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MONTANA BARLEY

PRODUCTION GUIDE

Kent McVay

Mary Burrows

Clain Jones

Kevin Wanner

Fabian Menalled



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	
	1 st 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	
	1 st node detectable	31	6	
	2 nd node detectable	32	7	
	3 rd node detectable	33		
	4 th node detectable	34		
	5 th node detectable	35		
	6 th 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		

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Editor

Kent A. McVay, associate professor and MSU Extension cropping systems specialist, Department of Research Centers, Montana State University, located at the Southern Agricultural Research Center, Huntley, MT.

Contributing Authors

All authors are faculty members of Montana State University. Kent McVay is the principle author, assisted by Clain Jones, associate professor and Extension nutrient management specialist in the Department of Land Resources and Environmental Sciences; Mary Burrows, professor and Extension plant pathology specialist in the Department of Plant Sciences and Plant Pathology; Fabian Menalled, professor and Extension cropland weed specialist in the Department of Land Resources and Environmental Sciences; and Kevin Wanner, an associate professor and Extension entomology specialist in the Department of Plant Sciences and Plant Pathology.

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Preface

The intent of this publication is to provide current information on barley 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 barley crop. More detailed information can be found on certain topics by following the links to the referenced websites. Hard copies of many of the references in this publication are available through MSU Extension Publications, as well as through your local county MSU Extension office.

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Barley description and history

In 2015 Montana producers harvested 860,000 acres of barley at a value of over \$258.5 million (Anonymous, 2017). This number represents a decline in total barley acreage from a high of 2.4 million acres in 1986. Montana has ranked second in barley production since 2002 to North Dakota. Add in Idaho's 500,000 acres and these three states account for 77% of the nation's barley production. Barley is an important crop for Montana, fitting nicely into rotations with sugar beets and corn in irrigated production, as an alternate dryland crop to wheat, and as an annual feed and forage crop in dryland and irrigated production.

Variety selection

Barley products include malt, feed grain, hay and a minor amount of food. The end use market determines proper agronomic management of the crop. For example, for use as malt, stringent grain quality dictates acceptability in the market. Management for malt quality factors becomes more important than management for high yield (see Table 1), and generally requires more precision than management for feed. In the feed market, total barley grain yield and higher protein becomes more important than malt quality factors.

Variety selection is most important, and varieties for malt production are not always the best choice for the feed grain market. This is particularly true for dryland production, although many producers, without a malt barley contract, will speculate by growing a malt variety hoping for malt quality and use the feed grain market as a safety net. There are some open markets for malt barley although most malt barley is specified by contract with individual companies that require specific varieties. The AMBA website <http://ambainc.org/> provides a list of malt varieties recommended for the current production year. Maltsters are particular in the varieties they purchase and even narrow their choices within the list of AMBA approved varieties. If you are considering growing malt barley without a contract, first investigate the market prior to planting and be aware of the potential for reduced yields, particularly on dryland, when growing a malt variety as opposed to a feed barley. Insurance is typically not available for malt barley without a contract. Be sure to check with your insurance office prior to making the decision to plant.

Variety development for feed grain production has produced some outstanding varieties capable of high yield. Variety trials are conducted annually at the Montana Agricultural Research Centers. Results are published at the Southern Ag Research Center (SARC) website <http://www.sarc.montana.edu> as Annual Reports to the Montana Wheat & Barley Committee. Click on the link to 'Research Results', and then 'Reports to MWBC.' Results from the current year back through 1997 are available. Results are

also available on CD from SARC or the Montana Wheat and Barley Committee, Great Falls, MT, upon request. Montana Variety Performance Evaluations is another good source of variety information and is available from the MSU Plant Sciences and Plant Pathology Department website <http://plantsciences.montana.edu/crops/index.html>.

Tillage

Barley can be successfully produced in any tillage system. Soil management begins at harvest via residue management. It is important to distribute crop residue as evenly as possible during harvest. This is especially true if barley or any other crop is to be planted no-till, but is also important in tilled systems. Straw choppers and chaff spreaders on combines efficiently distribute residue, simplifying the next operation. In dryland operations, stripper headers which strip small grain from the straw rather than cutting the straw are a good option which leaves straw intact which requires no spreading.

In flood irrigation, conventional tillage is typically used to reduce residue levels for more uniform water distribution the following year. There are options for less tillage in irrigated systems. For example, following barley harvest, straw can be baled and the field left for a no-tillage establishment of sugar beets, corn, or canola the following spring. One or two heavy harrow passes shortly after harvest is effective in spreading residue and breaking it up in preparation for spring planting. A planter capable of no-tillage operations will be required because the remaining residue and more dense soil under no-till conditions will be difficult to penetrate. Straw can be burned, but burning is not recommended on a regular basis as this can lead to reduced soil organic matter over time. For overhead sprinkler systems options for less tillage are even better. In these systems, residue does not need to be removed for water distribution. Crop rotations (see below) rather than tillage become key to managing diseases and pests just like in dryland systems.

TABLE 1. Typical Two-Row Malting Barley Purchase Specifications. Be sure to check with your buyer for their current requirements.

Quality Factors	Two-Row Barley
Moisture	< 13%
Plump kernels (on 6/64 screen)	> 70%
Diseased and Damaged	< 5%
Germination	> 97 %
Protein	7.5 - 14 %
Skinned & broken kernels	< 3 %
Wild oat	< 2.5 %
DON (Vomitoxin)	< 1 ppm

No-till usually results in soil conditions that are wetter and cooler than tilled soils largely due to the residue, which reflects solar energy rather than absorbing it as does exposed soil. One benefit of keeping residue in place is improved soil moisture within the planting zone which helps stand establishment. The mulching residue protects the newly emerged crop from physical damage from wind, blowing soil, and rain. Planter openers such as 4- to 6-inch sweeps or residue managers ahead of openers will move residue from the row, allowing soils to warm quicker while keeping the area between rows covered. Watch for shifts in weed species when moving from tilled to minimum-till or no-till systems. Reduced tilled systems favor winter annuals so it is important to use a herbicide application like glyphosate prior to crop emergence.

Planting Dates and Rates

Barley crops grown in Montana are spring varieties; no winter varieties are currently adapted to this region. Barley is a cool-season crop, and will yield best when vegetative and early reproductive growth occurs while temperatures are cool. Spring barley will germinate at temperatures above 40°F. Optimal germination and emergence occurs

when soil temperatures are between 55°F and 75°F. In the spring, barley should be planted as soon as possible after killing grassy and other weeds. Delayed planting can result in lower yields and higher protein, which can be cause for rejection in the malt market. In general, early-seeded barley (late-February to mid-April depending on location) avoids injury from drought, high temperatures, diseases, and insect pests that occur late in the season. As a rule-of-thumb for Montana, potential yield is reduced approximately one bushel (bu) a day for each day planting is delayed after the first of May.

Planting depth should be 1 to 1½ inches. It's important that press wheels cover the entire width of the seed trough to ensure good seed-soil contact. This is especially true if using an air seeder with wider openers. Recent research (McVay and Khan, 2015) indicated no yield difference in irrigated malt barley production for plant populations that ranged from 9 to 28 plants/ft² (400,000 to 1.2 million plants/acre). Barley has a tremendous ability to compensate for poor stands by producing tillers. Irrigated malt barley populations should target a minimum of 750,000 plants/acre. That way if an early stand loss occurs that leaves as few as 9 plants/ft² (assuming uniformity across the field), a significant yield penalty would not likely occur. This is preferable to replanting, which usually lowers yield due to later establishment. For dryland production, malt barley populations should be about half that of irrigated. Dryland feed barley populations should be at least 500,000 plants/acre.

The number of seeds per pound varies by variety and within a variety each year depending on the quality of the grain. In central Montana in 2007, results from the variety performance trials showed that seed weights ranged from 8,500 to 13,000 seeds per pound. This large variation in seed size is one reason why a seed test should be used to calculate optimum seeding rates.

Crop Rotations

Recent studies in North Dakota (Krupinsky et al., 2006 and Tanaka et al., 2007) 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's strips oriented perpendicular to the first year's. This provided a data set of each crop on 10 different kinds of residue. Table 2 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% (relative yield of 1.5 to 1.6) 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

Barley Seeding Rates

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

Crop	Plants/acre x 1,000	Plants/ft ²
Irrigated malt	800 – 1,200	18 - 28
Dryland malt	400 - 600	9 - 14
Feed barley	500 - 720	11 – 17
Hay barley	850 - 950	18 - 22

Seeds per pound is usually provided on the seed test report. To calculate actual seeding rate on a pure live seed (PLS) basis, use the information from each seed lot to correct for seeding rate. For example, assume a seed test indicates the following information: density of 11,400 seeds/lb, germination of 95%. With experience you expect that your stand will be approximately 90% of what you plant. Calculate the planting rate to obtain 750,000 plants/acre as follows:

$$\text{Seed Rate (lb/acre)} = \frac{(\text{Desired plants/acre})}{(\text{Seeds/lb}) \times \% \text{ Germ} \times \% \text{ Stand}}$$

$$\text{Seed Rate (lb/acre)} = \frac{(750,000 \text{ plants/acre})}{(11,400 \text{ seeds/lb}) \times 0.95 \times 0.90}$$

$$= 77 \text{ lb/acre}$$

TABLE 2. Relative expected yield response of a crop following various previous crops. A value of 1.0 indicates yields were neither improved nor depressed due to the previous crop.

Previous Crop	CS grass	WS grass	CS Pulse	Canola	Sun or Safflower
CS grass	1.00	1.59	1.19	1.09	1.81
WS grass	0.84	1.00	1.04	0.93	1.84
CS 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

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 planting time. The low carbon to nitrogen (C:N) ratio of pea straw allows quicker decomposition than wheat straw, which reduces the total amount of residue on the ground the following season. Crops like canola and mustard produce less residue at harvest so alternating these crops with small grains, a high-residue-producing crop, is a good management practice. In irrigated cropping systems rotational crops such as sugar beets, dry beans, soybeans, peas, or alfalfa provide excellent disease management for Fusarium Head Blight (see "Managing Plant Diseases," page 10, for more information).

Irrigation Management

Proper irrigation is important to maximize yield, minimize waste, prevent offsite movement of nutrients and agricultural chemicals, and manage to reduce disease incidence. To properly manage irrigation, crop water use and water holding capacity of soils must be understood.

AVAILABLE WATER CAPACITY (AWC)

Soils vary in the amount of available water they can store. Sandy soils hold as little as 1.0 inch per foot of soil depth. Loams can hold more than 2.0 inches per foot of soil. Soil properties also vary by depth, so a composite number for total storage in a 3-4 foot profile is needed to determine how much water can be stored in the profile. This value is called the available water capacity of soils (AWC). Applying more water than can be stored in this soil profile will result in water moving below the root zone. Deep movement of water is discouraged as it is wasteful and can leach chemicals and nutrients such as nitrogen (N) below the root zone and toward the water table.

Available water capacity can be determined in a soil lab. Water content is determined by weight loss upon drying after bringing soils to benchmarks of field capacity and wilting point. The AWC is the volumetric difference in water content of field capacity minus water content at wilting point. Commercially-marketed measurement devices can provide indirect estimates of AWC. Several technologies are available such as neutron probes, time domain reflectometry (TDR), tensiometers, and gypsum blocks. Water content can also be estimated by feel and appearance of soil from field sampling (Anonymous, 1998). And soil properties

including AWC are available for specific locations online using Web Soil Survey, <https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm>. However you determine AWC, a composite value for the soil profile is necessary in order to properly schedule irrigation applications because the soil is the main reservoir for crop water use.

EVAPOTRANSPIRATION (ET)

The sum of water that is transpired through plants and evaporated from the soil surface is ET. Seasonal ET for irrigated barley in Montana ranges from 15 to 20 inches, with peak use occurring at flowering through soft dough stage. At flowering, barley can use up to 0.30 inches of water daily, a rate typically greater than what can be maintained through most sprinkler systems over a significant area.

The Southern Ag Research Center currently provides crop ET estimates for irrigation scheduling using the world-wide standard method of Allen et al., 2005, and ET estimates for any recent time period are displayed using the SARC "Irrigation Scheduling tool," http://www.sarc.montana.edu/php/wx_trends/. Two electronic weather stations located near Huntley, and Hysham, MT, provide estimates of ET for local growers. Estimates of ET for other locations can be found through MesoWest, <http://mesowest.utah.edu/>. Corrections for local precipitation at individual fields should always be made to a running water balance to manage irrigation timing for individual fields.

IRRIGATION SCHEDULING

Research has shown that optimum production of malt barley occurs when available soil moisture is maintained above 50% AWC. The two most critical periods to avoid water stress are tillering and boot stage. Drought stress during tillering can reduce the number and size of heads. Stress during boot stage can interfere with pollination, which can severely reduce yield by reducing the number of kernels per head.

Depending on the method of irrigation, best management keeps the soil at or above 50% AWC until soft dough stage.

Most pivot irrigation-systems will not be able to apply enough water to keep up with ET during the maximum use period. Building a bank or reserve of AWC in the soil profile prior to early boot is necessary to keep from stressing the crop during the reproductive period. Recent research in Idaho (Neibling et al., 2017) has shown that malt barley needs just 2.5 inches of available water after soft dough to maximize quality and yield. Excess water after the soft dough stage can result in lodging.

Harvesting and Handling Grain

For malting barley, grain quality is of utmost concern. Premiums are paid for malting barley that is in good condition and has been stored properly. Because the malting process requires complete and uniform germination, grain handling to minimize physical damage is very important. A high percentage of skinned and broken kernels results in inferior quality malt, so maintaining all augers and grain-handling equipment in good repair is very important.

No pre-harvest desiccants are labeled for malting barley, so none should be used. Barley is considered to be physiologically mature at approximately 35% moisture. It can be cut any time after this, but the grain is easily damaged by harvesting equipment at moisture levels above 18%. If malting barley is harvested at moisture levels above 13%, it must be dried before being stored. Natural air/low temperature drying is generally preferred as high temperatures can cause cracking and reduced germination and test weight of grain. Removing heat and moisture from stored grain directly after harvest increases the safe storage time for malt barley (Table 3). Grain moisture should be reduced to 11-12% for long-term storage.

All modern combines can be adjusted to thresh barley and specific settings by the manufacturer should be followed. While threshing, regular checks should be made for skinned and broken kernels. Minor adjustments may be necessary during the day to compensate for changes in humidity and moisture content. In general, slower cylinder speeds and close concave adjustments usually result in cleaner harvested grain.

Grain handling after harvest by on-farm elevators and augers can also lead to damaged kernels. Bent or dented

auger housings and ragged edges can cause damage to grain. Pneumatic elevators are recommended to move grain. Do not run this type of equipment above the recommended speed, as grain can be damaged by sharp angles, high velocities, and by moving grain long distances.

A detailed guide for Harvesting, Drying, and Storing Malting Barley can be found at the AMBA website, <http://ambainc.org/>, which provides guidelines on combine settings, drying procedures, and grain handling.

Fertility Management

Evaluating the soil's available nutrient levels is done with 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 will change slowly. 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.

NITROGEN (N)

Source. If N fertilizer is used correctly, there are no barley yield or quality differences between different N fertilizer sources (e.g., anhydrous ammonia [82-0-0], urea [46-0-0], urea ammonium nitrate [UAN, 28-0-0 or 32-0-0], ammonium sulfate [21-0-0-24]). However, nitrogen fertilizers have different potentials for N loss to leaching and volatilization (loss as ammonia gas to the air) depending on how quickly they convert to ammonium and nitrate and how long those are in the soil before crop uptake. Ammonium sulfate and urea ammonium nitrate have lower volatilization potential

TABLE 3. Malt barley safe bin storage time for combinations of grain temperature and moisture (days).

	11%	12%	13%	14%	15%	16%	17%	18%	19%
80 ° F	230	175	115	70	40	20	11	9	6
70 ° F	560	420	270	175	100	50	30	20	15
60 ° F	*	*	660	430	260	130	65	45	25
50 ° F	*	*	*	*	630	350	140	100	60

*Allowable storage time exceeds 700 days.
Source: Schultze et al., 1976.

than urea but equal leaching potential. Dry urea is still the best choice if it can be incorporated by tillage or more than 0.5-inch of water in a single event. For more information on ammonia volatilization please see MSU Extension publication *Management to Minimize Nitrogen Fertilizer Volatilization* (Jones et al., 2013).

Specialized products such as polymer-coated urea (e.g., ESN®), or urea treated with N-butylthiophosphoric 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, albeit based on wheat rather than barley studies.

NBPT delays urea conversion to ammonia, thus buying time for incorporation by precipitation and reducing volatilization loss (Engel and Jones, 2015). This can increase winter wheat grain protein (Engel and Romero, 2016), but the effect on barley yield and protein has not been tested.

Polymer-coated urea (PCU) products are designed for controlled release to match crop need and reduce loss to volatilization and leaching (Olson-Rutz et al., 2009). These may prove valuable under furrow irrigation. For example, in a three-year Idaho study, ESN® at 180 lb N/acre was found to increase N recovered as compared to urea, by 11.5 to 14.9% in furrow-irrigated spring wheat (Brown, 2008). In addition, grain yield at the optimum N rate was increased by approximately 10 bu/acre with ESN®, compared to urea in two of the three years (Brown, personal communication). Polymer-coated urea has not consistently increased wheat yields or protein in dryland production because the N release is temperature and moisture dependent. Under cool or dry conditions, N release tends to be slow. However, 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 worth it. Late winter and early-spring broadcast or subsurface applications do not usually benefit yield, but may increase protein. However, if substantial amounts of N is released near flowering, grain protein levels can be too high to meet malt quality. 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 in a dryland system is key to preventing yield losses in the subsequent 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 N credit after just one year, but the subsequent small grain yield goal needs to be adjusted lower than after fallow. After three cycles with dryland lentil green manure in northeast Montana, wheat yields were the same following green manure without additional N and fallow with 30 lb N/acre fertilizer. Over the long term (at least four cycles), wheat grain yield and protein was greater after cover crops than following fallow with less or no fertilizer N (Miller et al., 2015). The effect should be similar for barley. Legume cover crops release N more quickly than pulse crops. A pulse rotation can still increase barley yields planted three years after the pulse crop (Lupwayi and Soon, 2016). Legume N credit is greater in more productive systems, and highly variable among species and agronomic conditions.

Rate. Montana State University suggest 1.6 pounds of available N (soil nitrate-N plus fertilizer N) per bu of yield goal (lb N/bu) of feed barley and 1.2 lb N/bu of malt barley (Jacobsen et al., 2005). Recent work at the Southern Agricultural Research Center (McVay and Khan, 2016) indicates 1.3 lbs N/bu is optimum for MillerCoors varieties and 1.4 lbs N/bu optimized protein for maltsters at 11.5%. The suggested N rate for malt barley is designed to increase the potential for obtaining good malt quality, by decreasing the risk for high grain protein and low plump. Nitrogen fertility must be matched with growing season water to produce a crop with acceptable kernel plumpness. Producers with yield potentials of 70 bu/acre or less must watch their N closely, because if residual soil nitrate-N is greater than 55 lb N/acre, it could produce 75% plumpness without additional fertilizer. Top-dressing around tillering time is an option in high yielding conditions on fields with residual soil nitrate-N greater than 50 lb N/acre. Top-dress to adjust the total N fertility (soil nitrate in three feet of soil plus fertilizer N) to the anticipated yield at the rate of 1.2 to 1.4 lb N/bu to maximize yield while meeting plump specifications (Jackson, 2008).

Although there are no specific fertilizer guidelines for hay barley, N guidelines for grass hay at 25 lb N/ton can be used (Jacobsen et al., 2005). Pea can be inter-seeded with barley to increase total forage yield with higher protein content, but with lower N fertilization needs. If legumes are inter-seeded, no more than 60 lb N/acre is recommended, even when residual soil N is less than 30 lb N/acre (Chen et al., 2004). High nitrates can be caused by deficiencies

or imbalances of other nutrients, or by crop stress. Hay barley should be tested for nitrates which can be harmful to livestock, especially pregnant livestock, which should not be fed feed containing more than 0.035% nitrate-N (0.15% nitrate). For more information on nitrate in forages see MSU Extension Montguide *Nitrate Toxicity of Montana Forages* (Glunk et al., 2015).

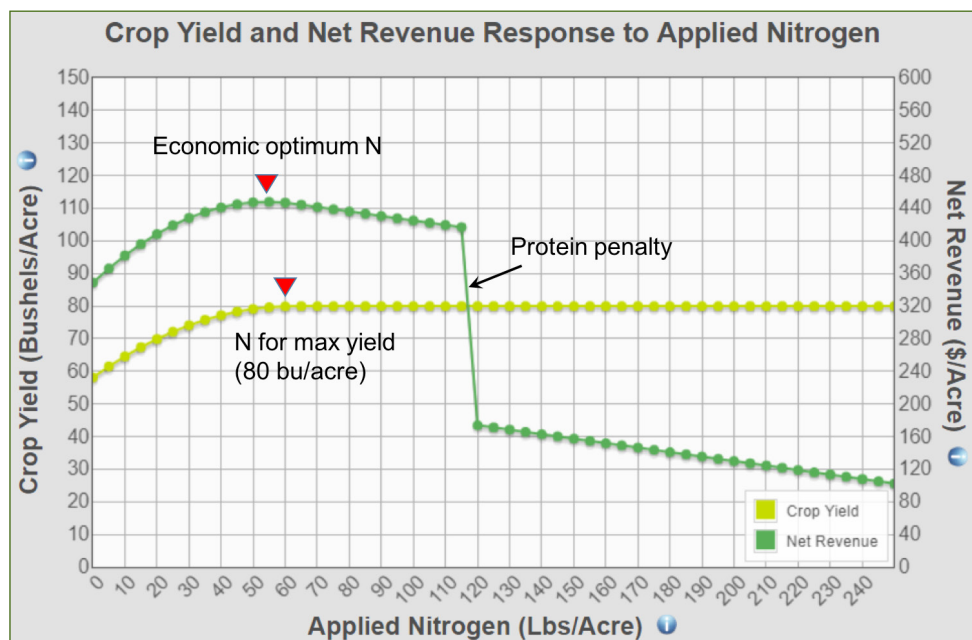
Although a set N rate per bushel is simple, it is generally not the best choice economically. Application rates should be adjusted based on N costs and grain prices. Montana State University's online Barley Economic Nitrogen Model, <http://www.msuxextension.org/econtools/nitrogen/> helps producers fine tune their N rates for malt and feed barley. The model is illustrated in Figure 1. The curved line representing yield in response to applied N is determined by the yield goal, soil organic matter, and spring soil nitrate. Marginal returns to soil N plus fertilizer N increase with grain yield to near the yield plateau (e.g., 60 lb N/acre applied and 40 lb soil N/acre to yield 80 bu/acre). But near the peak of the response curve, the additional cost for each pound of added N fertilizer exceeds the increase in gross revenue, reducing the optimum N rate from that based only on yield. In this example, with malt barley at \$6/bu and \$500/ton urea, 55 lb N/acre is the economically-optimal N to apply, compared to 60 lb N/acre for maximum yield. The difference between the rate for maximum yield and the economically-optimal rate is greater as N prices go up and grain prices fall, and vice versa, although according to the model, over a range of prices (urea = \$350 - \$700/ton, malt grain = \$4 - \$8/bu), the economically-optimal rate varied only by 15 lb N/acre for a yield potential of 80 bu/

acre. Currently this model is calibrated only for barley grown on fallow, and should not be used for recrop or irrigated systems. To assure that the best N rate is selected, it is critical that a representative soil sample be collected from each barley field to a depth of two to three feet and analyzed for nitrate-N, preferably in late winter/early spring.

To further optimize yields, N rates can be varied among "management zones" that are based on previous yield or soil characteristics. For more information on soil sampling strategies and management zones, see *Soil Sampling Strategies* (Dinkins et al., 2017).

Placement and Timing. Ammonia and ammonium-based fertilizers should be subsurface banded at least two-inches (before packing), or if broadcast (urea), 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. 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 + K₂O)/acre. Safe rates of seed-placed fertilizer are higher 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 can be seed-placed at two to three times the safe rate of conventional urea.



Model input	Value
Urea	\$500/ton
Malt barley	\$6/bu
Feed barley	\$3/bu
Plump minimum	75%
Protein maximum	13.5%
Yield goal	80 bu/acre
Soil nitrate	40 lb N/acre
Soil organic matter	2%

FIGURE 1. Barley Economic Nitrogen Model based on example inputs. At N rates greater than needed for maximal yield the risk of barley being rejected as malt and falling to feed prices increases because of elevated protein or low plump.

TABLE 4. Phosphorus fertilizer guidelines for feed/malt barley based on soil analysis.

Olson P soil test level (ppm)	P rate (lb P ₂ O ₅ /acre)
	Feed and malt
0	50
4	40
8	30
12	20
16*	10

* At soil test levels greater than 16 ppm use crop removal rates (0.36 lb P₂O₅/bu grain and 4.1 lb P₂O₅/ton of straw).
Source: Jacobsen et al., 2005

Foliar applications risk leaf burn. No more than 30 lb N/acre of UAN and 45 lb N/acre of liquid urea should be applied to minimize burn and yield loss, and far less can be applied if tank-mixed with herbicide or fungicide. Only 8 to 11% of foliar N is taken up by the leaf compared with 37 to 67% of soil-applied N (Rawluk et al., 2000); therefore, foliar N is more effective if followed by about 0.5-inch of rain or irrigation to be washed into the soil. However, under dry conditions, the small amount of foliar N taken up by the plant might be more effective than surface-applied N which can be stranded on the soil surface. The ease of application of liquids can be outweighed by foliar damage, even with streamer bars, so consider granular urea prior to jointing as an alternative.

Nitrogen available to barley plants up through stem elongation generally benefits yield, while N available after stem elongation contributes directly to grain protein. Fertilizer-N conversion to plant available N (ammonium or nitrate) can take several weeks to months after application, depending on the N source, soil moisture and temperature.

How much P and K is removed annually by barley?

Assume a barley field yields 70 bu/acre, and in addition 1 ton straw/acre is removed. How much P₂O₅ and K₂O has been removed?

By substituting in the values for K₂O, approximately 47.5 lb K₂O/acre is expected to be removed.

$$P_2O_5 \text{ Removed} = \left[\frac{70 \text{ bushel}}{\text{acres}} \times \frac{0.36 \text{ lbs } P_2O_5}{\text{bushel}} \right] + \left[\frac{1 \text{ ton straw}}{\text{acre}} \times \frac{4.1 \text{ lbs } P_2O_5}{\text{ton straw}} \right]$$

$$= 29.3 \text{ lbs } P_2O_5 \text{ removed}$$

Removal rates of nutrients in barley

Nutrient	lb/bushel	lb/ton of straw
P ₂ O ₅	0.36	4.1
K ₂ O	0.25	30.0

Source: Jacobsen et al., 2005

TABLE 5. Potassium fertilizer guidelines for feed/malt barley based on soil analysis.

K soil test level (ppm)	K rate (lb K ₂ O/acre)	
	Feed	Malt
0	75	90
50	65	80
100	55	65
150	45	50
200	30	35
250*	20	25

* At soil test levels greater than 250 ppm use crop removal rates (0.25 lb K₂O/bu grain and 30 lb K₂O/ton of straw).
Source: Jacobsen et al., 2005

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 UAN) are best applied shortly before seeding up to mid-tillering to benefit yield and minimize over-winter loss.

Split applications allow for in-season N adjustment based on precipitation to date. Pre-plant and at-seeding N should be high 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 by jointing can then boost yield. Nitrogen applications after stem elongation are generally discouraged due to increased potential for volatilization losses, stranding N in dry surface soils, or potential for excessive grain protein in malt barley.

PHOSPHORUS AND POTASSIUM

Two granular phosphorus (P) fertilizers comprise most of the P used in Montana: monoammonium P (MAP; 11-52-0) and diammonium P (DAP; 18-46-0). MAP is used much more extensively because it provides less risk to seedling emergence due to its lower ammonium concentration. MAP also lowers pH near the granule which can temporarily increase P solubility. Liquid ammonium phosphate (10-34-0) is also available. Generally there are no yield differences among P sources as long as the actual P₂O₅ rate is the same. Therefore, the P source should be selected based on price per unit of P and on the equipment available for application. Potassium (K) is generally applied as potash (KCl; 0-0-60).

Phosphorus and K rates are based on soil test levels to a six-inch depth (Tables 4 and 5). Phosphorus is most effective when placed with seed and in bands adjacent to the seed. A starting point for safe seed-place P rates is 10 lb P₂O₅/acre. Because P is immobile in the soil, P levels can be built up (banked) in years when fertilizer costs are low. Phosphorus fertilizer can help increase drought tolerance in malt barley, even in soils with medium P availability (Jones et al., 2003).

Potash is best utilized when banded. If banded with the seed, limit the total amount to 10 lb (N + K₂O)/acre, adjusted as needed for seed bed conditions using an online safe seed-placed rate calculator (see Weblinks, page 18). Potash is also effective when broadcast at seeding.

SULFUR AND MICRONUTRIENTS

Research in the Golden Triangle area of Montana shows sulfur (S) should not be routinely applied to barley because it either produces no effect, or a slight negative effect on both yield and quality (Jackson, 2008). Soil S levels vary greatly across a field, and crop yields have not been found to correlate well with soil S test levels. The consideration to fertilize with S depends on crop and field history, crop appearance, and results of tissue testing. Shallow soils, sandy soils or soils that are acidic, or low in organic matter are more likely to be deficient in S. Unusually low protein when N is sufficient is a potential indicator of low S. If the prior crop showed S deficiency, then 10 to 15 lb S/acre before or at seeding could be a wise investment (Jackson and Engel, 2006). If S deficiency symptoms appear (uniform yellowing starting in the upper leaves and then moving down), or barley leaf tissue concentrations are below 0.10% (at any plant stage; Plank and Donohue, 2009) or 0.14% (flag leaf in the boot; Gupta, 1976), then a small amount of S (5 to 10 lb S/acre) should be top dressed. Ammonium sulfate (21-0-0-24) is a soluble, relatively available S source, and is effective when broadcast. Elemental S takes months to become available, therefore it should not be used to correct a deficiency, but can be used to build soil S for a couple of years' worth of crop needs in S-deficient soils. Elemental S can acidify the soil around the S fertilizer, therefore, it should be used cautiously on acidic and neutral soils.

Preventing and Managing Herbicide Resistance

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. To reduce the risk of creating 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, crop rotation is an excellent tool to reduce the selective pressure on herbicide resistant weeds.

More information on herbicide resistance can be found in the MSU Extension Montguide *Preventing and Managing Herbicide-resistant Weeds in Montana* (Menalled and Dyer, 2011).

Micronutrients are taken up in very small amounts and are rarely deficient in Montana barley 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. See *Nutrient Management Module 9* (McCauley et al., 2011) for help with diagnosing nutrient deficiencies. 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 the effect of fertilizer test strips on yield. Micronutrients are broadcast and incorporated, or applied as a chelated foliar. 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. Similar to S, Cl is mobile and highly variable in the soil, thus soil tests are not a reliable diagnostic tool. However, Cl deficiency should generally not be an issue if K fertilizer is applied as KCl each small grain crop year. Potash (KCl) at 20 lb K₂O/acre supplies about 13 lb Cl/acre.

ONLINE RESOURCES

The "Seed Damage Calculator," <http://seed-damage-calculator.herokuapp.com/> is an online tool that can help determine safe rates of fertilizer when placed with the seed. An online version of the Fertilizer Guidelines for Montana Crops is available at the Southern Agricultural Research Center website <http://www.sarc.montana.edu/php/soiltest/>.

Weed management

Although barley is a vigorous and competitive crop, weeds have the potential of reducing yields. Not only do weeds compete with barley for light, nutrients and water, they can also make crop harvest difficult, increase dockage, and encourage insect infestation or mold growth in stored grain. Weeds can reduce crop quality as barley contaminated with weeds may not achieve malting grades or may have reduced palatability when used as animal feed.

In Montana, grassy weeds including wild oat, cheatgrass (downy brome), green foxtail, and Persian darnel are among the most serious weed problems to many barley growers. Broadleaf weeds including kochia, Russian thistle, prickly lettuce, and field pennycress also pose a threat to barley growers. See the online Herbicide Selection Tool <http://www.sarc.montana.edu/php/weeds/> for selecting herbicides registered for barley production. To reduce the chances of developing herbicide-resistant weeds, weed scientists recommend to periodically rotate herbicide type. Most herbicide labels now include a group number <https://pnwhandbooks.org/weed> which specifies the mode of action

for that chemical. By knowing what chemical is applied on a particular field one year, a herbicide with a different mode of action can be chosen for the next year's crop. Herbicides with multiple chemicals may have more than one mode of action.

Although chemical options to manage weeds in barley exist, they can damage crops if not correctly applied. Mistakes usually occur when herbicide applications are not correctly timed, when weather conditions enhance barley susceptibility to herbicides, when non-recommended applications are applied, or when un-calibrated or contaminated equipment is used. Further, there are herbicides labeled for use on wheat that have plant back restrictions for barley as well as for most broadleaf crops.

For example, Puma (fenoxaprop) is a non-residual Group 1 herbicide with excellent activity on green foxtail and wild oat. However, when applied during stress conditions or cold (< 45°F) wet weather, it could injure barley plants. Growers can reduce the risk of barley injury from Puma by timing applications from the two-leaf to prior to the five-leaf stage (jointing). Tank-mixing Puma with MCPA ester can also minimize the risk of crop injury. However, tank-mix of Puma with Buctril (bromoxynil) or Bronate (bromoxynil + MCPA) can severely damage barley. Finally, it is important not to add a surfactant when tank mixing Puma with broadleaf herbicides in barley.

Achieve (tralkoxydim) is a Group 1 post-emergence herbicide that can be used to manage green and yellow foxtail, Persian dandelion and wild oat. Injury may occur in non-tillered barley plants which are exposed to temperatures lower than 40°F up to 48 hours either before or after application. Injury can also occur when Achieve is applied to tillered barley plants within 48 hours of freezing temperatures. Barley crops under stress due to high temperatures, drought, excess moisture, or lack of fertility can also be injured by Achieve.

Hoelon (diclofop methyl) is a post-emergence Group 1 herbicide commonly used to control annual grasses such as Italian ryegrass, wild oat, and green foxtail. In barley, Hoelon should not be applied more than once during a growing season. Also, it should not be tank mixed with crop oil concentrate or liquid fertilizers. Hoelon has the potential to give severe injury to barley if it is applied in cold or freezing temperatures (below 35°F) or when soil water content of the field is at field capacity. To prevent barley injury, Hoelon should not be tank mixed with Glean (chlorsulfuron) for weed control. If a broadleaf herbicide is used but is not tank mixed with Hoelon, treatment applications should be separated by a minimum of five days.

Axial (Pinoxaden) is a Group 1 herbicide (ACCase mode of action) labeled for post-emergence control of wild oat, foxtail species, annual ryegrass, and Persian dandelion. There are grazing restrictions of 30 days and harvest restrictions of 60 days. Axial can be tank mixed with any of the several different broadleaf herbicides listed on its label.

Fargo (Triallate) is a group 8 pre-emergence herbicide labeled for spring barley in Montana. It provides excellent control of wild oat, and suppresses downy brome, Japanese brome, and cheat. This herbicide is primarily absorbed by wild oat shoots from the treated layer of the soil. If weeds, including wild oat, have emerged prior to application, they must be controlled. Fall applications are recommended with at least two tillage operations for incorporation into the soil. Plant back options in Montana for crops other than domestic oats are not typically a problem. See the label for specific information.

Simple steps can help reduce the risk of herbicide injury in barley. Make sure to read and understand the herbicide label. Do not use complex, non-recommended tank mixes. Non-recommended herbicide mixes can also lead to a chemical reaction in the spray-tank which could damage equipment, affect your safety, or compromise the environment. Make sure that equipment is properly calibrated and that the spray-tank, lines, boom and nozzles are carefully cleaned at the end of each application. If crop injury to barley does occur, immediately contact the dealer who provided the herbicide or made the application. That way an assessment of the injury can be made as soon as possible and remedies can be identified and implemented to minimize potential yield impacts.

In Montana, biotypes of wild oat, Persian dandelion, kochia, and Russian thistle have been found to be resistant to several herbicides. Barley growers should be aware that the selection of herbicide-resistant weed biotypes threatens the long-term sustainability of this approach for weed control. Where resistant weeds are known to exist, growers should use caution when removing residues like straw to prevent movement of resistant weeds to new areas.

Developing an integrated weed management program is essential to successfully control weeds in barley. To do so, barley growers must start by preventing the introduction and spread of weeds in their fields. Cleaning of combines and equipment can prevent the introduction of new weeds from custom harvesters or moving from adjacent fields.

TABLE 6. Effect of increased seeding rate on barley yield loss.

Barley Seeding rate density (lb/acre)	Barley Yield loss (%)	Wild Oat Seed production (seed/ft ²)
0	–	2000
60	20	1600
120	10	1300

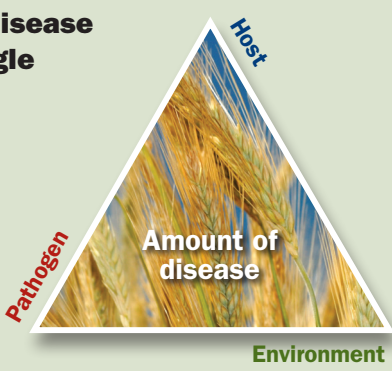
This preventive practice must be complemented with cultural practices to enhance crop competitiveness, rotation of crops, and chemical treatment when necessary. For example, field experiments conducted in Canada indicated that barley competitive ability against wild oat declined with delayed crop emergence in spring and increased with seeding rate (O'Donovan et al. 2000). Low barley seeding rates also allowed greater weed-seed production, increasing the chances of infestations in future years. Accordingly, research conducted by weed scientists at Montana State University determined that increasing the seeding rate of barley two-fold significantly decreased wild oat seed production (Table 6, page 9). Further, the higher seeding rate increased barley yield as well.

In some situations, haying the barley crop, to prevent weed seed production and spread, may be the most readily-implemented and economically-advantaged integrated weed management measure to implement.

Managing Plant Diseases

Plant diseases can severely impact barley yields. Management to prevent occurrence is preferred to treatment. (See Disease Triangle, below.) In most cases (but not all) crop rotation to reduce the amount of disease organisms (inoculum) present and to alter the environment so that the disease is not expressed is the best management practice for successful barley production. When diseases do occur, prompt identification is needed so that management of the condition can be used to salvage the current crop. The following descriptions may help to determine the cause of various plant disease and physiological problems.

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.

BACTERIAL DISEASES



Bacterial kernel blight is caused by *Pseudomonas syringae*. The 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 reduce irrigation during this period and to use clean seed. Do not save seed from affected fields.

Bacterial blight (sometimes called bacterial leaf streak or black chaff) is caused by *Xanthomonas campestris* pv. *translucens* (XCT). The symptoms begin as small, water-soaked spots on leaves which elongate into linear streaks that become necrotic tan or brown. The symptoms can often be confused with spot or net blotch or septoria leaf spot (below) which are caused by fungi. The head can also become infected and often takes on a pink or black color. This is known as glume blotch or black chaff. Under wet conditions an exudate can develop on the leaf surface, forming tiny yellow droplets or a glassy/shellacked appearance.

XCT can be controlled by crop rotation and planting seed that is free of the pathogen. A generally accepted threshold for XCT bacterial populations is 10³ cfu/g seed. Seed lots can be tested using laboratory methods.

FUNGAL DISEASES

Damping Off can significantly reduce seedling emergence and stand establishment. It can be effectively controlled using a seed treatment. Consult *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 pathogens. Use a product containing both a fungicide and metalaxyl or mefanoxam to control fungi and oomycete pathogens including Pythium, which is common in Montana soils.



M. Burrows

Root rots can be caused by a number of different fungi. Examples include common root rot, Pythium root rot, and Rhizoctonia root rot (bare patch). They are favored by wet, cool soil conditions and no-till. 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 internode and first few nodes may also be discolored.

Root rot can be partially controlled by seed treatment but crop rotation, good weed control, and eliminating the continuous presence of host plants, also known as 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 the risk of bare patch when seed is planted into a field before complete death of the plants. Eliminating the green bridge by planting 2-3 weeks after herbicide application is the most important control method for bare patch and a number of other diseases. Fall applied glyphosate is an effective tool for reducing volume of early spring Rhizoctonia inoculum through reducing the volume of early spring volunteer cereals and grassy weed vegetation and weed plant density.

LEAF DISEASES

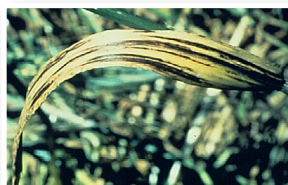


MSU Plant Pathology Slide Collection

Barley stripe is a seedborne disease caused by the fungus *Pyrenophora graminea*. Symptoms include yellow stripes, particularly on the leaf sheath and the basal portion of the leaf

blade. These stripes eventually extend the length of the leaf and become necrotic. They can coalesce and kill the entire leaf. The leaves split and fray at the ends, appearing shredded. Yield loss is proportional to the number of plants which are infected. Control can be achieved by using seed treatments containing imazalil and using clean seed. Do not save seed from affected fields.

Net blotch



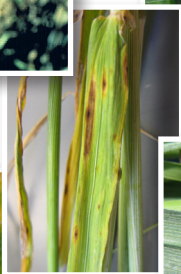
Spot blotch



Tan spot



Septoria



Scald



Tan spot, septoria, scald: Mary Burrows; Spot blotch: Justin O'Dea Cornell University

Net blotch, spot blotch, tan spot, Septoria leaf blotch and scald are all residue-borne pathogens favored by continuous cereal cropping, minimum or no tillage, and irrigation. They can be distinguished based on their symptoms, but controlled using similar techniques. Yield and quality reductions are proportional to the amount of leaf area affected, particularly the flag leaf.

Symptoms will vary according to barley variety, pathogen isolate, and environmental conditions, but generalizations can be made. Symptoms begin as small spots on leaves or stems and expand. Net blotch (*Pyrenophora teres*) forms netlike necrotic areas on the leaves, and can also occur in a spot form. Spot blotch (*Bipolaris sorokiniana*) causes round to oblong, brown lesions surrounded by a chlorotic margin. Tan spot (*Pyrenophora tritici-repentis*) symptoms are similar to spot blotch but the lesions are initially lens-shaped with a yellow halo and often a dark spot in the center of the lesion under moist conditions. Septoria leaf blotch (*Septoria spp.*) symptoms are also similar to spot blotch and tan spot but consist of grey- or tan-colored lesions that lack the yellow halo. Scald (*Rhynchosporium secalis*) can be recognized by its grey or watersoaked lesions with brown margins. All of these diseases can cause a glume blotch of the head and cause shriveling of the seed. These diseases can be confused with physiological leaf spot (below). Physiological leaf spot will occur on every leaf, not just the lower leaves, and no fungal structures (small black dots in the fungal lesion) will form if the leaves are put in a moist chamber (with a wet paper towel in a Ziploc bag or other sealed container) after 2-3 days.

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

Rusts (*Puccinia spp.*) including leaf rust, stripe rust, and stem rust, are dependent on the host for survival and generally blow in on weather systems every year from other wheat-growing areas. Some rusts can come into a barley crop from wild grasses, rather than infected barley. These diseases are favored by moisture. Yield loss will depend on variety resistance and the time of infection. They are easily recognized by the yellow to reddish or brown pustules that develop on leaves and/or stems. The fungal spores rub off on your finger. Control is achieved through the use of resistant varieties. Fungicides can be applied if necessary, but are not generally economical. All registered fungicides have a 45 day pre-harvest interval.

Leaf rust



Stem rust



Stripe rust



all photos by M. Burrows

HEAD DISEASES

Smuts and bunts are seed-borne, and have greatly decreased since the invention of systemic fungicide seed treatments and deployment of resistant cultivars. In Montana smuts are important primarily in hay barley crops. The fungus (*Ustilago spp.*) replaces the seed, and forms a powdery black substance which is fungal spores. This is how you can distinguish smut from ergot (below), since ergot is a solid mass of fungal hyphae and not powdery. Yield loss due to smut is proportional to the number of heads infected. Affected plants can be stunted before the head symptoms are obvious.

Loose and covered smut



MSU Plant Pathology Slide Collection

The different kind of smuts can be distinguished based on the symptoms on the head. For covered smut, a membrane remains around the smutted seeds until the plant is mature. For loose smut, this membrane ruptures and the spores are dispersed by the wind and leave a naked rachis (center of the head). To prevent smut, use a fungicide seed treatment or a resistant variety.

Ergot is a fungus (*Claviceps purpurea*) that forms compounds that are toxic to animals and humans. The source for plant infection is the sclerotia, a hard mass of fungal hyphae and a survival structure of 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.

Ergot bodies (sclerotia) contaminating healthy seed



MSU Plant Pathology Slide Collection

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 4 times as large as the original seed and protrude from the head.

If you suspect you have ergot, do not feed the contaminated grain to animals if the weight of the ergot sclerotia exceeds 0.05% of the total grain weight.

Ergot can be controlled by cutting hay before flowering several years in a row, tillage to bury the sclerotia, mowing headlands or roadways before the grasses mature, rotating out of grains for at least one year, and using less susceptible cultivars of barley.

Fusarium head blight (scab) is important because the fungus (*Fusarium spp.*) produces toxins including deoxynivalenol (DON). The disease also causes yield and quality losses. There is a very low (< 1 ppm) tolerance for DON in malt barley. Scab on barley has not been widely reported in Montana, but has been observed in heavy barley producing regions including Big Horn, Carbon, Gallatin, Stillwater, and Yellowstone counties. Appearance is very dependent on late season wet weather and is most common in rotation with corn.

Fusarium head blight (wheat) on left, note partial bleaching of head due to flower infection (right) Tombstone kernels on left due to Fusarium head blight (scab)



M. Burrows



J. Johnston

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 (left). If environmental 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 'tombstones' or shriveled seed 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 will provide a source of 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. Irrigation management, or cutting irrigation 10 days before head emergence to let the canopy dry out can reduce fungal infection. Another option includes spraying a systemic fungicide at head emergence or slightly before head emergence. Variety resistance is available, but not for malt barley varieties. Two-row barley varieties

are more resistant than six-row barley varieties due to their head architecture. 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.

VIRUS DISEASES



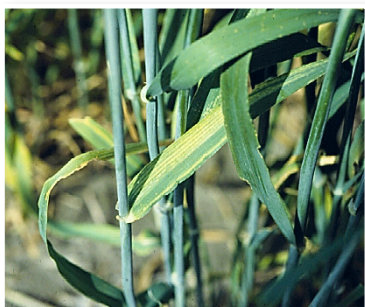
University of Nebraska-Lincoln

Barley yellow dwarf virus (BYDV) is an aphid-transmitted virus. Aphids generally come in on weather systems from other cereal-growing areas or from grasslands like CRP or range. This disease is sporadic in nature. There are several species of aphids which transmit several different strains of BYDV. The interaction

between the aphid and the virus is very specific, and not all aphid species will transmit all strains of BYDV. The severity of the disease will depend on how many plants are infected, the strain of BYDV infecting the plant, and the growth stage at which the plant becomes infected.

Symptoms vary by virus strain, 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 is very sporadic.

Late spring, mid-late May, cereal seedlings experience a higher frequency of yellow dwarf than the recommended earlier seeding dates.

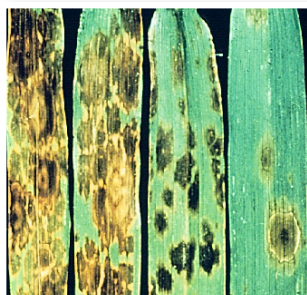


MSU Plant Pathology Slide Collection

Barley yellow streak mosaic virus (BaYSMV) is a mite-transmitted virus that was first identified in northcentral Montana. It is transmitted by the brown wheat mite. The symptoms first appear in water-stressed

areas of the field because the mite vector prefers to feed on stressed plants. Infected plants are stunted and may die. Leaf symptoms are very diagnostic and include light green to yellow dashes and streaks which develop into yellow and white streaks. These symptoms occur on only one-half of the leaf.

Crop rotation, residue reduction, and early spring seeding to reduce mite pressure are the best control measures. Miticides are generally not economical.



MSU Plant Pathology Slide Collection

Physiological leaf spots often resemble damage caused by septoria or other pathogens, but when tested no pathogen can be found. They are caused by plant physiology or by genetics. Often the margin of the spot is very distinct, not diffuse. Also, spots will occur

uniformly on all leaves of the plant, and will not be more severe towards the base of the plant, which you expect with an early-season leaf spot disease that is residue-borne. 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.

OTHER RESOURCES FOR BARLEY DISEASE IDENTIFICATION

- Compendium of Barley Diseases, 2nd edition. APS Press, St. Paul, MN.
- High Plains IPM Guide
- NDSU Barley Project
- Wheat Disease Identification

Insect Pests of Barley

Barley production in Montana typically has few insect pests that compromise yield, but fields should be scouted regularly during the growing season for signs of infestation.



HAANCHEN MEALYBUG

The Haanchen Mealybug (*Trionymus haancheni* [McKenzie] [Hemiptera: Pseudococcidae]) was first detected in northern California during the 1950s, infesting and

causing economic damage to Haanchen barley. Damaging populations were not detected again until 2003 when the mealy bug was found infesting barley in Idaho. Infestations and economic losses were reported in barley fields in Montana and Alberta in 2006 and in 2007, however, in 2008 this pest was difficult to find in Montana and Idaho. This pest can cause significant damage, but outbreaks seem to be very sporadic.

The first signs of damage consist of a cottony appearance at the base of the plants. These cottony masses, called ovisacs, usually contain an oval-shaped female adult along with hundreds of eggs. Adult mealybugs which are slightly

smaller than ¼ inch in length, and nymphs, damage plants by feeding with sucking mouthparts. All stages can be found in protected areas of the plant, such as the crown and upper portion of the roots and under leaf sheaths. Feeding damage can cause yellowing of the foliage leading to reduced vigor and extensive browning can occur quickly, particularly under dryland low moisture conditions. Movement is primarily by the nymphs, known as crawlers. They move around on the plant leaves. Only the males fly, so infestations are typically spotty, and slow to spread.

The concealed feeding habits of the adult females and the presence of the cottony ovisacs make chemical control difficult. Currently no insecticides are registered for Haanchen mealybug. Experience with other types of mealybugs in other crops indicate that insecticides alone are not effective. The conservation of beneficial insects such as predators and parasitoids through the careful and judicious use of insecticides coupled with crop rotation away from plants known to be hosts will likely provide the best long-term solution to this pest problem. Broad spectrum insecticide applications are known to contribute to insect pest outbreaks in other cropping systems by killing beneficial insects that help keep pest levels below damaging levels.

More detailed information can be found in a University of Idaho Extension publication, *Haanchen Barley Mealybug* (Alvarez, 2003). The High Plains IPM Guide also has relevant information in a note entitled *Haanchen Barley Mealybug*, http://wiki.bugwood.org/HPIPM:Haanchen_Mealybug.



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CEREAL LEAF BEETLE

Cereal leaf beetles (CLB) (*Oulema melanopus* [L.] [*Coleoptera: Chrysomelidae*]) can be a serious pest of many cereal crops including barley. The first sign of CLB activity is usually elongated, slender slits on the upper leaf surface in early spring. Although larvae do the majority of damage, adults cause similar damage.

Severe damage will make fields appear frosted. The adult is approximately ¼ inch long, with a brightly colored orange-red thorax, yellow legs, and metallic blue wing covers. The larvae look similar to a slug, with a light yellow body, brown head, and three pairs of legs located close to the head end of the body. Eggs are laid either singly or in groups of two or three on the upper leaf surface near the base of the leaf. Eggs are initially bright yellow, darkening to salmon, and then black as they mature. Egg hatch depends on temperature, and can range from 4 to 23 days.

When populations of larvae and eggs exceed three per plant before plants are in the boot stage, chemical control may be warranted. Damage to the flag leaf is more critical, so after the boot stage, when one or more larvae or eggs per flag leaf is found, chemical control should be considered.

Lady beetles prey on CLB larvae, and several parasitic insects have been introduced for control of CLB. Where large numbers of predators and parasitoid insects are present, cereal leaf beetle damage is usually kept in check. Since most grass species are hosts to this pest, rotation to broadleaf crops such as peas or lentils can be a good way to help reduce populations. A publication entitled *Cereal Leaf Beetle* (Knodel and Lubenow, 2016) produced by North Dakota State University describes the life cycle and feeding habit of this insect. For further details on economic damage thresholds and treatment options refer to the High Plains IPM guide http://wiki.bugwood.org/Oulema_melanopus.

RUSSIAN WHEAT APHID

Russian wheat aphids (RWA) (*Diuraphis noxia* [Mordvilko] [*Homoptera: Aphididae*]) at high enough populations can cause significant yield loss in barley. Aphids can be winged or wingless and will survive on volunteer wheat and barley as well as native wheatgrass species to infest fall-planted wheat fields.



Frank Peairs, Colorado State University, Bugwood.org

Aphids damage plants by sucking plant sap. As they feed, they produce honeydew which drips onto leaves and stems below leaving a sticky residue. Insects are pear-shaped, the adults 1/16 to 1/8 inch long. Juveniles look like miniature versions of the wingless adult. They typically colonize new leaves, sometimes preventing the leaf from unrolling. Severe infestations can cause stunting as well as white and purple streaking of leaves. Since they tend to colonize within the rolled leaf tubes and leaf whorls, control with insecticides is difficult because of poor coverage.

Resistant varieties are the most effective means of RWA management, although some cultural controls can be beneficial. Controlling volunteer wheat and barley can reduce the numbers that will survive into the winter. Stressed crops seem to be infected more often. Paying attention to soil fertility and planting certified, treated seed of a variety well-adapted to the local growing conditions will help reduce the impact from RWA.

There are several predator insects that feed on aphids including lady beetles and common lacewings. Chemical control may be warranted under severe infestations. Economic thresholds for barley in Montana are around 5-10% infested tillers prior to boot, 10-20% after boot stage, and greater than 25% after flowering. Further information and specific guidelines for chemical control can be found in the High Plains IPM Guide, http://wiki.bugwood.org/HPIPM:Russian_Wheat_Aphid.

A variety of aphids in addition to RWA can occasionally infest barley at economic levels. *Aphids of Economic Importance in Montana* (Tharp et al., 2005) is a good identification guide. Management guidelines for Bird-cherry oat aphid, English grain aphid and the rose-grass aphid that occasionally infest barley can be found in the High Plains IPM Guide, http://wiki.bugwood.org/HPIPM:Main_Page.

PALE WESTERN CUTWORM

The Pale Western Cutworm (*Agrotis orthogonia* [Morrison] [*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 larvae is about 1½ inch long.

The adult moths emerge from the soil in late summer to 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 not be cost effective.

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



Frank Peairs, Colorado State University, Bugwood.org

ARMY CUTWORM

The Army cutworm (*Euxoa auxiliaris* [*Lepidoptera: Noctuidae*]) larva can periodically cause significant damage in barley 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 (¼ inch) size of the early instar larva 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 cutworms are found per square foot. More information on both species of cutworms can be found in *Pale Western and Army Cutworms in Montana* (Blodgett et al., 2000).

WIREWORMS

Wireworms (many different species) are slender, jointed, and hard-bodied insects that can sometimes cause significant damage in barley and other small grain production. Larvae have three pairs of legs located just behind the head, with their last abdominal segment flattened. Full-grown larvae may reach 0.5 to 1 inch in length. Adult beetles emerge from the soil in late 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 lasts anywhere from 2 to 5 years. When fully grown, the larvae pupate in summer, and the adults emerge the following spring.



Frank Peairs, Colorado State University, Bugwood.org

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 4 to 5 larvae per square foot, insecticide seed treatment is recommended. 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.

Field Diagnostics

Fields should be scouted regularly during the growing season for signs of trouble. Early diagnosis is important to correct a deficiency or to determine an alternate management plan. Determining cause and effect is an art which improves with practice. Are symptoms universal? Or is the problem isolated to certain areas of the field? Is there a pattern? Plant damage from natural events will follow a different pattern than that caused by human error, such as herbicide overlap. Look at the ends of fields where double applications of fertilizer or agricultural chemicals may have occurred. Compare plants in these areas to those away from the field ends, or to those plants displaying damage symptoms.

When inspecting damaged plants, look for signs of mechanical abrasion, or signs of insect feeding such as ragged edges of leaves, or evidence of feeding on roots or stems. Compare plant color against those plants you deem to be normal. Use a sharpshooter, or shovel to excavate plants and compare root growth habit.



M. Burrows

HAIL INJURY

Hail injury (pictured above) is most damaging from heading through harvest. The number of days between heading and the time of hail damage is more indicative of yield loss than the number of stems left standing. Hail kinks and severs plant parts randomly. Other symptoms include drying and bleaching of damaged tissues, white heads, stem lesions, and spike bruising.

FROST INJURY

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

NUTRIENT DEFICIENCY

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. For Montana, the most common nutrient deficiencies are nitrogen, sulfur, phosphorous and potassium. Pictures of these disorders and others can be found in MSU Extension bulletin *Nutrient Management Module 9: Plant Nutrient Functions and Deficiency and Toxicity Symptoms* (McCauley et al., 2011).

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Weblinks

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- Plant Sciences and Plant Pathology Department <http://plantsciences.montana.edu/index.html>
- Extension <http://msuextension.org>
- Southern Agricultural Research Center <http://www.sarc.montana.edu/>
- Fertilizer Facts are available at <http://landresources.montana.edu/fertilizerfacts/index.html>

ENTOMOLOGY AND INSECTS

- Cereal Leaf Beetle <http://www.ag.ndsu.edu/pubs/plantsci/pests/e1230.pdf>
- Cereal Leaf Beetle http://wiki.bugwood.org/Oulema_melanopus
- Haanchen Barley Mealybug, <https://www.cals.uidaho.edu/edcomm/pdf/CIS/CIS1109.pdf>
- Haanchen Barley Mealy Bug, http://wiki.bugwood.org/HPIPM:Haanchen_Mealybug
- High Plains IPM Guide http://wiki.bugwood.org/HPIPM:Main_Page
- Russian Wheat Aphid http://wiki.bugwood.org/HPIPM:Russian_Wheat_Aphid

PLANT DISEASES AND PATHOLOGY

- Compendium of Barley Diseases, 2nd edition <http://apsnet.org>
- NDSU Barley Project <http://www.ag.ndsu.nodak.edu/aginfo/barleypath/disease.html>

SOIL FERTILITY AND PLANT NUTRIENTS

- IPNI Safe seed-placed fertilizer rate tool <http://seed-damage-calculator.herokuapp.com/>
- Barley Economic Nitrogen Model <http://www.msueextension.org/econtools/nitrogen/>
- Fertilizer recommendation tool <http://www.sarc.montana.edu/php/soiltest/>

WEEDS, HERBICIDES, AG CHEMICALS

- Pacific Northwest Weed Management Handbook <https://pnwhandbooks.org/weed>
- Herbicide Selection Tool <http://www.sarc.montana.edu/php/weeds/>

OTHER STATE, FEDERAL, AND ASSOCIATIONS

- American Malting Barley Association, Inc. <http://www.ambainc.org/>
- Montana Wheat and Barley Committee <http://wbc.agr.mt.gov/>
- Web Soil Survey <http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm>
- Growth and development guide for spring wheat <http://www.extension.umn.edu/agriculture/small-grains/growth-and-development/spring-wheat/index.html>
- ET estimates for Montana can be found at: <http://mesowest.utah.edu/>

