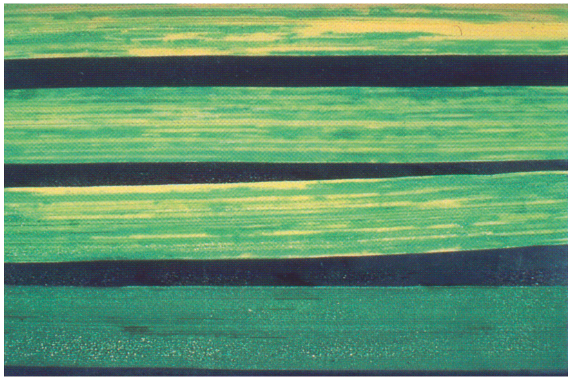
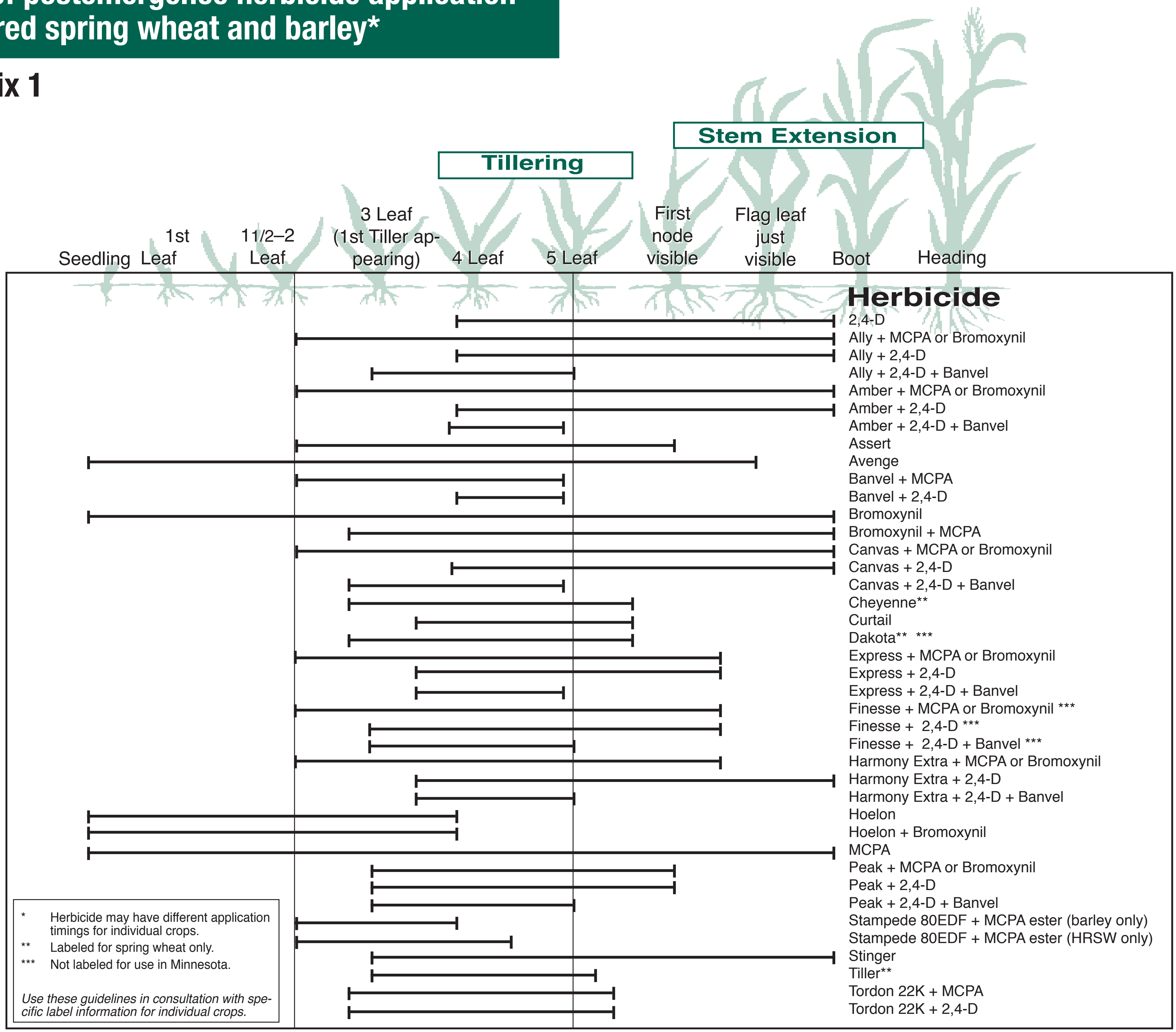


Photo 44 Plants infected with WSMV have green and yellow streaks that run parallel and are discontinuous on the leaf. Healthy leaf appears at the bottom.

Timing of postemergence herbicide application to hard red spring wheat and barley*

Appendix 1



* Herbicide may have different application timings for individual crops.
** Labeled for spring wheat only.
*** Not labeled for use in Minnesota.

Use these guidelines in consultation with specific label information for individual crops.

Adapted with permission from Identifying Leaf Stages in Small Grain, W-564, Terry Gregoire, Greg Endres, and Richard Zollinger, NDSU Extension Service, Fargo, 1997.

Trade and product names of herbicides used in spring wheat and barley

Appendix 2

Trade Name*	Product Name
Ally	metsulfuron
Amber	triasulfuron
Assert	imazamethabenz
Avenge	difenzoquat
Banvel	dicamba
Bison	bromoxynil
Bronate	bromoxynil+MPCA ester
Buctril	bromoxynil
Cheyenne	fenoxaprop + MPCA ester + thifensulfuron + tribenuron
Curtail	clopyralid + 2,4-D amine
Curtail M	clopyralid + MPCA ester
Cyclone	paraquat
Dakota	fenoxaprop + MPCA ester
Express	tribenuron
Far-Go	triallate
Finesse	chlorsulfuron + metsulfuron
Glean	chlorsulfuron
Gramoxone	paraquat
Harmony Extra	thifensulfuron + tribenuron
Hoelon	diclofop
MCPA	phenoxy-acetic acid
Moxy	bromoxynil
Peak	prosulfuron
Roundup Ultra	glyphosate
Stampede	propanil
Stinger	clopyralid
Tiller	fenoxaprop + MPCA ester + 2,4-D amine
Tordon	picloram
Treflan	trifluralin
2,4-D	phenoxy-acetic acid

*Reference to commercial products or trade names is made with the understanding that no discrimination is intended and no endorsements by the University of Minnesota Extension Service and North Dakota State University Extension Service are implied.

Glossary

Appendix 3

Alkaline soil — Any soil that has a pH value >7.3.

Biotype — A group of plants within a species that has biological traits that are not common to the population as a whole.

Chloroplast — A membrane-enclosed structure that contains the green pigment molecules (chlorophyll) essential for photosynthesis (i.e., food production).

Chlorosis — A yellowing in plant color due to a decline in chlorophyll levels.

Contact herbicide — A general classification for herbicides that are unable to move within a plant. A contact herbicide's effectiveness is highly dependent upon uniform coverage of treated soil or plant tissue.

Culm — The stem of a grass plant.

Denitrification — The biochemical reduction of nitrate or nitrite to gaseous nitrogen either as molecular nitrogen or as an oxide of nitrogen.

Herbicide mode of action — The sequence of events from absorption of the herbicide into the plant through plant death. Refers to all plant-herbicide interactions.

Herbicide site of action — The primary biochemical site that is affected by the herbicide, ultimately resulting in the death of the plant. Also referred to as herbicide mechanism of action.

Necrosis — The death of a specific plant tissue while the rest of the plant is still alive. Necrotic areas are generally dark brown in color.

Peduncle — Culm area just below the head and above the uppermost leaf of a barley or wheat plant.

Phloem — Plant tissue that functions as a conduit for the movement (translocation) of sugars and other plant nutrients.

Postemergence application — A time of herbicide application occurring after the crop and weeds emerge from the soil. Also referred to as a foliar application.

Preemergence application — A time of herbicide application occurring after a crop is planted but before the crop or weeds emerge from the soil.

Preplanting application — A time of herbicide application occurring before the crop is planted. Often followed by an incorporation (mechanical mixing) into the top 1 to 2 inches of soil. Often referred to as preplant incorporation treatment.

Pycnidium — A microscopic fruiting body that houses fungal spores.

Soil pH — The degree of acidity (or alkalinity) of a soil measured by an electrode or indicator at a specified soil-water ratio and expressed on a pH scale of 1 to 14.

Rosette — Short, bunchy habit of plant growth.

Systemic herbicide — A general classification for herbicides that are able to move away from the site of absorption to other parts of the plant.

Translocation — The movement of water, plant sugars and nutrients, herbicides, and other soluble materials from one plant part to another.

Xylem — Plant tissue that functions as a conduit for the upward movement (translocation) of water from the roots to above-ground plant parts.

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Photo 34
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Produced by the Educational Development System, University of Minnesota Extension Service.