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MONTANA WHEAT
PRODUCTION GUIDE

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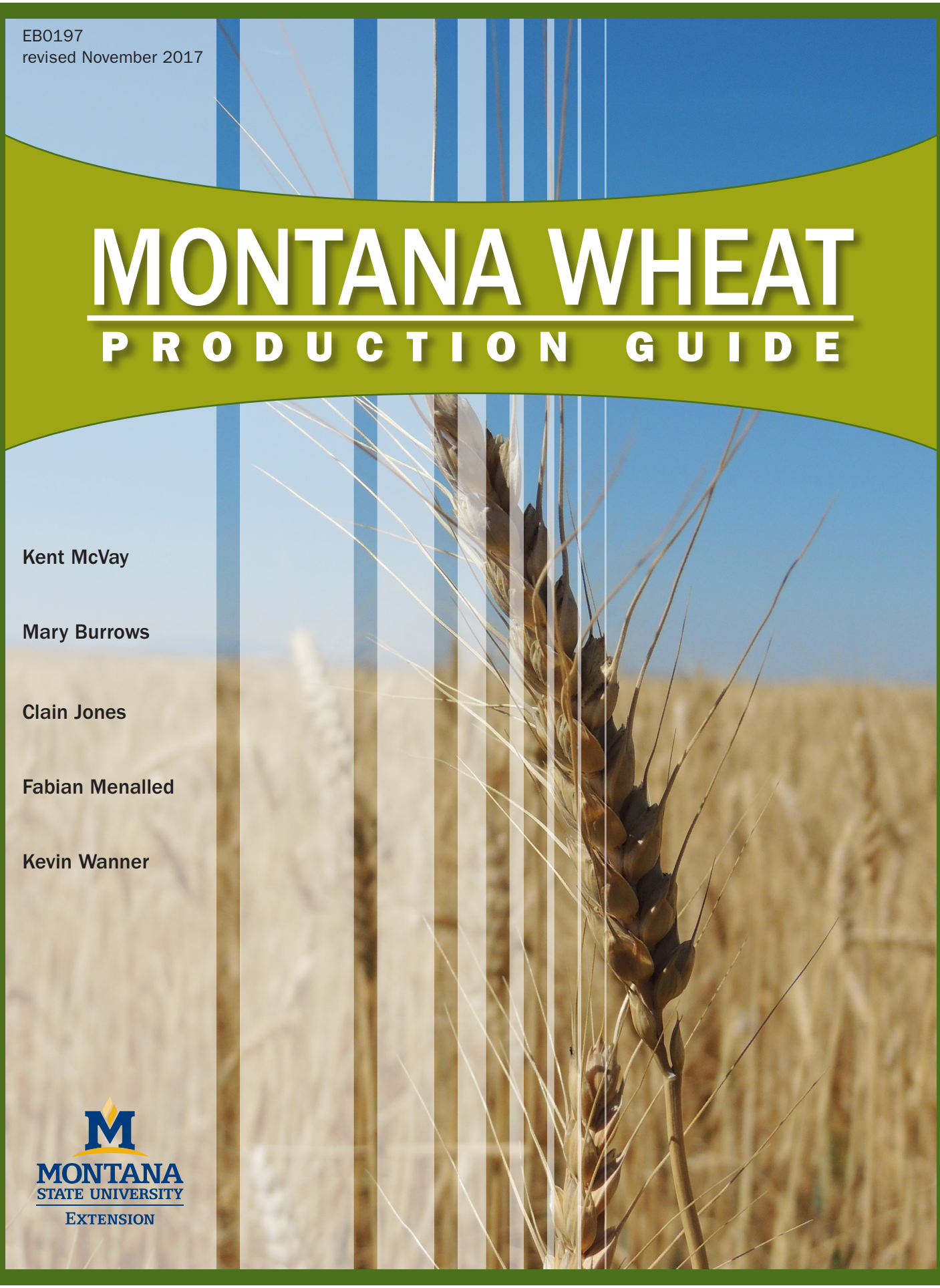

MONTANA STATE UNIVERSITY
EXTENSION

Cereal Grain Development Scales

Growth Stage	Description	Zadoks	Feekes	Haun
Germination	Dry seed	00		
	Start of imbibition	01		
	Imbibition complete	03		
	Radicle emerged	05		
	Coleoptile emerged	07		
	Leaf at coleoptile tip	09		0.0
Seedling Growth	First leaf through coleoptile	10	1	
	1st leaf unfolded	11		1.+
	2 leaves unfolded	12		1.+
	3 leaves unfolded	13		2.+
	4 leaves unfolded	14		3.+
	5 leaves unfolded	15		4.+
	6 leaves unfolded	16		5.+
	7 leaves unfolded	17		6.+
	8 leaves unfolded	18		7.+
	9 or more leaves unfolded	19		
Tillering	Main shoot only	20		
	Main shoot and 1 tiller	21	2	
	Main shoot and 2 tillers	22		
	Main shoot and 3 tillers	23		
	Main shoot and 4 tillers	24		
	Main shoot and 5 tillers	25		
	Main shoot and 6 tillers	26	3	
	Main shoot and 7 tillers	27		
	Main shoot and 8 tillers	28		
	Main shoot and 9 or more tillers	29		
Stem Elongation	Pseudo stem erection	30	4-5	
	1st node detectable	31	6	
	2nd node detectable	32	7	
	3rd node detectable	33		
	4th node detectable	34		
	5th node detectable	35		
	6th node detectable	36		
	Flag leaf just visible	37	8	
	Flag leaf ligule/collar just visible	39	9	

Cereal Grain Development

Growth Stage	Description	Zadoks	Feekes	Haun
Booting	Boot Initiation	40		
	Flag leaf sheath extending	41		8-9
	Boots just swollen	45	10	9.2
	Flag leaf sheath opening	47		
	First awns visible	49		10.1
Inflorescence Emergence	First spikelet of inflorescence visible	50	10.1	10.2
	¼ of inflorescence emerged	53	10.2	
	½ of inflorescence emerged	55	10.3	10.5
	¾ of inflorescence emerged	57	10.4	10.7
	Emergence of inflorescence complete	59	10.5	11.0
Anthesis	Beginning of anthesis	60	10.51	11.4
	Anthesis half-way	65		11.5
	Anthesis complete	69		11.6
Milk Development	Kernal watery ripe	71	10.54	12.1
	Early milk	73		13.0
	Medium milk	75	11.1	
	Late milk	77		
Dough Development	Early dough	83		14.0
	Soft dough	85	11.2	
	Hard dough	87		15.0
Ripening	Kernel hard (difficult to divide by thumbnail)	91	11.3	
	Kernel hard (no longer dented by thumbnail)	92	11.4	16.0
	Kernel loosening in daytime	93		
	Overripe, straw dead and collapsing	94		
	Seed dormant	95		
	Viable seed giving 50% germination	96		
	Seed not dormant	97		
	Secondary dormancy induced	98		
	Secondary dormancy lost	99		

Modified from www.extension.umn.edu/agriculture/small-grains/growth-and-development/spring-wheat/index.html

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MONTANA STATE UNIVERSITY EXTENSION

Preface

The intent of this publication is to provide current information on wheat production for producers within the state of Montana. The authors have attempted to provide all the basic information necessary for the establishment and management of a wheat crop. More detailed information can be found on certain topics by following the links to the referenced websites. Many of the references in this publication are available through MSU Extension Publications, as well as through your local county Extension office.

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Introduction

Between five and six million acres of wheat are harvested annually in Montana, representing an annual market value greater than $1 billion (Anonymous). For the years 2007-2016, approximately 48% of this acreage was spring wheat, 42% winter wheat, and 10% durum. Durum acres have been steady at a half million acres for the past decade while spring wheat acreage has fluctuated from 2.5 to nearly 3 million, trading acreage mostly with winter wheat. Recent trends show spring wheat acreage approaching that of winter wheat by 2016. During this same period pulse acreage in Montana has grown from 300 thousand to over 1 million acres with little impact on total wheat acreage. The increase in pulse acreage has likely come from a decline in fallow practices but also includes some acreage from the Conservation Reserve Program (CRP) as contracts expire. Interestingly reduction of fallow has not reduced winter wheat yields. On the contrary, yields have increased an average of 0.4 bu/year over this same time period.

This production guide is designed to help both new and experienced growers and agricultural consultants find science-based answers when time is short and a management decision must be made. The goal of this publication is to provide those answers and connect you to relevant sources for wheat production information.

Growth and Development

Wheat *(Triticum aestivum* L.) is an annual grass with both winter hardy and spring cultivars. Winter wheat generally has greater yield potential than spring wheat, especially when moisture is adequate. Yields reported by National Agricultural Statistics Service (Anonymous) for the past 10 years (2007-2016) indicate Montana spring wheat averaged 29 bu/acre while winter wheat averaged 40 bu/acre. As a general rule, in any given year spring wheat yield will be about two-thirds that of winter wheat.

In Montana, winter wheat is more likely to be grown following fallow than spring wheat. For some regions of the state like the northeast, winter kill of winter wheat can be a significant limitation. A large acreage of durum wheat *(Triticum durum* Desf.) is produced in Northeast Montana where breeding efforts, industry support, and sufficient summer rains favor this crop.

It is important to understand growth and development of the wheat plant in order to correctly use fertilizers, plant growth regulators, and pesticides for crop production. Many pesticide labels restrict application to when the crop is at certain growth stages referred to as either Feekes or Zadoks growth scales (see front inside cover of this publication). Applications of nutrients, herbicides, plant growth regulators, fungicides, and irrigation water should be based on the stage of crop development rather than calendar dates. Poor timing of these operations can reduce effectiveness or result in crop injury and yield loss. Crop growth rates will vary depending on variety, planting date, and growing conditions, including nutrient and water availability.

Variety Selection

One of the most important management decisions a producer makes is the choice of variety. Variety trial information is compiled each year from trials conducted near each of the Research Centers in Montana. This data is available in several formats but one of the easiest ways to find data is through the Variety Selection tool on the Southern Agricultural Research Center website (www.sarc.montana.edu/php/varieties/). Results for the past 10 years are available in a format that gives the user control. By choosing locations, and years, the results displayed will be an average over your inputs. For example if you want to see one year's data, select a location and year and that data is retrieved. The displayed results can then be resorted by yield, test weight, or protein to help compare varieties. To average two locations, just select both locations for a particular year and then the data is recalculated and displayed. In this way you can build average results for multiple locations over multiple years. This is exactly how you should evaluate a variety. Select a variety that performs well over multiple trials in space and time. Yield may be most important, but protein and test weight are important as well. Disease and insect resistance or tolerance are important characteristics that should also be compared. By selecting the variety name on this web tool, a written description with further information on disease resistance and characteristics such as solid stems will be retrieved. By choosing multiple varieties with disease resistance and other defensive traits, risk can be spread in case of pest outbreaks.

Across the state, but especially in Montana's Golden Triangle region, spring wheat is very susceptible to sawfly damage. Where sawfly pressure is high our current best management recommendation is to grow a solid-stem or semi-solid stem variety of wheat to provide some resistance to damage. This and other information on specific varieties can be found in the annual "Performance Evaluation and Recommendations" publication located on the MSU Plant Sciences and Plant Pathology (PSPP) website (plantsciences.montana.edu/crops/index.html). The latest evaluations of varieties under sawfly pressure are presented in table form and can be found within the written variety descriptions.

Winter kill of winter wheat can be a concern for many producers. Winter survival and associated yields are evaluated each year in the Sidney and Williston, ND, areas. Data is presented in the Annual Performance Evaluation and Recommendation publication found on the PSPP website. Use this information to help you decide on the right variety for your operation.

Several herbicides are labeled for control of downy and Japanese brome in winter wheat. These herbicides have specified conditions for use to ensure winter wheat tolerance and effective control of the annual bromes. Another option for brome and grassy weed control is the use of 'Clearfield' wheat, varieties which are specifically bred for tolerance to the herbicide Beyond (imazamox). Beyond will control downy brome and other select weeds. Check the label. Clearfield crops should not be grown more than 2 in 4 years as per the Beyond label. This restriction is designed to reduce the risk of developing herbicide-resistant weeds to Beyond by rotating chemical modes of action and reducing selection pressure.

New varieties are released each year. Yield levels have steadily increased over time, end use qualities have improved, while pest resistances have been broadened through efforts of breeders. Periodically check how the variety you grow performs as compared to the latest new releases. Evaluate new varieties that are available and look for a variety that shows greater yield potential or has the specific disease or insect-resistant package you need to address current challenges. If the variety you plant is more than five years old, there is likely a new variety that is better adapted, higher yielding or of higher quality.

Seeding Dates and Rates

Winter wheat should be planted early in the fall as to have four to six weeks of growth prior to dormancy. This provides ample time for plants to establish a root system, a crown, and a number of tillers. Tillers that form during the fall produce most of their growth in the spring. Planting too early can result in rank growth in the fall, increase the potential for the infestation by diseases which are spread through a "green bridge" (see Plant Disease section, beginning page 10), and risk depleting the soil of water which can leave the crop susceptible to winter kill. Planting too late can result in small plants with few tillers and shallow root systems that may also be at risk of winter kill. Row spacing of winter wheat has not been found to be critical between 4" and 12" for grain yield in the Northern Great Plains (Lafond and Gan, 1999). Closer rows tend to crowd out weeds and provide slightly higher plant populations likely due to less inter-seedling competition. But, wider rows in no-till tend to perform better since less movement of surface residue occurs when seeding is required.

For dryland winter wheat, a planting rate of 40 to 60 lb/acre (15 to 21 seeds/ft^2) of pure live seed (PLS) is usually sufficient to establish the crop. In high residue no-till systems, increasing the rate to 60 to 80 lb/acre (21 to 28 seeds/ft^2) PLS is recommended to compensate for some poorly placed seeds that won't establish. Seeding rate should be increased if seeding is delayed to compensate for the likelihood of reduced tillering. As a rule, don't drill into a green (weedy) seedbed. First either spray or till the field prior to planting so that the seedbed is weed-free. Try to plant into moisture. Seeds should be placed at least 1 inch below the surface, but if moisture is deeper, set the drill to place seeds up to 3 inches deep. It's best to plant into moisture to get the crop established on time rather than to drill into dry soil and be dependent on subsequent precipitation to establish the crop. If time is running out in the fall, wheat can be successfully dusted in and will establish after moisture is received. A good management practice by most producers is to first wait for and then spray a flush of winter annual grasses like downy brome or cheatgrass prior to planting winter wheat.

Spring wheat should be planted when average soil temperature at 2 inches exceeds 40°F. Planting earlier can delay germination resulting in weaker, less vigorous plants. If a pre-plant herbicide has been applied, for example a triallate, delayed emergence can increase seedling mortality from herbicide poisoning. Both spring and winter wheat will continue to grow into the summer season as long as soil moisture is available and maximum daily air temperatures remain below the 90s°F. For this reason, delayed planting of spring wheat typically results in reduced yields because of a shortened grain-filling period.

Wheat seeding rates

Desired populations when planted on time. Increase seeding rate if planting is delayed.

Crop	Plants/acre x 1,000,000	Plants/ft^2
Dryland winter wheat	0.7 – 0.9	15 -21
Dryland spring wheat	1.0 – 1.2	22 - 28
All irrigated wheat and durum	1.3 – 1.4	30 - 32

For unusually large or small seed, correcting for seed density (seeds/lb) is a good practice. Use the following formula:

$$\text{Seed Rate (lbs/a)} = \frac{\text{Desired plants/a}}{\text{Seeds/lb x \%Germ x \%Stand}}$$

Example: Assume your seed has a density of 17,500 seeds/lb.

The germination is 98% and you expect to establish 90% of what you plant.

$$\text{Seed Rate (lbs/a)} = \frac{1{,}000{,}000}{17{,}500 \times 0.98 \times 0.90}$$

$$= 64 \text{ lb/acre}$$

Soil temperature is affected not only by air temperatures, but also by residue levels. In tilled or fallow soils where much of the residue has decomposed, soils will warm more quickly in the spring than where high levels of residue remain. Previous crops of peas or lentils produce less residue which will largely decompose by the following spring. These conditions allow soils to absorb solar energy and warm more quickly as compared to fields with high levels of residue.

If planted on time for your region, dryland seeding rates for spring wheat should be 60 lb/acre PLS (21 seeds/ft^2). If spring wheat planting is delayed, the seeding rate can be incrementally increased up to 90 lb/acre (30 seeds/ft^2). Spring wheat tillers less than winter wheat so plant a high enough population to optimize yield potential. Irrigated spring and winter wheat should be seeded at 90 to 100 lb/acre (30 to 34 seeds/ft^2). Row spacing of spring wheat has not been shown to influence grain yield in the range of 6 to 12 inches for dryland production, but tighter rows for irrigated systems is recommended because of the higher plant populations.

Seeds should be placed at 1 to 2 inches below the soil surface into good soil moisture. Shallow planted seed typically emerges quicker. A minimum planting depth of 1 inch will ensure that the crown of the plant develops and remains below the soil surface.

Recent research in Alberta, Canada (Beres et al., 2011), indicates an interaction of wheat stem sawfly (WSS) with plant populations of spring wheat or durum. The solid-stemmed cultivar Lillian generally had optimized grain yield and high and stable pith at seeding rates of 23 to 33 seeds/ft^2. A higher seed density for hollow-stemmed treatment was warranted based on the findings that WSS infestation rates decreased and parasitism of WSS increased at higher seeding rates. For wheat produced in regions prone to WSS infestation the authors encourage seeding rates of $\leq$ 28 seeds/ft^2 for solid-stemmed cultivars and increased seeding rates of 37 to 42 seeds/ft^2 for hollow-stemmed varieties.

Cropping Systems

FALLOW SYSTEMS

The 2012 Ag Census indicated 25% of Montana's over 12 million crop producing acres were fallowed. This amount is down from 29% in 2007 and includes land planted to cover crops that were not harvested. In the early 20th century, the practice of fallowing land was widely adopted across the Great Plains to reduce the risk of crop failure in dry years. Fallow cropping is most successful where soils are deep. Soil texture is also important. For example, a silt loam soil can hold 10 inches of available water in a 5 foot profile (depth). Plants extract water from wherever they establish roots. A deep silt loam soil, once charged with water, provides a great safety net for crops like winter wheat which can establish roots to 5 feet. But spring and durum wheat only produce roots to a depth of about 4 feet. That limits their access to the soil water reservoir. Because of their texture, lighter sandy soils hold less water and thus store less water. Shallow soils are also restricted in how much water they can store because of the lack of soil depth. For example, a 3 foot sandy soil over a cobbly subsoil may only retain 4 to 5 inches of available water. Fields with restrictions in soil water storage like this are not good candidates for fallow systems. They provide a poor safety net of soil water storage for crop production in dry years.

It is important to keep the soil weed-free during the fallow period as weeds use water. Herbicides such as glyphosate are typically used during the fallow period. To help prevent the development of glyphosate resistant weeds, tank mixing of products with other modes of action for use during the fallow period is recommended. Tillage can be used but is not as effective in retaining moisture as chem-fallow systems. Crop residue on the surface reduces soil evaporation, helps capture precipitation by preventing soil crusting and sealing, and mulches the soil surface, all which helps to retain moisture.

Precipitation storage efficiency (see Box below) varies through the year and the existing soil water status. During the summer, when evaporation potential is highest, PSE is typically lower than during the fall and winter. In fact PSE can actually be negative, which means more water is lost than is gained through precipitation. This occurs regularly during the summer following the crop year as shown in Figure 1, page 4 (Nielsen, Unger, and Miller, 2005).

Designing cropping systems to minimize fallow during the low efficiency period of May through September is one way to improve water use efficiency. In a wheat-fallow system 51% of the non-crop period occurs during the highly efficient

Precipitation Storage Efficiency (PSE)

Definition: the amount of water stored in the soil as a percentage of the total amount of precipitation received.

Example: Assume your field receives 12 inches of precipitation over the course of one year. If soil moisture is determined at the beginning of this period, and again at the end, the total amount of water stored can be calculated. Assume we can account for an increase of 9 inches of soil moisture.

PSE = 9/12 X 100

= 75%

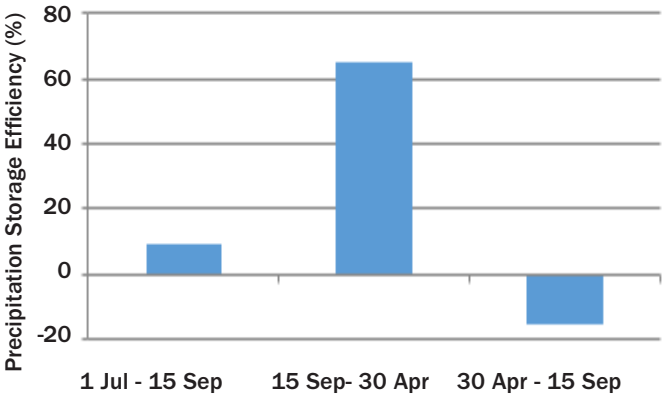


FIGURE 1. Precipitation storage efficiency in three time intervals in the fallow period of a wheat–fallow system in NE Colorado.

fallow period directly following harvest while a significant 31% occurs in the summer when fallow efficiency is low. By using a more intense rotation of wheat–corn–proso millet, Colorado researchers were able to shift the periods of fallow or non-crop time so that 79% of the fallow was in the highly efficient storage period directly following a crop while only 5% remained in the low-efficient period. This practice improved precipitation storage efficiency, which in return improved profitability.

In Montana, it's difficult to successfully grow warm-season grasses like corn and millet in dryland production systems, but there are cool-season crop options that may be used to improve water use efficiency. For example, alternating wheat with pulse crops such as peas or lentils in continuous crop production can make better use of stored moisture from the fall and winter non-crop period following wheat harvest. Pulses are shallow rooted, using moisture only from the upper 2-3 feet of soil. They grow quickly and mature early as compared to wheat, providing a short but highly efficient fallow period following harvest. Late summer and fall rains can recharge the surface soil for fall or spring planting while deep moisture is retained for the crop that can be used the following year.

With the advent of no-till production systems, the need for fallow has been lessened. It is no longer necessary to perform tillage operations prior to planting to prepare a seedbed. Most modern-day equipment can plant through high levels of residue. And when the land is continuously cropped, yields and the accompanying residue are more manageable as compared to the high level of residue that can occur in a wheat-fallow system. In fact when a producer makes the move from fallow systems to continuous cropping, rather than working the soil to reduce residue levels, management to maintain residue on the soil surface to help retain precipitation becomes one key to success.

TILLAGE

Wheat can be successfully produced under any tillage system. As no-till and reduced-till systems have become the norm for Montana dryland wheat production, the questions have changed from "Will using no-till reduce my yield?" to "Will an occasional tillage operation hurt or improve my wheat yield?" The benefits of reduced-till systems include: lower labor and fuel costs, reduced soil erosion and loss from wind and rain, less labor or time in the field, and more efficient use of stored soil moisture. The trade-off is a greater need for herbicide use, greater potential for disease or insect damage and more expensive planting equipment.

In most instances the benefits of no-till systems outweigh the costs. Comparing overall herbicide programs of no-till and conventional-till systems reveals that the difference in expenses for a no-till system occurs primarily during the fallow period. Within-crop herbicide use is likely to be similar across tillage systems. The risk of greater disease or insect pressure in a no-till system can be offset by adopting appropriate crop rotations and by choosing varieties with better disease and insect resistance. When it is time to replace a grain drill, consider choosing equipment that provides greater flexibility. Some soil conservation districts have no-till drills available to try, which gives producers hands-on experience. A no-till seeder can achieve good stands in diverse and difficult seedbeds and many have the added benefit of delivering fertilizer in bands separate from the seed row. Successful no-till begins with harvest and residue management. It's important to evenly distribute straw and chaff across the width of the harvested swath. Adding straw choppers to the combine helps to distribute straw and accelerate residue break down. An alternate option is to use a stripper header that strips the grain from the head without cutting the straw. This eliminates the need for redistribution and does the best job of maintaining an even distribution of residue in the field.

In irrigated cereal grain production, the levels of straw associated with high yields requires management to prepare the field for the next crop. Options include tillage, baling, or burning the straw. Annual burning of straw is not considered a sustainable practice as soil organic matter content will decline under sustained burning. Using short-statured, semi-dwarf varieties can help reduce total tonnage of residue. Tillage is common especially in flood-irrigated systems where water flow and uniform water distribution is critical to production of the next crop.

As found in dryland systems, there are benefits to not tilling the soil in irrigated systems. The challenges to irrigation in a no-tillage system are residue and water management. But even if straw is removed, enough disease organisms in the remaining residue or soil will survive to potentially infect the next crop. So crop rotation is even more important in a no-tillage irrigated system. Grain drills and planters must be of no-tillage quality to cut through residue and correctly place the seed. Greater

success can be found by upgrading irrigation systems to overhead sprinkler or drip systems to maintain uniform water distribution. There are efforts being directed toward the use of cover crops to help manage residue and disease pressure but no recommendations for their use can be made at this time. One theory is that diverse cover crop species help break down residue by lowering residue C:N ratios. There is a window of time after cereal grain harvest to include a cover crop, but for irrigated crop rotation situations in Montana, the next crop is likely corn, sugar beet, or canola. These crops grow late into the fall and many times are harvested after soils have begun to freeze and the snow is beginning to fly. The next crop following a full season crop is usually a cereal planted just as spring emerges. There is little time for a cover crop in that early spring window. Residue management in no-till systems can be addressed through crop choice. Dry beans or soybeans have a place in southcentral Montana and result in lower residues (as compared to cereals) after harvest. Chickpeas and dry peas produce less residue and may be crops that could be economically competitive under irrigated management. Chickpea yields over 4000 lb/acre have been achieved on small plot variety trials at Huntley.

CROP ROTATIONS

Recent studies in North Dakota (Table 1) have helped quantify the rotation benefit of crops in a study largely independent of the impact of pests. These researchers used a matrix of 10 different crops planted in strips in two consecutive years with the second year strips oriented perpendicular to the first year's strips. This provided a data set of each crop on 10 different kinds of residue. Table 1 shows results combined over crop types. Warm season grasses like corn, grain sorghum, and millet and oilseed crops like sunflower and safflower give positive yield responses of 50 to 60% to rotation, while the cool season grass crops like barley and spring wheat show little yield response due to rotation. These results should not be taken to mean rotations don't improve crop production. On the contrary, crop rotation is a great way to help manage residue and reduce pest levels of weeds, diseases and insects. Additionally crops such as spring pea, mustards, canola, sunflower, and safflower can be rotated with small grains in continuous crop systems to help manage the amount of residue present at wheat planting time. The low C:N ratio of pea residue allows it to decompose quicker than wheat straw, which reduces the total amount of residue on the ground at wheat planting time. Crops like canola and mustard produce less residue at harvest so alternating these crops with wheat, a high residue producing crop, is a good management practice.

Nutrient Management

A soil's available nutrient level is accomplished by conducting a soil test. Fall soil tests are suitable for phosphorus (P) and potassium (K) sampling, however, spring soil tests best represent plant-available nitrogen (N). Sandy or shallow (< 2 feet deep) soils with greater than 60 lb N/acre are likely to lose N over winter (Jones et al., 2011). Ideally, fields should be sampled each year, and over time a predictable history of soil fertility levels will emerge (e.g., N loss or gain over winter). Mobile nutrients such as N and sulfur (S) can vary greatly from year to year, depending on fertilizer applications, prior rotation, precipitation, crop type and yield. As such, fertilizer recommendations for these nutrients may fluctuate more and are largely influenced by yield goal. In contrast, non-mobile nutrients in the soil, such as P and K, are more stable and fertilization rates are determined by soil test levels. Other soil properties like pH and organic matter are also fairly stable and are slow to change. Because of inherent variability, both in soils and in sampling patterns, greater faith can be placed on a running average for these soil parameters rather than results from any single soil test.

Nutrient removal can be significant for wheat, especially if straw is harvested (Table 2, page 6). Typically in Montana the three nutrients that need to be supplied within a fertility program are N, P, and K, while the rest of the essential nutrients are usually adequately supplied by the soil. Potassium is a comparatively large component of straw so soil K levels should be monitored especially when haying or removing straw. Pictures and descriptions of nutrient deficiency symptoms can be found in the MSU Extension Publication *Plant Nutrient Functions and Deficiency and Toxicity Symptoms* (McCauley et al., 2011).

TABLE 1. Relative expected yield response of a crop following various previous crops.

Residue	CS grass	WS grass	CS Pulse	Canola	Sun or Saf
cool season grass	1.00	1.59	1.19	1.09	1.81
warm season grass	0.84	1.00	1.04	0.93	1.84
cool season Pulse	1.02	2.09	1.00	1.16	2.04
canola	0.99	1.75	1.00	1.00	1.67
sun or safflower	0.95	1.13	0.99	1.00	1.00
average	0.96	1.51	1.05	1.04	1.67

Source: data from (Tanaka et al. 2004 and 2007)

TABLE 2. Nutrients removed in wheat grain and straw.

Nutrient	Grain lb/bushel	Straw lb/ton
Nitrogen, N	1.25	14.5
Phosphate, P_2O_5	0.62	3.6
Potash, K_2O	0.38	25.0
Sulfur, S	0.08	3.7
Calcium, Ca	0.025	4.4
Magnesium, Mg	0.15	2.2
Copper, Cu	0.0008	0.007
Manganese, Mn	0.002	0.11
Zinc, Zn	0.0035	0.03

NITROGEN

Nitrogen is the nutrient needed in the greatest quantity, and its application typically provides the biggest yield boost. Nitrogen deficiency symptoms are characterized by an overall yellowing of the plant followed by generally stunted growth (Wiese, 1996). Since N is mobile within the plant, under limited N conditions, N from the lower leaves will move to newer leaves causing chlorosis in older tissues. Reduced cell growth and cell division as well as slowed protein synthesis can result in smaller plants and conditions more favorable for disease.

Rate In Montana, winter wheat requires an average of 2.6 lb N/bu for 12.5% protein grain, and spring wheat requires an average of 3.3 lb N/bu for 14% protein grain. If growers want higher protein in winter wheat, MSU suggests using the spring wheat fertilizer guidelines. Credit is given for any nitrate present in the soil, for residue from previous crops high in N (e.g., legumes), and for soil organic matter (SOM) greater than 3%. Additional N is required if SOM is less than 1% and for continuous cropping on small grain stubble.

Montana research shows the N benefit to wheat following legumes averages approximately 10 lb N/acre after one rotation of annual legume (e.g., peas, lentils), 20 lb N/acre after three or more rotations of annual legume, and 40 lb N/acre after alfalfa or sweet clover. In contrast, stubble left from a prior small grain crop will tie up (immobilize) some N. An additional 10 lb N/acre is suggested for each 1,000 lb stubble, up to a maximum of 40 lb N/acre. Reduced and no-till management lowers the rate at which N becomes available from plant residue. Therefore, dryland wheat may require an additional 20 lb N/acre for up to 15 years after conversion to no-till management.

Variable-rate or site-specific rate technology adjusts N rates for within-field growing conditions. It has the potential for maximizing net revenue and N use efficiency (Barroso et al., 2014), yet, at this time, the economic benefit of variable-rate technology is inconsistent in our region. In a simplified version, fields can be divided into zones with historically low, medium, and high productivity with N rates adjusted by those zones.

The effectiveness of N fertilization practices can be evaluated by compiling several years of grain protein levels. In Montana, if winter wheat protein is under 12.5%, then yield and protein have likely been N limited. To gain one protein point (%) in winter wheat would require approximately an additional 22 lb N/acre with less than six inches of growing season precipitation or 33 lb N/acre with more than 12 inches of growing season precipitation. For spring wheat, grain protein under 13.2% indicates that yield and protein have been compromised by under-fertilization (Jones and Olson-Rutz, 2012).

There are two excellent tools available online to help calculate fertilizer needs. Fertilizer Recommendation tool (http://www.sarc.montana.edu/php/soiltest) requires the user to input soil test information, crop and yield goal, and then calculates the MSU suggestions as specified in *Fertilizer Guidelines for Montana Crops* (Jacobsen, et al., 2005). Another tool that takes into account fertilizer costs, grain prices, and protein discounts is the Economic Nitrogen Calculator (http://www.msuextension.org/econtools/nitrogen/index.html). This tool provides an N recommendation as well as an interactive graph revealing the sensitivity of input variables. MSU Extension MontGuide *Developing Fertilizer Recommendations for Agriculture* (Dinkins and Jones, 2013) provides the steps for 'hand-calculating' fertilizer rates.

Placement Ammonia and ammonium-based fertilizers (like urea [46–0–0]) should be subsurface banded at least two-inches (before packing), or if broadcast, then incorporated either with tillage (at least three inches) or through irrigation or precipitation. A minimum of 0.5-inch of liquid precipitation is needed in a single event to move urea sufficiently into the soil to minimize volatilization loss (loss as ammonia gas to the air). See *Management to Minimize Nitrogen Fertilizer Volatilization* (Jones et al., 2013) and Crop and *Fertilizer Management Practices to Minimize Nitrate Leaching* (Jones and Olson-Rutz, 2011) for more information.

A starting safe rate for seed placed N is 10 lb ($N + K_2O$)/acre. Safe rates of seed-placed fertilizer increase under the following conditions: as soil texture goes from light (sandy loam) to heavy (clay); with moist rather than dry soils; in soils with greater than 3.5% soil organic matter or pH less than 7; with wider openers; and as row spacing decreases. Polymer-coated urea (PCU) can be seed-placed at two to three times the safe rate of conventional urea. Use online safe seed-placed fertilizer rate calculators (see Weblinks on page 27).

Timing Nitrogen available to wheat plants up through stem elongation generally benefits yield, while N available after

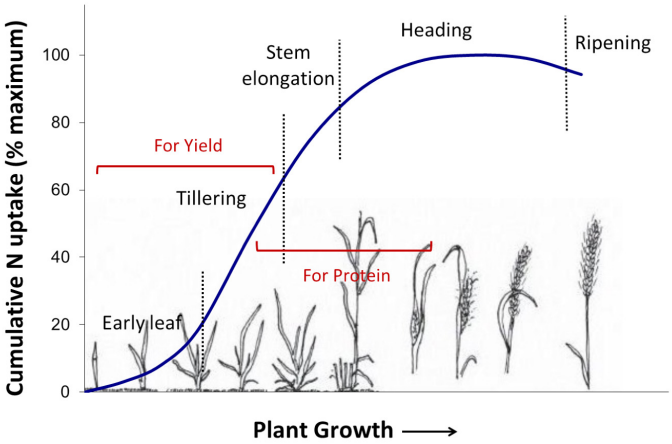


FIGURE 2. Cumulative N uptake by wheat over the growing season (Jones et al., 2015).

stem elongation contributes directly to grain protein (Figure 2). Fertilizer-N must convert to plant available N (ammonium or nitrate) and reach the plant roots. This can take several weeks to months after application, depending on N source, soil moisture, and temperature.

Sources that slowly provide N, such as polymer-coated urea (e.g., ESN), manure, or legume residue, are generally best incorporated in the fall in order to provide N for early growth. Fertilizers with readily available N (e.g., urea and urea ammonium nitrate [UAN; 28-0-0 or 32-0-0]) are best applied shortly before seeding or until mid-tillering to benefit yield and minimize over-winter loss. Nitrogen for protein can be applied later.

Split applications allow for in-season N adjustment based on precipitation to date. Pre-plant and at-seeding N should be great enough to meet the crop's early needs and for longer if there is a risk that high rainfall amounts would interfere with in-season field access. Topdressing can then boost yield and/or protein. Applications after stem elongation have less chance of causing lodging and will go towards grain protein. Ideally, N for protein is applied at flowering. However, in dryland production, the ability to incorporate fertilizer applied anytime between boot to shortly after flowering with rainfall is more important than timing the application exactly at flowering.

Nutrient Uptake Timing by Crops: to assist with fertilizing decisions (Jones et al., 2015) provides information on nutrient accumulation by crops to guide fertilization application timing. *Practices to Increase Wheat Grain Protein* (Jones and Olson-Rutz, 2012) provides information to make decisions about late-season N application for protein (e.g., flag leaf N concentration and chlorophyll readings).

Source Nitrogen fertilizers have different potentials for N loss to leaching and volatilization depending on how quickly they convert to ammonium and nitrate and how long those are in the soil before crop uptake. Ammonium sulfate (21-0-0-24) and urea ammonium nitrate have lower volatilization potential than urea but equal leaching potential. Dry urea is still the best choice if it can be incorporated by tillage or by more than 0.5-inch of water in a single event.

Specialized products such as polymer-coated urea (e.g., ESN), or urea treated with N-butyl-thiophosphoric triamide (NBPT, e.g., Agrotain®, N-Fixx, Arborite® AG) or other enzyme inhibitors (NBPT + NPPT, e.g., Limus), have lower volatilization losses than regular urea. These products are constantly evolving and haven't all been tested for a range of growing conditions; however, some generalities are emerging.

NBPT delays urea conversion to ammonia, thus buying time for incorporation by precipitation. This can increase wheat grain protein by up to 0.75 percentage points but may not significantly increase grain yield (Engel and Romero, 2016).

Polymer-coated urea products are designed for controlled release to match crop need and reduce loss to volatilization and leaching (Olson-Rutz et al., 2009). They have not consistently increased wheat yields or protein in our region because their release of N is temperature and moisture dependent. Under cool or dry conditions, N release tends to be slow. Fall seed-placed polymer-coated urea may increase yield over fall broadcast urea, especially in wet conditions when urea may leach over winter. If fall seed-placed application is used to avoid a spring broadcast application, then the extra cost might be justified. Late winter and early-spring broadcast or subsurface applications of polymer-coated urea do not usually benefit yield, but may increase protein. An option is to use a blend of urea and a slow- or controlled-release N fertilizer, yet even with a blend the yield or protein benefit might not offset the extra cost (Walsh et al., 2016).

Legumes in rotation are an economical N source. The benefits of legumes depend on the species, stage at which they are terminated, whether they are harvested for seed, forage or grown for green manure cover crops, and the number of times planted in rotation.

Termination of cover crops by approximately first bloom is key to preventing yield losses in the subsequent wheat crop because of high water use after bloom (Miller et al., 2006). Legumes should make up more than 50% of a cover crop biomass in order to contribute substantial available N to the following crop (Sullivan and Andrews, 2012).

Based on Montana studies, legumes can provide an N credit after just one year, but the wheat yield goal may need to be lowered as compared to following fallow. After three cycles with dryland lentil green manure in northeast Montana, wheat yields were the same following green manure without additional N and following fallow with 30 lb N/acre fertilizer. Fewer legume rotations were needed to

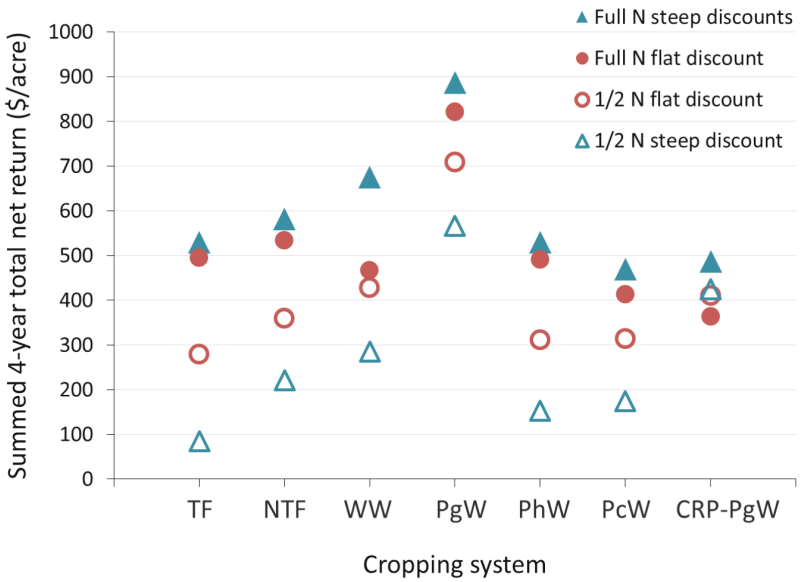


FIGURE 3. Four-year total net returns for tilled fallow-wheat (TF), no-till fallow-wheat (NTF), continuous wheat (WW), pea grain–wheat (PgW), pea hay-wheat (PhW), pea green manure-wheat (PcW), and alfalfa/pea grain-wheat (CRP-PgW) with full (3 lb available N/bu) and half recommended N rate, and flat and steep wheat grain protein discounts (2013-2016; Miller et al., 2015).

match wheat grain protein after fallow than to match grain yield. Over the long term (at least four cycles), pea in rotation can provide similar or higher economic returns than fallow systems. In wet years pea rotations provide greater stability against protein discount fluctuations by reducing the reliance on fertilizer N (Miller et al., 2015). Even in dry years (2013-2016), pea grain-wheat produced greater net returns than any other combination of pea, wheat or fallow (Figure 3). The full suggested N rate of 3 lb N/bu produced greater return than 1.5 lb N/bu, and notably, pea grain-wheat at ½ N rate produced the same economic return as fallow-wheat at the full N rate.

Legume cover crops release more N more quickly than pulse crops. However, a pulse rotation can still increase small grain yields planted three years after the pulse crop (Lupwayi et al., 2016). Legume N credit is greater in more productive systems, but highly variable among species and agronomic conditions.

PHOSPHORUS

Phosphorus is important for healthy root growth and tillering. Phosphorus deficiency in wheat is expressed as slow growing and late maturing plants (Wiese, 1996). Phosphorus deficient plants can be darker bluish-green than normal. Leaf tips may die back, and the foliage of some cultivars will turn red or purple in color. Phosphorus deficiency is more likely in cold soils when P release from organic matter is reduced due to low microbial activity and P movement is slow. Phosphorus is also more likely limiting in calcareous soils, soil with pH greater than 7.5 or less than 6, and in highly weathered, sandy soils.

Phosphorus fertilizer rates are based on soil test levels in the top six inches (Table 3). If soil test levels are below an Olsen test of 16 ppm P, wheat yields can respond to P applications. Phosphorus is most effective when placed with seed, and in bands adjacent to the seed, especially for spring and durum wheat when soils are cold and root growth can be slow (see What about banding fertilizer? below). A starting point for safe seed-place P rates is 10 lb P_2O_5/acre. Use online calculators to get safe seed-placed rates (see Weblinks, page 27). Because P is immobile in the soil, P levels can be built up (banked) in years when fertilizer costs are low.

The primary P fertilizer sources in Montana are monoammonium P (MAP; 11-52-0), diammonium P (DAP; 18-46-0), and liquid ammonium P (10-34-0). All sources are considered equal on a lb P_2O_5/acre basis, although MAP is the preferred source since it has a lower ammonium content which allows a greater amount to be placed with the seed. DAP is very risky to place with seed.

An enhanced efficiency P fertilizer uses organic compounds that are similar to root exudates to bind cations from the soil solution hindering the formation of less soluble phosphates. This can help maintain P locally in a plant-available form. Limited Montana research on these products has been completed to be able to fairly evaluate their effectiveness. Further discussion and recommendation on the use of these and other products can be found in *Enhanced Efficiency Fertilizers* (Olson-Rutz et al., 2009).

What about banding fertilizer? (Mengel & Rehm, 2000)

Advantages:

- A zone of enhanced nutrient availability is created by minimizing contact between the fertilizer and soil.
- It is a simple and efficient method of applying small amounts of fertilizer.
- Efficiency of volatile products like urea is enhanced.

Disadvantages:

- Only a limited portion of the root system has a high probability of coming in contact with the fertilizer
- Damage to germination can occur when high rates of some products are placed close to the seed.
- Higher cost of equipment for banding.

TABLE 3. Phosphorus fertilizer guidelines for wheat based on soil analysis.

Olson P soil test level (ppm)	P rate (lb P_2O_5/acre)	
	Spring wheat	Winter wheat
0	50	55
4	45	50
8	35	45
12	30	40
16*	20	35

* At soil test levels greater than 16 ppm consider using crop removal rates (Table 2). Source: Jacobsen et al., 2005.

TABLE 4. Potassium fertilizer guidelines for wheat based on soil analysis.

K soil test level (ppm)	K rate (lb K2O/acre)
0	135
50	115
100	90
150	70
200	40
250*	10

* At soil test levels greater than 250 ppm consider using crop removal rates (Table 2). Source: Jacobsen et al., 2005.

POTASSIUM

Potassium deficiency is rare for Montana crops but can occur in sandy coarse-textured soils, or in fields where grain and straw are both removed. Deficiency symptoms show first on lower leaves which may appear scorched, bronzed, or blighted along the leaf edges. Since K is such an important component of straw, deficiency may lead to weak straw and increased lodging. Diseases such as powdery mildew may be accentuated on K deficient plants.

Potassium fertilizer rates are based on soil test levels to six-inch depth (Table 4). Fertilizer source is primarily potash (KCl, 0-0-60) and is best utilized when banded. If banded with the seed, limit the total amount to 10 lb (N + K_2O)/acre, adjusted as needed for seed bed conditions using an online safe seed-placed rate calculator (see Weblinks, page 27). Potash is also effective when broadcast at seeding.

SULFUR AND MICRONUTRIENTS

The potential for S deficiency is increasing as fertilizer sources contain less S impurities and coal is burning cleaner, thus less deposition of S from air pollution. Sulfur is critical for building protein. If wheat is not responding to N or protein levels are low with adequate N fertilizer, then S may be deficient. As with N deficiency, leaves are pale yellow, but sulfur deficiency results in the upper, younger leaves turning yellow rather than the older, lower leaves that are yellow with N deficiency.

Soil S levels vary greatly across a field, and crop yields have not been found to correlate well with soil S test levels (Jackson and Engel, 2006). The consideration to fertilize with S depends on crop and field history (shallow soils and soils that are sandy, acidic, or low in organic matter are more likely to be low in S). If the prior crop showed S deficiency, then 10-15 lb S/acre before or at seeding could be a wise investment. If the uppermost leaves just before heading contain just 0.20 to 0.25% S, a 3 to 5 lb S/acre application near time of heading of ammonium thiosulfate or ammonium sulfate could salvage yield and protein. Sulfate S sources are best applied in the spring, as they can be lost to leaching over-winter. Elemental-S is slow to become plant available and should be applied with the prior crop or in the fall. Elemental-S can be banked for two to three years of crops' needs.

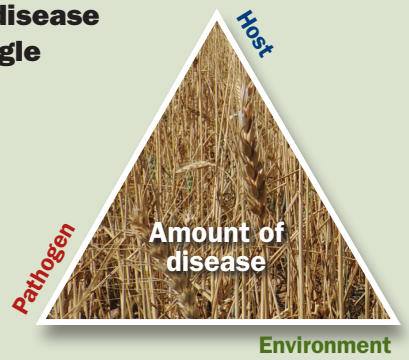
Micronutrients are taken up in very small amounts and are rarely deficient in Montana wheat production. Exceptions include soils low in organic matter, or those recently leveled for irrigation where topsoil has been buried or diluted with deeper soils. Deficiency symptoms may appear under cool wet conditions, only to disappear as the soil warms. Published critical soil and tissue test levels should be used only as rough estimates of sufficiency (Jacobsen et al., 2005). The best test for deficiency is to establish fertilizer test strips and measure yield. Micronutrients can be broadcast and incorporated to the soil, or applied to foliage as a chelated product. Use caution. Too much can be more limiting to yields than a deficiency.

Chloride (Cl) deficiency has been studied more than most other micronutrients, especially in connection with disease resistance. Too few Cl fertility trials have been conducted to use Cl soil tests to determine Cl fertilizer rates. Wheat yields have been found to increase with Cl applications. If deficiency is suspected, Cl can be applied at 0.20 lb Cl/bu (Schumacher 1988). For example, wheat at 40 bu/acre would need 8 lb Cl/acre or about 17 lb potash per acre (potash, KCl is 48% Cl). Starter 0-0-60 to meet K needs is often close to this amount so additional Cl may not be needed for 40 bu/a wheat.

STARTER FERTILIZER

Pop-up fertilizer can help wheat get off to a quicker start, especially in no-till fields which have higher levels of residue and where soils are typically colder. Nitrogen, P and K can all be beneficial in the seed row. However, the fertilizer salt content can disrupt germination and seedling growth. Urea has the additional concern of ammonia toxicity. Seed-placed rate limitations have been discussed earlier under each nutrient section. Start with these guidelines and alter fertilizer amounts depending on seed bed conditions. A separation of seed and fertilizer by one to two inches eliminates any restrictions.

The disease triangle



For disease to occur all three parts of the triangle must be present:

- the pathogen
- a susceptible host
- an environment that allows infection to occur.

Cropping systems should be designed to eliminate (or minimize) at least one of these factors as a defense against disease.

Plant diseases of importance in Montana wheat

Plant diseases can severely impact wheat yields. Management to prevent occurrence is preferable to treatment. In most cases (but not all), crop rotation to reduce the amount of disease organisms (pathogens or inoculum) present and alteration of the host (crop, variety) or environment so the disease is not favored is the best management (see Disease Triangle, above). When diseases do occur, rapid identification is needed so management can be implemented. The following section describes common diseases of wheat in Montana, their identification and management recommendations. When in doubt submit a sample to the diagnostic lab through your county Extension agent. A proper sample consists of entire plants (including roots) showing symptoms, a 'healthy' comparison where available, and if possible, photographs of the field to illustrate the pattern of the problem. Submission forms can be found at the Schutter Diagnostic Laboratory website (http://diagnostics.montana.edu). Diagnosis can often be accomplished remotely with a good description of the problem and a photograph, but submitting a physical sample is often required. Pictures of the following disorders can be found on the High Plains IPM Guide (http://wiki.bugwood.org/HPIPM:Main_Page).

ROOT AND CROWN DISEASES

Dry seed decay is caused by *Penicillium* spp. and other soil-inhabiting fungi. Any soil condition that prevents rapid germination and emergence of winter wheat seed increases the possibility of seed decay. This includes dusting winter wheat into dry soil. Light showers that are sufficient to germinate seed but not sufficient to sustain growth can cause poor stands if adequate moisture does not follow. Dry seed decay is often misdiagnosed as winterkill or Rhizoctonia root rot (below). Seed treatments will prevent dry seed decay for 3-4 weeks after planting. Imazilil gives the best control of dry seed decay, but other seed treatments are effective.

Damping off and ***root rots*** can be caused by a number of different fungi including Pythium and Rhizoctonia. They are favored by wet, cool soil conditions. Symptoms include decreased seedling emergence (seed rot/damping off), poor seedling vigor, decreased number of lateral roots, shorter roots, browning or necrosis of roots, chlorotic leaves, small heads, and sometimes white heads at maturity. The subcrown internodes and first few nodes may also be discolored. Damping off can be controlled using a seed treatment. Consult the *Small Grain Seed Treatment Guide* (Dyer et al., 2012) for current recommendations. Seed treatments are generally effective for 3-4 weeks after planting, and do not protect the entire root system from fungal pathogens.

M. Burrows

In bare patch (above), look for localized circular areas with stunted, dull-grayish-blue or dead wheat plants.

Root rot (bare patch) can be partially controlled by seed treatment but crop rotation, good weed control, and eliminating the 'green bridge' are all important management techniques. There is research from Oregon showing that glyphosate (Roundup) application to volunteer cereals and grassy weeds can increase the amount of Rhizoctonia and increase the risk of bare patch when seed is planted into a field with green plants remaining. Eliminating the green bridge by planting 2-3 weeks after herbicide application is the most important control method.

Crown rot fungi are both soil- and residue-borne, and can also infect grassy weeds. Fusarium crown rot is caused by *Fusarium* spp., common root rot by *Cochliobolus sativus,* and take-all by *Gaeumannomyces graminis* var. *tritici.* Crown rots are commonly present but are often not noticed until they significantly decrease yield. Symptoms include discoloration of the crown and/or subcrown internode, reduced seed weight and size, and white heads at maturity.

M. Burrows

J. Johnston, MSU

M. Burrows

Fusarium crown rot (L), common root rot (C) and take-all (R).

These diseases can be difficult to control in a continuous wheat cropping system. Recommendations include crop rotation, variety selection, proper fertilization, irrigation management to maintain continuous (not fluctuating) moisture, and tillage where practical to reduce residue levels. Seed treatments are of limited efficacy for crown rot control since they only last 3-4 weeks after planting, but are recommended for plant health during seedling establishment.

LEAF DISEASES

Bacterial leaf blight and ***bacterial stripe*** (both commonly known as black chaff) are caused by *Xanthomonas campestris* pv. *translucens* and *Pseudomonas syringae* pv. *syringae*. The leaf symptoms begin as small, water-soaked spots on leaves which elongate into linear streaks that become necrotic tan or brown. Often the tips of the leaves become shredded. Leaf tip shredding can also be caused by drought stress, but in the case of drought stress, the leaf lesions characteristic of bacterial leaf diseases will not be seen on the leaves. Bacterial-caused symptoms can also be confused with spot or net blotch or Septoria leaf spot, diseases which are caused by fungi (see below). The leaves of bacterial-infected plants often have a varnished or 'slick' feel, whereas leaves infected by fungi do not. Under very wet conditions, beads of bacteria will be exuded from leaves or glumes infected by the bacterial pathogen. Symptoms often appear late in the season or after physical damage from a hail storm or heavy, driving rain which wounds the plant.

M. Burrows

Bacterial leaf blight (L) & bacterial stripe (below).

When bacteria infect the head of wheat or barley, it is known as black chaff. Symptoms include pink, tan, or black streaks on the glumes, and discolored and shriveled seed. Under wet conditions an exudate can develop on the glume and seed surfaces forming tiny yellow droplets and a glassy or shellacked appearance. Seed symptoms include discoloration of the embryo end of the kernel and can be confused with black point, which is caused by a number of different fungi. Both bacterial kernel blight and black point are encouraged by moisture during heading and seed filling. The best method of control is to use clean seed and to cut irrigation during late maturity. Do not save seed from affected fields. There are no effective pesticides for control of bacterial diseases of wheat.

In order to distinguish between bacterial and fungal leaf diseases, one can put leaves in a plastic bag or container with a wet paper towel, check for fungal structures (little black dots in the lesions) after two to three days. Bacterial lesions will ooze cloudy beads of sticky liquid along the length of the lesion. When in doubt, submit a sample to the Plant Disease Diagnostic Clinic through your county Extension agent.

M. Burrows

J. Johnston, MSU

Sharp eyespot (L) and eyespot or strawbreaker foot rot (R).

Eyespot diseases can be difficult to distinguish in the field as they cause similar symptoms as crown rot including reduced yield, white heads at maturity, and lodging. Cool, moist conditions near the base of the plant favor infection. Either soil- or residue-borne spores can infect through the leaf sheath at the base of the plant. The lesions of the two diseases are distinct. Sharp eyespot *(Rhizoctonia cerealis)* causes circular to elliptical light brown lesions surrounded by a thin, necrotic, dark brown border. Eyespot *(Pseudocercosporella herpotrichoides)* causes eye shaped lesions, initially white to tan-brown and developing to dark brown lesions that cannot be stripped off by peeling off the leaf sheaths. Lesions of either fungi may girdle the plant.

Control is generally not economical but if infections are serious, management may be recommended. Spring wheat and late-seeded winter wheat are less exposed to conditions favoring infection. Reduction in seeding density reduces moisture in the canopy. Rotation away from wheat for 2 or more years plus fungicide application at tillering can be helpful. No resistant varieties are available.

Tan spot *(Pyrenophora tritici-repentis)* and ***Septoria leaf blotch*** *(Septoria* spp.) are residue-borne and encouraged by continuous cereal cropping, minimum or no tillage,

M. Burrows

Tanspot (L) on leaf showing typical eye-shaped spots with halos. Septoria leaf blotch symptoms (R) are usually more diffuse shaped, grey or tan colored and lack the yellow halo.

and irrigation. They can be distinguished based on their symptoms, but controlled using similar strategies. Yield and quality reductions are proportional to the amount of leaf area affected, particularly the flag leaf.

Symptoms will vary according to variety, pathogen isolate, and environmental conditions, but generalizations can be made. Symptoms begin as small spots on leaves or stems which then expand. Tan spot symptoms are similar to septoria but the lesions are initially lens-shaped with a yellow halo and often contain a dark spot in the center of the lesion. Septoria leaf blotch symptoms consist of grey or tan colored lesions that can lack the yellow halo. Septoria can cause a glume blotch of the head and shriveling of the seed. Periods of warm dry sunny weather inhibit spread of disease to new leaves.

Management can be achieved by crop rotation, fungicide application, variety selection, irrigation management, tillage to reduce residue, and good grassy weed control.

M. Burrows

Powdery mildew on wheat leaf.

Powdery mildew *(Blumeria graminis* f. sp. *tritici)* is commonly observed on lower leaves of winter wheat, particularly in irrigated fields or during cool, humid weather. Signs include white to gray fluffy fungal mycelia on the leaves, often in patches that expand to cover the entire leaf. Old infections appear brown and powdery. Small black fungal structures called cleistothecia may also form in the hyphal mass. It is generally not economical to control, but many fungicides are effective.

Snow mold occurs when winter wheat is covered by snow for extended periods, particularly if the snow falls on ground that is not yet frozen. It often occurs in areas of the field which are the last to thaw. Pink snow mold is caused by *Microdochium* (synonym Fusarium) *nivale*. The fungus attacks plant parts during wet, cool weather, but is not dependent upon snow. Speckled snow mold is caused by *Typhula idahoensis* and the similar T. *ishikariensis.* Both species are restricted to areas with deep snow. Less serious is T. i*ncarnata*, which has a wider geographical range and is found even in areas without prolonged snow cover. Pink snow mold produces pinkish mycelium and conidia that cover dry yellow or dead leaves. Leaves attacked by speckled snow mold appear scalded or bleached-white or tan in color and have a tendency to crumble. Fungal structures called sclerotia are scattered on leaves and give the disease its common name. Plant vigor may be markedly reduced, and in severe cases, the crowns are killed. Surviving plants recover slowly and are sensitive to additional stresses.

T. Murray, WSU

Snow mold has reduced this stand, and has weakened the remaining plants.

Fungicide applications have not been effective since residual efficacy is only 3-4 weeks after application. High populations of downy brome *(bromus tectorum)* favor pink snow mold. Crop rotation to legumes or other non-cereal crop is effective. Attempts have been made to hasten snow melt by using blackening agents, but cost, difficulties of application, and unpredictability of post-application snowfall make this method unreliable.

J. Johnston, MSU

Cephalosporium stripe usually appears as one or two continuous stripes on leaves.

Cephalosporium stripe invades through roots and causes symptoms on leaves. Only winter wheat is susceptible, particularly continuously cropped dryland winter wheat. The fungus *(Cephalosporium tritici*) enters roots through wounds induced by freezing and thawing (frost heaving) of the soil. During jointing and heading, affected plants appear dwarfed with continuous yellow stripes on leaves. Normally, only one

or two stripes and discolored veins are present on each leaf. Darkened stripes on stems appear during crop maturity, and nodes may be darkened. At heading and during grain filling, the awns of diseased plants tend to turn outward and the heads turn white. White heads are either empty or filled with shriveled kernels. Plants in severely-infected fields may mature early. Delayed fall seeding reduces root volume reducing potential for root breakage and number of potential infection sites.

M. Burrows G. Padgett, LSU M. Burrows

Stripe rust (L), will occur in distinct stripes. Leaf rust spores (C) will be red to brown, and occur as scattered pustules on leaf surface. Stem rust can occur on both leaf or stem (R) and is red to black in color.

Rusts *(Puccinia* spp.) are dependent on the host for survival, and generally blow in on weather systems each year from other wheat-growing areas. The exception is stripe rust *(Puccinia striiformis)*, which can overwinter on wheat and grassy weeds in Montana. Rust spores occur in spots or stripes called 'pustules' and they will rub off on your finger.

The rusts can be distinguished based on their appearance and preferred environmental conditions. Stripe rust, also called yellow rust, is a 'cool-season' rust, preferring temperatures of 41 to 59°F. Symptoms include yellow to orange spores occurring in stripes. It is most common on winter wheat but can infect spring wheat. Leaf rust spores are red to brown and occur in discrete pustules unless the infection is very advanced and the pustules have merged together. Stem rust spores are red to brown/black and occur on both leaves and the stem. The edges of the pustules have frayed edges from the leaf epidermis (skin) where the pustule erupted. Infections of rusts are favored by at least 6-8 hours of dew which allows the spores to germinate and infect the leaf. Leaf rust prefers temperatures of 60 to 80°F for infection, and stem rust is favored by warm days of 77 to 86 °F and cool nights of 59 to 68°F.

Yield loss will depend on variety resistance and the time of infection. Control is achieved through the use of resistant varieties and fungicide application. For best control when using a fungicide apply at the first appearance of symptoms. See fungicide efficacies (Table 5, page 17) for more details.

HEAD DISEASES

Bunts and smuts are seed-borne, and have greatly decreased since the invention and use of systemic fungicide seed treatments and deployment of resistant cultivars. The fungus replaces the seed, and forms a powdery black substance which is a mass of fungal spores. You can distinguish smut from ergot (p.14) by trying to crush the black substance: ergot is a solid mass of fungal hyphae and not powdery like smut or bunt. Yield loss due to smut is proportional to the number of heads infected. Affected plants can be stunted before the head symptoms are obvious. The different kind of smuts can be distinguished based on the symptoms on the head.

Common bunt also called stinking smut and covered smut *(Tilletia tritici* or T. *laevis)* has a membrane that remains around the smutted seeds until the plant is mature. Most people will detect a distinct fishy odor associated with common bunt. Bunt spores released during threshing are combustible. Most inoculum originates with contaminated seed but soil-borne spores can infect winter wheat seedlings. Soil-borne spores do not survive the winter. Seed treatments can provide control.

MSU Plant Pathology Slide Collection

Loose and covered smut (L); Dwarf bunt (R); Seed replaced with common bunt spores called 'bunt balls' (bottom).

Dwarf bunt (T. *controversa)* is very similar to common bunt and has the same distinct odor. However, it is caused by a different species, has unique requirements for spore germination and infection, infected plants are stunted, and spores can live in the soil for years. A prolonged period of very low-intensity light accompanied by temperatures between 32 and 40°F is necessary for infection. These conditions generally exist in late fall. Infection can occur at the snow-soil interface when snow falls on unfrozen ground and stays there for several months. The spores germinate best when soil or seedbed temperatures are in the range of 40 to 60°F. Then,

the fungus grows within the growing point of the infected shoot and completes its life cycle by growing into the ovaries and producing smut balls in place of kernels. Resistant varieties and seed treatment are methods of control.

Loose smut *(Ustilago tritici)* is strictly seedborne. Symptoms appear at crop maturity. Infected heads emerge before healthy heads. A thin membrane covering the spores ruptures and the spores are dispersed by the wind leaving a naked rachis (center of the head). Spores infect the open flowers of neighboring plants, infecting the seed embryo and perpetuating the disease cycle. To prevent smut, use a systemic fungicide seed treatment.

M. Burrows

Ergot bodies, above, replace the seed in wheat with bodies.

Ergot *(Claviceps purpurea)* is a fungus that forms compounds that are toxic to animals and humans. The source of the fungus is the sclerotia, a hard mass of fungal hyphae and a survival structure for the fungus. Ergot is introduced into a field by contaminated grain, grassy weeds or wild grasses. The fungus infects during the flowering period, so moist conditions at flowering favor this disease. Light frost during flowering increases the incidence of ergot.

The first symptom of ergot is honeydew, a moist sticky substance which occurs during flowering under moist conditions. Insects can be attracted and feed on this substance. As the disease progresses, the fungus replaces the seed and forms an ergot body. This black structure can be up to four times as large as the original seed and protrudes from the head.

If you suspect the grain has ergot, do not feed it to animals. Ergot contamination of 0.05% by weight can be toxic. Ergot can be controlled by cutting wheat for hay before flowering, tillage to bury the sclerotia, mowing contaminated headlands or roadways before the wheat matures, and rotating out of small grains for at least one year.

Fusarium head blight or ***scab*** *(Fusarium* spp.) is important because the fungus produces toxins including deoxynivalenol (DON). The disease also causes yield and quality losses. Scab on wheat has been reported in some areas of the state, primarily in irrigated spring wheat, durum and barley and occasionally in winter wheat.

The primary symptom of scab is partial bleaching of the heads. This disease is residue-borne and the fungus infects through the flower, much like ergot (above). If environmental

M. Burrows

Symptoms of Fusarium head blight include partial bleaching of the head. Whole heads can also be bleached.

conditions are very moist, a pink fungal growth may be seen on the head. This can also be seen if the heads are put into a moist chamber for a few days (a Ziploc bag with a wet paper towel). Seed symptoms include shriveled seed or 'tombstones' sometimes with crusty white fungal growth on them. They are lighter than non-affected seeds and can be blown out of the combine while harvesting by increasing the fan speed. However, this practice has the downside of providing inoculum for the following crop.

Since this is a residue-borne disease, reducing grassy residue via crop rotation or tillage will reduce the amount of inoculum in the field. When irrigated, management to let the canopy dry out during the 10 days before head emergence can reduce fungal infection. Another option includes spraying a systemic fungicide at head emergence or slightly before head emergence (see Table 5, page 17). Variety resistance is available for spring wheat. Seed treatments are not effective against scab since the inoculum comes from the crop residue, but seed treatments are routinely recommended to protect against soil-borne pathogens.

T. Murray, WSU

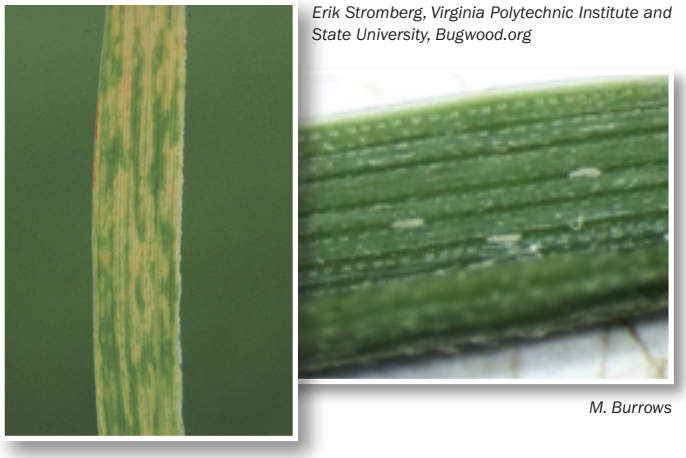
Sooty mold is favored by wet weather, particularly after heading through harvest.

Sooty mold is caused by a number of different fungi. The fungi are favored by wet weather, particularly after heading through harvest. Sooty mold is noticed particularly when harvest is delayed. Heads that are shaded, weakened, undersized, prematurely mature, and deficient in nutrients, lodged, or damaged by other diseases also are prone to sooty

molds. In some cases, plants weakened by other diseases such as take-all or Cephalosporium stripe are more prone to sooty mold development. Sooty mold may decrease grain quality by causing a black point or kernel smudge. There are no fungicides available for control of sooty mold after flowering; the best control is to harvest and dry the grain.

VIRUS DISEASES

Wheat streak mosaic virus (WSMV), Wheat mosaic virus (WMoV, formerly known as High Plains virus), and ***Triticum mosaic virus (TriMV)*** are wheat curl mite-transmitted viruses found in Montana. Symptoms include yellow to white streaks on leaves, stunting, and delayed maturity. The three viruses cannot be distinguished based on symptoms, but when multiple viruses are infecting one plant symptoms can be more severe. Yield loss will depend on the virus species, virus strain, wheat variety, time of infection, and environmental conditions.



Erik Stromberg, Virginia Polytechnic Institute and State University, Bugwood.org

M. Burrows

Three distinct virus diseases have similar symptoms which include white to yellow streaks on leaves, stunted plants, and delayed maturity. Laboratory tests are required to determine which virus is present. These viruses are transmitted by the wheat curl mite (right).

The best method of control is avoiding the green bridge. The virus and the mite are dependent on green tissue for their survival. They survive on wheat, barley, oats, corn, rye and grassy weeds, but volunteer or cultivated wheat is the ideal host for both the virus and the mite. Eliminating the green bridge by destroying volunteer wheat and grassy weeds using herbicides or tillage (2-3 weeks before planting) is the most important control method. Most herbicides don't kill weeds immediately. Volunteers and grassy weeds must be completely dead in order to no longer serve as a disease source. This means an extended period is needed in order to break the green bridge prior to planting. Fields managed as large blocks rather than strips minimize the field edges that are exposed to mite-infested volunteer wheat or grasses. No effective seed or foliar acaricides are registered for use. Delayed planting in the fall will minimize exposure of seedlings to mite infestations due to cool temperatures which reduce mite activity.

A delicate balancing act exists for managing WSMV by use of planting date. Early planting to establish a vigorous plant for yield potential must be weighed against planting late enough to avoid the transmission of WSMV by the wheat curl mite. Although planting date is no guarantee to avoid disease, cooler fall temperatures will minimize mite migration and virus transmission. General guidelines for winter wheat planting date is after September 5 in northern Montana, September 15 in central Montana, and September 20 in southeastern Montana. Fall planting depends on local weather conditions. If it is unseasonably warm when fall planting should begin, it may be necessary to postpone seeding as warm weather keeps mites active for a longer time and wheat may become infected. Spring wheat crops should be planted as early as possible; no later than the end of April. Late-seeded spring wheat does expose susceptible seedlings to an active population of the mite with the higher temperatures. Spring wheat should not be planted near winter wheat with symptoms of WSMV, or in fields that were heavily infested with the wheat curl mite the previous fall. Spring control of volunteer winter wheat with glyphosate up wind from emerging spring wheat has resulted in severe spring wheat mortality from WSMV infection.

M. Burrows

Barley yellow dwarf virus causing yellow to purple discolored leaves.

Barley yellow dwarf virus (BYDV) is an aphid-transmitted virus. Aphids generally arrive on weather systems from other cereal-growing areas or from adjacent grasslands like CRP or rangeland. Incidence is higher in late-seeded spring wheat and early-seeded winter wheat. This disease is sporadic in nature. There are several species of aphids which transmit different species of BYDV. The interaction between the aphid and the virus is very specific, and not all aphid species will transmit all species of BYDV. The severity of the disease will depend on how many plants are infected, the species of BYDV infecting the plant, and the growth stage at which the plant becomes infected.

Symptoms vary by virus, plant variety, environmental conditions and time of infection. Yellowing of the leaves can be confused with nitrogen deficiency or stress. The flag leaf is sometimes purple or red in color. Plants are stunted or dwarfed, and leaves may be shortened or curled and sometimes have serrated edges. This disease is generally not economical to control in Montana and occurs sporadically.

M. Burrows

M. Burrows

CIMMYT

M. Burrows

Wheat can show abiotic, or non-disease disorders in the field. From left to right, damage symptoms include frost injury, hail, melanism, and physiological leaf spots.

ABIOTIC DISORDERS

Frost injury is caused by freezing temperatures after plant emergence. The worst damage occurs when wheat is damaged at the 2-leaf stage or at heading. If injury occurs during heading or pollination, symptoms will include white heads, sterility, white awns, watersoaking, and shriveling at the base of the head.

Hail injury is most damaging from heading through harvest. Hail kinks and severs plant parts randomly. Other symptoms include drying and bleaching of damaged tissues, white heads, stem lesions, and spike bruising (circular white patches on the glume).

Melanism occurs as brownish-black to dark purple spots, streaks, or blotches on the leaf sheaths, stems, and/or glumes. It is caused by production of melanoid pigments, and is common in some varieties. The dark brown color usually develops on the glumes and peduncles. The symptom may be confused with black chaff or stagonospora blotch, but no leaf symptoms of those diseases will be present.

Physiological leaf spots often resemble leaf spots caused by pathogens, but with no pathogen present. They are caused by plant physiology or by genetics. Leaf spotting has also been associated with chloride deficiency in some wheat varieties in Montana. Often the margin of the spot is very distinct, not diffuse. Spots will occur uniformly on all leaves of the plant, and will not be more severe towards the base of the plant, as is expected with a stubble-borne leaf spot disease such as tan spot or Septoria leaf spot. If leaves are placed in a moist chamber (plastic bag with a wet paper towel) for 2-3 days no fungal structures (black dots) will develop. Send samples to the diagnostic lab if you are not certain. Varieties vary in their susceptibility to physiological leaf spotting.

Nutrient deficiency symptoms include stunted or uneven growth, yellowing, poor vigor, reduced tillering, and low yield and seed quality. Most symptoms occur between tillering and heading when there is high demand for nutrients. Diagnosis can be obtained from plant or soil analyses. In Montana the most common nutrient deficiencies are nitrogen, sulfur, phosphorous and potassium. (For more details see the Nutrient Management section, page 5.)

FUNGICIDE EFFICACY FOR CONTROL OF WHEAT DISEASES

The North Central Regional Committee on Management of Small Grain Diseases (NCERA-184) has developed the following information on fungicide efficacy for control of certain foliar diseases of wheat for use by the grain production industry in the U.S. Efficacy ratings for each fungicide (Table 5, page 17) were determined by field testing the materials over multiple years and locations by the members of the committee. Efficacy is based on proper application timing to achieve optimum effectiveness of the fungicide as determined by labeled instructions and overall level of disease in the field at the time of application. Differences in efficacy among fungicide products were determined by direct comparisons among products in field tests and are based on a single application of the labeled rate as listed in the table. Table 5 includes most widely marketed labeled products, and is not intended to be a list of all labeled products. Comments on stem rust are based exclusively on trials in Bozeman, MT in 2009.

TABLE 5. Efficacy of fungicides for wheat disease control based on appropriate application timing

Fungicide(s)				Powdery mildew	Septoria leaf blotch	Tan spot	Stripe rust	Leaf rust	Stem rust	Head scab	Harvest restriction
Class	Active ingredient	Product	Rate/A (fl. oz.)								
Strobilurin	Azoxystrobin 22.9%	Quadris 2.08 SC	6.2 - 10.8	F(G)[1]	VG	E	E[2]	E	–	NR	45 days
	Pyraclostrobin 3.6%	Headline 2.09 EC	6.0 - 9.0	G	VG	E	E[2]	E	G	NR	Feekes 10.5
Triazole	Metconazole 8.6%	Caramba	10.0 - 17.0	–[3]	–	–	E	E	E	G	30 days
	Propiconazole 41.8%	Tilt 3.6 EC PropiMax 3.6 EC Bumper 41.8 EC	4.0	VG	VG	VG	VG	VG	–	P	40 days
	Prothioconazole 41%	Proline 480 SC	5.0 - 5.7	–[3]	VG	VG	–	VG	E	G	30 days
	Tebuconazole 38.7%	Folicur 3.6 F[4] Embrace 3.6 L Monsoon Muscle 3.6 F Orius 3.6 F Tebucon 3.6 F Tebustar 3.6 F Tebuzol 3.6 F Tegrol Toledo	4.0	G	VG	VG	E	E	–	F	30 days
	Prothioconazole 19% Tebuconazole 19%	Prosaro 421 SC	6.5 - 8.5	G	VG	VG	E	E	E	G	30 days
Mixed mode of action	Metconazole 7.4% Pyraclostrobin 12%	Multiva TwinLine	6.0 - 11.0	G	VG	E	E	E	VG	NR	Feekes 10.5 and 30 days
	Propiconazole 11.7% Azoxystrobin 7.0%	Quilt 200 SC	14.0	VG	VG	VG	E	E	VG	NR	Feekes 10.5
	Propiconazole 11.4% Trifloxystrobin 11.4%	Stratego 250 EC	10.0	G	VG	VG	VG	VG	–	NR	35 days

[1] Efficacy categories: NR=Not Recommended; P=Poor; F=Fair; G=Good; VG=Very Good; E=Excellent. Efficacy designation with a second rating in parenthesis indicates greater efficacy at higher application rates.

[2] Efficacy may be significantly reduced if solo strobilurin products are applied after stripe rust infection has occurred.

[3] Insufficient data to make statement about efficacy of this product.

[4] Generic products containing tebuconazole may not be labeled in all states.

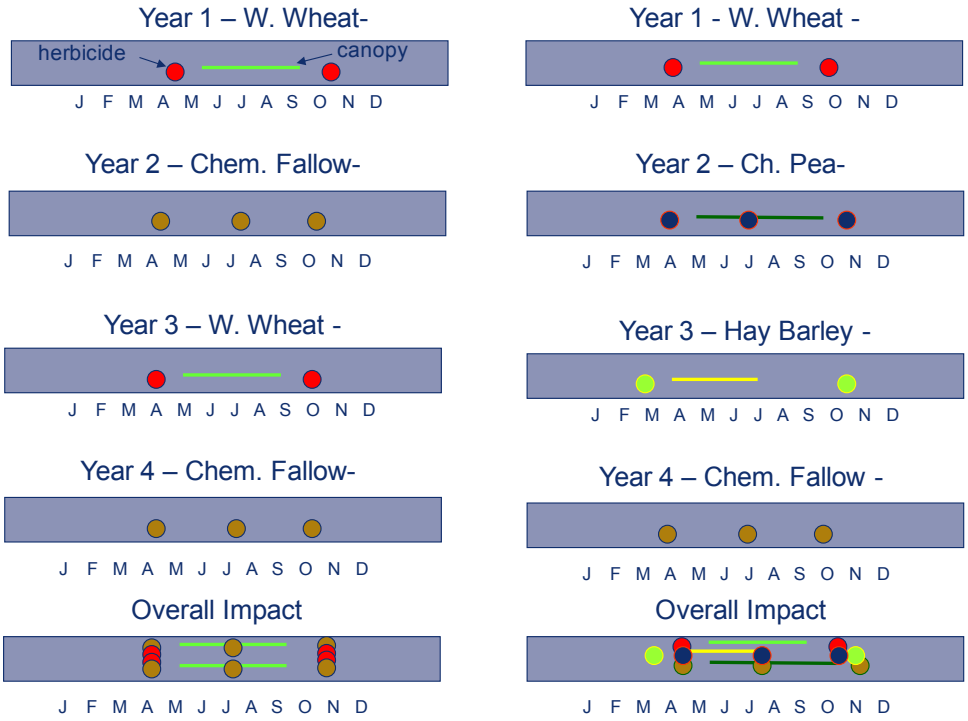


FIGURE 4. Conventional and (left) diversified (right) crop rotations differ in the type and timing of seeding dates, canopy closure times (lines) and herbicide applications (symbols). In the diversified rotations, variations in management practices and in crop type, make it very difficult for a specific weed to adapt to the changing environmental conditions.

Integrated management of weeds in wheat

Growing a successful wheat crop requires close attention to weed management. If left unmanaged, weeds have the potential of reducing wheat yield and quality as they compete with the crop for light, nutrients, and water. Furthermore, weeds can interfere with harvest, contaminate the harvested grain, and can harbor diseases, nematodes, or insects that attack wheat.

Research and experience shows that the integration of cultural and mechanical practices with careful use of herbicides is at the core of a successful integrated weed management (IWM) program in wheat fields. In essence, IWM combines the use of different control practices to manage weeds, so that reliance on any one weed management technique is reduced. This is one of the most powerful tools to reduce the spread and impact of herbicide resistance. Selecting the proper combination of management strategies requires an understanding of:

- the time at which both the wheat crop and the weeds emerge and grow
- the relative size and growing stage of the wheat and the weeds
- the kind of weeds present in the field and their relative abundance
- the cropping system (previous crops and herbicide applications, planned crops, etc.)
- the environmental conditions (soil type, moisture, nutrient availability, temperature)
- the management goals
- the availability of resources (time, labor, and equipment)

More information on IWM can be found in *Integrated Strategies for Managing Agricultural Weeds* (Smith and Menalled, 2012).

PREVENTION

Reducing the spread of weeds is an important step in weed management. This can be achieved through careful sanitation practices such as use of clean equipment before entering a field, keeping field borders clean, and use of certified seeds. Seeds of jointed goatgrass, cheatgrass (downy brome), Persian darnel, kochia, and prickly lettuce are common contaminants of noncertified wheat seeds

F. Menalled

FIGURE 5. Herbicide damage on lentils (left) and untreated control (right).

Preventing seed production and dispersal reduces the spread of weeds across fields. A case study: Wild oat

Limit seed production

Wild oat is usually found in patches. Minimizing seed production can reduce patch expansion. For example, a 6-year study monitored wild oat patch expansion in farmers' fields. Wild oat patches that were treated to prevent seed production and dispersal increased by 35 percent; while untreated patches increased by 330 percent.

Limit seed dispersal

Wild oat seeds are heavy and do not disperse more than 6 to 9 feet from the parent plant. However, seeds can be moved long distances (>450 feet) when taken up by a combine harvester and returned to the ground with chaff. Methods that reduce seed dispersal during harvesting operations can reduce the spread of wild oats within and across fields. For example, chaff collection removes up to 74 percent of wild oat seeds that would otherwise be dispersed by the combine.

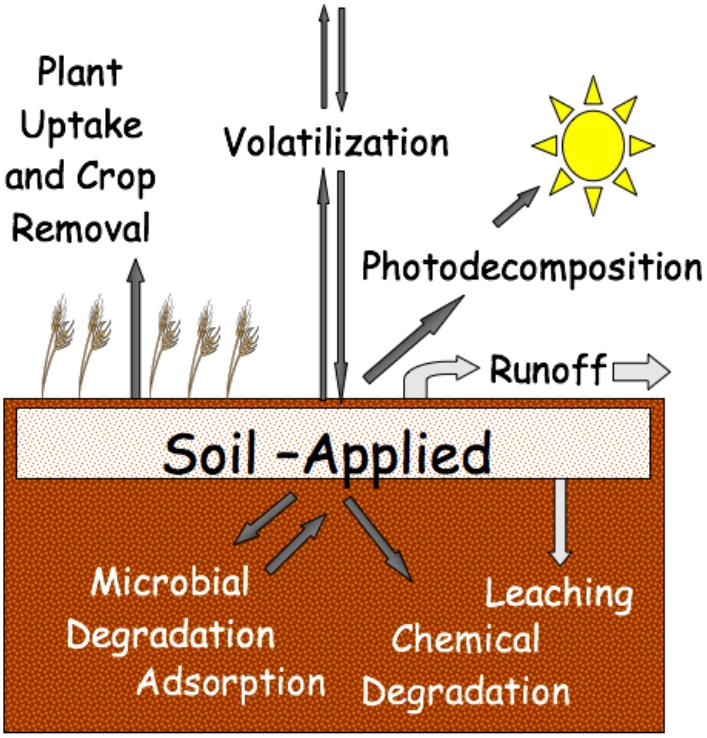


FIGURE 6. Factors affecting the fate of soil-applied herbicides.

that can create problems for many years. Removing weeds before they produce seeds, either through spot spraying, tillage or mowing and cleaning combines prior to entering a field, and collecting weed seeds in chaff wagons pulled behind the combine can help reduce the spread of weeds within and among fields. Prevention can help farmers minimize the risk of importing seeds of herbicide-resistant weeds into their fields.

CROP ROTATION

When farmers follow a strict wheat-fallow rotation, weeds which are well-adapted to compete with the crop thrive. Examples include wild oat, Persian darnel, jointed goatgrass, and cheatgrass. Planting different crops is one of the most powerful tools in the development of an IWM program. Properly selected crop rotations prevent the buildup of problematic weeds. Not only can different herbicides be used in each phase of the rotation, the crop itself can act as an excellent barrier to prevent the spread of certain weeds (Figure 4, page 18).

When designing a crop rotation, producers should select crops that physically out-compete problematic weeds, which will result in the gradual weed population decline. Diverse rotations, including small grains, forages, and annual broadleaf crops provide the full benefit of crop rotation. For example, in Montana wheat and peas are generally sown as early as possible, while canola is usually planted later to avoid spring frost. Not only is the use of any specific herbicide associated with each crop lower in a diversified rotation, which can delay the selection of herbicide resistant biotypes, but changing the yearly seeding and herbicide application date means that specific weeds cannot adapt to the changing environmental conditions. For example, rotating spring and winter wheat can help farmers manage problematic weeds. Winter wheat provides greater suppression and management options of wild oats than spring wheat and spring wheat provides more options for control of cheatgrass. Yet, a rotation which includes only winter and spring wheat will be marginally beneficial and farmers should consider annual broadleaf crops.

Producers interested in developing a diversified crop rotation should pay special attention to reduce the risk of crop damage due to herbicide carryover (Figure 5, page 18). For example, the labeled rotation restrictions of wheat herbicides such as Assert, Ally, Glean, and Finesse range between 10 and 34 months when rotating to peas, lentils, canola sunflower, or safflower. A field bioassay is required following the use of some herbicides before seeding the rotational crop. Herbicide labels list harvest intervals to reduce the risk of crop injuries due to herbicide residues. More information on tools to minimize carryover impacts due to soil applied herbicides can be found in *Getting the Most from Soil Applied Herbicides* (Menalled and Dyer, 2010).

Fate, effectiveness, and persistence of soil-applied herbicides

Soil-applied pre-plant incorporated (PPI) and pre-emergence (PRE) herbicides are valuable tools; they control early season weeds and, if they have residual activity, can provide extended weed control. They are especially useful when wet weather delays post-emergence spraying or cultivation. However, miscalculations in the use of soil-applied herbicides could cause crop injury or fail to control weeds.

To minimize the risk of crop damage due to soil-applied herbicides, it is important to understand the different factors affecting their fate (Figure 6, page 19). After spraying, the concentration and persistence of soil-applied herbicides depends on the herbicide properties, the weather conditions, and soil factors such as texture, pH, moisture and organic matter. Further, delayed emergence, due to cold weather, can result in fatal poisoning of wheat seedlings by some soil active herbicides (for example: triallate).

Knowing the length of time that an herbicide persists in the soil can help you reduce the risk of crop injury and determine the expected weed control period. For herbicides with residual activity, the label will list the crop rotation interval based on the chemical's half-life, defined as the length of time it takes for 50% of the herbicide to break down to inactive compounds. Herbicide adsorption and breakdown varies with soil temperature, soil pH, and soil moisture.

More information on approaches to reduce the spread and impact of herbicide resistance weeds can be found in *Getting the Most from Soil-Applied Herbicides* (Menalled and Dyer, 2010).

RESOURCE AVAILABILITY

Adequate fertility is required to establish a highly competitive wheat stand. Excess fertilizer, especially N, can enhance weed competitive ability resulting in decreased yields. For example, cheatgrass has been shown to be more responsive to N, reaching maximal size at lower N availability than wheat.

Banding fertilizer near the crop row and applying it at the appropriate time enhances the ability of the wheat to compete with weeds. For example, band placement of fertilizer in the root zone has been shown to increase early wheat growth and grain yield, while decreasing weedy grass populations. These effects are particularly pronounced in reduced-tillage cropping systems.

CROP ESTABLISHMENT AND GROWTH

Decreasing row spacing and/or increasing seeding rates enhances the competitiveness of wheat relative to the weeds so that fewer resources are available to support weed growth. Using tall wheat varieties with high leaf area has been shown to be more competitive than short varieties with low leaf area (Figure 7). For example, an analysis of 13 winter wheat cultivars found that there was a 40% yield difference between the two most weed-suppressive cultivars (Mason, 2006).

CHEMICAL WEED CONTROL

Several foliar- and soil-applied chemical options exist to manage grassy and broadleaf weeds commonly infesting wheat fields. However, not all selective products provide control for all weed species. Therefore, the proper selection of herbicides is critical for effective weed management. An online Herbicide Selection Tool (http://www.sarc.montana.edu/php/weeds/) for selecting post-emergence herbicides for small grain production has been developed for use at Montana State University. This tool narrows the choices of registered herbicides by using user inputs of current crop, weeds present, and planned crop rotations for specific fields.

Fabian Menalled, MSU

FIGURE 7. Increasing seeding rate and planting a tall spring wheat variety (right) can significantly reduce wild oat seed production.

The selection of an herbicide or combination of herbicides should be based on several factors. Among them:

- Label approval for use
- Presence of herbicide-resistant weed biotypes
- Weed abundance and spectrum
- Crop and weed application timing
- Crop rotation restrictions
- Ground and surface water pollution concerns
- Potential for drift and soil carryover damage
- Weather conditions
- Herbicide cost
- Soil texture, soil pH, and soil organic matter content

The effectiveness of an herbicide and the potential for crop damage is governed by the interaction of environmental factors such as temperature and rainfall, managerial factors such as planting depth and application time, and biological factors such as weed species and wheat variety present in the field.

MANAGING HERBICIDE RESISTANCE

The overreliance on chemical control practices has led to the selection of herbicide-resistant weed biotypes. Herbicide resistance is the innate ability of a weed biotype to survive and reproduce after treatment with an herbicide dose that would normally be lethal. Producers should be aware that the selection of herbicide-resistant weed biotypes threatens the long-term sustainability of this approach for weed control. In Montana, biotypes of wild oat, cheatgrass, green foxtail, marestail (horseweed), Persian darnel, kochia, and Russian thistle have been found to be resistant to several herbicides commonly used by wheat growers. Several weed biotypes have been selected to be resistant to two or more herbicides with different sites of action when applied at labeled rates, a phenomenon called "multiple herbicide resistance." Also, there are biotypes of kochia, marestail, and Russian thistle in Montana that can no longer be controlled with glyphosate, the active ingredient of Roundup and other commercial products.

To reduce the risk of selecting herbicide-resistant biotypes, producers should rotate among herbicides with different modes of action, applied either as tank mixes, premix formulations or sequential applications. Also, producers should rotate management practices, such as the incorporation of timely cultivation. Finally, the development of IWM program is an excellent tool to reduce the selective pressure for herbicide-resistant weeds.

More information on approaches to reduce the spread and impact of herbicide-resistant weeds can be found in *Preventing and Managing Herbicide-Resistant Weeds in Montana* (Menalled and Dyer, 2011).

Insect Management

WHEAT STEM SAWFLY

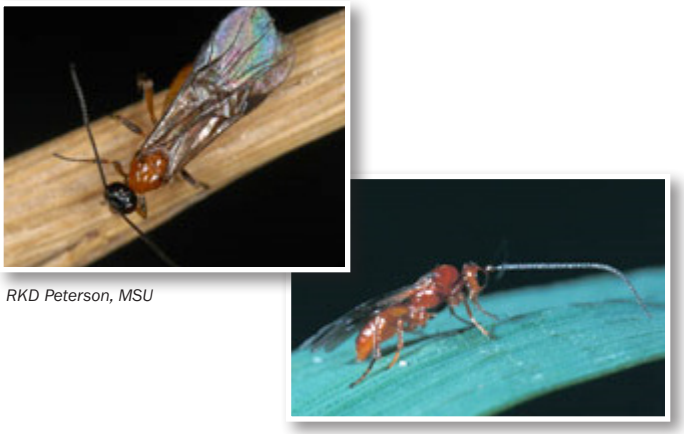
The wheat stem sawfly (WSS), (*Cephus cinctus* [*Hymenoptera: Cephidae*]), is the most important insect pest of wheat in Montana, and probably the most difficult to manage. The WSS is a small ¾ inch long elongate insect with black-and-yellow-colored banding on the abdomen. It has chronically infested wheat in the Northern Great Plains region since the beginning of the last century and causes grower-estimated crop losses of $25 to $100 million annually in Montana. After mating, female sawflies lay their eggs within developing wheat stems, typically during June. The elongated whitish larvae that superficially look like small caterpillars, feed and complete their development within the wheat stem. The duration of the overall flight period of the emerging adults (3-5 weeks) and the internal feeding behavior of the larvae make their control with contact insecticides highly unreliable. Eggs and larvae within the wheat stem are protected from insecticide sprays. Controlling adults is unreliable because it is difficult to time adequate spray applications and modern insecticides do not persist for the duration of the flight period. To date, new systemic insecticides applied as seed treatments have not been effective. Both spring and winter wheat can be heavily infested and damaged.

RKD Peterson, MSU

Adult wheat stem sawfly.

Damage is caused in two ways. The feeding activity of the larvae within the stem reduces the flow of nutrients to the developing seed head resulting in yield loss exceeding 20% under some circumstances. However, the most obvious yield loss is caused when the wheat stem breaks, falls over and lodges just before harvest. As the larvae mature they cut a V-shaped notch around the stem weakening it at the base. The stub is plugged by the larvae that overwinter within the stem, close to ground level. During the following spring the larvae continue developing to the next generation of adults that typically emerge and fly during June.

A variety of management options are available, some of which can be integrated together. One primary recommendation is the use of solid stem wheat varieties that were first developed in the 1940s. Solid stem varieties are not immune to damage, particularly at very high sawfly populations, but the solid stem can cause



RKD Peterson, MSU

***Bracon cephi* (R), and *Bracon lissogaster* (L) are small parasitic wasps important for biological control of wheat stem sawfly.**

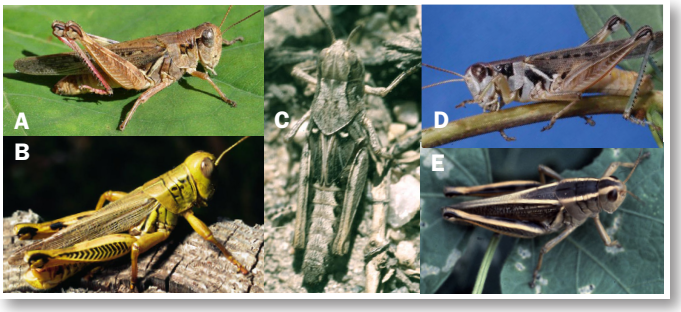
larval mortality up to 50% and it is also more resistant to lodging. An alternative strategy is to plant high yielding but susceptible hollow stem varieties, and reduce crop loss by swathing before significant lodging begins. This approach has no effect on the size of the sawfly population that will overwinter, it only conserves crop yield. Other management recommendations involve a variety of cultural practices that reduce sawfly numbers but not enough to impact population size the following year. Oats are resistant to sawflies and if used in a large-scale crop rotation, may aid in the reduction of sawfly populations.

Another approach is to conserve natural enemies of the WSS. Two related species of small parasitic wasps, *Bracon cephi* and B. *lissogaster,* are the two most important natural enemies of WSS. These wasps produce two generations per year as opposed to one for the WSS. The success of the second generation, which has much greater numbers, depends on the maturation of the wheat. Therefore, spring wheat typically has more parasitoids than winter wheat. Female parasitoid wasps lay their eggs through the wheat stem placing them directly onto sawfly larvae that they paralyze. The parasitoid larvae feed and develop within the sawfly larvae resulting in their death before they cut notches in the base of wheat plant. The parasitoid larvae then form pupae (the last stage before adults) within a cocoon located higher up in the stem, where they overwinter. The following spring new adults emerge a few weeks after the sawflies begin flying. Traditional harvesting methods remove more of the parasitoids that are overwintering higher up in the stems, compared to sawfly larvae that overwinter closer to ground level. One recommendation is to cut the crop at one-third of its standing height, to conserve the natural enemies for the following season. Burning crop residue, grazing and heavy tilling can also kill the parasitoids, while light tilling or weed control with herbicides has no effect.

As the most important pest of wheat in the Northern Great Plains region, the WSS is also the most researched insect pest of wheat in this region. Research reviews were written as early as 1917. Research at MSU continues to investigate a variety of new management techniques. Ongoing research includes investigating the nature of resistance that oats have to sawfly larval feeding, pheromone traps, degree day models for monitoring, and planting attractive trap crops around less attractive varieties.

GRASSHOPPERS.

More than 70 species of grasshoppers can be found in the Northern Great Plains Region but only a handful attack and damage small grain crops. Grasshopper populations tend to increase over a 2-4 year period and one or a few species make up the majority of the outbreak. Species that feed on a variety of host plants tend to move into small grain crops from the surrounding borders, including the two-striped *(Melanoplus bivittatus)*, migratory (M. *sanguinipes)*, clearwinged *(Camnula pellucida),* differential (M. *differentialis)* and redlegged (M. *femurrubrum)* grasshoppers. Most grasshoppers complete their life cycle (egg, nymph, adult) during a single season. Eggs hatch in the spring and the juveniles go through a series of molts to become adults later in the summer. Grasshoppers develop to adults by incomplete metamorphosis, meaning the juveniles resemble the adults in appearance. Nymphs are distinguished by their wing buds that increase during each molt, only becoming full-sized and functional for flying in the adult stage.



In Montana there are five grasshoppers of economic importance in small grain production. A. redlegged; B. differential; C. clearwinged; D. migratory; E. two-striped.*

The Northern Plains Agricultural Research Laboratory (NPARL) in Sidney, MT, maintains a grasshopper website (https://www.sidney.ars.usda.gov/grasshopper/) with extensive information on grasshopper identification, biology and management. Resources on this website include grasshopper survey and hazard maps (https://www.sidney.ars.usda.gov/grasshopper/Extras/index.htm) and an electronic key (https://www.sidney.ars.usda.gov/grasshopper/Support/lucid.htm) for identification.

Grasshoppers will move into small grain cropland as the summer progresses and emerging winter wheat can be at risk in the fall. Grasshopper densities should be visually estimated within the fields and along the field margins.

** A. Russ Ottens, Univerity of Georgia; B. David Riley, University of Georgia; C/E. Whitney Crenshaw, Colorado State University; D. Joseph Berger. All from Bugwood.org.*

Several estimates should be averaged. Monitoring methods including the 'Visual 18 ft^2 Method' are provided in *USDA Grasshopper Guidebook* (https://www.aphis.usda.gov/import_export/plants/manuals/domestic/downloads/grasshopper.pdf). When threshold levels (Table 6) are reached, chemical control is warranted.

Spring Wheat Grasshoppers typically move into small grain crops as the summer progresses. Early scouting to determine the source and density of grasshopper in the crop border is important. If required, treating the crop margin or the border area (150 feet wide) surrounding the crop may be adequate for control. If grasshopper densities are high, control may require up to a quarter mile border treatment. Under extreme pressure, control may be difficult and multiple border treatments may be required. Border areas and crop margins should be monitored after treatment to ensure that grasshoppers do not re-enter the field. For larger areas such as rangeland, a "skip pass" tactic can be used, also termed the Reduced Agent/Area Treatment Program or 'RAATs' (https://www.sidney.ars.usda.gov/grasshopper/Research/lockwood.htm). Ground or aerial equipment can be used to alternate treated and untreated strips in the target area, reducing the cost of application. Control is achieved because grasshoppers are exposed to the insecticide as they move from untreated to treated areas. Insecticides such as zeta cypermethrin (Mustang Max), carbaryl (Sevin) and diflubenzuron (Dimilin – an insect growth regulator) are commonly used to control grasshoppers. Semaspore bait is a biological insecticide containing *Nosema locustae,* a microsporidia pathogen that infects and kills grasshoppers. Semaspore and Dimilin need to be applied earlier in the season and are not effective against adult grasshoppers.

Winter Wheat Border treatments applied as insecticidal sprays or seed treatments are the main recommendation for protecting emerging winter wheat. Typically, spraying 150 feet beyond the edge of the crop or 1-2 passes with treated seed around the perimeter of the field is a sufficient border. Adult grasshoppers are more difficult to control, and the higher end of label rates are recommended. If grasshopper populations are very high they are difficult to control, borders up to a quarter mile and repeated applications may need to be considered. When applying border sprays, timing is critical. Border sprays need to be applied just before the wheat emerges; if it is applied too early there may not be enough residual, if it is applied too late, the damage may have already occurred. Systemic seed treatments eliminate the timing concern, but systemic insecticides require consumption, so some feeding damage will occur but it should be reduced considerably. Carbaryl and pyrethroid insecticides are commonly used as sprays and imidacloprid is used for seed treatments. Dimilin and Semaspore bait are not effect against adult grasshoppers. In general, baits may not be as effective at controlling adults compared to the juvenile nymphs.

Frank Peairs, Colorado State University, Bugwood.org

Pale western cutworm (L) and Army cutworm (R) larvae.

PALE WESTERN CUTWORM

The pale western cutworm (*Agrotis orthogonia* [*Lepidoptera: Noctuidae*]) is a subterranean soft-bodied caterpillar. It is grayish-white without spots or stripes with two distinct vertical brown bars on the front head capsule. A fully developed larva is about 1½ inch long.

The adult moths emerge from the soil in late summer or early fall. The moths lay their eggs in loose soil. Some eggs may hatch in the fall, but the majority hatch in the spring. The pale western larva feeds underground on newly emerging plants, tillers, and roots. Because the pale western cutworms cut stems, they can destroy the plant's growing point resulting in plant or tiller death. Field damage many times appears as poor or spotty stands. Larvae can be found by scraping the soil surface and either passing the soil through a fine screen or looking for the small larvae against a white board or paper. Treatment may be justified if 2 to 3 small larvae (< ½ inch) per foot of row are present. Large larvae indicate near completion of feeding, and treatment may be too late to be cost effective.

TABLE 6. Threshold levels of grasshoppers for Spring Wheat*

Number of Grasshoppers Per Square Yard		Treatment Required
Within Field	Field Border	
0-2	5-10	No, Non Economic
3-7	11-20	Light, Treatment Questionable
8-14	21-40	Moderate, Likely Economic
> 15	>41	Heavy, Requires Treatment

*For winter wheat, larger adult-stage grasshoppers moving into emerging fields are more difficult to control. Therefore thresholds for emerging winter wheat are lower at 3-7 grasshoppers per square yard within the field, or 11-20 per square yard within the field border.

ARMY CUTWORM

The Army cutworm (*Euxoa auxiliaris* [*Lepidoptera: Noctuidae*]) larvae can periodically cause significant damage in wheat fields. The adult moths lay eggs beginning in late August just beneath the soil surface. These eggs hatch in the fall, and the cutworm species overwinters in the larval stage. The larvae are greenish-brown to greenish-gray with the dorsal (top) side darker than the ventral (underside). A narrow, pale mid-dorsal stripe is usually present. The head is pale brown with dark brown freckles.

Plant damage occurs as feeding on plant leaves and stems in early spring. They feed during the night and can occasionally be found feeding on overcast days. The small ($^1/_{16}$ inch) size of the early instar larvae coupled with their nocturnal behavior makes them difficult to detect even though foliar damage is quite apparent. Treatment may be warranted when 4 to 5 army cutworm are found per square foot. More information on both species of cutworms can be found in the *Pale Western and Army Cutworms in Montana* (Blodgett et al., 2000).

WIREWORMS

Wireworms (many different species) are slender, jointed hard-bodied insects that can sometimes cause significant damage in wheat and other small grains. Wireworms are the larval stage of click beetles. Early larval stages are white in appearance and feed on germinating seeds or young seedlings. Larvae have three pairs of legs located just behind the head, with their last abdominal segment flattened. Larvae may reach 0.5 to 1 inches in length. When fully grown, the larvae pupate in summer, and adults emerge the following spring. The females then lay eggs in loose or cracked soil. The young wireworms hatch and begin feeding on roots or germinating seeds. The larval stage can last anywhere from 2 to 5 years. This extended time as larvae can cause crop damage to recur in 'hot spots' over several years causing wheat stands to appear thin or as areas of poor germination.

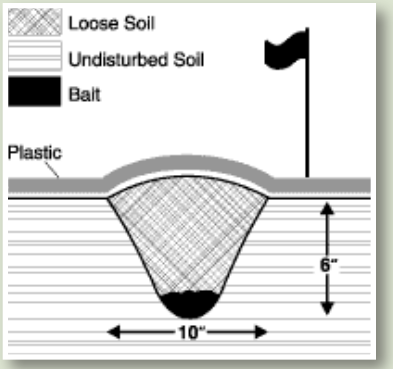
High Plains IPM

Juvenile wireworms (left) remain in this growth stage for several years. Adult stage (right) also known as click beetles are not of economic importance.

Monitoring for wireworms

Wireworms can be monitored using a bait station. This is a good approach because wireworm impacted areas are not always consistent from one year to the next. To create a bait station: Bury ½ cup of wheat or a 50:50 mix of presoaked wheat or corn in a hole measuring 3-4 inches deep and 9-10 inches wide. Wireworms are attracted to the germinating seed. The seed should be covered with loose soil and slightly mounded in a dome shape, and covered with black plastic to warm the soil. Bait stations, marked with a flag so they can be easily located, should be deployed 2-3 weeks prior to planting. A threshold of two or more wireworms per bait station may warrant treatment with an insecticide.

Wireworm bait stations



graphic courtesy of www.ag.ndsu.edu/pubs/plantsci/pests/e199-1.htm

Plant damage from wireworms can be confused with cutworm damage. With wireworms, damaged plants will be wilted and discolored, but the plant remains attached to the root. With cutworms, the plants are usually cut off completely at or near the soil surface. Topsoil down to approximately 6 inches should be sieved to look for wireworms, repeating the process at different areas of the field. When populations exceed an average of two larvae per bait station, insecticide seed treatment may be necessary. Generally, healthy, well-fertilized plants tend to outgrow wireworm damage. For wireworm control, seed treated with approved insecticides has proven effective. More information can be found at the High Plains IPM Guide (http://wiki.bugwood.org/HPIPM:Main_Page).

ORANGE WHEAT BLOSSOM MIDGE

Orange wheat blossom midge, (*Sitodiplosis mosellana* [*Diptera: Cecidomyiidae*]) has a broad distribution in the Northern hemisphere. Economic damage to wheat by this insect has been reported in the Canadian prairies as well as North Dakota, Montana and Idaho. In Montana, economically damaging infestations have occurred in Flathead County around the Kalispell area. However, the insect has also been present in the northeastern part of Montana for some time

and monitoring efforts have detected populations of this insect in the Golden Triangle.

The small orange-colored midge resembles a mosquito in appearance, but is about half the size. Adults emerge after pupating in the soil in late June or early July. After mating, the short-lived females lay their eggs on newly emerged wheat heads. The eggs hatch and the small orange larvae feed on the developing kernels, reducing yields and grain quality. The larvae then fall to the soil and overwinter in cocoons.

P. Glogoza, Univ.

The crop is most susceptible to damage from early heading through pollination. Damage to the crop is not readily visible since the infested wheat heads have no external symptoms. As such, the only way of detecting their presence is to thresh the heads and inspect the kernels. The adult insect can be monitored by scouting fields at dusk, or by the use of pheromone traps and sticky traps. Several insecticides are labeled for control, but timing is critical. Economic threshold levels for Montana have not been established.

Researchers at MSU and the Northwestern Agricultural Research Center have released the spring wheat variety Egan that has the SM1 gene that provides resistance to the orange wheat blossom midge. The SM1 gene is highly toxic to the midge larvae. To prevent resistance to SM1 from developing in the midge populations the seed is sold as a certified blend that contains 10% seed that does not contain the SM1 gene (referred to as “refuge in a bag”). Insecticide efficacy trials are being conducted as well as temperature-based models to predict the development of the insect. See *Orange Wheat Blossom Midge* (Stougaard et al., 2014) for more information.

Frank Peairs, Colorado State University, Bugwood.org

Colony of Russian wheat aphids in a wheat leaf.

APHIDS

Aphids are small insects with sucking mouthparts which they insert into the host plant. Aphids can reproduce asexually and their populations can expand quickly if conditions permit. Damage to small grains can occur directly or indirectly from feeding. English grain aphids can move to the wheat head during the boot stage where they cluster around the bracts. If aphid numbers are high enough, the wheat kernels shrivel as a result of feeding damage.

Greenbug and Russian wheat aphids damage small grains by injecting toxic saliva into the plant as they feed. As they suck plant sap, the aphid injects toxic salivary secretions into the plant cells. Yellow or reddish stippling on the leaves is a result of the toxin that kills the plant cells. Aphids also damage crops indirectly by vectoring viruses. The greenbug and English grain aphids both can be vectors of the barley yellow dwarf virus that can infect wheat. For more information refer to *Aphids of Economic Importance in Montana* (MT200503AG).

The High Plains IPM Guide (http://wiki.bugwood.org/HPIPM:Main_Page) lists management recommendations for aphid that periodically cause economic damage in Montana, such as the greenbug, Russian wheat and English grain aphids.

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Weblinks

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- Economics of Fertilizer Application in Grain Production http://www.msuextension.org/econtools/nitrogen/
- Extension Bulletins and MontGuides are available through MSU Extension Publications: https://store.msuextension.org/
- Fertilizer Facts are available at http://landresources.montana.edu/fertilizerfacts/index.html
- Fertilizer Recommendation Tool http://www.sarc.montana.edu/php/soiltest/
- Herbicide Selection Tool http://www.sarc.montana.edu/php/weeds/
- Variety Selection Tool http://www.sarc.montana.edu/php/vareties/
- Schutter Diagnostic Laboratory website http://diagnostics.montana.edu
- Small Grains for Montana Performance Evaluation and Recommendations http://plantsciences.montana.edu/crops/index.html
- Many of Dr. Jones publications are available through his website at: http://landresources.montana.edu/soilfertility/index.html

SAFE FERTILIZER RATES FOR SEED-PLACED PRODUCTS

- International Plant Nutrition Institute – safe seed-placed rates http://www.ipni.net/article/IPNI-3268
- Manitoba Agriculture and Rural Development – safe seed-placed rates http://www.gov.mb.ca/agriculture/crops/soil-fertility/print,seed-placed-nitrogen-fertilizer—a–second-opinion-please.html
- Saskatchewan Ministry of Agriculture – safe seed-placed rates https://www.saskatchewan.ca/business/agriculture-natural-resources-and-industry/agribusiness-farmers-and-ranchers/crops-and-irrigation/soils-fertility-and-nutrients/guidelines-for-safe-rates-of-fertilizer-applied-with-the-seed

ENTOMOLOGY AND INSECTS

- High Plains IPM Guide http://wiki.bugwood.org/HPIPM:Main_Page
- Northern Plains Agricultural Research Laboratory Grasshopper website https://www.sidney.ars.usda.gov/grasshopper/
- Wireworm bait stations http://www.ag.ndsu.edu/pubs/plantsci/pests/e199-1.htm
- RAATS, Reduced Agent/Area Treatment Program https://www.sidney.ars.usda.gov/grasshopper/research/lockwood.htm
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