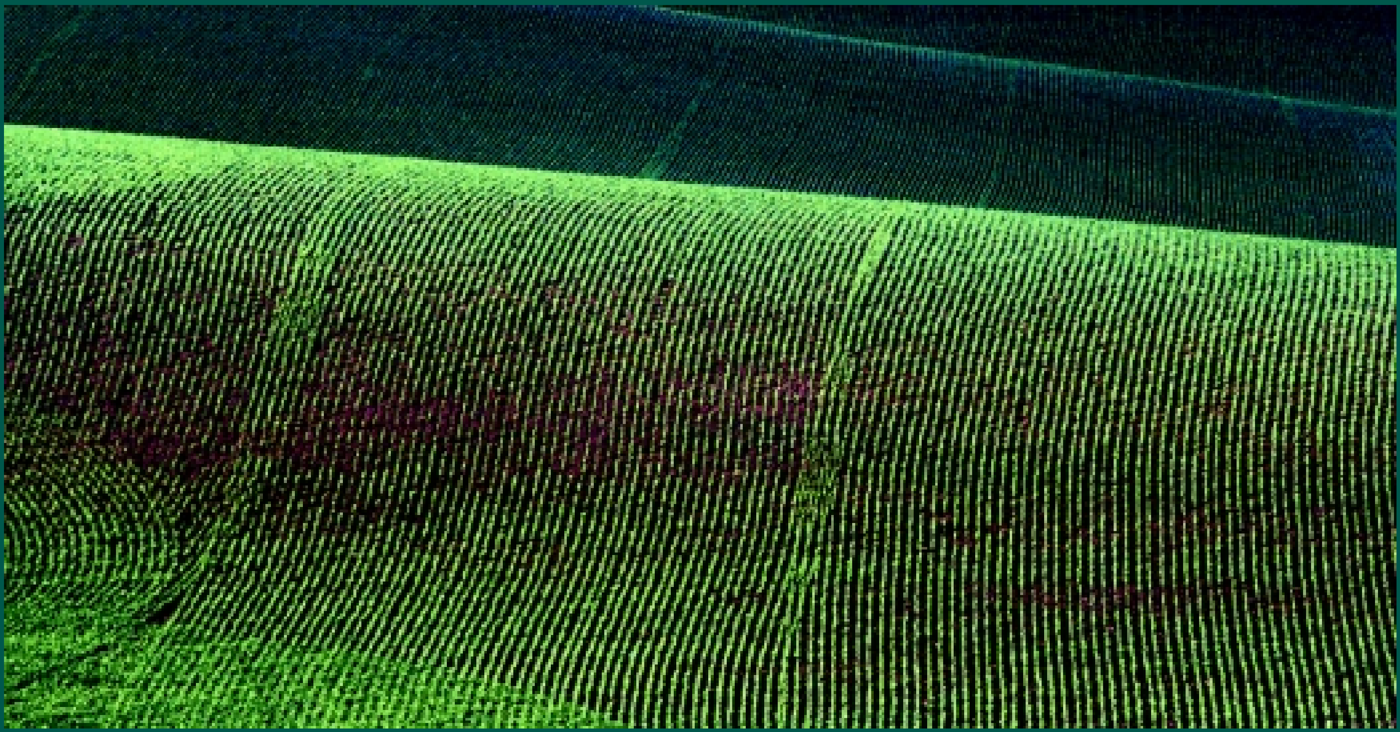
Southern Idaho Dryland Winter Wheat Production Guide



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University of Idaho
College of Agricultural and Life Sciences

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Southern Idaho Dryland Winter Wheat Production Guide

Basic Recommendations

- Winter wheat production can be improved and input costs reduced with good knowledge of growth and development. Learn to recognize the various growth stages and the impact of various management inputs.
- Make an annual production management and marketing plan prior to beginning the crop season.
- Minimize the number and intensity of tillage operations before and after winter wheat crops to control soil erosion, reduce water loss and soil compaction, and improve soil productivity.
- Use rotations and cultural practices to minimize weed, disease, and insect problems, and reduce chemical use.
- Choose varieties carefully with appropriate disease resistance, maturity, and quality characteristics for the intended use.
- Prepare seedbeds carefully to conserve adequate moisture for germination and emergence, and to ensure good seed-soil contact. Seed at the proper time, depth, and rate for the chosen variety.
- Use only high quality seed. Plant certified seed to ensure seed purity and viability.
- Soil test to determine nutrient needs. Apply only the amounts of nutrients needed and at the proper time to avoid nutrient loss, wasted inputs, and environmental contamination.
- Control weeds, insects, and diseases through variety choice, timely scouting, and application of the correct pesticides at the correct time and rate.
- Plan ahead for storage and marketing needs. Become familiar with alternative marketing options.
- Adjust combine properly to reduce kernel damage and dockage.
- Store the crop in clean, insect-free bins, and check frequently for developing trouble spots.
- Manage residues properly to avoid problem chaff rows and to conserve soil and moisture.
- Use a systems approach to combine the best management options into an integrated crop production and marketing system. Use enterprise budgets to evaluate options and track progress.

Acknowledgements

This production guide is made possible through the encouragement and generous support of the Idaho Wheat Commission and, through them, all Idaho wheat producers. The editors and authors hope this compilation of research-based information will make dryland winter wheat production in southern Idaho more dependable, profitable, and environmentally sound. This area presents some of the most challenging management decisions of any wheat production area due to sporadic and limited moisture, rolling landscapes, low residue production, high erosion potential, and relatively low yields.

The editors especially thank all authors and manuscript reviewers for their diligence, patience, and professionalism. Appreciation is also expressed to the many secretaries and technical typists for their assistance and willingness to revise text after it was thought to be done. Lastly, appreciation is extended to the faculty and staff of the Agricultural Communications department for final reviews, suggestions, layout, and coordination of the printing process.

Chemical and Variety Disclaimer

Use of chemical names and trade names does not imply endorsement of named chemicals. These references are for comparison only.

Recommendations of use or non-use of a specific variety is not stated or implied.

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Introduction

L. D. Robertson

Wheat is an important crop throughout Idaho. Growers seed nearly 1.5 million acres every year and cash receipts total approximately $300 million. This makes wheat second only to potatoes in cash crop receipts. Winter wheat is an especially important crop in the dryland cropping areas of southern Idaho. Approximately 125,000 acres are harvested annually, producing over 4 million bushels of grain. Southern Idaho dryland accounts for approximately 20 percent of the total state winter wheat acreage and 10 percent of the total state wheat yield. Most production in this environment is hard red winter wheat with smaller amounts of soft white winter and hard red spring wheat. Production of hard white winter wheat is negligible at present but may increase in future years.

In addition to the challenges of maintaining profitable farming operations, wheat producers also face the challenge of conserving soil and water resources in this area of rolling landscapes with high wind and water erosion potential. High erosion potential, low crop residue production, and generally low, sporadic precipitation makes profitable and sustainable cereal production challenging in this area. The goal of every producer should be to obtain optimum yields that are affordable for both short and long term considerations and that maximize the efficient utilization of available land, management resources, and the environment. This production guide brings together the best available research information on management practices for economic and environmentally sound production of dryland winter wheat in southern Idaho.

Major Uses of Wheat

L.D. Robertson and S.O. Guy

More than 75 percent of all wheat produced in Idaho is exported. This requires a worldwide marketing effort. In addition, Idaho producers must grow high quality wheat of the types with high demand by wheat importers. Because wheat is a net export commodity for the U.S., it has a favorable impact on our national trade balance. In the U.S., annual per capita consumption of wheat products is near 144 pounds per person and fairly stable, but international consumption is expected to increase. Worldwide, wheat provides more nourishment for people than any other food source.

Wheat is used primarily as a human food but can be successfully fed to all classes of livestock. As a human food, the end use depends on a number of characteristics that are used to classify the wheat. Soft white wheat, the predominate class produced in Idaho, is used primarily for cakes, cookies, crackers, flat breads, batters, breakfast foods, and pancakes. Soft white wheat typically has low protein and weak gluten strength and produces soft-textured products. Hard red wheat predominates in dryland production areas of southern Idaho and is primarily used for breads, rolls, and other leavened food products. These products require wheat that has high protein and strong gluten to hold the gases that are produced during dough fermentation prior to baking. Durum wheat is used in all pasta products including macaroni, spaghetti, and similar foods. A relatively new class of wheat for Idaho growers is hard white wheat. This class is primarily used in oriental noodles and certain domestic food products that require more gluten strength than traditional soft white wheat, but less than hard red wheat. Wheat is also used in products such as chapatis, pie crusts, puddings, ice cream cones, pizza, baby foods, gravies, sauces, soups, candies, beverages, and some seasonings.

When wheat is priced close to barley or corn, it can be economically fed to livestock. All classes of wheat can be successfully fed. Wheat milling by-products such as bran, germ, and shorts are mostly used in animal feed products. Wheat is increasingly being utilized in other industrial uses for its unique starch and gluten characteristics. Many pastes and glues are wheat based. Wheat straw has potential for use in building materials as a compressed fiberboard.

Grain Quality – Idaho Wheat Production Guide

Dr. C.F. Morris, Director, USDA ARS Western Wheat Quality Laboratory

Introduction

Wheat growers are increasingly aware that their product is not just a single uniform commodity. They are producing a raw material for processing into a myriad of wholesome, nutritious foods and industrial products. With this awareness has come the attitude that "Quality is the No. 1 consideration." If a miller or baker or other end-user has difficulty processing your grain, then it is necessarily lower in value. This section is devoted to a brief description of the factors that contribute to variation in quality, that is, factors that make your grain more or less valuable.

Major uses of Idaho and Pacific Northwest soft white wheat include cookies, crackers, cakes, batters and breadings, and some types of noodles. Hard red spring and winter wheats are used for yeast-leavened pan and hearth breads, and stronger-gluten yellow alkaline noodles. In addition to these end-products, our wheats are known for their good milling properties, producing high yields of low ash, bright white flours.

Wheat quality is genetically complex. It is largely up to the breeder in conjunction with the cereal chemist to ensure that new wheat varieties meet the expectations of the milling and baking industries. In this sense, new wheat varieties are bred to be consistent with our existing system of market classes and grades.

The U.S. System of Grades and Classes

The U.S. system of marketing wheat relies on statutory standards set out by Congress and administered by the Federal Grain Inspection Service (FGIS) in the Grain Inspection, Packers, and Stockyards Administration (GIPSA) of the U.S. Department of Agriculture and its approved state inspection agencies. The standards define wheat classes and set out the rules for determining grades within classes. The standards have evolved over time to reflect important issues and concerns of the marketplace. Two examples are the recent split of the class White Wheat into Soft White Wheat and Hard White Wheat, and the tightening of foreign material limits for U.S. No. 1 from 0.5 to 0.4 percent. The official standards currently list the following eight classes and subclasses of wheat:

- Hard Red Spring Wheat
  - Dark Northern Spring Wheat
  - Northern Spring Wheat
  - Red Spring Wheat
- Durum Wheat
  - Hard Amber Durum Wheat
  - Amber Durum Wheat
  - Durum Wheat
- Hard Red Winter Wheat
- Soft Red Winter Wheat
- Soft White Wheat
  - Soft White Wheat
  - White Club Wheat
  - Western White Wheat
- Hard White Wheat
- Unclassed Wheat
- Mixed Wheat

Also note that, unlike the hard red wheats, no distinction is made among the white wheats as to whether they are winter or spring types.

In addition to class and subclass, individual lots of wheat receive a grade. Grades aim to describe in general terms the relative quality of different grain lots within a market class. As such, grade-determining factors largely reflect aspects of a grain lot that would pose a processing problem or advantage, or a potential health or sanitation concern. Table 1 lists the current grade-determining factors for wheat; a brief explanation of each and why it is important follows. Before the grade-determining factors are measured, dockage is removed. Dockage is mostly non-wheat material that can be easily removed by sieving and is separated using the Carter Dockage Tester. Dockage also includes underdeveloped, shriveled, and broken kernels that cannot be easily recovered from the separated portion. Dockage, foreign material, and shrunken and broken kernels, besides being costly to separate, represent non-millable material. Any value associated with this material often depends on the availability of pelletizing equipment and the proximity of feed markets.

It must be emphasized that although limits for damaged kernels, foreign material, and shrunken and broken kernels are set by the standards that determine official grade, customers may specify tighter limits. Also, although dockage is not a grade-determining factor, many of our "cash" customers overseas are setting tighter limits in their contract specifications. For example, contracts may specify maximum dockage in the range of 0.5 to 1 percent, but may further require that the dockage present be subtracted from the delivered weight. Increasingly, 2- to 3-fold discount penalties are applied for dockage levels above certain thresholds. Similarly, pressure continues to reduce levels of foreign material and shrunken and broken kernels. Recent analysis indicated that to be fully competitive with Australia and Canada, our industry would need to be able to consistently offer cleaned wheat with maximum 0.2 percent dockage, 0.2 percent foreign materials, and 0.7 percent shrunken and broken kernels. The message is clear: deliver cleaner wheat that is more nearly all convertible to flour.

Grade determining factors

Test weight The purpose of test weight is to provide an estimate of the plumpness of the wheat kernel and therefore its potential for efficient milling into white flour

Wheat Grades and Grade Requirements

Grading Factors	U.S. Grade Nos. 1	2	3	4	5
	Minimum pound limits of:				
Test Weight					
Hard Red Spring wheat or White Club wheat, lbs/bu	58.0	57.0	55.0	53.0	50.0
All other classes and subclasses, lbs/bu	60.0	58.0	56.0	54.0	51.0
	Maximum percent limits of:				
Defects					
Damaged kernels					
Heat (part of total)	0.2	0.2	0.5	1.0	3.0
Total	2.0	4.0	7.0	10.0	15.0
Foreign material	0.4	0.7	1.3	3.0	5.0
Shrunken & broken kernels	3.0	5.0	8.0	12.0	20.0
Total[1]	3.0	5.0	8.0	12.0	20.0
Wheat of other classes[2]					
Contrasting classes	1.0	2.0	3.0	10.0	10.0
Total[3]	3.0	5.0	10.0	10.0	10.0
Stones	0.1	0.1	0.1	0.1	0.1

1 Includes damaged kernels (total), foreign material, and shrunken and broken kernels.

2 Unclassed wheat of any grade may contain not more than 10.0 percent of wheat of other classes.

3 Includes contrasting classes.

U.S. Sample grade:

U.S. Sample grade is wheat that:

(a) Does not meet the requirements for the grades U.S. Nos. 1, 2, 3, 4, or 5; or

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

(c) Is heating or of distinctly low quality.

For grades U.S. Nos. 1-5, the maximum count limits of Other material are animal filth (1), Castor beans (1), Crotalaria seeds (2), Glass (0), Stones (3), unknown foreign substance (3), and total counts of other material cannot exceed 4. If any of the single or cumulative counts is exceeded, then the sample grade is assigned. For grades U.S. Nos. 1-5, the maximum count limit of insect-damaged kernels in 100 grams is 31; if exceeded then the sample grade is assigned.

of bright color and low ash content. Test weight also serves as a means of estimating the volume-bushel (weight) relationship in storage. Recently, there has been considerable controversy on this topic, however, especially among growers of soft red winter wheat.

Heat damaged kernels Heat damage reflects a prior history of adverse storage or handling conditions. Grain that was too wet in storage and thus suffered microbiological and physiological activity becomes heat damaged. For this reason, and the fact that heat damaged kernels cannot be readily cleaned out, fairly strict limits are set.

Damaged kernels (total) In addition to heat-damaged kernels, the Standards specify limits on "badly ground-damaged, badly weather-damaged, diseased, frost-damaged, germ-damaged, insect-bored, mold-damaged, sprout-damaged, or otherwise materially damaged" kernels. Percentages are determined on the basis of kernels, pieces of kernels, and other grains which remain after removing kernels in Dockage and Shrunken and Broken categories. Probably the most notorious of these for PNW growers is sprout damage. On a regular basis, sprout is not a serious regional problem. Occasionally, however, untimely rains delay harvest and may cause serious problems. The problem is exacerbated by the general lack of seed dormancy in our white wheat varieties and the relatively low tolerance of many soft white wheat end-products to α-amylase – the main enzyme associated with sprout.

Foreign material Foreign material includes all matter other than wheat that remains in the sample after dockage and shrunken and broken kernels are removed. Since foreign material is not easily removed by sieving and, by definition, it is not wheat, it presents more of a problem to the flour miller. Added expense is incurred as more elaborate cleaning processes are employed to remove the material.

Shrunken and broken Often referred to as "S & B", shrunken and broken refers to all material removed by sieving on a 0.064 x 3/8 inch oblong-hole sieve. S & B is determined after dockage is removed.

Defects (total) The sum of damaged kernels, foreign materials, and shrunken and broken cannot exceed the maximum limit set for each grade. For example, U.S. No. 1 Soft White Wheat may contain up to 2.0 percent total damaged kernels, 0.4 percent foreign material, or 3.0 percent shrunken and broken, but the total of the three cannot exceed 3.0 percent. Wheat that contained all three of these at the maximum level specified for U.S. No. 1 wheat would have 5.4 percent total defects and consequently would grade U.S. No. 3.

Wheat of other classes Wheat of other classes is divided into Contrasting Classes and Wheat of Other Classes, Total. The limits set for wheat of contrasting classes is more strict than for Wheat of Other Classes reflecting the greater problem of having wheat with contrasting end-uses. For both Soft and Hard White wheats, the contrasting classes are Hard Red Spring, Hard Red Winter, Soft Red Winter, Durum, and Unclassed wheats. For Hard Red Spring and Hard Red Winter wheats, contrasting classes are Durum, Hard White, Soft White, and Unclassed wheats.

Special grades and classifications Special grades and classifications relate to certain specific problems or contaminants in a grain lot. They include such things as ergotty wheat, light smutty wheat, and smutty wheat. For more information on the special grades, refer to the official standards.

Other important quality criteria

Grain protein The unique characteristics of gluten, the main protein constituents of wheat, are what makes wheat so universally appealing as a staple food. The quantity and quality of gluten are primary determinants of its suitability in a given end-product. For example, a high quantity of strong elastic gluten is best suited for pan bread, whereas a low quantity of weak extensible gluten is best suited for cookies and cakes. This difference in gluten strength, in addition to grain hardness and color, has served as the main means of differentiating wheat classes. Consequently, premiums are often paid for higher protein hard red spring and winter wheats, depending on availability, whereas lower protein soft wheats are more highly prized by cookie and cake bakers. Noodles often fall in between these two ranges, in which an optimum level of protein, usually within a one-half to one percent range, produces the best product. While protein quality is largely a genetic trait fixed during the breeding process, protein quantity is highly dependent on grower management, soil nitrogen, precipitation (or irrigation), and the environment in general. Obviously, some of these factors are under grower control while others are not.

Moisture content Moisture content is important because it largely determines whether the wheat may be stored safely, and relates to the actual amount of millable dry matter in a unit of wheat. For example, 100 pounds of wheat at 13 percent moisture has 87 pounds of millable dry matter. Depending on temperature and time in storage, wheat above about 13 to 14 percent moisture will develop mold growth or heat due to a combination of mold growth and physiological processes. Because of these issues, overseas millers tend to prefer drier wheat.

Wholesomeness of the grain and grain lot In addition to the aspects of grain quality described above, other issues related to wholesomeness or perceived wholesomeness are important. Specifically, these include the presence of vomitoxin resulting from scab disease, the presence of pesticide residues, and the presence of rodent and bird filth, insects, glass, stones, etc. In the Pacific Northwest, problems such as scab and insect infestations are rare. In the U.S., all wheat must also meet FDA (Food and Drug Administration) guidelines.

For more information, contact your local FGIS field office, listed under the U.S. Government section in the phone book, or write:

U.S. Department of Agriculture
Grain Inspection, Packers, and Stockyards Administration
Federal Grain Inspection Service
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Washington, D.C. 20090-6454

Information is also available on-line at http://www.usda.gov/gipsa/

Reference: Grain Inspection Handbook – Book II. Also available on-line at http://www.usda.gov/gipsa/reference-library/handbooks/grain-insp/grbook2/gihbk2.htm

Winter Wheat Growth, Development, and Physiology of Seed Yield and Protein Level

G. Murray

Winter Wheat Growth and Development

Note: The Growth and Development section assumes optimum growing conditions and the soft white winter wheat cultivar Stephens unless otherwise stated.

Winter wheat production can be improved and input costs reduced with good knowledge of growth and development. Seeding date, irrigation scheduling, fertilizer, pesticide, and plant growth regulator application are more effective if accurately timed to crop development. Growth and development are related but separate plant processes. Growth is often described as an increase in size or dry matter, while development involves differentiation into tissues and organs. Growth rate is determined by many factors, including genetics, soil type, soil fertility, planting depth, planting date, water availability, and planting density. Temperature, photoperiod, and crop class primarily determine development rate. Thermal time used to describe development rate is most often calculated as growing degree days (GDD).

Developmental stage is more important in timing of management inputs than is calendar time or dry matter accumulation. Physiological processes that determine grain yield occur at fairly well determined growth stages. Correct identification of growth stages is important for making in-season management decisions including irrigation scheduling, in-season fertilizer applications, herbicide and insecticide selection and timing of application, and harvest scheduling. The cereal plant uses water and mineral nutrients from the soil and carbon dioxide from the air to make the products it needs for growth and grain production.

Germination Minimum soil moisture for germination in a silt loam soil is about 8 to 10 percent on a dry weight basis. Changes in soil moisture content from 10 percent to field capacity influences seed germination and time to emergence less than changes in soil temperature from 41°F to 86°F. Median emergence time of Norstar hard red winter wheat planted in soil with about 10 percent soil moisture and temperature of 41°F was only two days later than wheat planted at 41°F in soil at field capacity. In contrast, median emergence time of seed planted in soil with 10 percent moisture and temperature of 41°F was 20 days later than wheat planted in soil at 10 percent moisture and temperature of 68°F (see Planting Date section). At 68°F, median emergence time from soil with 10 percent moisture and at field capacity was less than one day different.

Seed germination to seminal root emergence requires about 80 growing degree days (GDD), Centigrade (°C) basis, or 144 GDD, Fahrenheit (°F) basis. Growing degree days are calculated by adding the maximum and minimum daily temperatures and dividing that number by two to give an average daily temperature. The base temperature, 0°C or 32°F, minimum for wheat growth, is subtracted from the average temperature. The growing degrees for each day are added together to give accumulated GDD.

GDD = (max. temp. + min. temp.)/2 - min. temp. for growth (32 °F or 0°C)

The seminal or seed roots emerge from the seed first (Fig. 1). Coleoptile emergence requires 50 GDD, °C basis (90 GDD, °F basis), per inch of planting depth after germination. If the coleoptile hasn't emerged after 150 to 200 GDD, C° basis (270 to 360 GDD, °F basis), the field should be examined for crusting and other causes of delayed emergence.

Seedling Development The coleoptile ceases elongation when exposed to light. The primary leaf then begins expansion and emerges from the coleoptile. Rate of leaf formation is governed primarily by temperature, and averages 100 GDD for Stephens wheat, °C basis (180 GDD, °F basis), per leaf. Centurk, Scout, and Newton winter wheat required 126, 122, and 113 GDD, °C basis (227, 220, and 203 GDD, °F basis), respectively, per leaf. Spring wheats averaged 73 to 84 GDD per leaf, °C basis.

When three leaves are present on the main stem, a tiller forms in the axil of the first leaf (Fig. 1). At this time, nodal or adventitious roots form at the base of the mainstem in the crown region of the plant. Coleoptile tillers may form from the subcrown internode region between

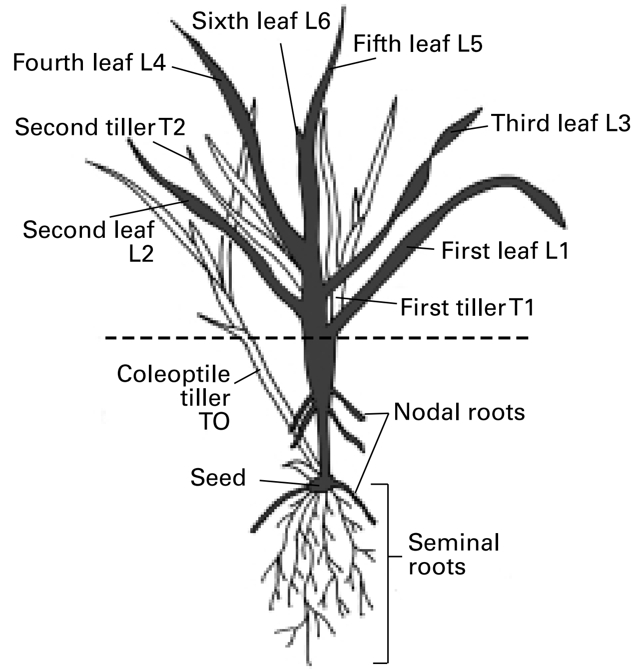

Figure 1. *Drawing of a young wheat plant showing identified leaves, tillers, and roots. The coleoptile node produces a tiller and nodal roots under good seedbed conditions (from Oregon State University Extension Service Publication EM 8542* Early Growth and Development of Cereals*).*

the seed and crown area of the plant. Moisture deficits reduced average coleoptile tiller formation of three hard red winter wheat cultivars and Stephens soft white winter wheat from 36 percent to 0 percent. Extremely shallow or deep planting also may prevent formation of coleoptile tillers.

With the development of each leaf after three leaves, primary tillers can form in the axils of the second, third, etc., leaf on the mainstem (Fig 1.). Primary tillers also can produce secondary tillers after reaching the third leaf stage. As with coleoptile tillers, moisture deficits delayed formation of tillers in the axils of leaves one to three on the mainstem.

Mixtures of nitrate forms of nitrogen and ammonia favor an increase in tiller production in spring wheat compared to either ammonia or nitrate nitrogen alone. Increased tiller number may increase yield if tiller number limits yield (see Seedbed Preparation and Seeding section).

Vernalization To produce heads, germinating winter wheat seeds or seedlings must be exposed to temperatures between 32°F and 50°F. The optimum temperature is 38°F. The exposure to cool temperatures must be continuous and not interrupted with warm temperatures. Temperatures above 50°F can stop or reverse the vernalization process.

The length of time required for exposure to cool temperatures varies from four to eight weeks. Cultivars show wide variance in time required to complete vernalization (Table 1).

Soft white winter wheat cultivars generally require shorter exposures to cool temperatures than hard red winter wheat cultivars.

Wheat can be vernalized as a germinating seed or as a seedling. The apical meristem of each stem, mainstem and tiller, and meristems capable of forming tillers are the receptors of the cold temperature. The vernalization stimulus is not transferable to non-vernalized tillers.

If early spring seeding of winter wheat is considered, cultivars with shorter (weaker) vernalization requirements should be chosen to ensure optimum heading (Table 1). Expected temperatures after planting also must be considered (see Planting Date section).

Spring wheat cultivars do not require vernalization but some respond with earlier heading after exposure to cool temperatures.

Table 1. Relative ranking of vernalization requirements of winter wheat cultivars.

Weak	Weak/Mod	Moderate	Strong
Hoff	Hyak	Gene	Eltan
Oveson		Rod	Dusty
		Malcolm	Kmor
		Madsen	Yamhill
		W301	
		MacVicar	
		Rhode	
		Stephens	
		Daws	
		Hill 81	

NOTE: Relative ranking:

Weak = shorter vernalization requirement

Strong = longer vernalization requirement

(Karow, 1995, personal communication)

Winter Hardiness and Cold Tolerance Winter hardiness is the ability of a plant to survive cold temperatures, desiccation, diseases, insects, water logging, ice encasement, wind abrasion, and other factors under field conditions. Cold tolerance refers only to the ability of a plant to withstand exposure to cold temperatures. Cold tolerance can be estimated by exposing wheat plants to freezing temperatures under controlled conditions. Temperatures required to kill 50 percent of the plants (LT 50) are often used as a means of uniformly comparing cold tolerance of cultivars.

Winter survival data from field-grown cultivars provide a relative measure of cultivar winter hardiness, called Field Survival Index (FSI). Several years may be required to get useful FSI values because temperatures may either be too cold or not cold enough to get differential survival in any given year. Field Survival Index values are more useful for predicting field survival than LT 50 values, which only measure cold tolerance.

Winter damage to wheat is dependent on cold tolerance of the cultivar, temperature level, duration of exposure to temperatures near or below the freezing tolerance of the wheat cultivar, and management. Management factors, particularly planting date, planting depth, seedbed preparation (residue management), and plant nutrition affect level and duration of temperature exposure. Other factors such as soil moisture deficits or excess, plant nutrition, diseases, and insects can affect cold tolerance. Healthy, vigorous plants have a greater ability to withstand winter damage than plants that are stressed.

Plant acclimation to cold temperature is necessary for maximum expression of cold tolerance. Exposure of wheat seedlings to temperatures between 0°C and 9°C (32°F and 47°F) for four to eight weeks is required for maximum expression of cold tolerance. Acclimation and vernalization often occur at the same plant growth stages and require similar environmental conditions, but are separate processes in the plant. Non-acclimated winter wheat and spring wheat seedlings have comparable minimum survival temperatures of -2.5°C (27.5°F).

Hard red winter wheat cultivars are more cold tolerant than soft white winter wheats. Field acclimated Norstar hard red winter wheat plants have maximum FSI values near 530 and minimum survival temperatures near –24°C. Nugaines soft white winter wheat has a FSI of 376 and a mean minimum survival temperature near –18°C.

Early planting and shallow seeding, particularly with no tillage, increased winter hardiness of Norstar and other hard red winter wheat cultivars in Canada compared to later, deeper plantings. In no-till trials, winter survival was significantly higher for wheat planted 0.4 to one inch deep, compared to wheat seeded as little as 0.7 of an inch deeper in four of seven trials. Yield was 11 percent higher with shallow seeding in trials that escaped serious winter damage. In a severe winter in Canada, planting two inches deep instead of one inch deep reduced cultivar winter hardiness by 100 FSI units. Planting four weeks before or after the recommended planting date reduced FSI 31 to 38 units, which for Nugaines is equivalent to a 10 percent reduction in FSI.

No-tillage and other practices that conserve surface residue aid survival by reducing soil moisture loss, which reduces plant desiccation, slows cooling of air and soil temperatures near plants, and helps trap snow. Snow cover reduces exposure of wheat plants to lethal temperatures (Fig. 2).

Phosphorus deficiencies and nitrogen excesses reduce winter survival of wheat. A 17 kg P_2O_5 per hectare (15 lb/acre) deficiency reduces FSI by 26 units, which is equivalent to 7 percent reduction in survival of Nugaines. Phosphorus may aid recovery in the spring more than increase winter hardiness directly. The soil nitrogen level does not usually affect winter survival unless applied in the seed row at planting time. Thirty pounds of nitrogen per acre applied in the seed row reduced FSI by 17 units while 60 pounds per acre reduced FSI by 34 units.

Dehardening can occur if water logging occurs or if wheat crown temperatures warm above 9°C (48°F). Dehardening occurs approximately three times faster than hardening, but frozen and wet soils warm more slowly than air temperatures, giving a buffering effect on rapid dehardening with fluctuating temperatures above 9°C. Prolonged exposure to cold temperatures above the lethal point also reduces hardiness.

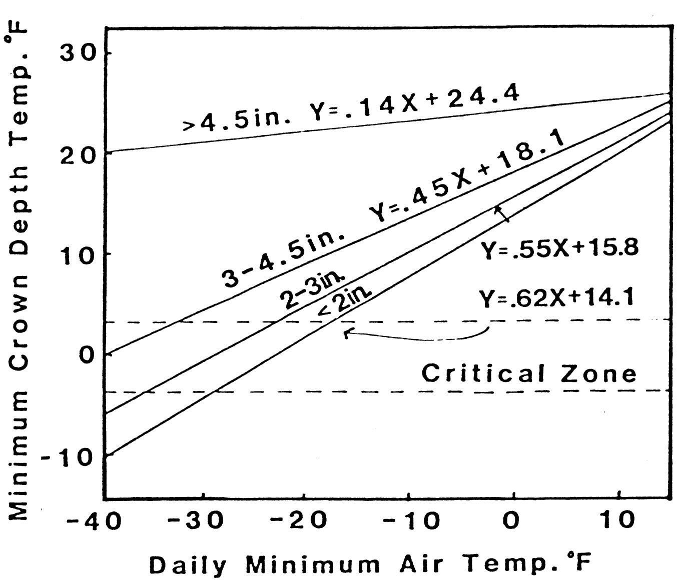

Figure 2. *Comparison of minimum crown depth soil temperature and daily minimum air temperature with different snow depths.*

Desiccation from wind causing evaporation or plant abrasion adds to the previously described winter stresses. Stubble and snow cover greatly reduce the opportunities for desiccation.

Assessment of winter damage can be done before or after spring green up. If it is before spring green up, remove small cores of plants from representative areas of the field and place plants at room temperature with lights. If air temperatures are below the lethal point during sampling, place plants in an insulated cooler to prevent cold temperature damage that could indicate more damage than exists in the field. Healthy plants should be examined for both new root and leaf development, as leaf development alone is not a good indicator of survival.

After spring green up, surviving plant stands can be assessed by using the wire loop method. The wire loop method uses a hoop 60 inches in circumference. Place the hoop in at least 10 representative places in the field. Count the plants and divide by two to get the plants per square foot (the area within a hoop with 60 inch circumference is two square feet). Replanting with a spring crop should be made by comparing yield potential of the surviving plant stand with expected yield potential of the spring crop (Table 2).

The best spring wheat yield with optimum planting date and high seeding rate was 55 to 60 bushels per acre. Therefore, even with four plants per square foot of healthy, vigorous Stephens and Madsen, it is better to leave the winter wheat rather than plant spring wheat.

Reproductive Development. Temperature and moisture at planting, and growing degree days after planting, are important variables that influence plant growth and development prior to exposure to cool temperatures for vernalization. Thus, plant size, leaf and tiller number, and general appearance of winter wheat is variable at time of vernalization and subsequent initiation of reproductive development.

The transition of a vegetative meristem to a reproductive meristem can be seen with a dissecting scope by examining the apical meristem at the base of the mainstem or tiller. The appearance of the meristem changes from a rounded to an elongated shape.

Formation of spikelets and florets begins at the base of the spike and progresses upward. Once the terminal spikelet has been formed, no further spikelets are possible. Under good conditions, 19 to 20 spikelets will form with an average of three well-developed seeds. Warm temperatures reduce the number of spikelets and florets by speeding up the formation of the terminal spikelet.

Table 2. Average plant stand and yield potential of Stephens and Madsen soft white winter wheat grown near Moscow, ID, and Genesee, ID.

Plant Stand (plants/ft^2)	Grain Yield (bu/a)
4.2	75.9 c*
7.2	84.0 b
9.9	91.8 a
15.0	93.1 a
16.0	93.1 a
19.6	95.7 a
20.6	95.7 a

* Means followed by the same letter are not statistically different (P=.05).

Late seeding of winter wheat delays the transition from a vegetative to a reproductive phase and thus contributes to reduced yield at this stage of development by reducing potential spikelet and floret numbers. Late seeding also reduces potential tiller numbers. Reduced tiller numbers potentially means fewer heads per plant. The combination of fewer heads per plant and fewer spikelets and florets per head reduces yield potential. Increased seeding rates may partially offset the lack of sufficient tiller numbers in the absence of diseases (see Seeding section).

Tiller Number and Yield The mainstem and first-formed tillers contribute the most to yield because of higher spikelet and kernel numbers per head. Additionally, kernel weights are usually higher on the mainstem and first-formed tillers because maturation of the kernels occurs with more favorable temperature and moisture supply.

Hard red winter wheat produced with 10 to 16 inches of precipitation in Colorado showed that the mainstem and tillers one, two, and three (T1, T2, and T3) from the mainstem accounted for 80 percent of the total yield (McMaster et al., 1994). The mainstem, T1, T2, and T3 contributed 29, 20, 19, and 12 percent, respectively. Tiller number 4 contributed 4 percent to yield while secondary tillers from the primary tillers contributed about 8 percent. The coleoptile tillers contributed 5 percent to the total yield.

Under optimum irrigation, the mainstem and tillers T1, T2, and T3 contributed 20, 18, 16, and 14 percent of the total yield, respectively. Secondary tiller contribution increased to 17 percent of the total yield compared to 8 percent under dryland conditions. Coleoptile tillers contributed about 2.5 percent to the total yield.

Stem Extension and Leaf Expansion (Jointing) With the formation of the spike and subsequent stem extension, tillering ceases. Apical dominance caused by auxin production in the developing spike and the lengthening days that speed reproductive development combine to prevent tillering. By the time the plant has reached the boot stage, all of the potential heads and sites for spikelets and florets have been developed.

Pollination, Heading, Anthesis Wheat is a self-pollinated crop. Pollination usually occurs by the time anthers have emerged (anthesis). These stages of plant development are particularly sensitive to moisture stress, frosts, and high temperatures. Plants that reach these stages during the hottest portion of the year because of late seeding are susceptible to heat and moisture stress and reduction of pollination and fertilization. Reduced pollination and fertilization decreases potential kernel number per head and yield.

Photosynthesis often exceeds demand at these stages because stem extension and leaf expansion is complete and kernel fill has not yet begun. Excess carbohydrate can be stored in the peduncle and second internode at this time. This carbon is later used as a source for kernel fill.

Kernel Development, Filling, and Yield Kernel development includes five stages: watery, milky, soft dough, hard dough, and mature. Current photosynthesis from the flag leaf, awns, and youngest leaf blades and sheaths provide 70 to 80 percent or more of the carbohydrates needed for kernel fill under good conditions of soil moisture and moderate temperatures.

If soil moisture is inadequate or if temperature and wind combinations cause temporary wilting or water deficits, photosynthesis is reduced. Temperatures above 90°F also reduce photosynthesis. If current photosynthesis cannot supply the kernel demands for carbohydrate, stored carbon can be re-mobilized from the peduncle, second internode, lower leaves and stems, and senescing tillers. Stored carbohydrates from the peduncle and second internode can contribute 10 to 20 percent of the needed carbon for kernel fill under good conditions.

If water deficits develop rapidly, stomates close quickly and rapidly reduce photosynthesis. Pre-anthesis stored carbon in secondary tillers, peduncle, and second internode accounts for 64 percent of the total carbon needs of the spike. If water deficits develop slowly, only 36 percent of the carbon going to the spike comes from carbon stored prior to anthesis.

Shading, or 50 percent loss of incident light, from one week before booting through the first week of kernel fill showed that later formed tillers, even though headed, preferentially supplied the mainstem and older tillers with carbon and nitrogen. Tiller mortality reduced spike number. Weight per kernel and number of kernels per spike also decreased. Combined effects of shading reduced yields 32 percent. The shading studies may partially explain why weeds, especially wild oats, reduce yields when the weed canopy is taller than the wheat canopy.

Grain Protein: Sources of Nitrogen and Stresses Wheat typically has taken up 80 percent of the total nitrogen utilized by the plant by anthesis. Winter wheat cultivars with higher protein usually take up more nitrogen after anthesis than plants with lower protein.

In addition, plant sources of nitrogen for grain protein vary with the cultivar. A study with nine cultivars of soft red winter wheat showed that the flag leaf contribution to spike nitrogen varied between 10 and 19 percent, peduncle contribution from 7 to 26 percent, lower stem and leaves from 35 to 53 percent, and total vegetative material from 52 to 92 percent (see Nitrogen Fertilization and Protein section).

During heading, water deficits from either inadequate irrigation or rainfall under dryland conditions also cause the plant to rely more on stored plant nitrogen than continued uptake from the soil after anthesis. Similarly to carbon re-mobilization, rate of water deficit development altered the amount of nitrogen re-mobilized. If water deficit develops quickly, 81 percent of the nitrogen going to the spike was stored by anthesis. If water deficits developed slowly, stored N only accounted for 40 percent of the N going to the spike.

Wheat Varieties

L.D. Robertson, E.J. Souza, R.S. Zemetra, J.M. Windes, S.O. Guy, B.D. Brown, and K. O'Brien

Choosing a variety is one of the most important management decisions made by wheat growers. The proper choice results in the most cost-effective means of addressing major disease problems and maximizes the return on investment of other production inputs. No one variety has the best traits for all production areas or conditions. Breeding programs develop and evaluate hundreds of new lines every year, and of those only a select few will be released as a new variety. The publication CIS 976 *Small Grain Variety Development and Adaptation in Idaho* provides a good overview of variety development and testing programs for public varieties. Whenever possible, university personnel also test varieties developed by private breeding companies before they become available to Idaho growers. Variety development is truly a cooperative venture among breeders, pathologists, entomologists, biochemists, cereal chemists, agronomists, and weed scientists. Close cooperation exists among state and federal research programs in Idaho, as in other states.

Snow mold and dwarf bunt are the two principal diseases that limit use of winter wheat varieties in dryland production areas of southern Idaho. Recently, effective seed treatments against dwarf bunt and several other diseases have been labeled for use on wheat. Use of these fungicides may allow additional varieties to be successfully grown in this area. Caution is advised against too great a dependence on fungicides in areas prone to dwarf bunt. Volunteer plants of susceptible varieties will still be a source of contamination.

Hard Red Winter Wheat

This class of wheat dominates production on dryland acreage in southern Idaho. Grain from hard red varieties is generally high in protein content (11% or higher) and is primarily used in breads, rolls, and other leavened products. Hard red varieties tend to be taller and have a higher level of winter hardiness compared to soft white varieties. Hard red varieties exhibit a number of different characteristics, and varieties should be chosen carefully to match the needs of the grower and the specific environment. Tables 1 and 2 give some agronomic, disease, and quality characteristics of currently available varieties.

Table 1. Yield and test weight summary for selected hard red winter wheat varieties, southeastern Idaho, dryland, 1993-1997.

	1993-1996 Preston		1993-1996 Rockland		1995-1996 Roy		1993-1997 Idaho Falls		1994-1996 Tetonia	
Variety	Yield	Test Wt.	Yield	Test Wt.	Yield	Test Wt.	Yield	Test Wt.	Yield	Test Wt.
	bu/A	lb/bu	bu/A	lb/bu	bu/A	lb/bu	bu/A	lb/bu	bu/A	lb/bu
Boundary	48	60.3	60	59.9	74	59.5	48	57.5	58	59.7
Weston	48	61.9	55	61.4	65	62.0	45	51.6	50	62.1
Manning	44	61.1	60	60.1	73	60.5	44	60.7	54	60.1
Promontory	45	62.0	59	62.3	79	63.0	49	61.5	55	62.4
Utah 100	48	62.3	63	60.2	80	60.0	48	58.1	58	59.2
Bonneville	48	61.2	50	60.5	64	61.0	45	61.7	51	62.5
Blizzard	47	61.4	54	59.7	70	61.5	45	63.2	52	61.6
Survivor							38	61.2		
Neeley							44	60.6		

Table 2. Hard red winter wheat yield, test weight, and stands when snow mold or poor emergence limits stands, 1989 - 1995.

	Snow Mold Sites 8 Site-Yrs			Poor Emergence Sites 5 Site-Yrs		
Variety	Yield	Test Weight	Spring Stand	Yield	Test Weight	Spring Stand
	bu/A	lb/bu	%	bu/A	lb/bu	%
Blizzard	59	60.7	55.0	36	58.8	71.5
Bonneville	60	60.5	59.3	33	59.0	74.5
Jeff	47	59.9	45.3	33	59.5	76.1
Manning	55	60.0	48.6	33	57.1	64.4
Meridian	51	58.7	49.8	32	57.5	68.4
Neeley	59	61.0	48.6	35	57.1	74.4
Promontory	53	62.1	44.3	35	59.0	73.1
Sprague	57	60.2	44.7	36	57.3	77.5
Survivor	55	60.1	61.4	31	58.1	67.7
Weston	54	61.5	47.5	35	59.4	67.2
LSD .05	7	1.1	10	6	1.7	15

Hard Red Varieties

Blizzard This variety was released by the University of Idaho and USDA-ARS in 1989. Blizzard is a tall, awned variety with light tan glumes, stiff straw, and erect to inclined heads. Blizzard is resistant to shattering, similar to Jeff. Blizzard is harder to thresh than other varieties. The height of Blizzard is intermediate between Weston and Manning. Blizzard has averaged two to four days later in heading than Manning and Weston. Blizzard shows a high degree of tolerance to snow mold and is highly resistant to dwarf bunt. Blizzard is moderately susceptible to stripe rust. In the absence of snow mold, Blizzard is comparable in yield to Manning, Weston, and Sprague. Where snow mold has prevailed, Blizzard will outperform other varieties. Test weight of Blizzard is intermediate between Manning and Weston. Grain protein averages higher than

Manning or Weston and the milling and baking quality is rated as acceptable, intermediate between Manning and Weston for most characteristics.

Bonneville This variety was released by the University of Idaho and USDA-ARS in 1993. Bonneville has excellent snow mold tolerance and dwarf bunt resistance. Yields of Bonneville have been superior to Survivor with stiffer straw and better test weight than Survivor or Blizzard. Bonneville's best performance has been in trials above 5,000 feet where yield is superior to Manning. Bonneville also has excellent seedling emergence, similar to Jeff. Milling yield and baking quality are excellent, better than Survivor, Weston, and Blizzard.

Boundary This variety was released by the University of Idaho and USDA-ARS in 1996. Boundary is an awnless, semi-dwarf variety with very good straw strength. Boundary has good resistance to snow mold but is moderately susceptible to dwarf bunt. Emergence is better than Manning even though height averages two inches shorter. Test weight tends to be less than most other varieties and protein content is lower than Weston and Bonneville but similar to Manning and Promontory. Milling quality is intermediate between Promontory and Weston. Baking quality is acceptable, although loaf volume tends to be low.

Deloris This variety was released by Utah State University in 2002. Deloris has excellent resistance to dwarf bunt and good tolerance to snow mold. Yield in southern Idaho has been better than Utah 100 and Bonneville. Test weight is similar to Utah 100 and 0.5 pounds per bushel lighter than Bonneville. It is three inches shorter than Utah 100, one inch shorter than Bonneville, and similar in heading date to Utah 100. Protein content of Deloris is similar to Utah 100 and the milling and baking quality is good.

DW This variety was approved for release in 2001 by the University of Idaho and USDA-ARS. DW has excellent snow mold tolerance and is resistant to dwarf bunt. Yields are similar to Boundary. Test weight and maturity are similar to Weston and Manning, and earlier than Bonneville. Height is shorter than Utah 100 and Bonneville and similar to Weston. Emergence under adverse conditions is not as good as Utah 100 and Bonneville. DW has good milling and baking quality.

Manning This is a bronze-chaffed variety released by Utah State University and USDA-ARS in 1980. Manning is intermediate to tall and has reasonably stiff straw. It is best suited to dryland areas that receive above average precipitation. Manning has a shorter coleoptile, similar to Promontory, and should not be planted deeply or it may have emergence problems. Manning is resistant to dwarf bunt and has some tolerance to snow mold. Manning is moderately resistant to Cephalosporium stripe and to stripe rust. Manning yields well under irrigation. However, this variety lodges and has a relatively low protein content. Test weight is lower than Weston and Blizzard.

Neeley This is a white-glumed variety released by the University of Idaho and USDA-ARS in 1979. Although primarily intended as an irrigated variety, Neeley yields well on dryland. However, it is susceptible to dwarf bunt and snow mold and should not be grown where those diseases are prevalent. Neeley is intermediate to tall in height, similar to Blizzard, taller than Manning, and shorter than Weston. In the absence of snow mold and dwarf bunt, Neeley yields have been slightly above Weston and similar to Manning. Test weight is lower than both Manning and Survivor. Milling quality is poor and baking quality is satisfactory, similar to Meridian.

Promontory This bronze-chaffed variety was released by Utah State University and USDA-ARS in 1990. In the absence of disease and when sufficient moisture is available, Promontory has the best yield potential of current hard red winter varieties. Promontory has excellent resistance to dwarf bunt but less tolerance to snow mold than Manning. Height is similar to Manning and shorter than Weston and Bonneville. Straw strength is good. Maturity is early, similar to Manning and Weston and earlier than Blizzard and Bonneville. Coleoptile length of Promontory is similar to Manning but shorter than Blizzard, Weston, and Bonneville. Promontory should not be seeded deeply as it may have emergence problems. Although protein content is lower than many other varieties, milling and baking quality is rated as excellent. Promontory can be produced under irrigation but lodging may occur under high yielding, high nitrogen conditions.

Survivor This variety was released by the University of Idaho and USDA-ARS in 1991. Survivor is intermediate to tall, being similar to Blizzard and Manning but shorter than Weston. Seedling emergence is very good. Survivor has excellent tolerance to snow mold, producing better spring stands than other hard red varieties and similar stands to the soft white variety Sprague. Survivor is resistant to dwarf bunt and is moderately susceptible to stripe rust. Straw strength is intermediate between Sprague and Blizzard. Yields of Survivor have exceeded those of Manning when snow mold significantly reduces stands of less resistant varieties. Survivor is also a clean threshing variety. Test weight is less than Blizzard but greater than Sprague. Survivor has intermediate protein content and excellent milling yield. Baking quality is similar to Neeley and Meridian.

Utah 100 This variety was released by Utah State University and USDA-ARS in 1996. Utah 100 has good resistance to dwarf bunt but has only moderate resistance to snow mold. It is taller than Manning, one of its parents, and has better emergence from deeper seeding. Yield results have been very good. Test weight is similar to Manning but less than Bonneville. Protein content is similar to Boundary and Manning. Straw strength is good; height is shorter than Weston but taller than Promontory. Milling yield is similar to Manning and Weston and less than Bonneville and Promontory. Loaf volume is greater than Boundary, equal to Bonneville, and less than Weston. Overall baking quality is acceptable.

Weston This is a tall, bronze-chaffed variety released by the University of Idaho and USDA-ARS in 1978. Weston has moderate to good resistance to dwarf bunt but only fair tolerance to snow mold. Weston has good emergence and has been the most popular dryland variety in the area for the past several years. Weston is shorter and has better straw strength than Jeff but is taller than Manning. In the absence of snow mold, Weston has better yield than Blizzard in the southern areas. Yields are slightly less at the higher elevation areas near Tetonia. Weston heads two days earlier than Manning and has higher protein content. Milling quality is satisfactory and baking quality is poor.

Other hard red varieties Other varieties of hard red winter wheat produced in southern Idaho are either older varieties that are not as productive as the listed varieties or are lacking resistance to dwarf bunt and snow mold. Varieties that lack resistance to snow mold and dwarf bunt should not be grown in areas prone to these diseases. For additional information on other varieties, consult a local county extension office or a UI Research and Extension Center.

Soft White Winter Wheat

This class of wheat is most important in irrigated areas of Idaho, but it is not as common in dryland areas as the hard red class. Varieties in this class tend to have higher overall yield potential, but may lack winter hardiness and other characteristics that allow broad adaptation. Grain from soft white varieties is usually low in protein (below 11%) and is used in producing cakes, cookies, and other pastries. In some lower-yielding environments or during drought years, protein content may be higher than desired by the industry. As a group, soft white winter wheat varieties are shorter and have better straw strength than hard red varieties. Agronomic, disease, and quality data are given for available varieties in Tables 3 and 4.

Soft White Varieties

Eltan This variety was released by Washington State University and USDA-ARS in 1990. Eltan has intermediate height, taller than Sprague but with stronger straw. Eltan is later in heading than Sprague and has better winter hardiness. Eltan is moderately resistant to dwarf bunt, has good tolerance to snow mold, and is moderately resistant to stripe rust. Yields have been better than Sprague in higher yielding environments. Protein content is about one percent lower than Sprague and flour yield is slightly higher. Cookie quality is not as good as Sprague. Test weight of Eltan is lower than most varieties, frequently below 58 lb per bushel.

Lambert This is a white-chaffed variety released by the University of Idaho and USDA-ARS in 1993. Lambert is an early maturing variety with above average height. It is primarily intended for use in northern Idaho. Lambert can be grown under irrigation but plant height may prevent use with wheel lines. In a limited number of southern Idaho dryland trials, Lambert yields have been higher than Sprague and Eltan. Lambert is resistant to stripe rust and has some tolerance to Cephalosporium stripe. Lambert is susceptible to dwarf bunt and has moderate tolerance to snow mold. It should not be used where

Table 3. Performance summary of selected soft white winter wheat varieties at Roy, 1992-1995.

Variety	4-yr Yield Average	Test Wt Average	Snow Mold Survival 3 yr
	bu/A	lb/bu	% stand
Eltan	62	55.5	44
Sprague	61	60.1	59
Kmor	60	54.9	48
Madsen	54	57.7	49
Daws	49	57.0	46
Lambert	47	58.0	49
Nugaines	43	57.0	49
Stephens	41	57.9	35

dwarf bunt is prevalent. Protein content of Lambert is equal to Stephens and higher than Kmor and Eltan. Milling and baking quality is considered excellent.

Madsen This variety was released by Washington State University and the USDA-ARS in 1988. Madsen is an awned semi-dwarf variety with good yield potential and good straw strength. Madsen is the first U.S. variety released with resistance to strawbreaker foot rot. Madsen is resistant to common bunt, powdery mildew, and leaf, stem, and stripe rust. Winter hardiness is not as good as Eltan but better than Sprague. Snow mold tolerance of Madsen is superior to Kmor but inferior to Sprague.

Sprague This variety was released by Washington State University and USDA-ARS in 1973. Sprague is a semi-dwarf variety that averages about four inches shorter than Manning and Promontory and eight inches shorter than Weston. It is intermediate in maturity and has moderately weak straw. Sprague has very good tolerance to snow mold but is moderately susceptible to dwarf bunt. Winter hardiness is significantly less than hard red varieties; Sprague should not be seeded in lower elevation fields that typically have limited snow cover. Sprague must be seeded early to develop full tolerance to snow mold. It is currently the most popular soft white dryland variety grown in southeastern Idaho.

Other soft white varieties Although there are many other soft white winter varieties grown in southern Idaho, they are adapted primarily to irrigated conditions. They lack resistance to dwarf bunt and snow mold and should not be grown where these diseases are present. For descriptions and additional information on these varieties, consult your local county extension office or UI Research and Extension Center.

Hard White Winter Wheat

This class of winter wheat, although not very popular at present, will likely increase in popularity and acreage over the next few years. Varieties are just becoming available for this wheat class. This class has functional (end-use) properties similar to hard red wheat but some are also more suited for export to the Asian noodle industry. Care should be exercised to insure these varieties do not get mixed with either hard red or soft white wheat.

Gary This hard white variety was approved for release in 2001 by the University of Idaho and USDA-ARS. Gary has excellent dwarf bunt resistance, snow mold tolerance, and stripe rust resistance. Gary has good emergence characteristics. Gary is similar in height and yield to Utah 100 and Golden Spike; test weight is greater. Heading date is the same as Golden Spike. Protein content is similar to Golden Spike and less than Boundary.

Table 4. Performance summary of selected soft white winter wheat varieties at Idaho Falls, 1992-1994, 1996-1997.

Variety	Yield	Test Wt	Protein[1]	Height	Date Head[2]
	bu/A	lb/bu	percent	inches	fr Jan 1
No. years	5	5	5	5	4
Daws	50	60.2	11.1	26	175
Eltan	52	59.0	11.1	28	177
Kmor	56	58.9	10.7	26	176
Lambert[3]	46	59.7	11.7	29	173
Madsen	52	59.5	12.3	27	175
Malcolm	49	59.9	11.7	26	174
Rod[3]	51	57.9	11.5	26	177
Sprague	48	60.7	11.3	26	171
Stephens	43	58.1	12.4	25	173
Average	**50**	**59.3**	**11.6**	**27**	**175**

Notes:
1. No protein data from 1997.
2. No date head data from 1992.
3. Rod and Lambert not grown in 1992-1993, data adjusted for missing values.

Golden Spike This hard white winter wheat variety was released by Utah State University in 1999. Although not the first hard white winter variety released, it appears to be well adapted in southern Idaho. Golden Spike is similar to Utah 100 in yield, test weight, and plant height. Maturity is later than Utah 100 and similar to Bonneville. Protein content is lower than Manning and similar to Bonneville and Boundary. Milling and baking scores have been average.

Seed Quality and Seed Production

L. D. Robertson and G. Lowry

Introduction

Seed quality is one determinant of crop yield. Good quality seed is true to variety and relatively free from crop mixture, weeds, and diseases. It has plump kernels of high germination and vigor. Every effort should be made to obtain the best seed available. Seed vigor tests have been used to describe seed quality in other crops but have not been widely used with cereal crops. According to the Association of Official Seed Analysts, "Seed vigor comprises those qualities which determine the potential for rapid uniform emergence and development of normal seedlings under a wide range of field conditions."

Many factors cause variations in the level of seed vigor, but the principle known causes are: (1) genetic constitution, (2) environment and nutrition of the mother plant, (3) stage of maturity at harvest, (4) seed size, (5) seed weight or specific gravity, (6) mechanical integrity, (7) deterioration and aging, and (8) existence of pathogens. Production of high quality seed requires extra care and is typically not done well by all wheat producers. Specialized seed production procedures help ensure that producers have an adequate supply of good quality seed.

Seed quality

Research has shown that seed size is one of the most important characteristics in determination of wheat seed quality. Test weight and protein per seed are also important characteristics that producers can easily determine. Figure 1 shows yields from Kansas winter wheat that was separated into fractions based on kernel weight or size and seeded at two different depths. In all cases, there was a reduction in yield from both the light seed and the small seed compared to heavy or large seed, or the unselected control. The largest yield reductions were from small seed that had been seeded deeply. These data also show yield reduction from planting deeper than necessary. The normal seeding depth is one and one-half inches, while the deep seeding had two and one-half inches of soil coverage. Oregon research has shown that large seed consistently produced plants that achieved greater early growth, making these plants more likely to be competitive with weeds and survive attack from pests. The authors concluded that yield was not only influenced by seed

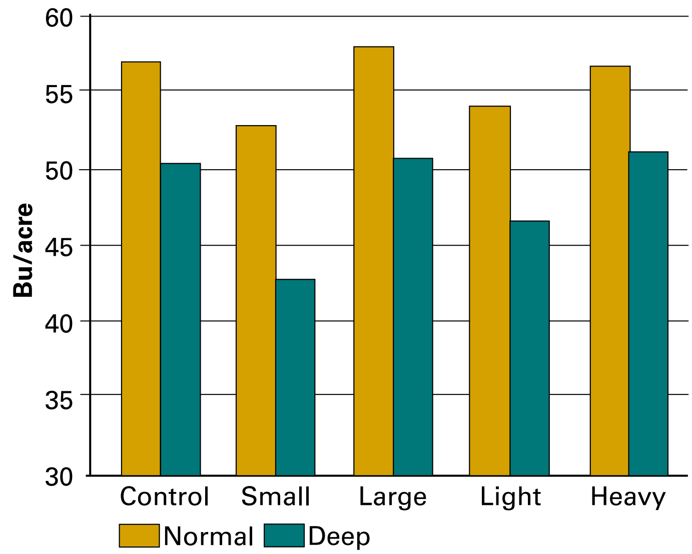

Figure 1. *Influence of kernel size and weight and planting depth (normal and deep) on winter wheat yield in Kansas.*

Table 1. Seed size and yield of Hyslop wheat, 18 seedlots, 1974.

	Yield (bu/A)	
Seed size	Hyslop Farm	Sherman Station
Ungraded	107.2	52.8
Largest half of lot	110.6	54.6
Smallest half of lot	104.4	48.9

Grabe, 1974

Table 2. Seed size and yield of Hyslop wheat, 9 seedlots, Hyslop Farm, 1975.

Seed size [1]	Yield (bu/A)
5 - 6	89.7
6 - 6 1/2	93.8
6 1/2 - 7	96.0
Over 7	99.6
Ungraded	94.4

[1] Seed passed through a 6/64 x 3/4 screen but held on a 5/64 x 3/4, etc.
Grabe, 1975

size, but also by initial seed quality (laboratory germination). Tables 1 and 2 show results from another Oregon study relating to seed size. In both of these studies, large seed had a yield advantage over small or ungraded seed. For every bushel increase in yield given by large seed, per acre income will increase with little if any added input cost. When a seedlot is cleaned and the small seed removed, the small seed can still be sold for grain.

In general, seedlots that have large seed size also have high test weight. High test weight is associated with a lack of stress during the grain filling period. Any stress encountered by the wheat plant during the grain filling period will have an adverse effect on seed performance. One stress that is routinely encountered in Idaho is freezing temperatures that may occur either prior to or after grain development begins. Grain frozen prior to the beginning of seed development may be lower yielding, but seed quality is not adversely affected by the freeze. Grain frozen during the grain filling period normally does not produce high quality seed. Table 3 compares wheat seed that had been frozen during the grain filling period to seed of the same variety that had not been frozen. Although laboratory germination was reduced in the frozen sample, it did not predict the almost complete failure of the frozen seed to emerge. Figure 2 shows the effects of freezing on wheat seedlings, many of which germinated but failed to develop a normal coleoptile. The coleoptile, sometimes called the spear-point, pushes through the soil from the seed to the soil surface and allows the first leaf to emerge at the soil surface. The coleoptile from the frozen seedlings failed to elongate normally, which prevented the first leaf from reaching the soil surface. Leaves that unfold below the soil surface are sometimes called accordion leaves due to their crinkled and folded appearance.

Various researchers have used a variety of physical and biochemical tests to measure seed vigor. However, none appear to have an advantage over these easily obtained test weight and seed size values.

Table 3. Comparison of seed characteristics and performance from non-frozen and frozen seed, Rick spring wheat, 1994.

	Non-frozen	Frozen
Test weight, lb/bu	60.2	52.2
Weight/1000 kernels, g	45.5	31.5
Germination, %	99.0	72.5
Emerged plants/2 ft, deep [1]	17.8	2.5
Average coleoptile length, mm	45.0	33.0
Emerged plants/2 ft, shallow [2]	18.0	4.3
Average coleoptile length, mm	38.0	29.0

[1] Seed coverage 2 inches deep.

[2] Seed coverage 1 1/2 inches deep.

Seed certification

Buying certified or "Blue Tagged" seed is the best way to ensure that one is getting good seed quality with minimal contamination from varietal impurities, weed seed, and other crop mixtures. All seed sold or offered for sale in Idaho must be labeled. The two types of labels that can be found on Idaho seed are an analysis tag (Figure 3) and a certification tag (Figure 4). The analysis tag must truthfully represent the analysis of the seed in the bag. By reading and understanding the contents of the seed analysis tag, one aspect of seedlot quality can be determined. While the analysis tag does not guarantee that the seed will be free from weed seed or other crop mixtures, it does state what was found when the seedlot was tested. Common seed in Idaho is permitted by law

Figure 2. *Comparison of frozen (right) and unfrozen (left) spring wheat seed on seedling performance.*

to have up to four wild oat seeds per pound. At a seeding rate of 60 pounds per acre, this is equivalent to 240 wild oat seeds per acre. Common seed has no limits for such quality factors as pure seed content, inert matter, other crops, and germination percentage, and allows up to 1 percent weed seed. Certified seed, in contrast, has limits of at least 98 percent pure seed, not more than 2 percent inert, not more than 0.03 percent weed seed and not more than 0.05 percent other crop seed. Germination must be at least 85 percent with no more than two seeds per pound of other varieties and no noxious weeds found in the sample submitted for examination. An added benefit of certified seed is that during the cleaning process, small and light seeds are removed from the seedlot, thus improving the overall quality of the seed.

Certification of wheat seed is a function of the Idaho Crop Improvement Association (ICIA) and involves several steps to ensure high quality seed. Production of a class of certified seed involves many steps, including proof of seed origin, application, field inspections, seed inspections, and germination tests. The grower and ICIA document each of these steps. Certified seed production of cereals involves a four-step classification starting with the "breeder" seed that is directly under the control of the originating breeding organization or the firm holding marketing rights. Breeder seed is used to produce "foundation" seed. This class of seed is generally grown by only a few growers that exercise extra care in all aspects of production of the crop. Field requirements, varietal purity, and weed content is very closely monitored and tolerances are very rigid. Foundation seed is used to produce "registered" seed. This seed requires the same procedures as foundation seed but the tolerances and requirements are slightly less rigid. Registered seed is used to produce "certified" seed. The same procedures and documentation are required for this class but tolerances and requirements are slightly less rigid than for the registered class. Seed cannot be certified until after harvest and seed conditioning when seed inspections have been completed.

Except for seed germination, certification standards and seed certification are distinct and separate from the seed quality characteristics discussed earlier. Certification standards are also separate from any standards associated with wheat end-use quality (i.e. protein content and quality, milling, or baking characteristics).

KIND:	*WHEAT*
VARIETY:	*GARY*
LOT NO.:	*02-420W*
TEST NO.:	*23-01091*
GERM. DATE:	*09/10/02*
NOX. WEED SEEDS/LB:	*0*
% PURE SEED:	*99.44*
% INERT MATTER:	*0.56*
% WEED SEEDS:	*0*
% OTHER COM SEEDS:	*0*
% GERMINATION:	*98*
% HARD SEEDS:	*0*

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Figure 3. *Example of a seed analysis tag.*

Figure 4. *Example of a seed certification tag. This tag is for certified seed. Foundation or registered seed would be marked as such on their respective tags. Tag colors differ for foundation, registered, and certified seed.*

Rotation, Cropping Systems, and Field Selection Factors

L.D. Robertson, R.J. Veseth, B.D. Brown, and S.O. Guy

Winter wheat is a versatile crop that can be successfully grown on many soil types and under many environmental conditions. Winter wheat can be grown in rotation with other non-cereal crops with few restrictions. Rotation of winter wheat with non-cereal crops is one of the most effective pest management tools. Winter wheat tends to break disease, insect, and weed cycles associated with previous crops. Likewise, non-cereal crops break disease, insect, and weed cycles associated with winter wheat monoculture. In much of the dryland winter wheat production area, wheat has been grown in a wheat-fallow-wheat rotation or recropped, primarily because of a lack of suitable alternatives. In these cases, diseases, insects, and weeds will increase to limit the actual yields that could be obtained with proper rotation. Rotating to non-cereal crops will help break the yield-limiting effects associated with short winter wheat rotations. However, growers must avoid using long-residual soil herbicides as they may persist in the soil and injure the wheat crop.

Rotating to other cereal crops (i.e., spring wheat or barley) can help break disease, insect, and weed cycles, but it is generally not as effective as rotating to non-cereal crops. Volunteer plants from previous cereal crops may harbor disease and insect pests that can infect the new crop. These should be controlled in the fall and/or early spring. Proper cultivation and other weed control practices prior to seeding as well as harvesting techniques that minimize grain loss will help control volunteer problems.

Pacific Northwest-based research has shown that longer crop rotations reduce winter wheat yield response to soil fumigants. Soil fumigation has been used as a research tool to eliminate root diseases and evaluate the attainable yield as limited only by available water and other environmental constraints (Figure 1). Based on 15 years of research in the Inland Northwest, yields with continuous winter wheat were increased an average of 70 percent by soil fumigation. With a two-year winter wheat-pea, -lentil, or -fallow rotation, there was a 22 percent average yield increase with fumigation. In three-year crop rotations, with two years out of winter wheat, there was only a seven percent average yield response to fumigation.

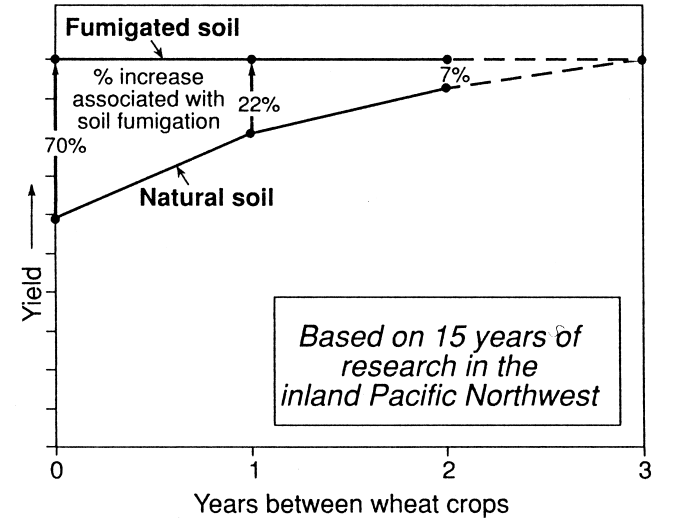

Figure 1. *Yields of winter wheat in response to soil fumigation, as influenced by the length of crop rotation in eastern Washington and northern Idaho. (Data of R. J. Cook)*

These research results demonstrate that crop rotation is nearly as effective as soil fumigation for controlling many soilborne root diseases, which can cause severe yield losses under conservation tillage – it just takes longer.

Dryland winter wheat production is ideally suited to conservation tillage systems. Conservation tillage is an integrated system of crop production practices, generally in rotation, that minimize tillage, control erosion, and leave most crop residue on the soil surface. A conservation cropping system study conducted near Pullman, Washington, between 1985 and 1991 documented benefits of longer crop rotations and conservation tillage in winter wheat production. The study was conducted with field-scale equipment on an 80-acre research site in a 21-inch annual cropping precipitation zone. Winter wheat grown after spring peas in a three-year rotation of winter wheat, spring barley, and spring peas under conservation tillage produced higher yields than winter wheat following either spring wheat or winter wheat in a rotation of winter wheat, winter wheat, and spring wheat, under both conservation tillage and conventional intensive tillage. Following either peas or spring wheat, winter wheat yielded more under conservation tillage than with conventional tillage. Winter annual grass weeds, root diseases, and other pests were not a problem under conservation tillage in the wheat-barley-pea rotation, and this production system was the most economical and least risky.

A summary of the experimental treatments and results are in the Washington State University (WSU) Research Bulletin XB1029, IPM Research Project for Inland Northwest Wheat Production. The project research is also highlighted in "Profitable Conservation Cropping Systems – Insights from the USDA-ARS IPM Project," a 30-minute video (VT0029) from WSU Cooperative Extension. The publication and video are available from: Cooperative Extension Bulletin Office, Cooper Publications Bldg., Washington State University, Pullman, WA 99164-5912 (Telephone: 509-335-2999).

Growers are encouraged to study other sections of this publication and to take a cropping systems approach to managing their winter wheat crop. A cropping systems approach involves all considerations of crop management and the interactions between the various factors. Effects of one management choice will likely have an effect on the physical and biological factors that affect crop performance through plant health, nutrient availability, weed control, yield, and grain quality.

Wherever possible, fields that have excessive weed and volunteer problems should be managed separately from fields with no problems. Previous crop performance and pest problems should be used to guide management decisions.

Seedbed Preparation and Seeding

L.D. Robertson and J.C. Stark

Seedbed Preparation

Seedbed conditions that promote rapid germination and uniform emergence are desirable for winter wheat production. Dryland winter wheat can be successfully produced from soil that is managed for no-till, minimum-till or conventional tillage. Regardless of tillage system, wheat requires a seedbed that maximizes contact between the seed and surrounding soil. Good seed-soil contact maximizes rapid seed germination and promotes uniform, rapid emergence. Overworking a seedbed depletes soil moisture and promotes soil crusting. Loose or overworked seedbeds can be firmed prior to seeding but this is costly and should be used only in exceptional situations. Properly working the soil only enough to insure a moderately fine but firm seedbed while conserving surface residues is much preferred. When seeding is done into no-till soils, care must be taken to insure that seed openers and packer wheels are properly adjusted so that the seed furrow is closed and good seed-soil contact is achieved. Tilled seedbeds should maintain enough clods on the surface to prevent wind erosion.

One of the goals of dryland seedbed preparation should be maintaining moderate amounts of residue on the soil surface. Maintaining crop residues on the soil surface has the following advantages:

1. reduced soil erosion from wind and water
2. increased moisture penetration
3. increased uniformity of soil moisture across the field
4. reduced evaporation from the soil surface
5. trapping of snow and less damage from drifting snow
6. cooler soil temperatures at seeding time

Improperly managed residues and/or unadapted seeding equipment can cause residues to interfere with proper seed placement and seedling growth. Heavy residues require specialized drills that place seed into moist soil at the proper depth without either clogging or placing residue in the seed row. Residues in the seed row are often "hair-pinned" and generally result in poor seed-soil contact and a seed row that dries faster than the seed can germinate due to wicking action of the straw residue. Refer to the section on residue management for additional information.

After primary tillage during the fallow period, tillage implements are often set to work the soil at about the same depth. This creates a tilled layer of soil (sometimes referred to as a dust mulch) on top of a firm layer that helps prevent excessive moisture loss prior to seeding. If the tillage layer is too shallow, the firm layer may become dry and hard, making it difficult for the drill to penetrate. This may cause seed to be sown in a dry layer and at an improper depth. If the tillage layer is excessively deep, soil moisture loss may be higher than desired. This condition can lead to seeding depths that are too deep for rapid, uniform seed emergence if care is not taken during the seeding operation. Preplant fertilizer and herbicide applications should be made to the tilled soil prior to final seedbed tillage operations. The final tillage operations should be close to seeding time to insure that growing weeds are killed prior to seeding the wheat crop but far enough ahead of seeding to prevent the "green-bridge" effect from volunteer cereal plants. About three weeks is generally considered minimal between killing the volunteer plants and sowing the next wheat crop without serious risk of disease.

Seeding Dates

Improper seeding dates, either early or late, have many adverse consequences (Table 1). Optimum seeding dates encourage uniform and high seed germination, strong plants, and a vigorous root system. Dryland winter wheat in southern Idaho should be seeded early enough to allow tiller and crown development and adequate root growth to occur before winter dormancy. Well-developed crowns have been associated with resistance to damage from snow mold and also winterkill from freezing temperatures. Adequate root growth is necessary to avoid plant moisture stress during the winter. Seeding too early in the fall leads to excessively large plants that use valuable soil moisture and also exposes the plants to several potential disease and insect problems. Altering planting dates primarily to control a disease or pest should be considered only if there is no other acceptable method of control of the disease or pest. Refer to disease and insect management sections for further discussion of these problems.

Optimum seed germination with wheat occurs at about 75°F and coleoptile elongation is maximized at about 60°F. Seeding should be timed, when practical, to coincide with available soil moisture so seed does not have to be placed too deeply in the soil. Optimal seeding dates vary with geographic location and year, but approximate dates for several major production areas are:

Washington County: early September

South-central counties: late August to mid-September

Southeastern counties (lower elevations): mid-August to early September

Southeastern counties (higher elevations): mid- to late August

Wheat requires about 180 growing degree days (using Fahrenheit degrees) to emerge from one inch of soil and another 180 degree days to develop each main stem leaf. A good goal would be to have five to six main stem leaves developed prior to winter. A plant of this size should also have two to three developed tillers and would require approximately 1080 to 1260 growing degree days. Using long-term average temperatures, this size plant would be achieved by planting between September 2 and September 9 at Aberdeen. Planting dates for other areas would have to be adjusted based on their average temperatures.

Seeding date affects heading date the following spring and consequently the time that grain fill occurs. In general, for every three to four days of delay in seeding date during the normal seeding time, heading date will be delayed by one day. This delay decreases with earlier seeding and increases as seeding date is delayed past the optimum time. Recent research has investigated the effects of very late fall seeding. Compared to seeding during the normal time, late seeding has resulted in decreased yields, later heading dates, and reduced test weights. Spring wheat varieties seeded at these very late dates have produced slightly higher yields than have winter wheat varieties seeded at the same date and the effect of delayed heading is minimized. This practice should only be used when earlier seeding could not be done. In some fields that have low erosion potential and good surface residue, this management practice may be preferable to

Table 1. Effect of seeding date on grain yield, test weight, and date head, Aberdeen, 1991-1997.[1]

Planting date	Yield bu/A	Test Weight lb/bu	Date Head fr Jan 1
Winter wheat			
Sept 20-Oct 3	119.3	59.3	159
Oct 8-20	112.9	58.2	165
Oct 22-Nov 8	105.1	57.5	171
Spring wheat			
Oct 22-Nov 8	104.5	59.8	166

[1]All dates were not represented in all years. Data were adjusted for missing years.

$$\frac{\text{Desired seeding rate (lb/acre)}}{\text{(\% germination/100) X (\% seed purity/100)}} = \text{Actual seeding rate (lb/acre)}$$

Example:

$$\frac{\text{Desired seeding rate 50 lb/acre}}{\text{(98\% germination/100) X (99\% seed purity/100)}} = \text{Actual seeding rate (lb/acre)}$$

$$\frac{50}{.98 \times .99} = 51.5 \text{ lb/acre}$$

waiting until spring to seed. Additional research data is needed to more fully understand this management alternative.

Seeding Rates

Dryland winter wheat should be seeded at rates of 40 to 70 pounds of pure live seed (PLS) per acre, depending on variety, seed size, soil moisture, and seeding date. This number corresponds to approximately 12 to 22 seeds per square foot. Actual seeding rates on a PLS basis are calculated by dividing the desired seeding rate by the percentage of pure, live seed in a seedlot as determined from standard germination and purity tests.

Seeding rates that are too high result in excessive vegetative growth, which uses valuable soil moisture and reduces grain yields. Seeding rates that are too low produce reduced yields and may result in higher weed pressure due to lack of crop competition.

As seeding rates go from low to very high, grain yields respond by rising rapidly, reaching a plateau over a wide range, then declining slowly. Different yield components are affected as interplant competition increases. When seeding rates are too low, yields are limited by the number of plants per unit area, although most other yield components are at their highest levels. Tillers per plant and yield per tiller interact to cause a broad plateau in grain yield as seeding rates increase. Excessive seeding rates produce excessive vegetative growth, which can use too much water and leave too little for grain production. Interplant competition reduces yields at excessive seeding rates by reducing tiller number and yield per tiller. These factors are more important in dryland than irrigated production due to the limitation of soil moisture.

Environmental resources and cultivar characteristics influence the optimum seeding rate for wheat. Low seeding rates give maximum yields when environmental conditions are most limiting. Favorable environments, especially for moisture, temperature, and nutrients, support higher seeding rates. Generally, early seeding dates can achieve maximum yields with lower seeding rates than later seeding dates. Most often, increasing seeding rates will only partially offset yield reductions due to late seeding.

Seeding Depth

Best germination and emergence of winter wheat occurs from seeding depths of 1 to 1.5 inches. Seeding less deep can be done if soil moisture is adequate at the soil surface and good seed-soil contact can be achieved. The main threat from shallow seeding is that the seed-row may become too dry before the seed can germinate and send roots into deeper moist soil. Planting at deeper depths results in reduced stands, especially from semi-dwarf varieties that have a short coleoptile. Deeper seeding also alters plant morphology and development and results in lower yields. Plants emerging from deeper depths require more water, more time, and face greater risks from soil crusting. Available soil moisture is the single most important factor in determination of proper seeding depth but soil temperature, texture, surface conditions, and variety should also be considered.

Crowns of shallow-seeded plants are more shallow and are able to survive winter conditions better than deeper-seeded plants with deeper crowns. Shallow-seeded plants have a more prostrate growth and more vigorous root development. Plants from deeper plantings generally have reduced tiller numbers, especially the T0 and T1 tillers, compared to plants from shallow plantings. Wheat crops that have been precision-seeded (soil coverage is the same for all seed) give a more uniform emergence, higher yield, and are easier to manage as all plants are at the same stage of development.

Row Spacing and Direction

The type of planting equipment used and consequent row spacing is largely determined by soil moisture, seedbed conditions, and anticipated precipitation potential. Double disk-type openers are most often used when soil moisture is adequate near the soil surface. This type of drill generally has narrower row spacing than hoe-type drills that are commonly used when there is a substantial amount of dry soil at the soil surface. Hoe-type openers are less exact in seed placement but can be used with less seedbed preparation and are effective in moving dry soil to ridges between seed rows to allow seed to be placed into moisture without excessive soil coverage. Double disk drills typically have a range of 6 to 10 inches between rows and hoe-type drills typically have row widths of 10 to 16 inches. Generally, narrower row widths with proper seed placement and depth give higher yields when moisture is adequate. Striving for narrow rows in moisture-stressed environments is generally not practical. Recently, paired-row spacing has become more common. In this system, pairs of rows are spaced close together with wider spacing between pairs of openers. This seeding arrangement is commonly used with heavier no-till drills that also place fertilizer between the narrow pair of openers. In the Pacific Northwest, yields have not shown an increase or decrease from paired-row spacing compared to uniform row spacing as long as plant density, seeding date, variety, fertilizer rate, and access of plant roots to fertilizer are identical.

In some areas, wheat grain yields were higher in east-west rows than in north-south rows. Row orientation perpendicular to prevailing winds might increase harvest index of wheat and decrease stress and wind erosion. Spike density and kernels per spike were also higher in east-west rows. Plants in north-south rows intercept more light and produce more vegetative growth. This may lead to more inefficient water use by the wheat plants.

Seeding Rate Determination

How to accurately determine seeding rates for seeds per square foot, pounds per acre, and seed per linear foot of row.

1. Determine the number of pure live seed per pound of the seedlot by:
   a. Request information from seed dealer.
   b. Count 1000 seeds, weigh them, and convert to pure live seed per pound according to the following formula:

$$\frac{\text{1000 seed}}{\text{weight in grams}} \times \frac{\text{454 grams}}{\text{pound}} \times \frac{\text{\% germination}}{100} \times \frac{\text{\% purity}}{100} = \text{Pure Live Seed/Pound (PLS/P)}$$

Example: 1000 seed weight = 36 grams Germination = 98% Purity = 99%

$$\frac{\text{1000 seed}}{\text{36 grams}} \times \frac{\text{454 grams}}{\text{pound}} \times \frac{98}{100} \times \frac{99}{100} = \text{12235 PLS/P}$$

2. To determine seeding rate, use one of the following formulae:
   a. When you know the number of seed per square foot desired and want to get pounds per acre:

$$\frac{\text{seed}}{\text{sq ft}} \times \frac{\text{43560 sq ft}}{\text{acre}} \times \frac{\text{PLS}}{\text{P}} = \text{pounds per acre}$$

Example:

$$\frac{\text{16 seed}}{\text{sq ft}} \times \frac{\text{43560 sq ft}}{\text{acre}} \times \frac{\text{pound}}{\text{12,000}} = \text{58.1 pounds of seed per acre}$$

   b. If you know the pounds per acre used and want to determine the seed per square foot:

$$\frac{\text{Pounds}}{\text{acre}} \times \frac{\text{PLS}}{\text{P}} \times \frac{\text{acre}}{\text{43560 sq ft}} = \text{seed per square foot}$$

Example:

$$\frac{\text{58 pounds}}{\text{acre}} \times \frac{\text{12,000 seed}}{\text{pound}} \times \frac{\text{acre}}{\text{43560 sq ft}} = \text{16 seeds/sq ft}$$

3. To convert the number of seed per square foot to number of seeds per linear foot based on row width, consult the following table:

Row Width (inches)	Seed per square foot: 5	10	15	20	25	30	35
	Seed per linear foot						
6	3	5	8	10	13	15	18
7	3	6	9	12	15	18	21
8	3	7	10	13	17	20	23
9	4	8	11	15	19	23	26
10	4	8	13	17	21	25	30
12	5	10	15	20	25	30	35
14	6	12	18	23	29	35	41
16	7	13	20	27	33	40	47

4. To determine the pounds per acre when the number of seeds per square foot and seed per pound is known, use the following chart:

Seed/lb	Seed per square foot: 5	10	15	20	25	30	35
10,000	21.8	43.6	65.3	87.1	108.9	130.7	152.5
12,000	18.2	36.3	54.5	72.6	90.8	108.9	127.1
14,000	15.6	31.1	46.7	62.2	77.8	93.3	108.9
16,000	13.6	27.2	40.8	54.5	68.1	81.7	95.3

Nutrient Management for Dryland Wheat Production in Southern Idaho

J.C. Stark, R.L. Mahler, and T.A. Tindall

Introduction

These fertilizer guidelines are based on research data from the University of Idaho and USDA-ARS. The fertilizer rates suggested are designed to produce the yields shown if other factors are not limiting production. Thus, the fertilizer guide assumes good crop management.

Proper soil sampling is essential to accurately estimate fertility requirements of dryland wheat. Soil fertility conditions often differ both within and among production fields. Each soil sample submitted to a soil testing laboratory should consist of subsamples collected from at least 20 individual sites within a representative area to a depth of 24 inches. Collect 20 subsamples from the 0- to 12-inch depth and 20 subsamples from the 12- to 24-inch depth. Subsamples should not be taken from gravelly areas, turn rows, wet spots, and field borders. Thoroughly mix the 20 subsamples from each depth in a clean plastic bucket. Place approximately one pound of soil from each depth into a plastic-lined soil bag and label with grower name, depth, date, and field number before submitting to a testing laboratory.

Nitrogen

Nitrogen (N) is the plant nutrient most often limiting dryland wheat yields in southeastern Idaho. Fertilizer N rates are needed to optimize yield of wheat from available stored soil moisture and expected growing season precipitation. Available soil moisture and previous cropping history should be used to estimate potential yield. The total amount of N required to produce a given potential yield for both spring and winter wheat is presented in Table 1. The total fertilizer needed to produce a crop includes: residual inorganic N (from soil test), mineralizable N, and fertilizer N.

The amount of fertilizer N that should be applied can be determined by subtracting mineralizable N (Table 2) and soil test or inorganic N (Table 3) from the N value obtained from Table 1. Producers need to be aware that nitrogen efficiency for spring wheat in dryland production systems is less than that for winter wheat.

Mineralizable N is the amount of N released by microorganisms from the breakdown of soil organic matter over a growing season. Microorganisms convert organic N (unavailable N) to inorganic N (plant available N) under favorable environmental conditions. The amount of N mineralized during the growing season can be estimated from percent organic matter in the surface 0- to 12-inch depth of soil (Table 2).

Table 1. Total nitrogen needs of winter and spring wheat crops based on potential yield.

	Total N. Needed	
Yield	Winter Wheat*	Spring Wheat**
(bu/A)	(lb N)	
10	27	33
15	41	50
20	54	66
25	68	83
30	81	99
35	95	116
40	108	132
45	122	149
50	135	165
55	149	182
60	162	198
65	176	215
70	189	231

* Based on a requirement of 2.7 lbs N per bushel of winter wheat.

** Based on a requirement of 3.3 lbs N per bushel of spring wheat.

Table 2. Estimated nitrogen contribution to wheat crop from soil organic matter decomposition based on percent organic matter in the surface 0-12 inches.

Soil Organic Matter Content	N Contribution
%	lb/A
<0.5	10
0.5-1.0	15
1.0-1.5	20
1.5-2.0	25
>2.0	30

Residual inorganic nitrate (NO_3^-) and (NH_4^+) can be assessed by soil testing. Soil test NO_3-N and NH_4-N values are typically reported as parts per million (ppm). To convert soil test NO_3-N and NH_4-N values to pounds N/A, add the soil test N value (ppm) for each foot and multiply by 4 as shown in Table 3.

Nitrogen recommendation without a soil test

If no soil test information is available, the long term average wheat yield of a field can be used to estimate fertilizer N requirements of a dryland wheat crop. The approximate amount of fertilizer N to apply can be estimated from Table 4.

Table 4. Estimated amount of N to apply for dryland wheat when soil test is not available.

Yield	N-fertilizer to apply[1] Winter Wheat	Spring Wheat
bu/A	lb/A	
10	0	0
15	0	0
20	0	0
25	10	15
30	20	30
35	35	45
40	50	60
45	65	75
50	80	90
55	95	105
60	110	120

[1] For yield potentials above 60 bu/A add 2.7 lbs of N for every bushel increase in winter wheat and 3.3 lbs N/bu for every bushel increase in spring wheat.

Table 3. Example calculation of residual N from soil test.

Depth	Soil Test NO_3-N	NH_4-N	Total	Multiplier	Total Inorganic N
(inches)	(ppm)	(ppm)	(ppm)	(multiplier)*	(lb/A)
0 to 12	4	1	5	x 4	20
12 to 24	2	1	3	x 4	12
Total	6	2	8	x 4	32

* ppm x 4 = lb/A per foot of soil

Calculation

The amount of fertilizer N required can be determined from three inputs using the following:

1. N needed based on yield potential (Table 1) __________
2. Minus mineralizable N (Table 2) __________
3. Minus soil test N (Table 3) __________
4. Fertilizer N required __________

Example Calculation

Given a yield potential of 40 bu/A for winter wheat, soil organic matter content of 1.4%, and the soil test N values shown in Table 3, the amount of fertilizer N required is calculated as follows:

1. N needed based on yield potential (Table 1) 108 lbs N
2. Minus mineralizable N (Table 2) -20 lbs N
3. Minus soil test N (Table 3) -32 lbs N
4. Fertilizer N required 56 lbs N/A

Grain Protein

Grain protein content can be increased by N fertilizer. Protein response lags behind yield, with yield receiving the initial benefit. If available N levels have met the plant's yield requirements, additional N will be used to increase protein content. If the historical winter wheat grain protein content is less than 12 percent, the crop could probably benefit from additional N fertilizer if soil moisture is adequate for normal yields. An additional 15 to 20 lb N/A could be applied in the spring at tillering, possibly in combination with a herbicide treatment. The probability of a response is reasonably good if the nitrogen content of the leaves is below 3.5 percent and soil moisture is adequate.

Phosphorus

Phosphorus (P) is critical to wheat growth. Wheat will respond to P fertilizer application if soil test P levels are below critical levels. Soil samples should be taken from the 0-12 inch depth. Phosphorus fertilizer rates based on soil test P levels are shown in Table 5.

Some of the most effective methods of P application are to drill-band the fertilizer with the seed, or below seed depth within two to three inches from the seed row at planting. Drill-banding is an efficient application method and may reduce the fertilizer P required compared to broadcasting. If the fertilizer is banded directly with the seed, do not drill-band high rates of P fertilizer materials that contain ammonium, such as 11-52-0, because of potential seedling damage. Generally not more than 20 lb N/A of ammonium-based N fertilizer is suggested when placed with the seed unless soil moisture content is high.

Table 5. Phosphorus fertilizer rates for dryland winter wheat based on soil test P and percent free lime.

Soil Test P[1]	Percent Free Lime[2]		
(0-12 inches)	0	5	10
(ppm P)[1]		($lb/A\ P_2O_5$)[3]	
4	176	216	256
6	144	184	224
8	112	152	192
10	80	120	160
12	48	88	128
14	16	56	96
16	0	24	64
18	0	0	32
20	0	0	0

[1] $NaHCO_3$– extractable P.

[2] Acid equivalent lime.

[3] Based on broadcast P applications.

Potassium

The potassium (K) fertilizer requirement of dryland cereals is relatively low. Since most soils in southern Idaho are relatively high in K, K fertilizer requirements are usually small.

To determine the K status of a soil, samples should be taken in the first foot of soil. Soils testing less than 100 ppm K should receive applications of 80 lb K_2O per acre. If drill-banded directly with the seed, do not exceed 15 to 20 lb per acre.

Sulphur

Sulfur is required in protein formation. Sulfur (S) deficiency appears as a general yellowing of the plant early in the season and looks much like N deficiency.

Most dryland southern Idaho soils should have sufficient levels of S. Where levels of S are less than 10 ppm in the 0- to 12-inch soil depth, 10 to 20 lb per acre of S (as sulfate) should be applied. A useful guide is to apply 1 lb per acre of S for every 10 lb per acre of N applied. Soils likely to respond to S include those fertilized exclusively with fertilizer containing only N, e.g. anhydrous ammonia, urea, or ammonium nitrate.

Micronutrients

Yield responses to iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), and boron (B) are rarely observed on dryland cereals in southern Idaho. Therefore, micronutrient applications are not recommended except where deficiencies are documented with soil and plant tissue tests.

Fertilizer Placement

Pacific Northwest research on conservation tillage has shown that deep fertilizer banding below seeding depth and below or near the seed rows for early root access often increases cereal yield potential. Some advantages include: increased early plant vigor for more competitive crops; lower populations of grass weeds, such as wild oat and downy brome; an improved ability of the crop to compete with weeds; less nutrient tie-up from microbial decomposition of residue; increased winterhardiness of fall-seeded crops; and higher fertilizer use efficiency. This fertilizer placement research has greatly influenced the design of no-till and minimum tillage drills and fertilizer applicators in the region.

Research on patterns of cereal root development has played an important role in fertilizer placement strategies in conservation tillage. Cereals have two types of roots: seminal roots originating at the seed, and crown or nodal roots originating at the base of the crown. As tillers emerge, corresponding crown roots develop. Until the cereal plant has four leaves and one tiller, it is entirely supported by the seminal root system. Plant stress from low nutrient availability, root disease, or other environmental factors as early as the two-leaf stage can result in the skipping or abortion of the first tillers, which are the highest grain-producing tillers. Consequently, fertilizer placement below seeding depth and near the seed row for early seminal root access can often be important in conservation tillage, which is often a more stressful seedling environment than conventional tillage.

Fertilizer placement for early root access is a good production practice, although crop response to different fertilizer placement options is influenced by crop rotation, which affects root disease potential and other pest problems. Fertilizer placement below or near the seed row and below seeding depth has been shown to reduce root disease effects when cereals are planted after cereals. Conversely, fertilizer placement is less important when cereals are planted after non-cereals.

Yield-Water Relationships of Winter Wheat

R.O. Ashley, L. Robertson, and S. Gortsema

Introduction

In general, water is the most limiting factor in dryland wheat production in southeastern Idaho. Important decisions such as plant populations, fertilizer rates, and several other inputs must be made with respect to the amount of water that is available and expected to be available during the growing season. The producer who understands the yield-water relationships and recognizes conditions that support high yield will be able to capitalize on these good growing conditions. On the other hand, when less than favorable growing conditions are present, the same producer will be able to avoid over-use of expensive inputs.

Estimating Yield Goals

Several methods of estimating or setting a yield goal have been used by producers. These methods rely primarily on past production history as a basis for setting yield goals. During years with below-normal precipitation, average levels of some inputs such as nitrogen fertilizer will exceed crop requirements. During years with above-normal precipitation, average nitrogen applications will fall short of what the crop requires to meet full potential. Both quantity and quality of winter wheat produced will be affected if production inputs are not used in accordance with currently available soil moisture and expected precipitation. Under-application of nitrogen fertilizer in relationship to available water will result in reduced yield and low protein. Low protein values may result in discounts when grain is marketed.

Yield goal approaches suggested in publications by various agronomists:

- 5- or 6-year average.
- 5-year average + 5%.
- Historical yield + 10%.
- 3- to 5-year average + 10%-20%.
- Set yield goal so that goal is attained or exceeded one year in five.
- Average yield + 1 standard deviation. Set level so that goal is attained or exceeded only one year in six.
- 5-year average + 10 bushels per acre.

Source: Jenny, R. 1992.

Estimating Yields Using Stored Soil Water and Growing Season Precipitation

Levels of stored soil water and growing season precipitation can be used to predict winter wheat yields. This approach uses the stored soil water to a depth of the effective root zone and expected precipitation during the crop's growing season. Then, the available water is substituted into the proper equation to estimate yield. Expected yield can be further adjusted during the growing season by estimating the water use of winter wheat in relation to plant development stage. This method requires knowledge of water use, rooting depth, water-holding capacity of the soil, and times and amounts of precipitation, as well as periodic soil moisture measurements.

In using this method, an estimate of stored soil water is made in April, soon after the snow has melted, the ground has thawed, and crop dormancy has broken. A yield can then be calculated by substituting the expected available water (soil moisture plus expected growing season precipitation) into the appropriate equation, either the hard red winter wheat yield equation or the soft white winter wheat equation.

Water-Use Efficiency

Water-use efficiency is affected by a number of factors. These factors include fertility levels, disease, growing season temperatures, variety, elevation, and timeliness of precipitation. Well-adapted winter wheat varieties with adequate fertility levels and few disease and physiological problems will be more efficient in using water to produce grain than a poorly adapted variety grown under poor fertility and disease management practices.

The influence of stored soil water and seasonal precipitation on hard red winter wheat and soft white winter wheat yields based on field observations across dryland areas of southeast Idaho from 1991 through 1996 are plotted in Figures 1 and 2. Stored soil moisture was estimated in April using the Brown soil moisture probe. Rainfall was measured and recorded by participating producers shortly after precipitation events. Both stored soil water and precipitation were considered to be of equal value in this procedure. Crops were considered to be physiologically mature 14 days prior to harvest. Precipitation events occurring after physiological maturity were discounted.

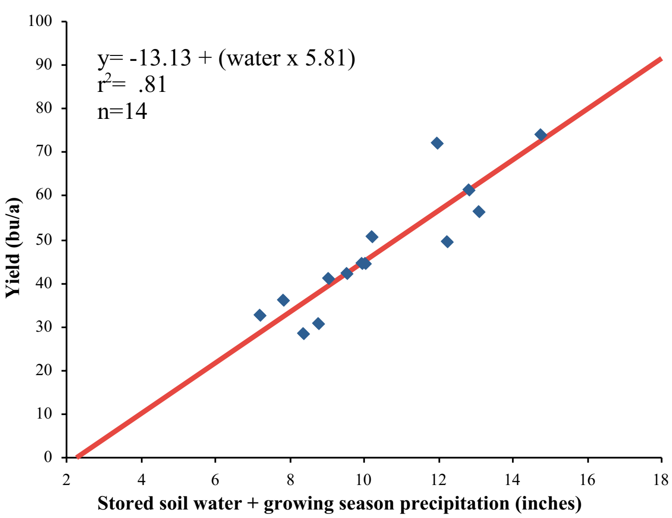

Figure 1. Water-use efficiency of hard red winter wheat for southeast Idaho, 1991 - 1996.

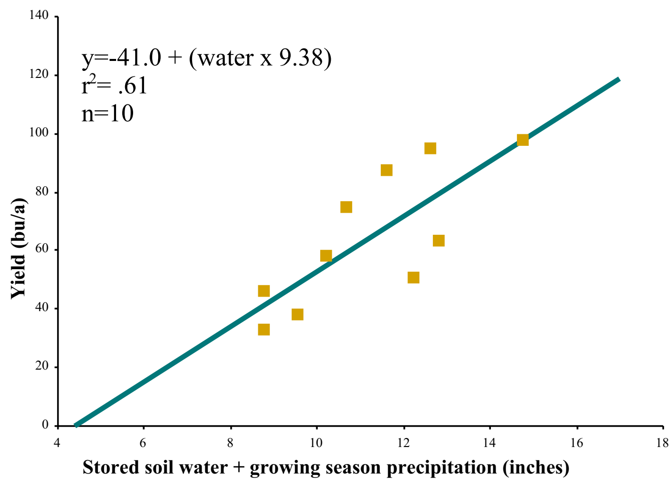

Figure 2. Water-use efficiency of soft white winter wheat for southeast Idaho, 1991 - 1996.

Water-Use in Relation to Plant Development Stage of Winter Wheat

The relationship of evapotranspiration to plant development stage is curvilinear for winter wheat (Figure 3). Water use for winter wheat from emergence to Haun stage 5 is about two inches. After Haun stage 5, water use is essentially linear, with an average rate of about one inch per plant development stage until kernel hard stage (Haun stage 15). Water use up to the heading stage is about 6.7 inches for winter wheat under dryland conditions. This amount is less than 50 percent of the total water use to kernel hard stage.

Root growth in winter wheat will average about 0.9 inches per day, assuming onset of downward penetration begins with "spring green-up." Winter wheat can extract water from a depth of four feet during the heading stage and from 4- to 5-foot depths during grain filling. However, estimation of yield potential shortly after dormancy break should not be made on stored soil moisture that exists much deeper than 3 to 3.5 feet. Crown derived roots do not penetrate or extract water much deeper than about three feet. Water extraction from greater depths is a function of the seminal root system. Seasonal precipitation patterns will influence root water extraction depth.

It is important to recognize that this information is applicable to deep, well-drained soils. Soil barriers, either physical or chemical, can prevent root penetration. Water content itself, either excess or deficient, can be a barrier to root penetration on deep, well-drained soils.

Information on rate of root penetration and plant development stage relative to rooting depth has useful implications for fertilizer N management decisions. It is not unusual, for example, to have a relatively large quantity of nitrate-nitrogen in fields at depths greater than two feet. Fertilizer needs can be readily determined with information available about plant N content needs at a given plant development stage, the quantity of available soil N at given depths, and root penetration.

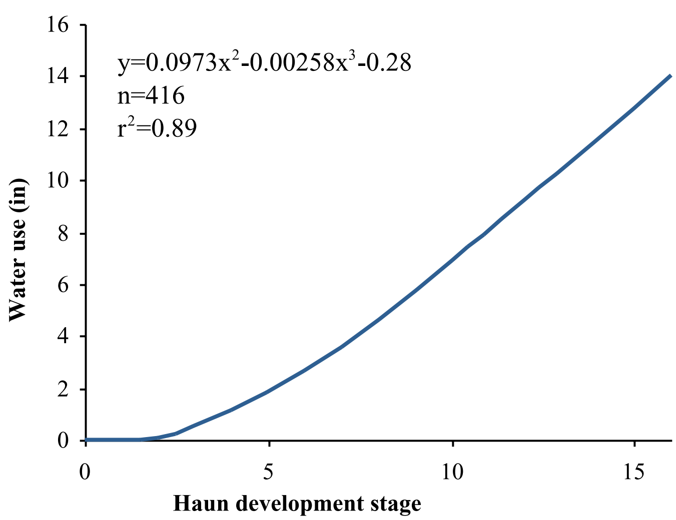

Figure 3. Water use by evapotranspiration from winter wheat in relation to plant development stage, Mandan, North Dakota, 1983-1986.

(Modified from A. Bauer, A.L. Black, and A.B. Frank, 1989)

Estimating Yield Potential Based on Stored Soil Water and Expected Precipitation

Estimating yield potential based on stored soil water and expected precipitation provides producers opportunities to adjust inputs such as fertilizer to more closely match the need for this input. In years with high yield potential, producers should apply additional nitrogen. In years with low yield potential, less fertilizer is needed.

Effective crop-rooting depth, water-holding capacity, and available water

While winter wheat has the capability of extracting water from depths of five to six feet, the majority of water is drawn from the first 3 to 3.5 feet of the root zone. Dry soil layers commonly found in dryland conditions will limit root development. Plant roots cannot grow through dry soil layers; therefore, producers should only consider moisture from the surface to the dry layer, unless precipitation eliminates this restriction. Total depth of the effective root zone for dryland winter wheat may also be restricted by other physical or chemical factors such as water saturated or compacted soils and salt or sodic soils. The maximum depth for using water to estimate wheat yield is 3.5 feet. If one of the restrictions mentioned above is found at a shallower depth, then the maximum rooting depth should be at the depth that the restriction is found.

Water is held in soil as a film around soil particles and in spaces between soil particles and aggregates. The amount of water held in soils is dependent upon several factors, but texture has the greatest influence. Water-holding capacity is greatest in medium-textured soils (silt loam) and least in coarse-textured soils (sand). Soils have a limited capacity to hold water against gravity. This limit is referred to as field capacity. Water in excess of field capacity is subject to drainage or removal by gravity. Under dryland conditions, precipitation will wet the surface of the soil. As soil near the surface approaches field capacity, moisture moves to lower depths where soil water is generally at less than field capacity. This wetting front moves through the soil until all soil between the surface and the lower limits of the wetting front are at field capacity.

Stored soil moisture can be estimated using a soil moisture probe because of the way the wetting front moves through the soil. Soil holding water near field capacity becomes "plastic," that is, it will flow around the probe easily as it is pushed into the ground. When the probe encounters dry soil, the probe will no longer penetrate the soil. The probe's penetration can also be stopped by rock, gravel, and frozen soil. A minimum of ten areas in a quarter section should be tested to determine the average depth of moist soil.

Soil texture should be determined at the time of probing for soil moisture. Water holding capacities for various soil texture classifications and soil series can be obtained from county soil surveys available from the local Natural Resource Conservation Service and Soil Conservation Districts. Older soil surveys may not list water-holding capacity, but soil texture information will be available that can be used to estimate water-holding capacity. Once soil textures and probe depths are determined, water-holding

Table 1. Water-holding capacity for various textural classes of soils (to be used when soil series is unknown).

Soil Texture Class	Water Holding Capacity (inches/inch)	Water Holding Capacity (inches/ft)
Sand	0.04	0.43
Loamy sand	0.08	0.94
Sandy loam	0.14	1.67
Sandy clay loam	0.14	1.67
Loam	0.17	2.10
Silt loam	0.20	2.44
Silt	0.18	2.12
Clay loam	0.16-0.18	2.0-2.16
Silt clay loam	0.18	2.16
Silt clay	0.17	2.04
Clay	0.16	1.94

Source: R.E. McDole, G.M. McMaster, and D.C. Larson. 1974.

capacities can be estimated from Table 1. Texture values can be recorded just once for each field.

Stored soil water can then be determined by multiplying the inches of water-holding capacity per inch by the depth in inches that the Brown probe was pushed into the soil. This provides the total amount of stored soil water that the producer has to work with at the beginning of the growing season.

Sometimes more than one soil type is present in a field. If each soil type occupies a significant portion of the field, adjustments in yield levels for the field should be made. Making these adjustments will become easier with the adoption of site-specific management practices now in development.

Expected Precipitation

In any one particular year, the quantity of water received from precipitation through the growing season is seldom average. Knowledge of the probabilities of receiving specific amounts during the growing season can help producers make cropping decisions. Annual precipitation probabilities are given in Table 2. Table 3 shows the amount of precipitation that can be expected during the normal period for winter wheat growth and development from April 1 through the end of July for 24 locations in southeast Idaho.

Producers should select a probability level of receiving precipitation during the growing season for winter wheat. Many producers select the 70 percent probability for a given field location. This can be determined for specific field locations from Table 3. Once this value is determined, the value can be added to the soil moisture to arrive at the total expected water availability.

Summary

Producers who will take the effort to monitor soil moisture and use seasonal rainfall probabilities have a much greater chance of matching production inputs with yields. Savings in unneeded inputs in low yielding years and increases in yield in higher yielding years will be obtained by following the steps in this section. The production goal should be to manage purchased inputs in accordance with the yield potential given by available soil moisture and soil capability.

Table 2. Amount of annual precipitation exceeded for a given probability by weather station.

STATION	Years	Mean	Probability (%)									
			5%	10%	20%	30%	40%	50%	60%	70%	80%	90%
			Inches									
American Falls 1 Sw	29	11.85	20.73	18.29	15.60	13.83	12.43	11.20	10.06	8.93	7.72	6.24
Arbon 2 Nw	29	16.11	25.61	23.10	20.28	18.40	16.89	15.55	14.28	13.00	11.61	9.86
Ashton	30	20.27	30.05	27.53	24.68	22.74	21.17	19.77	18.44	17.07	15.57	13.63
Blackfoot 2 Ssw	30	9.22	17.86	15.39	12.71	10.98	9.63	8.47	7.41	6.38	5.30	4.03
Driggs	28	15.94	23.29	21.41	19.27	17.82	16.64	15.58	14.57	13.54	12.40	10.92
Dubois Exp. Sta	30	12.79	17.82	16.56	15.11	14.12	13.31	12.58	11.88	11.15	10.35	9.29
Grace	30	15.44	23.64	21.51	19.10	17.47	16.16	14.99	13.88	12.76	11.53	9.95
Hamer 4 Nw	29	9.35	13.53	12.47	11.25	10.42	9.75	9.15	8.57	7.98	7.33	6.48
Henry	17	17.39	28.66	25.64	22.28	20.03	18.24	16.66	15.18	13.70	12.09	10.08
Idaho Falls 2 Ese	29	11.16	19.00	16.88	14.51	12.95	11.71	10.62	9.60	8.59	7.50	6.15
Idaho Falls 16 Se	30	15.95	21.71	20.27	18.63	17.49	16.56	15.72	14.91	14.08	13.14	11.91
Idaho Falls Faa Ap	30	10.85	15.30	14.18	12.90	12.02	11.30	10.66	10.04	9.40	8.70	7.78
Lifton Pumping Sta	30	10.81	17.24	15.54	13.63	12.36	11.33	10.42	9.57	8.70	7.76	6.58
Malad City	29	14.28	22.01	20.00	17.72	16.19	14.95	13.85	12.81	11.76	10.60	9.12
Massacre Rock St Pk	18	11.67	17.91	16.28	14.45	13.21	12.21	11.32	10.48	9.63	8.69	7.50
Montpelier R S	30	14.59	20.85	19.27	17.45	16.22	15.21	14.31	13.44	12.55	11.56	10.28
Palisades	30	19.97	28.39	26.26	23.83	22.17	20.81	19.59	18.42	17.23	15.89	14.16
Pocatello Wso Ap	30	12.12	18.11	16.57	14.82	13.63	12.67	11.81	10.99	10.16	9.25	8.07
Preston-Kach	22	13.28	26.38	22.60	18.50	15.87	13.83	12.08	10.49	8.96	7.36	5.50
Rexburg Ricks College	14	13.38	21.66	19.46	16.99	15.35	14.03	12.87	11.77	10.67	9.47	7.97
St Anthony 1 Wnw	30	12.83	22.79	20.04	17.01	15.02	13.45	12.08	10.81	9.55	8.21	6.58
Soda Springs Ap	12	14.23	25.68	22.50	19.00	16.71	14.91	13.35	11.89	10.47	8.95	7.10
Swan Valley 2 E	29	16.56	23.41	21.68	19.70	18.35	17.25	16.26	15.31	14.33	13.24	11.83
Tetonia Exp. Sta	30	16.61	22.43	20.99	19.33	18.18	17.24	16.39	15.57	14.72	13.77	12.52

Source: Myron Molnau, State Climatologist, Dept of Ag Engineering, University of Idaho, Moscow, ID.

Table 3. Amount of annual precipitation exceeded for a given probability for April 1 through July 31 by weather station.

STATION	Years	Mean	Probability (%) 5%	10%	20%	30%	40%	50%	60%	70%	80%	90%
			Inches									
American Falls 1 Sw	29	4.33	8.03	6.99	5.85	5.11	4.53	4.03	3.57	3.11	2.63	2.06
Arbon 2 Nw	29	5.59	10.58	9.17	7.63	6.62	5.84	5.17	4.55	3.94	3.31	2.55
Ashton	30	6.58	11.29	10.01	8.59	7.65	6.90	6.25	5.64	5.04	4.39	3.58
Blackfoot 2 Ssw	30	3.43	8.93	7.15	5.31	4.19	3.37	2.71	2.14	1.63	1.15	0.67
Driggs	28	6.37	10.65	9.49	8.21	7.36	6.68	6.08	5.52	4.96	4.36	3.61
Dubois Exp. Sta	30	5.62	10.31	9.00	7.56	6.63	5.89	5.25	4.66	4.08	3.47	2.73
Grace	30	5.82	10.15	8.96	7.65	6.78	6.10	5.50	4.94	4.39	3.80	3.07
Hamer 4 Nw	29	4.22	7.18	6.38	5.49	4.90	4.43	4.02	3.64	3.25	2.84	2.33
Henry	17	6.26	10.83	9.58	8.20	7.29	6.56	5.93	5.34	4.76	4.13	3.36
Idaho Falls 2 Ese	29	4.48	7.87	6.94	5.91	5.23	4.69	4.23	3.79	3.36	2.90	2.34
Idaho Falls 16 Se	30	5.55	8.80	7.94	6.98	6.34	5.82	5.36	4.93	4.49	4.01	3.41
Idaho Falls Faa Ap	30	4.25	7.22	6.41	5.52	4.93	4.46	4.04	3.66	3.27	2.86	2.35
Lifton Pumping Sta	30	4.22	7.48	6.58	5.59	4.94	4.43	3.98	3.56	3.15	2.71	2.18
Malad City	29	5.65	9.52	8.47	7.31	6.54	5.93	5.39	4.89	4.38	3.84	3.17
Massacre Rock St Pk	18	4.24	7.58	6.65	5.64	4.97	4.44	3.98	3.56	3.14	2.69	2.15
Montpelier R S	30	5.09	8.69	7.71	6.63	5.91	5.34	4.84	4.38	3.91	3.42	2.80
Palisades	30	7.13	10.87	9.90	8.80	8.06	7.46	6.93	6.42	5.91	5.34	4.62
Pocatello Wso Ap	30	4.22	7.20	6.39	5.50	4.90	4.43	4.02	3.63	3.24	2.83	2.32
Preston-Kach	22	5.07	10.10	8.64	7.07	6.06	5.28	4.61	4.00	3.41	2.80	2.09
Rexburg Ricks College	14	5.38	9.55	8.40	7.13	6.30	5.64	5.07	4.54	4.01	3.45	2.77
St Anthony 1 Wnw	30	4.78	11.25	9.24	7.14	5.83	4.85	4.04	3.32	2.66	2.01	1.31
Soda Springs Ap	12	6.07	11.73	10.12	8.36	7.23	6.34	5.58	4.89	4.21	3.50	2.67
Swan Valley 2 E	29	6.58	10.50	9.47	8.30	7.52	6.90	6.35	5.82	5.30	4.73	4.00
Tetonia Exp. Sta	30	6.69	10.81	9.72	8.49	7.67	7.02	6.44	5.89	5.34	4.75	4.00

Source: Myron Molnau, State Climatologist, Dept of Ag Engineering, University of Idaho, Moscow, ID.

Lodging

S.O. Guy and B.D. Brown

Lodging in winter wheat may cause serious losses in productivity, grain quality, and harvest efficiency (Fig. 1). Lodging increases at higher production levels. Winter wheat lodging can be physiological (inadequate straw strength) or due to *Pseudocercosporella* foot rot. Lodging can be reduced with many management practices.

Losses Due to Lodging

Reductions in winter wheat grain yield and quality due to lodging depend on lodging extent, timing, and severity. The earlier lodging occurs, the greater the potential for damage. Early lodging can trap moisture in the plant canopy that can increase foliar disease. Early lodging also allows weeds more competitive space in the interrupted crop canopy. The greatest losses with early lodging are due to decreased photosynthesis prior to physiological maturity and decreased grain filling in the matted plants. Lower test weights due to poorly filled grain can reduce market grade and price.

Additional crop loss from both early and later lodging comes from delayed drying and increased losses associated with crop harvest. Harvest losses include the inability to pick up or recover all the grain from the matted wheat. More grain is lost during threshing because more and often wetter plant material is picked up and processed by the combine.

When the crop is lodged but physiologically mature, moisture from rain or dew stays on the grain longer and increases the potential for grain sprout, mold, and kernel discoloration (Figure 1). Lodging negatively impacts wheat quality, possibly impacting market price, due to decreased grain test weight, sprout, and mold. Increased moisture can delay harvest and increase the risk of losing grain from hail or sprout resulting from rain at harvest.

Harvesting lodged grain results in increased harvest costs due to slower harvest speed, increased combine wear, and greater fuel and labor costs. Higher dockage due to less efficient grain cleaning in the combine can lower the market price for growers.

Winter wheat grain yield losses exceeded 30 percent when high N fertilizer rates induced extensive lodging in a 1985 study (Table 1). Combining high seeding rate with high N applications increased lodging and reduced yields. Lodging was less severe and yields were higher with a lower seeding rate. This study shows that many management factors can contribute to lodging and lodging yield loss.

Figure 1. *Winter wheat showing severe lodging before harvest, which can increase harvest losses, increase harvest costs, and delay grain drying.*

Lodging Contributing Factors

Lodging occurs when the plant stem is unable to support its own weight. Winter wheat varieties vary greatly in lodging susceptibility due to differences in straw strength, plant height, and head size. Susceptibility to lodging limits the ability of a variety to utilize or respond to management factors such as fertility and irrigation. Lodging susceptibility can be an important variety selection criterion, especially in high yielding environments. Lodging ratings are presented in the variety section in this report.

Pseudocercosporella foot rot causes lodging because the "eyespot" lesions on the base of the stem weaken the supportive tissue, which can cause the stem to collapse and fall over. This type of lodging creates a disorganized appearance, with affected plants falling in many tangled directions. Disease-caused lodging creates a mat that is very close to the ground from which the plants cannot straighten.

Table 1. Impact of fertilizer level and seeding rate on lodging and yield in winter wheat.

Fertilizer treatment (lb/a)			Seeding rate (lb/a)			
N	P_2O_5	K_2O	60	60	120	120
			Ldg[1]	Yld[2]	Ldg[1]	Yld[2]
100	0	0	0	133	0	133
200	0	0	8	127	25	114
300	0	0	57	103	88	86
300	180	0	64	102	90	91
300	180	90	70	100	91	92

Ldg $LSD_{.10}$= 9, Yld $LSD_{.10}$= 4

[1]Ldg=% lodged area

[2]Yld=grain yield (bu/a)

Physiological lodging tends to be more orderly, with plants lodging or leaning in one direction and usually not bending over as near to the ground as with foot rot lodging. The upper stems and heads of lodged wheat can become more upright after physiological lodging if plant stems are not broken. High levels of soil nitrogen and other nutrients can make winter wheat more prone to physiological lodging by inducing more fine-stemmed tillers, taller growth, more grain, and reduced straw strength (see Table 1). Excessive available N early in the season promotes vegetative growth and increases lodging potential. High seeding rates can also increase lodging potential because crowded plants produce more fine-stemmed tillers and taller growth (see Table 1). Improper irrigation timing can cause lodging, especially when plants are past the soft dough stage. Lodging often occurs when sprinkler irrigation or rainfall adds additional weight to the plants and wind then bends the plants over. Severe weather, such as a thunderstorm, can cause lodging even under the best crop management conditions.

Lodging Control

Several crop management practices can reduce lodging of winter wheat:

1. Select varieties with better resistance to lodging as long as yield potential and quality are not sacrificed. See variety section.

2. Apply nitrogen at recommended rates and intervals to avoid excessive vegetative growth. See fertility section.

3. Avoid excessive seeding rates that result in weakened stems.

4. Control *Pseudocercosporella* foot rot by crop rotation (two years between winter wheat crops), later fall planting (after October 1 in northern Idaho), choosing a resistant variety (Madsen, Hyak), low to moderate fall N fertilizer application (less than 50 lb/a), and avoiding acidic soils (<6.0 pH).

Plant Growth Regulator Application

Despite best efforts to manage productivity factors, lodging can occur, especially under high yield conditions. The plant growth regulator Cerone® is currently registered for application to irrigated wheat in Idaho and should be considered for use when lodging has been a problem in the past and is anticipated in the current crop. Cerone® has proven to be effective in reducing the severity of lodging and resulting yield loss.

Cerone® contains ethephon that breaks down within the plants to ethylene, a naturally occurring hormone produced by plants in all stages of growth. The high level of ethylene in the plant due to Cerone® application reduces stem elongation, leading to stronger plant stems. Cerone® shortens the last two or three internodes, particularly the peduncle (see Figure 2). A shortened, stiffened peduncle will reduce the tendency for wheat to lodge, thus reducing the potential loss of grain yield and quality.

Proper application of Cerone® is critical to effectiveness. Cerone® is registered for application to irrigated wheat in southern Idaho. ***Always read and follow instructions on the label when using a registered material for wheat production.*** Cerone® should be applied at 0.25 to 0.50 lbs of active ingredient (ai) per acre (8-16 oz/ac) using at least seven gallons of water per acre. Use the 0.25 lb ai/ac Cerone® rate for moderate expected lodging, 0.38 lb ai/ac for heavy expected lodging, and up to 0.5 lb ai/ac for severe lodging situations. Apply Cerone® while the wheat crop is in the flag leaf to boot stage but prior to awns appearing, or Zadock's growth stage 37 to 45 (see growth and development section). Applications of Cerone® at other than the proper growth stage or rate can reduce yield. Exposing wheat heads to Cerone® spray solution could result in flower sterility.

Application should be made to healthy plants when rain or irrigation is not expected for six hours.Most plants respond to treatment in the following seven to ten days. Treatment typically results in a wheat crop 3 to 5 inches shorter at maturity (Fig. 2).Cerone® application will not eliminate lodging under adverse growing conditions but should reduce the extent and severity of lodging when it does occur. Preventing a small loss in yield or quality could easily pay for the Cerone® application when lodging has been a problem in the past and is anticipated in the current crop.

Further Reading

See disease section and Chap. 4, No. 17 in the PNW Conservation Tillage Handbook Series, September 1993.

Figure 2. *Treatment with Cerone® (left field) produces shorter, stronger straw compared to the control (right field).*

Weed Control in Dryland Winter Wheat

D.W. Morishita and D.C. Thill

Weed control is an integral part of producing a successful winter wheat crop. In winter wheat, downy brome or cheatgrass (*Bromus tectorum*), wild oat (*Avena fatua*), and Italian ryegrass (*Lolium multiforum*) are some of the most troublesome grass weeds. Of the annual broadleaf weeds, flixweed (*Descurainia sophia*), tumble mustard (*Sysimbrium altissimum*), shepherd's-purse (*Capsella bursa-pastoris*), Russian thistle (*Salsola kali*), and kochia (*Kochia scoparia*) are among the most common broadleaf annuals. Perennial weeds such as Canada thistle (*Cirsium arvense*), field bindweed (*Convolvulus arvensis*), and quackgrass (*Elytrigia repens*) also are problems in many winter wheat fields.

The most successful weed control is accomplished by utilizing as many weed management practices as possible. An integrated approach to weed management includes preventive, cultural, mechanical, chemical, and biological weed control. Relying on only one method of weed control increases the chance of failure.

Preventive weed control

Preventive methods include sanitizing tillage and harvesting equipment, controlling weeds in rotation crops and field borders, spot treating new infestations, and planting clean seed. Many new infestations begin along field borders, especially those adjacent to field entrances and public roadsides. The importance of purchasing clean seed for planting was demonstrated in a University of Idaho cereal drillbox survey conducted in 1983 (see University of Idaho CIS 767, *Weed Seed Contamination of Cereal Grain Seedlots—A Drillbox Survey*) and in a survey conducted by Utah State University in 1988 (see Table 1). The Utah survey shows an overall decline in weed seed found in grain drillboxes from 1958 to 1988, but detected the presence of jointed goatgrass (*Aegilops cylindrica*) in the 1988 survey.

Cultural and mechanical weed control

Cultural practices can be the least expensive method of weed management but can mean the difference between success or failure in a weed management program.

Table 1. Percent of drillboxes contaminated with weed seed in Utah small grain drillbox surveys from 1958 to 1988.

Sample	1958	1968	1978	1988
All weeds	52	39	37	31
Noxious weeds	40	25	26	17
Wild oat	36	23	24	14
Quackgrass	3	0	4	4
Field bindweed	5	5	5	3
Jointed goatgrass	0	0	0	6

Source: S.A. Dewey and R.E. Whitesides, Utah State University.

Well-adapted disease resistant varieties planted at the proper time and seeding rate with adequate soil moisture and fertility will aggressively compete with many weed species. Wheat plants that emerge before weeds capture more water, nutrients, and light, which helps to make the crop more competitive against the weeds.

Rotating winter wheat with a spring crop is an important cultural practice because it helps prevent the invasion of winter annual weeds. Differences in tillage, planting time, length of growing season, and type of herbicide used for different crops disrupt weed life cycles or destroy weed seed in the soil. Cultural weed control is essentially a manipulation of the relationship between the crop and the weed to favor the crop at the expense of the weed.

Tillage is important not only from the standpoint of preparing a seedbed for planting, but also as an important weed control practice. The longer the delay between the last tillage operation and planting, the greater the opportunity for weeds to germinate and emerge before the wheat. This gives weeds an advantage over the crop because of space capture (light, water, and nutrients). Thus,

Figure 1. *Flixweed at 2.75 inches in diameter. This is a winter annual that is often confused with tansy mustard. These two weeds are very similar in appearance and are controlled by the same herbicides.*

tillage at or just prior to planting will destroy germinating or emerged weeds and help give wheat the competitive advantage.

Mechanical weed control in dryland wheat production has declined over the years because of a greater awareness of soil conservation benefits from reduced (minimum) or no-tillage practices. Drawbacks to excessive tillage include increased soil erosion potential, soil compaction, and increased production costs. Mechanical weed control is effective on annual and biennial weeds, but is generally ineffective on perennials unless the soil is tilled frequently over a long period of time. Where tillage cannot be used for weed control, other weed management practices must be utilized.

Biological weed control

Currently, there are no biological agents being used for weed control in winter wheat production. Research is underway to investigate the possibility of bacterial strains that may selectively control downy brome and jointed goatgrass in winter wheat. It is unlikely that biological weed control will ever be the complete solution to weed control, but it could potentially be used as one component of an integrated weed management program.

Chemical weed control

Herbicides are, by far, the most widely used method of weed control for most winter wheat producers. Chemical weed control in conjunction with other weed control strategies is essential to insure optimal herbicide performance.

Weed identification Correct identification of weed species is necessary for proper herbicide selection, application rates, and timing. Weeds are most difficult to identify in the seedling stage when herbicides are most effective.

Figure 2. *Kochia at 0.5 inches in diameter. An annual broadleaf that can be very competitive, especially under dry conditions.*

Figure 3. *Russian thistle at 1.5 inches tall. An annual broadleaf with very narrow leaves in the seedling stage.*

University of Idaho Extension educators, weed scientists, and industry crop advisors can help identify weed seedlings. Pictures of some common weed seedlings found in dryland winter wheat fields are shown in Figures 1 through 6.

Variety-herbicide interactions Winter wheat cultivars are tolerant but not resistant to registered winter wheat herbicides. Tolerance is the degree to which plants are undamaged by an applied herbicide at the labeled rate. Tolerance to herbicides registered for use on winter wheat may vary among winter wheat cultivars, and also may be affected by environmental conditions. Known winter wheat varieties that are susceptible to injury from registered wheat herbicides usually are listed on the herbicide label. However, not all varieties are tested for sensitivity to all herbicides. If a variety is not listed for use on the herbicide label, contact the herbicide manufacturer's representative or other expert before treating an unlisted variety. Never treat susceptible varieties listed on the her-

Figure 4. *Wild oat at the two-leaf stage (2 inches tall). An early emerging annual weed. Note the hairs on the leaf margins and counter-clockwise twist to the leaves. Wheat leaves twist clockwise.*

Figure 5. *Downy brome at the one-leaf stage (2 inches tall). A winter annual grass, also called cheatgrass and June grass. Note the fine hairs on the leaf and stem.*

bicide label. Always read and follow instructions on the label when using a registered herbicide for winter wheat production.

Herbicide rotation restrictions Always read and study crop rotation restrictions on herbicide labels. Some herbicides can persist in the soil and injure subsequent rotation crops. Herbicide persistence is related to soil characteristics such as soil texture, pH, moisture, temperature, and cation exchange capacity. The herbicide application rate and interval between crops also influence crop injury from herbicide carryover.

Herbicide selection This publication makes no herbicide recommendations as herbicide registrations and permissible herbicide practices change frequently. For specific herbicide recommendations, refer to the current year's Pacific Northwest Weed Management Handbook. It is revised and published annually by the extension systems of the University of Idaho, Washington State University, and Oregon State University. This publication can be found on-line at http://weeds.ippl.orst.edu/pnw/weeds.

Remember, it is critical to correctly identify seedling weeds in order to select the appropriate herbicide(s) for application at the proper rate and time. Perennial weeds generally require repeated herbicide applications or other repeated weed control measures for long-term control.

Herbicide-resistant weeds Herbicide resistance is the ability of a weed biotype to survive a herbicide treatment at rates many times higher than the rate needed to control the original population. This is a relatively new problem compared to chemically resistant insects and pathogens. However, more than 165 different herbicide-resistant weed species have been identified. Also, the occurrence of herbicide-resistant weeds has been reported for eighteen families or classes of herbicides. Triazines and sulfonylureas are examples of herbicide families.

It is commonly believed that herbicide-resistant weeds exist naturally in plant populations at extremely small numbers (less than one in a million). The repeated use of the same herbicide or herbicides with the same mode of action (herbicides that kill weeds the same way) allows these few plants to survive and reproduce. The number of resistant plants then increases in the population until the herbicide no longer effectively controls the weeds. Several herbicide resistant weeds can be found in Idaho wheat fields, including kochia, wild oat, prickly lettuce, and Russian thistle. Recommendations for herbicide-resistant weed management include crop rotation, using herbicides with different modes of action, using short residual herbicides, and using integrated weed management practices. Extension publication PNW 437 *Herbicide-Resistant Weeds and Their Management* provides additional information on herbicide-resistant weeds, their management, and an explanation of the various herbicide families and their mode of action.

Figure 6. *Field bindweed seedling 2 inches in diameter. A perennial, this plant can emerge from root segments.*

Insect Pests of Fall Seeded Wheat in Southern Idaho

J.M. Alvarez, L. E. Sandvol, and R. L. Stoltz

Fall Pests

Three species of aphids comprise the key insect pests of fall-seeded wheat in southern Idaho. These are Russian wheat aphids, greenbugs, and bird cherry oat aphids. Occasionally other insects, such as grasshoppers, cutworms, or wireworms, may cause economic damage.

Because insecticide registrations change frequently, resulting in more or fewer available insecticides and changes in permissible insecticide practices, this publication makes no specific insecticide recommendations. For current recommendations, refer to the Pacific Northwest Insect Management Handbook (http://pnwpest.org/pnw/insects), published and revised annually by the extension services of the University of Idaho, Washington State University, and Oregon State University. Always read and follow instructions on the label when using a registered pesticide for winter wheat production.

Jack Kelly Clark, UC Statewide IPM Program, www.ipm.ucdavis.edu

Figure 1. *Russian wheat aphids in the form of wingless nymphs.*

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Figure 2. *Russian wheat aphids in the form of winged adults.*

Russian wheat aphids

Russian wheat aphids (*Diuraphis noxia*) are light green, spindle-shaped aphids found inside rolled leaves (Figs. 1 and 2). Cornicles are very short and not noticeable. Antennae are short compared with those of most other aphid species. A projection above the tail gives Russian wheat aphids a two-tailed appearance. Hosts for Russian wheat aphids include wheat, barley, triticale, and several grass species.

Aphid feeding prevents young leaves from unrolling. Large numbers of aphids are produced inside rolled leaves. Insecticide coverage is difficult because of this behavior. The rolling also interferes with the potential effect of natural enemies such as predators and parasitoids. Aphids se-

Figure 3. *Russian wheat aphid damage causes light-colored streaks on leaves. Leaves often take on an onion leaf (rolled) appearance which may cause head distortion as the heads emerge from the leaf sheaths.*

crete a toxin that causes white or purple streaks on the leaves (Fig. 3). Purple discoloration is more common in cool weather, while white streaks and leaf rolling are prominent in warm weather. Heads of infested plants may become twisted and distorted or may not emerge. Heavy infestations may cause severe yield losses due to aphid feeding and toxic secretions. Russian wheat aphids do not transmit viruses.

Unlike other aphids found on wheat, the Russian wheat aphid has a simple life cycle. No males or overwintering egg stage can be found in the U.S. As long as temperatures remain above 60°F, females continue to give birth to living young. As colonies become crowded or the host plant matures, winged forms are produced that move to other hosts. Russian wheat aphids overwinter as live aphids sequestered near the base of wheat plants. Winter mortality is usually very high and appears to be a reflection of the length of the winter more than amount of snow or extreme cold temperatures.

Russian wheat aphid damage can be minimized in the fall by planting after flight activity declines or by using a systemic insecticide. Fall wheat can tolerate fairly high numbers of aphids without severe damage occurring. However, during years of unusually long warm falls, Russian wheat aphid numbers will increase and continue to feed and may result in complete winter kill. Under these conditions, foliar insecticide treatment is warranted. In winter wheat growing areas volunteer grain should be eliminated, and late maturing spring grain should be avoided, whenever possible.

Planting dates can be adjusted according to suction trap data to reduce the need for chemical control. A suction trap system partially funded by the Idaho Barley and Wheat Commissions to monitor aphids in Idaho has been in existence for eighteen years. Insects are collected in canisters placed in these suction traps and sent weekly to the University of Idaho Aberdeen Research and Education (R & E) Center for identification. The information generated is distributed throughout the growing season by means of a free access website called the Aphid Flyer (http://www.uidaho.edu/so-id/entomology/Aphid_Flyer.htm), email, a newsletter, and the internet to alert growers to potentially damaging cereal aphid populations and virus epidemics.

Chemical control decisions for Russian wheat aphids should be based on infestation levels from crop emergence to the milk stage of kernel development. Early detection and control minimizes losses. Several contact and systemic insecticides are labeled for controlling Russian wheat aphids. See University of Idaho publication CIS 817 *Russian Wheat Aphid* for current thresholds and insecticide recommendations. Certain wheat varieties are resistant to Russian wheat aphids and can help reduce the need for insecticide treatments. However, a new Russian wheat aphid biotype virulent to the resistant varieties has been recently reported in Colorado.


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Figure 4. *Greenbug nymphs are lime green with a dark green stripe along the back of the abdomen.*


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Figure 5. *Winged adult greenbugs will migrate from mature grasses to newly emerging fall-planted wheat.*

Greenbugs

Greenbugs (*Schizaphis graminum*) are short, oblong-shaped aphids with a lime green body color and a dark green stripe along the back of the abdomen (Figs. 4 and 5). Greenbugs have pale green cornicles with dark tips that do not extend beyond the rear tip of the abdomen. Their antennae extend all the way to the rear abdominal tip.

Greenbugs live on a wide variety of grasses, including cereals. As these plants mature in late summer, large numbers of winged forms are produced that then migrate to newly emerging fall-planted wheat. Greenbugs appear to overwinter as eggs or as live aphids during mild winters, although this is not known with certainty.

Greenbugs normally do not cause economic losses as a result of direct feeding. However, because greenbugs are an important vector of barley yellow dwarf virus (BYDV), they are considered to be one of the most important insect pests of fall grain in southern Idaho. Losses can be minimized by planting after the winged summer migrations have subsided or by using a systemic insecticide.

Bird cherry oat aphid

Bird cherry oat aphids (*Rhopalasiphum padi*), formerly known as oat-bird cherry aphids, are small (1.7mm), dark green to dull black with a characteristic reddish-orange spot on the back end at the base of the cornicles (Fig. 6). Cornicles, legs, and antennae have a dark tip. The winged form of this aphid is darker than the wingless form. These are the only dark aphids found on fall grain in southern Idaho. Mature aphids found in winter and early spring may be the color of a blueberry, but they will give birth to more typical green aphids in the spring. The bird cherry oat aphid overwinters as a cold hardy egg stage on chokecherry bushes. Occasionally, adults may overwinter under a protective snow cover. It is present on grain crops (usually wheat) in the spring (April-June) and in the fall.

Bird cherry oat aphids colonize grain crops during the growing season and may become particularly abundant on corn, resulting in large migrations as the corn crop matures. Like corn leaf aphids, bird cherry oat aphids do not inject toxins while feeding. Therefore, even though heavy infestations can develop, injury is not readily apparent and plants appear to be able to tolerate large infestations without economic yield losses. However, this aphid is the most important vector of barley yellow dwarf (BYDV) virus in western Idaho.

Cereal Aphids in Spring

Cereal aphid populations experience a great deal of mortality over winter months. As a result, cereal aphids are rarely a problem in winter wheat in the spring because populations start out low and rarely reach damaging levels before the wheat matures. Likewise, if winter wheat has not become infected with BYDV in the fall, problems with BYDV in the spring are unlikely.

The spring cereal aphid complex includes six species. These are, in diminishing order of importance, English grain aphid, Russian wheat aphid, greenbug, rose grass aphid, bird cherry oat aphid, and corn leaf aphid.


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Figure 6. *Bird cherry oat aphids (with nymph in center) are the only dark aphids found on fall grain in southern Idaho.*

The three most damaging of the six species listed above overwinter in winter wheat. Their presence in the crop gives them an early start if spring conditions are favorable for aphid population increase. It may take several months in the spring before overwintering aphid populations have increased sufficiently for significant flight activity. Thus, fall populations of English grain aphids, greenbugs, and Russian wheat aphids provide the major source for spring infestation. The best control strategy for spring aphids is to plant late enough in the fall to prevent heavy aphid infestations that can overwinter and subsequently cause problems in the spring.

English grain aphids

English grain aphids are the most likely of the six species to cause damage in the spring. They can be recognized by their dark cornicles, dark antennae, and striped legs (Fig. 7). They are highly variable in color, ranging from brown to green to yellow to red or even bright orange. The most common place to find them is between the developing kernels of the heads.

English grain aphids overwinter as eggs in winter wheat, so populations begin to build as soon as it is warm enough for eggs to hatch. In years when high populations occur, most damage is done soon after heading because English grain aphids prefer to feed on developing heads.

Wheat crops should be inspected for English grain aphids after heading and prior to flowering. Insecticide treatment is recommended if English grain aphid populations reach two per head at flowering or ten per head before milky dough stage. No benefit can be achieved by spraying after soft dough stage.

Greenbugs

Greenbugs are potentially more damaging than English grain aphids but do not occur as frequently. Greenbug feeding is toxic to wheat, producing characteristic brown and yellow blotches and spots on leaves. The most serious damage occurs when greenbugs feed on the stems directly beneath developing heads. The recommended action threshold is similar to that for English grain aphids.

Russian wheat aphids

Occasionally, Russian wheat aphids may overwinter in winter wheat in large numbers. If this occurs, populations can build up very quickly in the spring and cause damage. This is seldom the situation in Idaho unless the winter is unusually mild and dry. However, fields that were heavily infested in the fall should be inspected shortly after green-up in the spring for fresh damage or reproducing colonies. Even if colonies can be detected, treatment may not be necessary, as most spring populations will diminish without treating. The more the crop matures, the more Russian wheat aphids it can support without economic damage.

In Idaho, winter wheat rarely if ever becomes newly infested with Russian wheat aphids after heading. Occasionally, very high populations of Russian wheat aphids, exceeding 100 individuals per head, will develop in heads of maturing wheat. Treatment thresholds for Russian wheat aphids in heads are similar to those for English grain aphids and greenbugs; however, it is best to avoid having to apply insecticide to maturing wheat by inspecting the crop at an earlier stage.

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Figure 7. *English grain aphids can be recognized by their dark cornicles, dark antennae, and striped legs.*

Other species

Bird cherry oat aphids and rose grass aphids normally overwinter as eggs on chokecherry and rose bushes, respectively. New spring colonies arising from hatched eggs must pass through two to three generations before winged spring migrants are produced that can infest winter wheat. Normally, wheat has matured to the point where little damage occurs by the time it becomes infested by these two species.

Proper control decisions for aphid pests depend on accurate identification. For identification help, two University of Idaho publications are available: CIS 816 *Aphids Infesting Idaho Small Grain and Corn* and MS 109 *Keys to Damaging Stages of Insects Commonly Attacking Field Crops in the Pacific Northwest*. University of Idaho extension agricultural agents, industry consultants, and fieldmen can also help with identification. Insect specimens can also be sent for identification to the Entomology Division, Department of PSES, University of Idaho, Moscow, ID 83844-2339. Be sure to include a specimen submission form, which can be obtained at your closest extension office.

Wireworms

Wireworms (Coleoptera: Elateridae) are considered the most important soil-dwelling pest of crops in the Pacific Northwest and are becoming increasingly important in several other regions in the U.S. Possible explanations for increasing damage to crops are increased rotations with grasses for the cattle industry or small grain production,

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Figure 8. *Wireworms are found in the soil where they feed on the roots of various cereals. Damage is done by the larval stage, which is a yellowish brown, thin worm that has a shiny, tough skin.*

relatively mild winters in the last several years, and the loss of registration of insecticides with long residual soil activity.

All species of larvae resemble mealworms and are usually hard-bodied, slender, elongate, shiny, yellowish to brown, and nearly cylindrical worms (Fig. 8). They are one-half to two and a half inches long, with three pairs of tiny true legs behind the head and an ornamented shield-like segment on the tail end of the body. The life cycle of the most common wireworms in grain requires three to four years under favorable conditions.

Wireworms spend the winter in the soil either as partially grown larvae or as new adults. The adults, known as click beetles or snapping beetles, are elongated, parallel-sided, and somewhat flattened. When placed on their backs, these beetles characteristically "click," snapping their thoracic segments to cause their bodies to flip in the air to right themselves. The adults require little or no food and cause no economic damage, with the larvae being the cause of wireworm-associated damage.

Wireworms (Limonius and Tenicura species) feed on the underground portions of living plants. Because grasses, including wheat, are a preferred host of wireworms, they may build to extremely high numbers in a continuous wheat rotation. They injure wheat by feeding on seed, underground stems, and boring into larger stems. Damage may be observed as bare areas resulting from no seedling emergence or as plants that turn yellow and die even after emerging.

The use of commercial insecticide seed treatments labeled for wireworms can be effective in suppressing wireworm damage in some situations. However, it is important that the seed treatment be carefully applied to make sure there is full coverage. Field history is the best guide to determine when seed treatments are needed.

Cereal Leaf Beetle

The cereal leaf beetle (*Oulema melanopus*) is considered a serious pest of small grains in the U.S. and is becoming increasingly important in Idaho. It is an introduced pest in this country, first detected in Michigan in 1962. Since the first report of the cereal leaf beetle in Idaho in 1992, the insect has invaded 29 of the state's 44 counties. While both adults and larvae (plural of larva) of this insect feed on small grain foliage, larvae cause the most damage and are the primary target of control measures.

The cereal leaf beetle overwinters as an adult and becomes active in the spring when temperatures reach 50°F, moving into grain fields and feeding and mating on small grains or grasses. Oviposition begins about seven days after mating and may be extended over a two-month period. Eggs are deposited singly or in pairs on the midrib of the upper leaf surface of the host plant. Each female lays between one and three eggs per day with a total of fifty to 250 eggs per female. Eggs hatch in eleven to thirteen days and larvae commence feeding immediately. The larvae have four instars for a total larval life of nine to sixteen days (length may be prolonged due to cool weather). When mature, the larvae crawl down the plant to the soil where they burrow to a depth of 1.2 to 2.8 inches. A pupal chamber is constructed by hardening the soil with a secretion. Pupation occurs about seven days after the larva enters the soil and lasts from seventeen to twenty-six days. Adults emerge and feed intensively on any available succulent grass and then disperse to overwintering sites. Males emerge several days before females. The cereal leaf beetle undergoes an obligate diapause. There is one generation each year.

In Idaho, we have observed cereal leaf beetle adults leaving hibernation sites and invading the fields in late April or early May. Oviposition commences about May 20 and continues until the end of July. The larval stages are found from the beginning of June until early August and pupae from the middle of June until the middle of August. Of course, the onset of oviposition and the presence of subsequent stages will vary by weather conditions within Idaho counties.

While both adults and larvae of the cereal leaf beetle feed on grain plant leaves in the vegetative growing stage or post-harvest, most of the damage is caused by the larvae, which feed on the upper leaf surface. Adults and larvae feed from the tip of the blade to the base, chewing completely through the leaves and creating longitudinal narrow slits. With heavy infestations, damage appears similar to frost injury when seen from a distance, due to larval feeding that whitens the tips of the leaves.

Existing thresholds for implementing control measures were developed many years ago in states in the east and Midwest. Current thresholds prescribe insecticide applications when infestations of three eggs and/or larvae per plant are encountered before the boot stage (including all the tillers present before the emergence of the flag leaf). The threshold is decreased to two larvae per flag leaf at the boot stage.

Several biological control agents have been released in Idaho. The larval parasitoid Tetrastichus julus has been established in Bonneville and Cassia counties. A management program for cereal leaf beetle has been initiated in southeast Idaho, with the objective of developing a practical monitoring system for this insect. The program uses a pheromone trap combined with biological control agents to reduce cereal leaf beetle populations. The results of the first season are not too encouraging since no differences were observed between traps with and without the pheromone at all sites. However, new improvements in the trap are expected for 2004.

Cutworms and Armyworms

Cutworms and armyworms (several species) are common pests of different crops in Idaho including barley. Cutworms and armyworms are the larval stage of moths in the family Noctuidae (moths that fly at night and are attracted to lights). The adults, eggs, and pupae of these moths are similar in appearance. Larvae of armyworms and cutworms (the caterpillar stage) are usually smooth and dull-colored (Fig. 9) and are often the overwintering stage of these moths. Once the winter is over, these larvae come out of the soil and resume feeding to complete their larval life cycle in late April and May. Some other species overwinter as pupae in the soil.

The caterpillar stage is the one that causes economic damage to crops by defoliating the plants. Armyworms are active at night and get their name from their behavior of frequently migrating from field to field in large numbers in search of food. Cutworms are also nocturnal in habit and get their name from their behavior of feeding on the roots and shoots of some plants, and often cutting them off at or below ground level. The larvae are up to 2 inches long when mature and hide under crop debris or soil clods during the day.

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Figure 9. *Western yellowstriped armyworms are black with yellow or orange stripes along the side. Mature larvae of both species may reach 2 inches in length.*

Caterpillars become pupae and remain in the soil for about two weeks, depending on the temperature and the species. One or more generations may occur per year, depending on the species. Moths usually emerge in May or June, with the majority emerging during a short period. The dusky-brown to gray miller moths are commonly observed flying around house lights during the summer in Idaho. The moths have a wingspan of 1.5 to 2 inches and each forewing is marked with spots, lines, and other dark and light markings. Shortly after emergence, the moths migrate to the Rocky Mountains to spend the summer in a cooler place feeding on flowering plants. These moths are an important protein source for bears in the mountains. They return to Idaho in the fall to lay their eggs in grassy areas.

Outbreaks of armyworms and cutworms are sporadic and unpredictable. Control programs for these insects are aimed only at seriously damaging infestations because chemical control is difficult and natural enemies generally hold the populations in check. If chemical control is necessary, any number of broadcast granular insecticides or a foliar-applied insecticide may be effective. Weed control in previous crops and along field edges also aids in reducing cutworm damage.

To scout for armyworms, examine areas with defoliated and lodged plants. Look for larvae around these damaged plants or under stones or soil clods close to the plants. According to the extension services of Nebraska, Colorado, Wyoming, and Montana, a treatment should be considered in small grains if all of the following conditions are met:

1) Larval counts per square foot exceed 5 prior to heading or 2 after heading.

2) Larvae are larger than 0.75 inches.

3) Most larvae are not parasitized (look for white eggs behind the head or small brown cocoons attached to the body).

4) Leaf feeding or head clipping is evident.

Grasshoppers

Grasshoppers are pests of barley and other grain crops only during years when they migrate out of uncultivated areas. Usually their populations are small and their damage is inconsequential. During outbreak years they can defoliate grain crops. While there are more than 100 species of grasshoppers in the Pacific Northwest, four main species are typically seen damaging grain crops in eastern Idaho: the two-striped, the red-legged, the striped sand, and the migratory grasshoppers. Most of the grasshopper species in Idaho belong to the family Acrididae.

Grasshoppers lay their eggs in inch-long pods, each containing ten to seventy-five eggs, deposited slightly below the surface of the soil in late summer or fall. Each female may lay from eight to twenty pods. Grasshoppers prefer to lay eggs in areas where the soil is less likely to be disturbed (hard uncultivated ground) and where there is plant food available for the nymphs once they hatch. Eggs are sometimes found on the edges of cultivated fields, along ditch banks, and in pastures and hay fields.

The eggs hatch from March to June, depending upon the weather conditions and grasshopper species. The nymphs resemble the adults, but are smaller and without wings. Both nymphs and adults do damage. They feed on foliage, heads, or often on stems just beneath the heads, causing them to drop. They may attack any of the cereal crops. There is one generation per year and the nymphs become mature in summer or early fall. Studies suggest it is difficult to predict grasshopper outbreaks. Dry conditions seem to favor grasshopper populations.

Control programs need to be initiated only when populations become high and significant defoliation (10% to 15%) occurs. For control of grasshoppers, growers can use the poison baits that are distributed by the Idaho State Department of Agriculture (ISDA) or use foliar or soil insecticides. The active ingredient in the poison baits is carbaryl, available in three formulations (granular, bran, and pellets). The bran formulation appears to work better but it is hard to apply with a spreader. Baits must be uniformly distributed in the field, and reapplications are often needed when baits are no longer attractive to grasshoppers. It is easier to reduce grasshopper populations in their first nymphal instars than when they reach adulthood. A bran bait with a disease organism, the protozoan *Nosema locusta*, is also commercially available. *Nosema* baits consumed by the grasshoppers produce infection, which causes diarrhea and dehydration and eventually death. The infections can be transmitted when healthy grasshoppers eat infected dead, or on egg pods laid by infected females. The disease can reduce populations over a period of several years but the *Nosema* baits do not prevent crop damage in outbreak years. *Nosema* is target specific and does not harm beneficial, terrestrial, or aquatic insects and other nontarget organisms.

Most common foliar insecticides will control grasshoppers. Infestations usually occur first in weedy areas of roadsides, fields close to irrigation ditches, and crop areas close to rangeland. Strip spraying along the field edge where an infestation begins is usually adequate to prevent losses. Insecticides are most effective when applied to grasshopper hatching areas while they are in early nymphal instars. In outbreak years, area-wide programs are more effective than field-by-field treatment for grasshoppers. Also, in outbreak years, watch for blister beetles that may move into the field edge and cause local defoliation. They are long beetles (5/8 to 1 1/8 inches) with conspicuous heads and necks. Their larval stages feed on grasshopper eggs. A website from the University of Wyoming (http://www.sdvc.uwyo.edu/grasshopper/) currently contains the best information available on North American grasshopper ecology, biology, and management.

Mormon Crickets

Mormon crickets are not true crickets (crickets are in the family Gryllidae). The Mormon cricket is actually a shield-backed katydid belonging to the family Tettigoniidae, which includes the long-horned grasshoppers and katydids. The Mormon crickets get their name from the fact that they were first encountered by early settlers in the Salt Lake area in Utah in 1948. They prefer feeding on range grasses but sometimes invade crops or yards, causing extensive damage. These large, wingless insects are light gray to dark reddish brown. They are common in southern Idaho, northern Utah, and Nevada. They have one generation per year. The female has a sword-like ovipositor that inserts the eggs in the soil during the summer. Eggs are the overwintering stage. Nymphs emerge the following spring. The nymphs resemble the adults. Wet and cold springs seem to suppress Mormon cricket populations probably because these conditions favor pathogen activity and also slow insect growth. Outbreaks are usually related to drought. It is not uncommon to observe high densities of Mormon crickets dispersing as a group from range to croplands in dry years. Therefore, trenches dug around fields may prevent invasions. They may attack any of the cereal crops that they find on their way. These insects can walk up to 1.25 miles per day. For control of Mormon crickets, growers typically use the same baits employed for grasshopper control.

Wheat Diseases: Identification and Management

R. Forster and M.Wiese

Disease management in winter wheat hinges primarily on prevention. Unlike many weed and insect problems, diseases and the yield losses they impose are difficult to control once infection and disease development have occurred. Chemical controls, often sought after disease symptoms and crop damage are apparent, are frequently not available or economical once wheat diseases become established.

Wheat disease development requires a susceptible host or variety, a virulent pathogen, and a favorable environment. Disease management, therefore, involves manipulating one or more of these three elements to suppress disease and achieve a biological or economic benefit. Complete disease control is seldom necessary and frequently not economically feasible. Selected crop rotations and seeding dates, for example, can be utilized to avoid pathogens that may be present in soil or crop debris. Utilizing certified pathogen-free seed and disease-resistant varieties is encouraged not only to limit disease development but to reduce pathogen populations. Other cultural practices such as nutrient supplementation or application of chemical pesticides may discourage disease development and augment crop performance.

In a broad sense, a disease is any abnormality that induces physiological changes in plants that eventually may be expressed as visible symptoms. Yellowing, distorted or stunted growth, wilting, spots, rots, and discolored tissues are some of the indications of disease. Such symptoms may result from infectious or noninfectious agents and may not be sufficiently specific to easily identify their cause. Noninfectious diseases include disorders and stresses caused by mechanical or environmental variables such as nutrition, temperature, moisture, and toxicants. Infectious diseases, which are the primary focus of this discussion, are caused by biotic or living plant pathogens such as bacteria, fungi, and nematodes. Viruses and virus-like agents, although not technically living organisms, also cause infectious disease. These agents of infectious disease are able to multiply or replicate, be dispersed from plant to plant, and cause new host infections.

Winter wheat is susceptible to many infectious diseases. At any given time, it may indeed serve as a host for several different pathogens and bear symptoms of several different diseases. Fortunately, most wheat crops are significantly impacted by only a few diseases each season. The most commonly encountered diseases affecting dryland winter wheat in southern Idaho include barley yellow dwarf, wheat streak mosaic, and root and foot rots caused by *Bipolaris* (syn. *Helminthosporium*), *Rhizoctonia*, *Fusarium*, and other soil fungi. These and many other diseases and their management are described in two comprehensive wheat disease publications: (i) the *Compendium of Wheat Diseases, 2nd edition*, 1987, APS Press, St. Paul, MN 55121, and (ii) the *Pacific Northwest Plant Disease Management Handbook,* which is published annually by the University of Idaho, Oregon State University, and Washington State University.

Viral Diseases

Barley Yellow Dwarf

Barley yellow dwarf (BYD), also called cereal yellow dwarf, yellow dwarf, and red leaf, occurs throughout Idaho on most small grain cereals and on numerous grasses. Many hosts of barley yellow dwarf virus (BYDV) remain symptomless while some severely infected crops may set little or no grain.

The symptoms of BYD are ambiguous and therefore often overlooked, mistaken for nutritional disorders, or attributed to cold, wet soil conditions. BYD is tentatively identified in the field by the prior presence of aphids and the occurrence of single or small groups of yellowed,

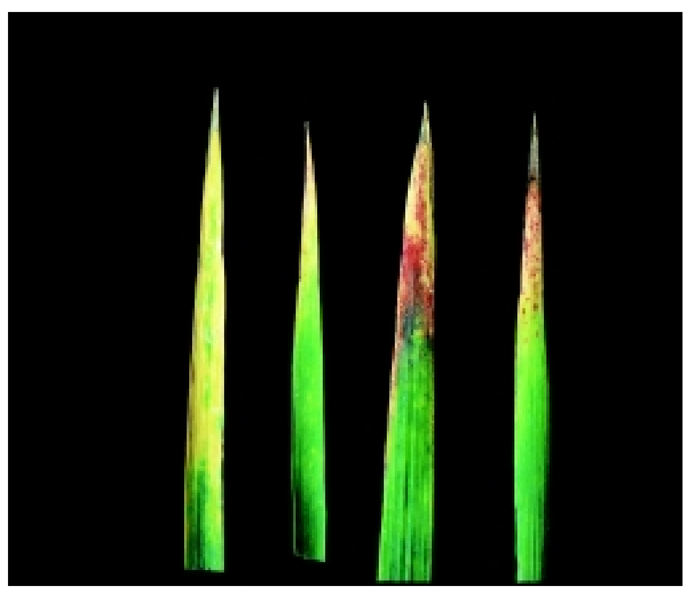

Figure 1. *Leaf discoloration caused by barley yellow dwarf virus.*

Figure 2. *Small area of yellowed and stunted plants affected by barley yellow dwarf.*

stunted plants. The distribution of such plants within wheat fields often reflects the pattern of aphid distribution by wind currents. Definitive diagnosis of BYD requires laboratory tests to specifically detect and transmit the causal virus.

BYDV infection often causes leaf discoloration in shades of yellow, red, or purple (Figure 1). It also causes reduced root growth and general stunting (Figure 2). Plants infected in autumn or before the 4- to 5-leaf stage are often severely stunted and may not head. Winter wheat plants infected in spring seldom suffer significant yield losses. Similarly, infections occurring after the boot stage produce few or no symptoms and may not impact yields.

BYD is caused by a group of related viral strains that are transmitted by several different cereal aphids. Aphids acquire BYDV by feeding on infected grain crops or grasses. In Idaho, the bird cherry-oat aphid, corn leaf aphid, English grain aphid, rose grass aphid, and greenbug transmit the virus to wheat. The Russian wheat aphid, which also infests wheat in Idaho, does not transmit BYDV.

BYDV persists in wheat, other small grain cereals, corn, grasses, and aphids. Its spread depends entirely on the movement of viruliferous aphids within and among wheat fields over several miles. There are no BYD-resistant winter wheat varieties adapted to southern Idaho. Early plantings of winter wheat have more exposure to aphids and are more likely to be infected relative to later plantings. Late autumn seeding may avoid aphid infestations and virus infections and is also beneficial in controlling some root rots (see below). Growers are advised to check with their extension educators for the most recent aphid flight data to determine when flights have subsided. Furthermore, winter wheat should not be subjected to undue moisture or nutrient stresses which would slow growth and enhance the severity of BYD.

Systemic insecticides can be used to control viruliferous aphids and in turn provide some level of BYD control. However, this practice typically is only partially effective against BYD, since aphid control is usually incomplete, and aphids may be able to transmit the virus before acquiring a lethal dose of insecticide (see Insect Pests-Aphids). Consult University of Idaho CIS 672 *Barley Yellow Dwarf* for more information on BYD in winter wheat.

Wheat Streak Mosaic

Wheat streak mosaic (WSM) is caused by a virus that is transmitted from plant to plant by the wheat curl mite (*Aceria tosichella*). These mites are very small (about 1/32 of an inch), cream-colored, and cylindrical in shape (Figure 3). Detection requires magnification with a hand lens. Corn and certain grasses also are hosts for wheat streak mosaic virus (WSMV) and the wheat curl mite. Wheat, however, is the principal host for the virus. Winter wheat is more vulnerable to infection than spring wheat and becomes infected as mites carrying the virus are dispersed

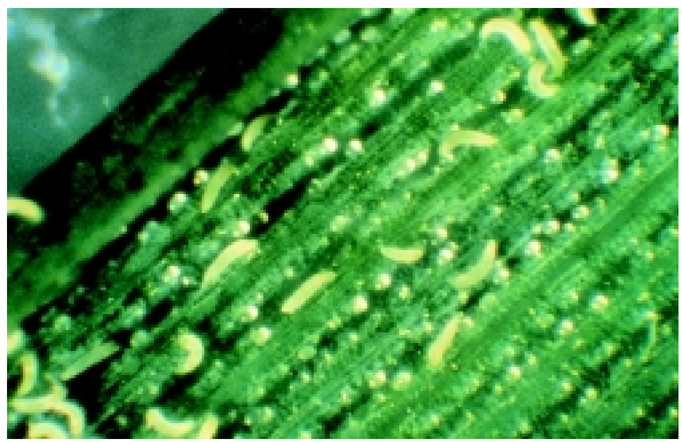

Figure 3. *Wheat curl mites on a leaf surface. Photo courtesy of Univ. of Nebraska.*

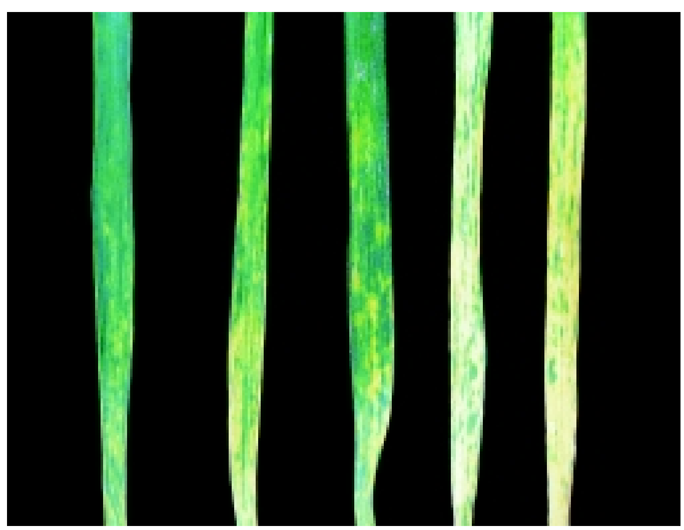

Figure 4. *Leaves variously affected by wheat streak mosaic virus.*

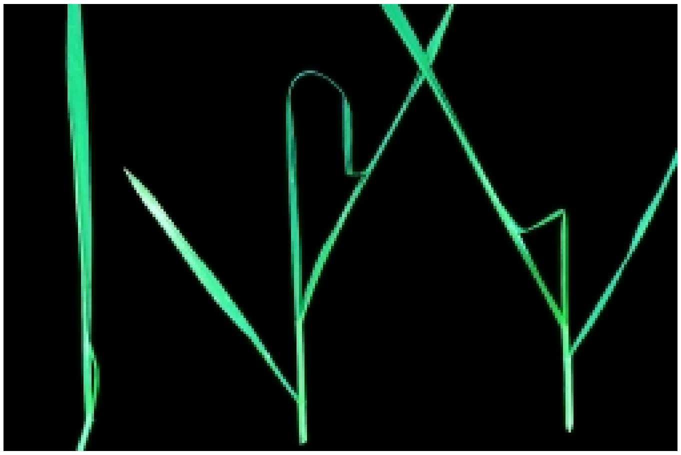

Figure 5. *Young leaves distorted by infestations of wheat curl mites.*

Figure 6. *Symptoms of black chaff on seedling wheat plant. Note dark green, water-soaked spots on leaves.*

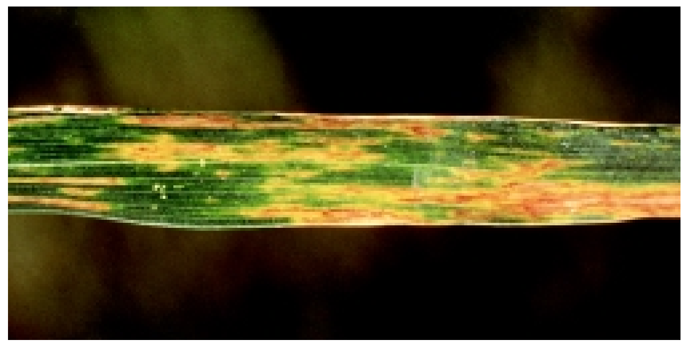

Figure 7. *Symptoms of black chaff on mature leaf.*

from plant to plant and from field to field by wind.

Symptoms of WSM include stunting and green or yellow streaks or spots on leaves (Figure 4). Leaf margins may be rolled tightly upward by the feeding activity of the mites, occasionally trapping the succeeding leaf (Figure 5). Symptoms become more dramatic as temperatures increase and plants mature. Heads that form may be totally or partially sterile. Conditions that benefit the spread and development of BYD, especially early fall seeding, also benefit the spread and development of WSM. In fact, mixed infections of WSM and BYD occur occasionally, and yield losses under those conditions may be more severe than would be the case for either disease individually.

Late autumn seeding reduces the likelihood of mite infestation and WSM development. Management practices that encourage rapid wheat growth in the spring minimize the impact of WSM. Since WSMV and wheat curl mite are sustained on green living tissues of cereals, grasses, and volunteer wheat, it is important to eliminate this green bridge from the vicinity of the new planting. Beyond breaking this green bridge through cultivation, chem fallow, and selected planting dates, growers should be alert to utilizing wheat varieties with tolerance or resistance to WSM. Butte hard red spring wheat has some tolerance to the WSMV.

Bacterial Diseases

Black Chaff

Black chaff, also called bacterial blight, bacterial streak, or bacterial leaf streak, is primarily a problem in irrigated wheat, especially sprinkler-irrigated wheat. It is occasionally found in dryland wheat in years with above-average spring and summer precipitation. Leaves, stems, or heads of plants may be affected. Symptoms on wheat leaves appear initially as water-soaked streaks and spots (Figure 6) that eventually turn brown and may be surrounded by a lime-green halo (Figure 7). Symptoms may also appear on the upper-stem region between the head and flag leaf as dark purple stripes or lesions with light yellow centers. The name black chaff comes from the conspicuous dark blotches that develop on glumes (Figure 8). Awns on infected heads may develop a striped barber-pole appearance caused by alternating bands of darkened, diseased tissue and healthy, lighter-colored tissue.

Black chaff is caused by a bacterium (*Xanthomonas translucens* pv. translucens). Under wet or humid conditions, diseased tissues may exude bacterial cells as a slime or in viscous droplets. When dry, the slime masses become fragile, light-colored, and scale-like. Some resemble yellow sugar crystals.

The black chaff bacterium is primarily seedborne but may persist also on plant residues or on alternative host plants such as orchard grass and hare barley. It moves from wheat seed and from neighboring infested and infected plants to wounds and natural openings in develop-

Figure 8. *Glumes darkened due to black chaff infection.*

ing wheat plants when free water is available. Splashing water from rain or irrigation spreads the bacterium from diseased to healthy plants in the field. Direct contact between plants and with insects may also distribute the bacterium.

Because black chaff bacteria are seedborne, only seed free of the pathogen or containing low levels of the bacteria should be sown. In this regard, wheat seed lots can be assayed for contamination by black chaff bacteria by the University of Idaho Seed Pathology Laboratory in Moscow. Where possible, sprinkler irrigation should be avoided when seed has not been shown to be free of the pathogen. No currently registered chemicals control black chaff, either on infested seed or in the field. In addition to using pathogen-free seed, growers should avoid seeding wheat into grain stubble fields that had black chaff the previous year. More information on black chaff is available in University of Idaho CIS 784, *Black Chaff of Wheat and Barley*.

Fungal Diseases

Black Point

Black point describes the discolored appearance of wheat kernels infected by one or more field fungi during their development (Figure 9). Precipitation or irrigation occurring after the crop has matured favors fungal growth that causes kernels to darken and appear weathered, shriveled, or smudged, especially at the embryo end. After harvest, such discolored grain is considered damaged and is discounted in value because it can contribute to discolored or toxic food and feed products. U.S. No. 1 wheat permits just 2 percent damaged kernels while U.S. No. 2 wheat permits just 4 percent. Severe black point infections may also reduce seed germination. Fungal growth and black point damage may increase when infected grain is stored under high moisture or humid conditions.

Several fungi can cause black point including *Alternaria, Cladosporium, Fusarium* and *Bipolaris* (syn. *Helminthosporium*) species. Kernel infection by these and other common field fungi is favored by high relative humidity and kernel moisture. Thus, black point is more prevalent under irrigated than dryland conditions, especially when sprinkler irrigation occurs after the soft dough stage of crop development (no further irrigation is normally necessary at this stage).

Since it is impossible to exclude fungi from maturing wheat kernels in the field, black point control measures aim only at decreasing their activity. All grain, especially seed grain, should be stored under dry conditions. Developing crops should be protected from excessive irrigation, especially late in the season. Sprinkler irrigation, if necessary after heading, should be used judicially. Chemical seed treatments may protect seedlings from some fungi carried on black-pointed seeds but are ineffective later against fungal infection of maturing kernels. Consult University of Idaho CIS 536 *Aeration for Grain Storage* for the most appropriate grain storage conditions.

Photo courtesy of S.K. Mohan, University of Idaho

Figure 9. *Wheat kernels discolored by black point fungi.*

Cephalosporium Stripe

Cephalosporium stripe occurs widely in northern Idaho and was recently detected for the first time in southern Idaho. The disease is especially prevalent in winter wheat that follows susceptible cereal or grass crops. While most winter cereals and grasses are susceptible, winter wheat is the major economic host. Yield losses result from reduced seed set and weight, and from premature death of infected tillers.

Cephalosporium stripe is a soilborne disease that is favored by wet and acid soil conditions. The disease is most

Figure 10. *Leaf with Cephalosporium stripe.*

conspicuous during jointing and heading when one or more long, yellow stripes appear on expanding green leaves (Figure 10). These prominent stripes with one or more darkened veins within them are often continuous over the entire length of the leaf blade, leaf sheath, and culm. In late winter and early spring, infected leaves may show a mosaic-like yellowing rather than distinct stripes. Severely striped leaves and tillers are stressed by the fungus within them. They often set little or no seed and may die prematurely to form conspicuous white heads.

A soilborne fungus, *Cephalosporium gramineum*, causes Cephalosporium stripe. The fungus survives in the residues of infected cereals and grasses that remain moist on or near the soil surface. Such residues permit the fungus to form numerous spores in specialized fruiting structures called sporodochia that are visible, flat, gray-black, and easily dislodged from wheat straw. These spores germinate and the fungus passively enters the roots of developing wheat plants through natural wounds or wounds caused by frost heaving, insect feeding, or other mechanical disturbances. Once inside vascular tissues the fungus multiplies and moves upward from roots to leaves with transpirational streams. Tissues surrounding infected vessels are adversely affected and contribute to leaf stripe development.

Cephalosporium stripe is reduced by crop rotation, residue management, and variety selection. Winter wheat that follows other infected cereal or grass crops is at greatest risk of infection. Wheat that follows non-host crops such as legumes is at reduced risk. Infested crop residues that harbor the fungus should be minimized or eliminated. Removing such infected residue by burning, when permitted, or by deep tillage reduces disease symptoms in subsequent wheat crops. However, such practices should be weighed against erosion control and nutritional objectives. Winter wheat varieties truly resistant to Cephalosporium stripe are not available, but varieties such as Eltan, Lewjain, Crest, Nugaines, Winridge, and Luke show tolerance to the disease. Liming or other treatments to keep soil pH at acceptable levels of acidity (> 5.5) limit the survival of the fungus. Chemical controls are not available.

Common Bunt (see also Dwarf Bunt)

Common bunt, also called stinking smut or covered smut, is caused by two closely related seed- and soilborne fungi, *Tilletia tritici* and *T. foetida*. Spores of these fungi germinate in the soil at temperatures of 40°F to 60°F (5°C to 16°C) and infect developing wheat seedlings prior to emergence. Infected plants may be somewhat stunted but are difficult to identify before heading. The causal fungus makes its way to the developing head where it replaces the kernels with darkened bunt balls (Figure 11). Four bunted kernels, or smut balls (Figure 11 lower right), contain numerous black spores with a characteristic fishy odor. These bunt balls are easily broken during harvest, releasing the spores to be spread readily on seed and in wind currents (Figure 12). The same plant may have both healthy and diseased heads, and both healthy and bunted kernels can occur within the same head.

Common bunt can reduce grain yield and crop quality but this rarely occurs in Idaho. Smutted grain, however, may retain the pungent, fishy odor and be discounted in value in commercial markets. The use of resistant varieties, clean seed, and chemical seed treatments have nearly eliminated common bunt in Idaho. Commercial seed treatment formulations containing either carboxin, PCNB, or difenoconazole are most effective in controlling common bunt (Table 1).

Figure 11. *Glumes flared by bunt balls of common bunt and dwarf bunt appear similar.*

Figure 12. *Spore cloud released during harvest of wheat infected with common bunt.*

Common Root Rot

Common root rot is caused by a complex of soilborne fungi including *Bipolaris* (syn. *Helminthosporium*) and *Fusarium* species. Damping-off (sudden death) of emerging seedlings, seedling blight, and leaf infections caused by these fungi can occur, but are rare in Idaho. Infected plants appear stunted, have reduced root areas, and exhibit decay of the crown and subcrown area (Figure 13). Common root rot is favored by conditions such as soil compaction, drought, and cool temperatures that restrict root growth and plant development.

Control of common root rot is achieved primarily by cultural practices such as crop rotation, avoiding soil compaction, and supplying adequate nutrition. N and P should be applied according to soil test recommendations to encourage vigorous root and shoot growth, enabling plants to resist or tolerate infection. Later seeding dates and proper seeding depths permit uniform germination and emergence under cooler soil temperatures and limit common root rot infections. Rotation with non-cereal crops and control of grassy weeds can also reduce the population of common root rot fungi in soil.

Post-emergent fungicides are not available for control of common root rot. Commercial seed treatment fungicides that prevent seed rot and damping-off by these fungi offer varied protection (Table 1). Seed treatment formulations of the systemic fungicide imazalil are registered for control of common root rot and provide some benefit.

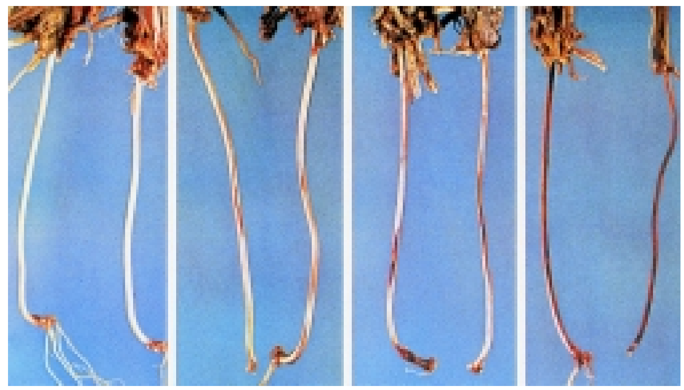

Figure 13. *Subcrown internodes partially or wholly darkened by common root rot. Roots on left are healthy. (Source: Vol. 53, No. 3, Can. Dis. Surv., Sept. 1973)*

Table 1. Seed treatment fungicides registered for use on winter wheat in Idaho. Applicators should strictly follow label directions.

	Wheat Seed Treatments									
Product	Common root rot (Bipolaris)	Seed decay and damping off	Pythium damping off	Fusarium root, crown, and foot rots	Take-all	Common bunt seedborne	Common bunt soilborne	Dwarf bunt	Flag smut	Loose smut
Allegiance FL			C							
Baytan 30	S			S	S	C	C		C	C
Captan 400		C	S							
Dividend XL	S	C	C	S	S	C	C	C	C	C
Imazalil products	C	S								
Maxim XL		C	C	C		C	C			
Metalaxyl products			C							
PCNB products						C	C			
Raxil-Thiram	S	C	S	S		C			C	C
Raxil-MD	S	C	C	S		C			C	C
Raxil MD Extra	C	C	C	S		C			C	C
Vitavax-Thiram RTU	S	C	S	S		C	C		C	C
TBZ products		C		S		S	S	S		
Thiram products	S	C	S	S		S				

C = Control S = Suppression

Dwarf Bunt

Dwarf bunt is also known locally as TCK smut, dwarf smut, and stubble smut. Dwarf bunt and common bunt are similar diseases caused by closely related fungi. Unlike common bunt, dwarf bunt is less widely distributed and is highly dependent on cold temperatures and persistent snow cover. In Idaho, the incidence of dwarf bunt in winter wheat is generally low and highly variable. Dwarf bunt attracts more attention as a international trade barrier than as a yield-limiting disease.

Dwarf bunt is not known to occur in spring wheat. In most years and areas, winter wheat fields are free of dwarf bunt. In winter wheat, its incidence is erratic and related to cold temperatures and persistent snow cover. In any given year, fields and areas with a history of dwarf bunt may remain free of the disease or show from a trace to greater than 50 percent bunted heads. In 1993, dwarf bunt was identified in the following Idaho counties: Bannock, Bear Lake, Benewah, Bingham, Bonneville, Boundary, Camas, Caribou, Cascade, Clearwater, Elmore, Franklin, Fremont, Kootenai, Latah, Lewis, Madison, Nez Perce, Oneida, Power, Teton, and Washington.

The economic impact of dwarf bunt may include reductions in grain yield and quality, a discount in market price, and market exclusion. In the field, dwarf bunt replaces developing kernels with a smut ball (bunt ball), a kernel-like structure that is filled with fungal spores (see Figure 11) and is easily broken during harvest. After harvest, wheat contaminated with smut balls, smut spores or their fishy odor may be graded "smutty." The loss of export markets for Idaho wheat because of its association with dwarf bunt is significant. Using common harvest, transport, and storage equipment in the Pacific Northwest puts most Idaho wheat at risk for contamination with dwarf bunt spores.

Figure 14. *Wheat plants infected with dwarf bunt (left) and healthy plants (right).*

As with common bunt, symptoms of dwarf bunt become apparent after heading. Immature plants of some varieties respond to dwarf bunt infection by producing additional tillers and small chlorotic (yellow) flecks on expanding leaves. Diagnostic symptoms after heading include one or more dwarfed stems (Figure 14), increased numbers of tillers, and shortened, spreading heads with bunt balls that replace the kernels (see Figure 11). Height reduction of individual stems (Figure 14) may range from 20 to 70 percent. Individual plants may have some or all tillers infected and some or all of their kernels converted to bunt balls. The expanding bunt balls normally are larger than the wheat kernels they replace and force glumes and awns to spread, giving the head a feathered or ragged appearance (see Figure 11).

Dwarf bunt is caused by the fungus *Tilletia controversa* Kühn, from which the name TCK smut originated. Although the dwarf bunt fungus can infect barley, rye, and grasses, its usual host is winter wheat. Infections almost exclusively originate from spores borne in soil rather than on seed. Spores of the fungus are uniquely adapted to germinate at cold temperatures between 40°F and 50°F (5°C-10°C). Infection of developing tillers occurs in unfrozen soil under snow cover. Spores buried deeper in the soil tend to remain dormant until brought near the surface by tillage and other cultural operations. Some spores may lie dormant in soil for ten years or more before being induced to germinate.

The dwarf bunt fungus eventually makes its way to the growing point of the stem where it invades the developing head and kernels. As the infected head matures, the fungus within developing kernels separates into masses of dark spores. At harvest some of the released spores adhere to healthy kernels, others become attached to harvesting and grain handling equipment, while still others are dispersed by air currents to soil and adjacent fields.

The use of dwarf bunt resistant wheat varieties can effectively limit but not eliminate this disease (see Table 4 on page 64). Most soft white winter wheat and many hard red winter wheat varieties adapted to Idaho growing conditions are susceptible in varying degrees to dwarf bunt. Growers should select clean uninfested seed to avoid introducing the fungus to new fields and areas.

Table 2. Effect of seeding date and Dividend® (difenoconazole) seed treatment on the percentage of dwarf bunted heads in winter wheat[1] at selected locations in 1993.

Location	Seeding Date	Untreated Check (%)	Dividend Rates[2] 0.06 (0.25) (%)	Dividend Rates[2] 0.12 (0.50) (%)
Logan, UT	4 Oct	82	0	0
Kalispell, MT	18 Sep	82	1	0
	2 Oct	68	0	0
	15 Oct	40	0	0
Pullman, WA	11 Sep	10	3	2
	5 Oct	2	0	0
Cavindish, ID	21 Sep	93	27	trace
	5 Oct	94	6	trace
	19 Oct	93	0	0

[1]Dwarf bunt susceptible varieties Hatton and Nugaines.

[2]Grams active ingredient per 100 kilogram seed (ounces formulation per 100 pounds seed).

Fungicide seed treatments such as Vitavax 200, Baytan, and Mertect LSP are generally ineffective against dwarf bunt. In contrast, the systemic fungicide Dividend® (difenoconazole) has been highly effective in field trials (Table 2). In addition to limiting disease development in the field, seed treatment fungicides reduce seedborne inoculum and the spread of the fungus on seed.

Deep seeding and early or late winter wheat seeding reduces the severity of dwarf bunt. Winter wheat should not be seeded at depths less than one inch (2.5 cm). Areas of persistent snow cover such as on north slopes or near fences, wind breaks, or other barriers that trap snow should also be avoided.

Heavily smutted wheat should not be harvested, since the harvest operation efficiently distributes dwarf bunt spores on grain, machinery, and in wind currents. Grassy weeds that can harbor the dwarf bunt fungus and other smut fungi should be controlled around field margins. Smut spores from grasses may contaminate healthy wheat at harvest and contribute to lowering its grade, market price, and exportability.

For more information about dwarf bunt consult:

Wiese, M.V. (editor). 1991. *Dwarf bunt (TCK smut) of wheat in the northwest*. Proceedings of Research Review. Pullman, WA. 25 pp.

Sitton, J., et al. 1995. *Dwarf bunt of winter wheat in the Pacific Northwest*. PNW 489. University of Idaho, Oregon State University and Washington State University Extension Service. 6 pp.

Karnal Bunt

Karnal bunt (KB) was reported for the first time in the U.S. (Arizona and California) in March of 1996. It has not been detected in Idaho. It is a minor disease of wheat, durum wheat, and triticale that has had a major impact on U.S. policy and production due to its status as a quarantine disease.

Like common and dwarf bunt, it is spread by spores but, unlike these two diseases, infection occurs after heading. Developing wheat kernels are randomly infected and usually only partially converted to the fungus, which is why KB is sometimes called partial bunt. No toxins are produced, and yield losses are usually negligible. As with other smut and bunt diseases, KB may reduce flour quality, and grain graded as smutty is reduced in value.

Compared to the fungi that cause common bunt (stinking smut), dwarf bunt (TCK smut), and loose smut of wheat, the KB fungus is unique and very difficult to control. Chemical seed treatments used to control other bunt and smut diseases of wheat are not effective for control of KB because there is insufficient chemical in the plant at heading, which is when infection occurs.

Fungicide seed treatments have been used to reduce the spread of inoculum via seed. However, there are only a few fungicides currently registered for use against bunts in the U.S., and none is known to kill KB spores on the seed surface. Registration of fungicides such as PCNB and carboxin + thiram (Vitavax 200 or RTU -Vitavax-Thiram) for use against KB is being sought, since they are reported to inhibit the germination of seedborne KB spores in Mexico.

Currently, resistance in wheat varieties adapted to Idaho is unknown. There are some good sources of resistant germplasm in the CIMMYT (International Maize and Wheat Improvement Center) collection and elsewhere that could be exploited in future breeding efforts. For more information on KB, please refer to the University of Idaho College of Agriculture Current Information Series No. 1067 (a web-only publication available at http://info.ag.uidaho.edu/resources/PDFs/CIS1067.pdf).

Ergot

Ergot is widely distributed on wheat, rye, triticale, and grasses but also can occur on barley and oats. While ergot is not likely to inflict serious yield losses in Idaho, the disease is showy and still draws attention. The ergot fungus produces conspicuous signs (i.e., ergot bodies) and toxic alkaloids in the developing seed head. Ergot is perhaps best known as the cause of illness and death in humans and animals that eat ergoty grain.

Ergot is caused by the fungus *Claviceps purpurea*. It produces purple-black, horn-like ergot bodies ("ergots" or sclerotia) that replace one or more seeds in the head. The ergots protrude from the glumes and may be up to 0.5 inches in length (Figure 15a). After falling to the soil surface or being planted with the seed, they germinate in late spring to produce ascospores that are spread by wind and rain to the open florets of emerged wheat heads. In turn, infected florets form a sticky "honeydew" that contains newly produced spores (conidia) that are readily spread to other florets by wind, rain, and attracted insects. The chances of wheat infection are increased by wet, cool weather that prolongs flowering and by infestations of grassy weeds that may be infected with the ergot fungus.

Figure 15a. *Ergots developed from infected florets and protruding from spikelets. Photo courtesy of Univ. of Wisconsin.*

Figure 15b. *A sample of ergoty wheat seed.*

After harvest, intact and broken ergot bodies are mixed with harvested grain (Figure 15b). Grain that exceeds market tolerances for ergot contamination, whether from infections in wheat or in grassy weeds, is discounted in value and may be toxic if eaten by humans or animals. Ergot bodies from grasses, which are normally smaller and more slender than ergots from wheat, are sometimes totally responsible for contaminating harvested grain.

Ergot can be avoided by the use of seed free of ergot bodies, by crop rotation, and by deep, clean cultivation. Commercial seed cleaning operations normally remove most ergot bodies from seed. Tillage operations that bury sclerotia two or more inches deep prevent spore release. Grassy weeds that may harbor ergot infections should not be allowed to set seed. Rotating wheat with noncereal crops should reduce soilborne inoculum. Where available, wheat cultivars resistant to ergot should be selected. For more information on ergot, consult University of Idaho CIS 145 *Ergot—A Loser for Grain Growers and Livestock Owners*.

Foot Rot (eyespot or strawbreaker foot rot)

Foot rot, also called eyespot and strawbreaker foot rot, is an economically important disease in northern Idaho but rarely causes losses in southern Idaho. It is named for the damage done to the base of wheat plants. Winter cereals are more susceptible to foot rot than spring cereals, and wheat is more susceptible than barley, rye, or oats. Winter grasses also may harbor the disease.

Foot rot causes lesions that may weaken the base of

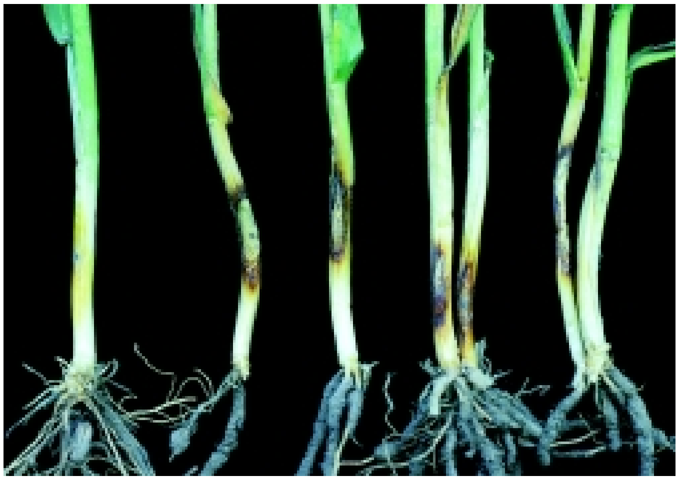

Figure 16. *Foot rot lesions at the base of tillers. Note diffuse lesion margins and greyish centers.*

tillers, causing them to fall in random directions or ripen or die prematurely. Infected tillers typically set smaller and fewer seeds. As harvest approaches, foot rot contributes to areas of lodged wheat, which is difficult and costly to harvest. Mild infections in tillers often go unnoticed since such tillers remain erect and may not prematurely ripen.

The disease is identified by distinctive tannish-brown, elliptical or eye-shaped lesions that develop on stems near the soil line (Figure 16). Such lesions become visible in the spring and may grow deeper and darker during jointing and heading. They may develop to over an inch in length and girdle the stem. At first superficial on outer leaf sheaths, they become especially damaging when they grow deeper and make the culm brittle and easily kinked or broken by wind or other mechanical pressure.

Foot rot is caused by the soilborne fungus *Pseudocercosporella herpotrichoides*. It often produces a dark fungal mass on the surface of stem lesions and a white tuft of fungal growth beneath the lesion within the hollow culm. It makes numerous spores while in living tissue but also when it occupies wheat straw. Such spores are splashed by rain onto the base of developing culms and cause infections during the winter and spring. Infections and lesions develop slowly at cool temperatures and are slowed or stopped under warm conditions. Thus, foot rot is favored by high soil moisture, cool temperatures, a dense crop canopy, early fall seeding, and recurrent winter cereal crops.

Late or thin seeding reduces relative humidity at the soil line and the quantity of susceptible vegetation exposed to infection during winter. Rotations that avoid winter cereal crops for at least two years reduce inoculum levels in soil. Local winter wheat varieties are not highly resistant but some like Madsen and Hyak have moderate levels of resistance to the disease. Registered fungicides may be applied in the spring to slow developing lesions and protect other tissues from infection. The fungus, however, is variable and may show resistance to fungicides such as benomyl, thiophanatemethyl, or thiabendazole.

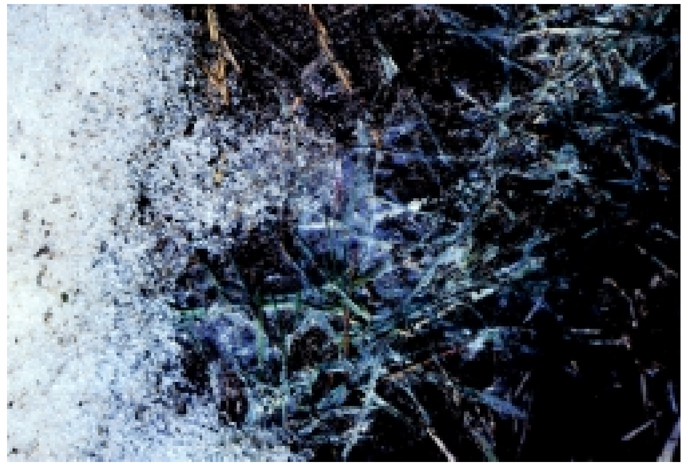

Figure 17. *Melting snow reveals snow mold-infected wheat. Note cottony fungus growths on leaves.*

Figure 18. *Wheat leaves killed by speckled snow mold. Black spots on leaves are fungal bodies (sclerotia).*

Snow Molds

Snow molds are caused by fungi that grow in high moisture conditions at or near the soil surface beneath snow cover. In such environments, winter cereals such as wheat, rye, and barley and several grasses are susceptible to infection and damage by snow molds. Ironically, snow cover protects plants from freezing and desiccation but simultaneously favors the growth of fungi that grow at temperatures slightly above freezing. Snow molds are most damaging where snow persists for long periods above unfrozen ground.

Snow mold symptoms are most obvious as wheat plants emerge from beneath melting snow. On such plants, snow molds appear slimy and thready on living and dead plant parts (Figure 17). Small dark spherical fungal bodies (sclerotia) may be present on the affected tissues (Figure 18). Black spots on leaves are fungal bodies (sclerotia). Dead leaves may have a pink cast. Leaves and other tissues will be variably damaged, wholly or partially necrotic, or rotted. Entire plants may be killed in areas covered by persistent snow, resulting in areas of spotted or thinned spring stands. If crowns are not damaged, plants may recover, produce new leaves, and develop satisfactory grain yields.

Important snow mold fungi that attack winter wheat in Idaho include *Microdochium* (*Fusarium*) *nivale,* which causes pink snow mold, and *Typhula* spp., the cause of speckled snow mold. These fungi are nonspecific pathogens that may occur alone or in combinations. They all persist in association with wheat residues and other host debris. They may form specialized structures for survival in soil apart from growing plants.

Wheat varieties with tolerance to snow molds (Survivor, Blizzard, and Bonneville hard red wheats and Sprague and John soft white wheats) are available but none show a high level of resistance (Table 4). Seed treatment with registered fungicides affords partial protection but post-seedling leaves in contact with soil are difficult to protect. Rotating winter wheat with spring crops reduces snow mold inoculum. Fertilizer application should be managed to permit good crown development but avoid lush foliar growth in autumn. Hastening snow melt by applying ash or coal dust in February decreases snow cover and snow mold injury and has improved yields in some cases.

Rusts

Rust diseases occur in all wheat-producing regions of Idaho. Named for the dry, dusty, rust-like pustules that erupt through infected plant tissues, they are among the oldest, most widespread, and destructive wheat diseases known.

Three distinct rust diseases occur on winter wheat. All are caused by rust fungi (*Puccinia* species) that are readily windborne. Stripe rust is caused by *P. striiformis*, leaf rust is caused by *P. recondida* f.sp. *tritici*, and stem rust is caused by *P. graminis* f.sp. *tritici*. All three of these rust fungi have complex life cycles and require living host plants to survive and multiply. All three rust diseases have two distinct development stages on wheat. A "red" or "uredial" stage produces spores (urediospores) that infect other wheat plants in the same growing season. A "black" or "telial" stage produces spores in late summer or autumn that are not infectious to wheat.

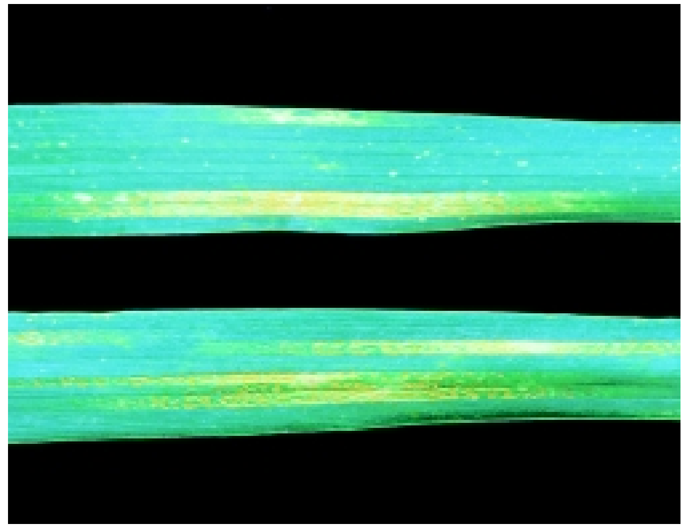

Figure 19. *Stripe rust infections on wheat leaves.*

Urediospores are most important in damaging wheat. They can be carried long distances by wind and can rapidly spread rust diseases over large production areas. Rust urediospores usually do not overwinter in Idaho, but are readily blown in from other regions. The use of resistant varieties, control of alternate host plants, and the use of foliar fungicides are control measures for managing rust diseases in wheat. Early detection of rust diseases is important to minimize their impact on yield and crop quality.

Stripe Rust - Stripe rust is the most common cereal rust disease in Idaho, attacking wheat, barley, rye, triticale, and several grass species. Oats are immune to stripe rust. Stripe rust reduces wheat yield, test weight, and grain protein.

Clusters of stripe rust infections form long, yellow, narrow stripes on leaves (Figure 19) and leaf sheaths, and smaller pustules may form on glumes and awns. Urediospores are released from these yellow lesions and infect other wheat plants, especially under conditions of cool, mild temperatures, intermittent spring rains, and heavy dews interspersed with bright sunny days. The stripe rust fungus persists through the summer on volunteer cereal grains and late season grasses and overwinters on grasses, wheat, and volunteer grains. Stripe rust urediospores may survive locally during mild winters if the tissue in which they are produced also survives.

Wheat varieties resistant to stripe rust (Table 4) should be selected for seeding. Where resistant varieties are not available, registered foliar fungicides may be applied to control the disease (Table 3). Protectant fungicides are less costly than systemic fungicides, but are not recommended for stripe rust control due to the systemic nature of infection.

Leaf Rust - Leaf rust affects wheat, rye, and triticale. It will occasionally occur on barley, while oats appear immune. Leaf rust appears as small, oval-shaped, brick-red pustules on the upper surface of leaves and leaf sheaths (Figure 20). Leaf rust pustules develop in random patterns based on spore deposition and do not cluster in parallel stripes like stripe rust. Development is favored by warmer, dryer weather than that which favors stripe rust. Thus, leaf rust usually does not appear until late in the cropping season. Leaf rust also persists through the summer months on volunteer grains. Significant yield losses can occur when leaf rust infects young plants or when late-maturing susceptible varieties are grown.

Many wheat varieties are resistant to leaf rust (Table 4). Foliar fungicides effective against stripe rust also may be registered for control of leaf rust (Table 3). Since leaf rust usually occurs late in the growing season, fungicide applications are usually not cost effective.

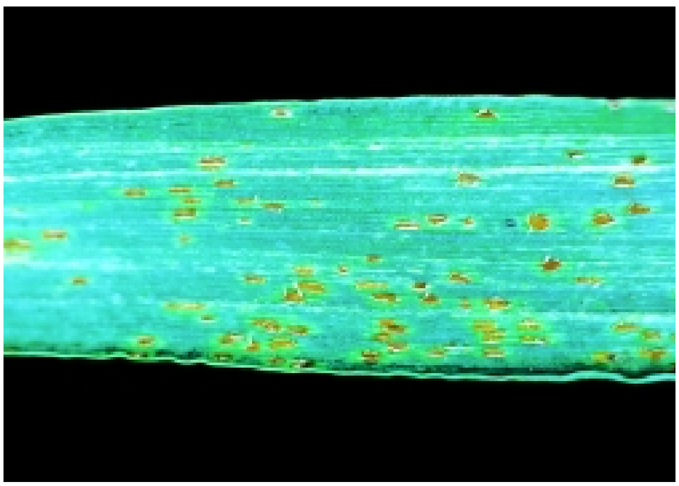

Figure 20. *Wheat leaves with signs and symptoms of leaf rust.*

Stem Rust - Stem rust occurs on wheat, rye, triticale, and barley. It first appears as oval, reddish-brown pustules on wheat leaves and stems, although all aerial portions of the plant are susceptible. Stem rust pustules are larger but similar in color to those of leaf rust. They also tend to occur most frequently on leaf sheaths and stem tissue. Stem rust pustules develop on both surfaces of infected leaves and possess very ragged edges compared to leaf rust pustules (Figure 21). The life cycle of the stem rust fungus is completed on common barberry (Berberis species), which serves as an alternate host.

Figure 21. *Stem rust infections on leaves and sheaths.*

Table 3. Guide for foliar fungicides registered for use on wheat in Idaho. Strictly follow label directions when using commercial formulations.[1]

Fungicide	Rates (a.i./acre	Foliar rusts: Stripe	Foliar rusts: Leaf	Foliar rusts: Stem	Powdery mildew
Protectant					
Mancozeb (Dithane®, Manzate®, and Penncozeb®)	1.6 lb		X		
Systemic					
Triadimefon (Bayleton®)	1 to 3 oz				X
	2 to 4 oz	X	X	X	
Propiconazole (Tilt®)	1.8 oz	X	X	X	X
Benomyl (Benlate®)	0.125 to 0.25 lb		X		X
+	+				
Manzate 200®	0.8 to 1.6 lb				

[1]X indicates registered for use of disease control within the range of labeled application rates.

Like leaf rust, stem rust is favored by warm weather and typically develops late in the growing season. Many wheat varieties are resistant to stem rust (Table 4). Most foliar fungicides effective against stripe rust and leaf rusts will also control stem rust (Table 3).

Powdery Mildew

Powdery mildew is a disease that affects the foliage and heads of wheat. White, cottony patches of the powdery mildew fungus (*Erysiphe graminis* f. sp. *tritici*) initially form on the upper surfaces of lower leaves (Figure 22). These generally occur under conditions of high moisture and relative humidity. These showy colonies may spread to all aerial portions of the plant. With time, these cottony patches turn dull gray or brown and develop fruiting structures (cleistothecia) that appear as dark specks embedded in the colonies.

Powdery mildew damages plants by utilizing plant nutrients, destroying leaf surfaces, reducing plant photosynthesis, and increasing plant respiration and transpiration. Dense stands, heavy N fertilization, lush growth, high humidity, and cool temperatures favor disease development.

Powdery mildew frequently occurs but rarely causes economic losses in wheat in Idaho's relatively dry climate. Losses associated with powdery mildew infections are usually not great enough to warrant fungicide applications. Systemic foliar fungicides such as Bayleton® and Tilt® are registered for the control of powdery mildew (Table 3), but their use is usually not cost-effective unless they are used to control other diseases such as stripe rust. Crop rotation and clean cultivation can reduce powdery mildew inoculum associated with crop debris on the soil surface. Abundant airborne spores and warm, moist conditions often limit the benefits of cultural control practices, however. Some wheat varieties show good resistance to powdery mildew.

Figure 22. *Colonies of powdery mildew on wheat sheaths. Tan to black colored spots in colonies on center stem are fruiting structures (cleistothecia) of the fungus.*

Rhizoctonia Root Rot

Since first recognized and reported in the United States in the 1980s, Rhizoctonia root rot is now known to occur throughout the Pacific Northwest but tends to go unnoticed unless roots are carefully examined. The *Rhizoctonia* fungus is active in the top layers of soil where it persists on roots and plant residues. It acts in subtle fashion to prune, rot, and inactivate rootlets, thus weakening the plant and accentuating drought and nutrient stress.

Photo courtesy of R. J. Cook.

Figure 23. *Roots affected by Rhizoctonia root rot exhibit spear tips and constrictions.*

Rhizoctonia root rot is rarely severe enough to kill plants outright. In rare cases when it is severe, distinct patches of stunted, lodged, or white-headed plants appear. Most plants respond to the disease by developing new roots and outgrowing it. However, under magnification, those plants will have root ends that appear reddish brown. Many such roots will darken and taper abnormally to a point, often referred to as "spear point" (Figure 23). Elsewhere on roots, lesions are usually small and isolated.

Rhizoctonia root rot is caused by the soilborne fungus *Rhizoctonia solani* that produces no spores. It grows on plant residues in soil, making large colonies of heavy white to brown fungal threads. It also makes compact masses of fungal threads called sclerotia that allow it to survive apart from live hosts or organic debris. It persists widely in soil where it utilizes nutrients from organic debris. Virtually all wheat plants are exposed to infection. Damage from this widespread disease in Idaho is usually slight, highly variable, and dependent on environmental conditions.

Wheat varieties resistant to Rhizoctonia root rot are not available. Crop rotations are only marginally beneficial because the fungus has a broad host range. Providing environmental conditions that promote root growth will limit its effects. One practical control practice is tillage to disturb the fungal network in soil and promote the decay of organic debris. Rhizoctonia root rot is favored by practices that keep soils cool and moist. Seed treatments with registered fungicides may offer partial protection.

Take-All

Take-all is a soilborne disease that especially affects irrigated wheat produced under recrop conditions. The take-all fungus infects the crown region and roots of the plant. Severely diseased plants are stunted, ripen prematurely, and exhibit distinctly bleached heads. Pulling severely infected plants from soil reveals crown rot, severely pruned feeder roots, and a shiny black appearance of the lower stem surface sometimes referred to as "black stockings" (Figure 24). The greatest yield losses due to take-all often occur in the second, third, and fourth years of continuous wheat or barley production.

Fungicides are not available for control of the take-all fungus (*Gaeumannomyces graminis* var. *tritici*). Rotation with non-host crops such as alfalfa and other broadleaf crops is an effective means of control. A one-year break in wheat cultivation is sufficient to reduce soilborne inoculum levels but will not eliminate the take-all fungus. Tillage operations that disturb crop residues and encourage decomposition limit survival of the take-all fungus in the soil.

Delayed fall seeding reduces the incidence of take-all. Adequate N fertility is important to encourage root and crown development, but the N form used can influence infection levels. Nitrate-based fertilizers favor take-all infection more than ammonium or urea fertilizers. Fertilizers containing chloride (i.e. ammonium chloride, potassium chloride) limit take-all in other wheat-producing regions. Similar chloride effects on take-all may also be exhibited in Idaho.

A phenomenon called "take-all decline" may also occur. After increasing in severity for the first two to five consecutive years of wheat production, take-all diminishes to low levels in subsequent crops. The decline is a form of biological control suspected to be caused by a buildup of microorganisms antagonistic to the take-all fungus. Take-all decline will persist only if continuous wheat crops are grown, and the field is not rotated to non-host crops.

Figure 24. *Wheat roots and lower stems affected by take-all. Leaf sheaths are stripped from two tillers on right.*

Scab

Scab or head blight infects wheat, barley, oats, and other small grains. It has been a serious problem in parts of Canada and the United States for more than 50 years but occurs only infrequently in southern Idaho. The last serious epidemic in southern Idaho occurred in 1984 and caused estimated yield losses up to 50 percent in individual fields. During the 1990s in the north-central U.S., scab has risen to be one of the most prominent and economically important wheat diseases.

Scab is caused by several species of the Fusarium fungus. The disease is characterized by the appearance of beige to tan or brown colored spikelets occurring before normal maturation (Figure 25). Part or all of the head may be affected. Salmon pink to orange patches may be seen on diseased heads and necks. These colored patches are the spores and fungus threads (mycelium) of the causal agent and are diagnostic for scab. The fungus may also produce toxins (i.e., mycotoxins) that adversely affect animals and humans.

The pathogen overwinters in infested small grain cereal and corn residues as mycelium and spores. Spores from these sources are the primary inoculum for infecting wheat heads. In the presence of moisture, they germinate and invade the flower parts, glumes, and spikelets. Infection occurs most frequently and is most serious at flowering (anthesis), which occurs about five to ten days after head emergence. Extended periods of wet, humid conditions and moderate temperatures (72°F -78°F) favor disease development. Symptoms may develop in three or four days under favorable conditions.

Control recommendations are limited and inadequate. No known resistant wheat varieties are commercially adapted for cultivation in southern Idaho. No fungicides (perhaps with the exception of mancozeb) are registered for scab control. Crop rotation and moldboard plowing are recommended to decrease primary inoculum. Since infection requires moisture during flowering, the disease is more prevalent under sprinkler irrigation than under rill irrigation. Therefore, sprinkler irrigation during flowering should be avoided, if possible.

For more information about scab, consult:

Mihuta-Grimm, L. and Forster, R.L. 1986. *Scab of Wheat and Barley.* University of Idaho College of Agriculture Current Information Series No. 783.

Figure 25. *Scab-infected wheat heads. Note tannish-colored glumes which have died prematurely.*

Diseases Caused by Nematodes

Nematodes are very small unsegmented roundworms that inhabit soil and water. Most nematodes are nonparasitic, but two species feed on wheat roots in Idaho. Nematode feeding causes direct plant injury and exposes developing roots to other soilborne pathogens that would otherwise have minimal impact on wheat crops. The economic impact of these nematodes on wheat is not fully known.

Cereal Cyst Nematode The cereal cyst nematode (*Heterodera avenae*) was first identified in Oregon in 1972 and has since been identified in southern Idaho. It reproduces by producing numerous eggs within the body of the female that swell to form a cyst. Such cysts may lie dormant in soil for many years. Cysts and eggs are spread in windblown soil, on contaminated equipment, in waste irrigation water, and on seed potato tubers. The nematode is most damaging to wheat grown in sandy soils and where large populations of cereal cyst nematodes exist. Where cereal cyst nematode damage has occurred, wheat and other small grains should be grown as infrequently as possible in rotation with broadleaf crops. Grassy weeds such as wild oats and ryegrass can sustain cereal cyst nematodes and should be controlled. Chemical nematicides are effective but may not be economical unless other soilborne pests are also controlled.

Columbia Root Knot Nematode The Columbia root knot nematode (*Meloidogyne chitwoodi*) parasitizes wheat but is not known to cause economic losses in Idaho wheat. A closely related species, the northern root knot nematode (*M. hapla*), also occurs in Idaho but does not reproduce on wheat. Chemical nematicides are not recommended for controlling root knot nematodes in winter wheat unless their application benefits other rotation crops in subsequent years.

Table 4. Disease reactions of winter wheat varieties.

Hard Red Varieties

	Common Bunt	Dwarf Bunt	Leaf Rust	Stripe Rust	Stem Rust	Flag Smut	Ceph Stripe	Foot Rot	Snow Mold
Andrews	MR	MR	VS	MR	S	R	S	S	MS
Blizzard	R	R	MS	MS	S	R	-	S	MR
Bonneville	R	R	MR	R	-	S	S	MR	R
Boundary	R	MS	MR	R	-	-	-	R	MR
Buchanan	MR	S	MS	MR	-	R	-	S	MR
Deloris	R	R	MR	R	-	-	-	-	MR
DW	R	R	R	R	-	-	-	MR	MR
Gary	R	R	MR	MS	-	-	-	MS	R
Golden Spike	R	R	MR	R	-	-	-	-	MR
Hatton	MR	S	S	S	S	R	S	S	MR
Jeff	R	MS	MR	R	S	-	S	-	S
Manning	R	R	S	R	R	-	MR	S	MS
Meridian	MR	MS	MR	MS	R	-	S	S	MR
Neeley	R	S	S	MR	R	-	S	S	S
Promontory	R	MR	MR	R	R	-	MR	S	S
Survivor	R	MR	S	MS	S	-	S	S	R
Utah 100	RR	MR	S	R	-	-	-	S	MR
Wanser	R	S	MS	MS	-	VR	MR	-	S
Weston	R	MR	MS	MR	R	R	-	S	MS

Soft White Varieties

	Common Bunt	Dwarf Bunt	Leaf Rust	Stripe Rust	Stem Rust	Flag Smut	Ceph Stripe	Foot Rot	Snow Mold
Basin	R	MR	MS	MR	R	R	MR	-	S
Brundage	S	S	S	MS	R	-	S	S	MS
Bruhle	MR	MR	MR	R	-	-	MR	MR	R
Cashup	R	S	MR	MR	R	R	MR	-	S
Daws	R	S	MS	MR	S	MS	S	S	S
Eltan	R	MR	MS	MR	S	-	MR	S	MR
Gene	S	S	MR	MR	-	MS	-	-	S
Hill 81	R	S	MR	MR	S	MS	MR	S	S
Hyak	MS	MS	MR	MR	R	S	MS	R	S
Kmor	R	MS	MS	R	S	-	MS	MS	S
Lambert	S	S	-	R	-	-	MS	S	MR
Lewjain	R	R	MS	MR	S	MS	MR	MS	MS
MacVicar	S	S	MS	MR	-	-	-	-	S
Madsen	R	MS	R	R	R	MS	MS	R	MS
Malcolm	R	S	MR	R	S	MS	S	MS	S
Moro	R	MR	S	S	S	MR	MS	S	MS
Rely	MS	S	R	MR	S	VS	MS	MS	S
Rod	R	S	MR	R	S	-	S	S	MS
Rohde	MR	S	MS	R	-	-	R	S	S
Sprague	R	MR	MS	MS	S	MS	MS	S	R
Stephens	R	S	MS	R	S	MS	S	MS	S
Tres	MS	S	MS	S	S	VS	MS	S	S

* Under conditions of severe disease pressure, percent infected heads may go up to 4%

VS = very susceptible S = susceptible MS = moderately susceptible MR = moderately resistant
R = resistant VR = very resistant - = information not available

Harvest and Storage

R. J. Veseth and L. D.Robertson

Management of a winter wheat crop for optimum health and production potential must continue through harvest. There are several factors to consider both during and after winter wheat harvest.

Moisture Content

Moisture content is critical in preventing preharvest and postharvest losses. To minimize preharvest losses, winter wheat must be harvested before wind causes shattering under dry conditions or rain causes sprouting in the head. The grain must be dry enough for safe storage, preferably less than 12 to 12.5 percent moisture by weight. If moisture content is higher than this, the grain must be dried prior to storage. The general recommendation is to thresh at moistures not greater than 20 percent and to dry with air not exceeding 110°F (43°C), especially if the wheat is to be used for seed, since higher temperatures can damage germination.

Combine Settings

Combines must be properly adjusted to minimize combine harvest losses and to avoid cracking the grain, which invites greater damage from storage molds and insects. Grain left on the ground, either because of shattering or improper combine adjustments, represents grain that cannot be sold as well as a source of future volunteer plants to host diseases and insects. Straw and chaff must be spread as uniformly as possible to reduce problems in planting and performance of the following crop (see section on management considerations for conservation tillage systems).

Minimizing Losses from Shattering and Sprouting

The first step in minimizing losses from shattering and sprout damage is to choose the appropriate variety of wheat for your area. Harvesting at the ideal time and moisture content can reduce shattering and sprouting, but this is often beyond the grower's control. Wheat can be harvested at a moisture content higher than what is recommended, but this grain will have to be dried before or immediately after it is placed in the bin. A second option for dealing with wet wheat is swathing and allowing it to dry in windrows on the stubble. Once the grain has reached the maximum-weight phase of grain fill (see growth and development section), the wheat can be swathed with no loss of yield. The grain is at physiological maturity by this stage, but the plant is still alive and has considerable moisture in the straw as well as in the grain. Swathing speeds the drying process for the plant and grain.

Minimizing Cracking and Combine Losses

Final combine adjustments to minimize cracking and combine losses must be made in the field, several times each day and in each new field. The tendency for kernels to crack or thresh out varies by day and even by time of day, depending on the moisture content of the grain and straw. Threshability of the grain also varies by wheat variety and by weed population. Late-season green weeds may require swathing or a preharvest burndown herbicide.

Critical adjustments on the combine include cylinder speed, fan speed, reel speed, and ground speed. The cylinder speed and concave clearance should thresh but not crack the grain. The fan speed should be adjusted to blow out chaff but not grain. Avoid header losses (broken heads) by setting the reel speed and cutting height to leave as much standing stubble as possible. Adjust ground speed to set the rate of straw feed to the straw walkers to optimize harvest efficiency. Initial adjustments should be made as close to the manufacturer's operator manual as possible, but final adjustments should be based on the actual field performance of the combine.

Growers can accurately measure and monitor combine losses, including shattering, header losses, leakage from the combine, and losses out the rear of the combine, by following a few simple steps. With the straw spreader disengaged, harvest a short strip of typical grain, then stop and let the combine clean out. Mark the rear of the header (position B in Figure 1) and in front of the rear wheels of the combine (position C in Figure 1), then back

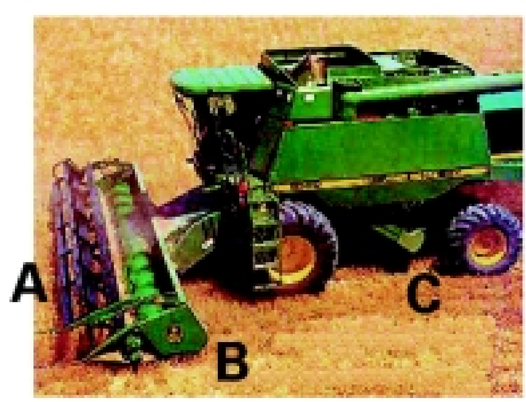

Figure 1. *Combine positions used to determine types of harvest losses.*

the combine to expose this strip. The actual losses and reason for these losses can be estimated by the location and the amount of grain on the ground.

Header losses can be distinguished from shattering by comparing the number of kernels and heads on the ground in the standing grain at position A, which represents loss from shattering, to the number at position B, which is header loss plus shatter loss. Count the number of kernels on the ground and in broken heads on the ground in at least five one-foot-square areas of standing and harvested grain at position A and B, then average the numbers for the respective areas. The one-foot square areas should be uniformly spaced across the header swath.

Assuming an average kernel weight of 30 mg, and a 60 lb/bu test weight, every 20 kernels/ft^2 is the equivalent of one bushel per acre. For lighter-weight grain, e.g., an average kernel weight of 25 mg, every 25 kernels/ft^2 on the ground is equivalent to one bushel per acre. For grain weighing in excess of 40 mg per kernel, from irrigated fields and varieties that produce large seed, 15 kernels/ft^2 is the equivalent of one bushel per acre.

Header losses usually indicate that either the reel is revolving too slow or too fast, or it is too high or low above the cutter bar. The reel should be eight to twelve inches in front of the cutter bar and should turn about 25 percent faster than the ground speed of the combine. For wheat that has lodged, a pick-up reel will minimize header losses. Stripper headers have been shown to be particularly effective in harvesting lodged grain. Both stripper headers and air reels generally reduce harvest grain losses and improve harvest efficiency compared to the traditional reels.

Growers can evaluate combine leakage by examining the grain on the ground between position B and C. The previous estimates of losses from shattering and damage from the header will indicate kernels already lost before the grain went into the combine. Concentrations of kernels in small areas indicate major leaks from the machine.

Improper fan speed adjustment may be responsible for grain loss. Kernels on the ground behind the combine may indicate that too much air is preventing the grain from settling through the chaffer and sieve. Too little air can cause the chaffer to clog with chaff and straw so the grain cannot settle out. Losses from the rear of the combine can also indicate that there is too much straw for proper separation. Unthreshed heads in the straw behind the combine may indicate that the cylinder speed and/or concave setting should be adjusted for better threshing, or that the grain is not ripe and is too wet to harvest.

Some varieties are more difficult to thresh cleanly. Growers should regularly check for unthreshed heads and whitecaps (pieces of heads where the glumes did not separate from the grain kernel) and make needed adjustments to improve grain cleanliness and combine efficiency. Environmental conditions during grain development and maturation will also influence ease of threshing.

Storage Management

The benefits of managing for optimal health and productivity of the wheat crop and harvesting with the highest possible efficiency can be lost if the grain deteriorates in storage because of molds or insects. Management of the grain must continue until the wheat is removed from storage.

The hazards to grain during storage, including molds, insects, loss of weight, and chemical changes, are all related directly or indirectly to higher moisture or temperature of the grain. Grain deterioration in storage can be minimized or prevented altogether by keeping the grain dry, cool, and free from insects. Grain moisture content should be 12 percent or less. Air should be below 50°F, and preferably lower. Every effort should be made to eliminate all sources of grain-storage insects from old grain left in the bin or grain auger or other sources. Even a few insects harbored in the bin or introduced with the grain can lead to a serious infestation over time, given the right conditions. Bins should be checked for insects and mold at least every two to three weeks, and more frequently during periods of large temperature fluctuations.

It is almost impossible to have a bin of grain with uniform moisture content. Consequently, aeration is the safest way to reduce both grain moisture in the bin and to reduce grain temperature. For additional information on grain storage, see University of Idaho CIS 518 *Maintaining Stored Grain Quality.*

Winter Wheat Production Costs and Budgeting

P. E. Patterson and R. L. Smathers

Wheat producers struggle with the same problem that all businesses face: how to best allocate their limited resources of land, labor, and capital as they attempt to develop or maintain a profitable farming operation. Resource allocation decisions are made in a dynamic economic environment where profit margins are thin if they exist at all. Poor management decisions can threaten the economic viability of the farm, especially given the high levels of production and price risk in agriculture. Knowing your cost of production will not guarantee a profit, nor will it eliminate risk. But costs and returns estimates will provide important information that can help you to better manage your operation. The terms cost of production, costs and returns estimates, and budgets will be used interchangeably in this section.

Costs and Returns Estimates

Commodity costs and returns estimates (CARs) are used to characterize the economic performance of a single commodity for an individual producer, a region, or even a nation. The intended use of a CAR estimate will influence the cost and revenue calculations and how this information is organized. Data availability will also influence the process. Even when CAR estimates are prepared for the same intended use, there can be differences of opinion as to which costs to include, how the costs should be calculated, and even how the costs should be organized. To reduce the chance of misinterpretation, the procedures, assumptions, and intended use of the CAR estimate should be clearly stated.

CAR estimates can be constructed using either historic or projected data. Cost data can be from actual farm records, or it can be synthesized or "generated" for a model farm using a standard set of assumptions and procedures. Growers who want to develop accurate cost of production estimates need to keep this use in mind as they develop their recordkeeping system. Even with detailed enterprise accounting, certain costs will still be tracked only on a whole farm basis. These whole-farm costs will need to be allocated to different enterprises, an issue that will be discussed later.

Enterprise Budgets

Budgeting is a systematic approach to organizing revenue and cost data used in comparing and analyzing alternatives and in making management decisions. Once prepared, budgets provide a useful benchmark for comparing what actually happens. Budgets provide revenue and cost estimates or projections and they should be an integral part of any planning process. It is certainly cheaper to "farm paper" and to identify and solve problems before the resources are committed.

An enterprise is any coherent portion of a farm business that can be separated and analyzed as a distinct entity. Traditionally, each crop is treated as a separate enterprise. Different enterprise designations can be made, however. Each field or pivot, for example, could be treated as a separate enterprise. The record system for the farm would have to be organized with this in mind, however, so that the account structure would support the enterprise structure. The crop enterprise budget tracks one production cycle—usually a 12-month period—and lists all expected revenue and costs per acre. The enterprise budget can also include the quantity, time of use, and cost of each input, along with the expected yield and price.

An enterprise budget can provide the base information needed to develop three other budgets used in farm management: whole farm, cash flow, and partial. They are also useful in developing marketing plans, negotiating lease agreements, negotiating for credit, and evaluating adjustments in the farming operation. Controlling and monitoring costs is important to a business. But you can only control and monitor what you can measure. The enterprise budget provides the needed measurements.

Idaho's Costs and Returns Estimates

Understanding the procedures used by the University of Idaho will help you understand the potential uses and limitations of these cost estimates. It should also help if you choose to modify these costs to fit your situation.

The University of Idaho's crop CAR estimates are revised and published on a biennial basis in odd-numbered years. Crop CAR estimates are developed for four distinct geographic regions of the state. These include: northern, southwestern, south-central and eastern Idaho. Climate and soil conditions not only influence which crops are produced in each region, but also influence the crop-specific production practices for the regions. Even within a region where production practices are similar, costs can and do vary from farm to farm. Each farm has a unique set of resources with different levels of productivity, different pest problems, and different management skills. While the CAR estimates developed by the University of Idaho serve as useful benchmarks, they represent only a single point estimate that cannot possibly capture the inherent variability that exists in production costs. The University of Idaho wheat production cost estimates are representative or typical for a region. They are NOT the average cost of producing wheat.

The University of Idaho cost of production estimates are affected by the assumptions made in depicting a representative farm for a region. Each region has a model farm (or farms), with assumptions about farm size, crop rotation, typical production practices, equipment used, and irrigation system.

The production costs published by the University of Idaho are based on survey data collected from Idaho farmers, farm supply businesses, and extension faculty, as well as private consultants and industry representatives. Information on tillage, planting, fertilization, pest control, irrigation, and harvesting is collected from growers. In addition to the type of machinery and the number of workers used to perform field or custom operations, the type and quantity of inputs used are also collected. Survey information is used to construct a model farm and to develop typical production practices that are replicated by the computer program to generate costs on a per acre basis.

The University of Idaho currently produces nineteen wheat budgets (see Table 1). A sample budget for eastern Idaho dryland winter wheat production (hard red) is shown in Table 2. This can serve as an example of what should be included in an enterprise budget. Copies of wheat and other crop costs and returns estimates are available from local county extension offices. They are also available on the Internet at the Agricultural Economics and Rural Sociology Department's homepage: http://www.ag.uidaho.edu/aers/ (click on Resources).

Budget Procedures and Assumptions

Historical input prices are used to generate the University of Idaho's costs and returns estimates. Input prices come from surveys of farm supply businesses collected in the year when the CAR estimates are revised. The commodity prices used in Idaho's crop CAR estimates are generally the long range planning prices developed by the Department of Agricultural Economics and Rural Sociology. The wheat price is a ten-year average for the marketing year (July-June). Commodity prices used in the CAR estimates are specific to the region, not statewide averages. The price in the hard red winter wheat budget in Table 1 approximates the 11 percent protein price. A background and assumptions page for each budget describes the key assumptions used in developing the costs and

Table 1. Idaho 2001 wheat costs and returns estimates by region.

Region		Market Class	Farm Size (acres)	Wheat (acres)
Northern:	Rain fed	Soft white spring	1,500	500
	Rain fed	Soft white winter	1,500	500
Southwestern:	Irrigated	Soft white spring	1,000	250
	Irrigated	Soft white winter	1,000	250
Southcentral:	Irrigated	Hard red spring wheat	1,500	500
	Irrigated	Soft white spring wheat	1,500	500
	Irrigated	Soft white winter wheat	1,500	500
Eastern	Irrigated	Hard red spring	1,500	1,000
	Irrigated	Hard white spring	1,500	1,000
	Irrigated	Soft white spring wheat	1,500	1,000
	Irrigated	Soft white winter wheat	1,500	1,000
	Rain fed: low	Hard red winter	3,000	1,400
	Rain fed: low	Soft white winter	3,000	1,400
	Rain fed: low	Hard white spring wheat	3,000	1,400
	Rain fed: high	Hard white spring wheat	2,100	1,900
Blaine/Lincoln Counties				
	Irrigated	Soft white spring wheat	600	200

Table 2. Costs and returns estimate for 2001 eastern Idaho dryland winter wheat (hard red).

	Quantity per Acre	Unit	Price or Cost per Unit	Value or Cost per Acre
Gross Returns	40	cwt	$3.35	$134.00
Operating Costs				
Seed:				
Wheat seed – HRW	60	lb	$0.15	$ 9.00
Fertilizer:				
Nitrogen – pre-plant	20.00	lb	$0.33	$ 6.60
P2O5 – pre-plant	15.00	lb	$0.20	$ 3.00
Sulfur – pre-plant	10.00	lb	$0.10	$ 1.00
Nitrogen – post-plant	30.00	lb	$.33	$ 9.90
Custom:				
Custom fertilize	1.00	acre	$4.50	$ 4.50
Custom combine	1.00	acre	$15.00	$ 15.00
Custom haul	40.00	bu	$0.15	$ 6.00
Pesticide:				
2,4-D Ester (LV6)	0.50	qt	$5.45	$ 2.72
Banvel SGF	0.20	qt	$11.40	$ 2.28
Other:				
Crop insurance	1.00	acre	$2.00	$ 2.00
Labor (machine)	0.84	hrs	$11.70	$ 9.79
Labor (non-machine)	0.07	hrs	$6.90	$ .48
Fuel - gas	0.70	gal	$1.51	$ 1.06
Fuel – diesel	5.47	gal	$1.07	$ 5.85
Lube				$ 1.04
Machinery repair				$ 4.50
Interest (operating cap.) 7.5%				$ 4.16
Total Operating Cost per Acre				$ 88.88
Operating Cost per Bushel	Based on 40 bushel			$ 2.22
Cash Ownership Costs				
General Overhead				$ 3.03
Land rent				$ 24.00
Management fee				$ 6.70
Property Insurance				$ 0.44
Total Cash Ownership Costs per Acre				$ 34.17
Non-Cash Ownership Costs				
Equipment depreciation and Interest				$ 18.01
Total Non-Cash Ownership Costs per Acre				$ 18.01
Total Costs per Acre				$141.06
Returns to Risk				$ -7.06
Total Costs per Bushel				$ 3.53

returns estimates. These assumptions include a description of the model farm's size, water source, and crop rotation, and the tillage, fertilization, and pest management practices. The machinery, labor, land, and capital resources used in the production of the crop are also described. This information is critical to understanding how the costs are generated, and the uses and limitations of these cost estimates.

The yield in a CAR estimate is used to calculate gross revenue. It can also be used to calculate breakeven prices needed to cover various costs. The yields used in most crop budgets are five-year rolling averages based on historical data from the Idaho Agricultural Statistics Service.

A computer program called *Budget Planner* from the University of California at Davis is used to calculate the cost estimates. The computer program replicates each field operation using tractors and equipment typical of that used by producers. The cost to own and operate machinery is computed by the program and summarized for the model farm. *Budget Planner* calculates machinery costs and labor requirements using standard engineering equations developed by the American Society of Agricultural Engineers. For more information refer to PNW 346 *The Costs of Owning and Operating Farm Machinery in the Pacific Northwest*.

The CAR estimates produced by the University of Idaho are based on economic costs, not accounting costs. Accounting costs typically include only out-of-pocket costs and ignore opportunity costs. Economic costs place a market value on all inputs, regardless of whether they are purchased (an out-of-pocket expense) or provided by the producer (a foregone opportunity). For resources supplied by the farmer, such as land or labor, there is foregone income, or an "opportunity cost." For example, a farmer who owned his own land could lease it to someone else and the farmer could be working for wages.

Enterprise Budget Structure

Crop costs and returns estimates are developed on a per acre basis, providing a common production unit for making comparisons between different crops. Gross returns or revenue is the first category in an enterprise budget. While it seems obvious, units for price and yield should correspond. Wheat yield can be measured in hundredweight, tons, or bushels, so the price should be expressed in the same units. If storage costs are not included, then a harvest-time price should be used. The price should correspond to the actual or assumed time of sale.

Costs in an enterprise budget are classified as either operating (variable) or ownership (fixed). Operating costs are those incurred only when production takes place and they are typically used up or transformed during the production cycle. Seed, fertilizer, fuel, pesticides, hired labor, and water are all operating costs. With the exception of labor and machinery costs, it is relatively easy to assign operating costs to a particular crop enterprise. It is also fairly easy for growers to modify the operating costs in a published CAR estimate to match those on their own farm.

In contrast to operating costs, ownership costs are associated with assets used in the production process that last for more than one production cycle. Many of these costs will continue even when production doesn't take place, hence the term "fixed cost." Ownership costs include the DIRTI-five: Depreciation, Interest, Repairs that are a function of time and not of use, Taxes, and Insurance. Assets generating ownership costs include machinery, buildings, and land (although land is not depreciated). In addition to lasting more than one production cycle, these assets are typically used on more than one enterprise. There are a number of different procedures that can be used in allocating these costs over time and among different enterprises (crops) on the farm.

Many growers find it more cost effective to use a custom operator than to own all the equipment or to supply all the needed labor. A fee paid to a custom operator is classified as an operating cost. Where the cost appears on a CAR estimate differs when growers perform the service themselves. The custom charge includes machinery costs that would be classified as ownership costs if the grower owned the equipment and provided the service. This can make a significant difference when comparing only operating costs or only ownership costs, especially when one CAR estimate uses owner-operator costs and another CAR estimate uses custom-based costs.

Operating costs

The CAR estimates published by the University of Idaho lists all inputs used in the production process. This makes it easier for users to modify these costs estimates to fit their situation and it also makes it easier to update and revise the cost estimates. The individual operating inputs are listed along with the quantity applied, the unit of measure, and the cost per unit of input. The quantity applied is multiplied by the price per unit to get the cost per acre. This is a fairly straightforward process for most operating inputs, especially purchased inputs. The computer program used to calculate production costs does place certain constraints on how inputs are classified or the sequence in which they appear on the printed copies. Similar inputs are grouped together under a common heading. These headings include fertilizers, pesticides, seed costs, and custom operations.

All the items listed below the "Other" category, except interest, are either for labor or for machinery operating costs. Unlike growers who typically do not track labor for individual crops, the simulation approach used by the computer program calculates and accumulates machinery hours associated with each field operation based on the equipment's width, speed, and field efficiency. Refer to UI Bulletin 729 *Custom Rates for Idaho Agricultural Op-*

erations for more information on calculating machinery hours. Machine labor is calculated by multiplying the machine hours by 1.2. This accounts for time spent getting equipment to and from the field as well as time spent servicing equipment. Machine labor is calculated for all tractors, trucks, and self-propelled equipment. A market value is attached to all labor. No distinction is made between hired labor and unpaid family labor. The non-machine labor is the category name given by the program for the less skilled workers used during planting and harvesting who do not operate machinery. The hourly labor charge includes a base wage plus a percentage for Social Security, Medicare, unemployment insurance, transportation, and other expenses. The overhead charge applied to the base wage used by the University of Idaho amounts to 15 percent for non-machine labor, 25 percent for irrigation labor, and 30 percent for machine labor.

Machinery operating costs include fuel (gas and diesel), lube, and machinery repairs. All these values are calculated by the computer program using equations derived by the American Society of Agricultural Engineers. Refer to PNW 346 *The Cost of Owning and Operating Farm Machinery in the Pacific Northwest* for more information on calculating machinery costs. Most producers track fuel and repair costs for the entire farm. The allocation of these whole farm expenses to specific crops can be made using a number of allocation schemes. Growers should use or develop a scheme that is both simple and reasonably accurate.

The last item listed is interest on operating capital. Producers use a combination of their own money and borrowed money and would only pay interest on what they borrow. But since the University of Idaho's cost estimates are based on economic costs, no distinction is made as to the source of the capital. A market rate of interest is charged against all expenditures from the month the input is used until the harvest month.

Calculating or allocating operating costs

The type of accounting system used will determine how easy or difficult it is to derive enterprise specific costs. Many producers have accounting systems that are designed to merely collect the cost information required to fill out IRS Schedule F (Form 1040). Most growers do not use enterprise accounting and it is not worth the effort to use enterprise accounting if the additional information available is not used for management decisions. The question is how does the value of the information gathered compare to the cost of keeping separate enterprise accounts. A sophisticated enterprise accounting system will have only limited value if the invoices from vendors do not provide the necessary detail needed to allocate the costs. Even without an enterprise accounting system it is possible to develop reasonable, easy-to-use allocations for the different costs.

Costs like fuel or labor are always going to present a problem unless you log each machine operation and worker by field, an unlikely scenario. Until you develop something specific to your operation, you might use the values in published enterprise budgets as proxy values or to calculate a percentage for allocation. Using the University of Idaho southeastern Idaho budgets, for example, fuel use per acre in potato production is roughly 2.5 times the amount used to produce an acre of wheat. If the total fuel bill for your 1,200-acre farm was $21,200, and you grew 400 acres of potatoes and 800 acres of grain, 44.4 percent of the fuel should be allocated to the grain and 55.6 percent to potatoes, or roughly $9,413 and $11,787, respectively. On a per acre basis for grain this comes to $11.77. You might allocate general farm labor using the same method, or even the same percentages.

Fertilizer, machine repair, interest on operating capital, and many other inputs may have to be allocated using an arbitrary allocation system unless you develop an enterprise accounting system. While a percentage allocation may not be as precise as an enterprise accounting system, it is better than making no attempt to allocate expenses to specific crops and it may be your best alternative.

Ownership costs

Ownership costs cover depreciation, interest on investment, property taxes, insurance, and repairs that are a function of time and not of use. Ownership costs are based on the initial value of the asset, which is generally the purchase price. While a farm has records to show the value of depreciable assets, what value should be used when a model farm is constructed? For many years the University of Idaho used 100 percent of the replacement cost for new machinery and equipment, resulting in much higher ownership costs than the average producer. Currently, a value of 75 percent of replacement cost for new machinery and equipment is used to calculate ownership costs.

When discussing ownership costs, a distinction should be made between tax depreciation and management depreciation. Depreciation is a measure of the reduction in value of an asset over time. For tax purposes, depreciation is spread over the tax life of an asset as defined by the Internal Revenue Service. Management depreciation, in contrast, spreads depreciation over the expected useful life. The tax life of most farm equipment is currently defined as seven years. The useful life could easily be ten to twenty years. Management depreciation is used by the University of Idaho and should be used by farmers in constructing enterprise budgets. For growers, this means keeping two depreciation schedules.

An interest charge based on the value of the equipment should also be calculated. It makes no difference whether the money is borrowed or supplied by the grower. In the first instance the interest charge would be an actual cash expense. In the second, the interest calculation is a non-cash opportunity cost. The money could have been invested elsewhere, so the cost to the grower is the foregone income from this alternative investment.

The Budget Planner software used by the University of Idaho uses the capital recovery method to calculate the depreciation and interest on machinery. The total for all equipment used in wheat production is listed as Equipment under the Non-Cash Ownership Costs (Depreciation and Interest).

Taxes and insurance are the other two ownership costs. In the University of Idaho costs and returns estimates, insurance is based on the average level of investment. The average level of investment is calculated by dividing the sum of the purchase price and the salvage value by two. Idaho eliminated property taxes on farm equipment in 2001, so there is no property tax shown in the CAR estimate. The annual insurance cost for each piece of equipment is calculated and then allocated to the appropriate crops based on the percentage of use.

For equipment that is used 100 percent on wheat, all the ownership costs are assigned to wheat. But certain equipment, such as tractors and trucks, are used in producing other crops as well. The ownership costs for this equipment needs to be allocated to the different enterprises in proportion to their use. This means that the ownership costs will not be simply divided by the total farm acres. For example, while the farm may have twice as many acres of grain as potatoes, the potato crop may account for half the ownership costs for trucks and tractors based on use.

Unlike other capital assets, land is not a depreciable asset, according to the Internal Revenue Service. And unless the land is being farmed in such a way as to degrade its productivity, excessive erosion for example, the land should last forever. But money invested in land could be invested elsewhere. To avoid the issue of whether land is owned or leased and to be consistent with calculating economic costs, the land cost in University of Idaho crop budgets approximates a one-year cash rent.

Two costs not related to land or equipment also show up as ownership costs. The first is general overhead. This is calculated at 2.5 percent of cash expenses and serves as a proxy for general farm expenses that are not typically assigned to a specific enterprise. This includes such things as legal fees, accounting and tax preparation fees, office expenses, and general farm utilities. The second non-land and non-equipment expense is the management fee. This is an opportunity cost and it is a residual in many costs and returns estimates. Because we choose to include a management fee as an economic expense, all costs are accounted for except returns to risk. The management fee is calculated as 5 percent of gross returns.

Calculating ownership costs

While not as precise as the capital recovery method, calculating depreciation on a straight-line basis over the years of useful life is certainly appropriate. This should be done for each piece of equipment. In a similar vein, interest can be calculated on the average level of investment.

Calculating annual ownership costs may be time consuming, but it is not difficult. The purchase price minus the expected salvage value gives total depreciation. Depreciation should be spread over the years of expected life to get annual management depreciation. If the machine is used exclusively for one crop, the entire amount is allocated to that crop. The annual depreciation can then be allocated on a per acre basis by dividing by the number of acres of that crop. If the machine is used on more than one crop, then part of the annual depreciation needs to be allocated to each crop. This value is then spread over the relevant acres.

For example, two 12-foot grain drills that cost a total of $20,000 are expected to last ten years and have a $3,000 salvage value.

Annual Depreciation = (Purchase Price – Salvage Value) ÷ Useful Life

Annual Depreciation = ($20,000 - $3,000) ÷ 10 or $1,700

If the grain drills are used on 1,000 acres, the annual per acre management depreciation is $1.70.

Calculating annual depreciation for a tractor on this farm could follow the same procedure. The annual depreciation should be allocated to the different crops based on the hours the tractor is used on each crop. Since most farms do not track machine time to specific crops, an approximation (informed guess) will suffice. The crop specific depreciation can be allocated per acre in the same manner used for the grain drills.

While the interest on investment calculation is slightly different, the allocation procedure to the different crops on which the machine is used is the same. Interest should be calculated on the average level of investment, or the purchase price plus the salvage value divided by two.

Average Investment = (Purchase Price + Salvage Value) ÷ 2

Using the grain drill example:

Average Investment = ($20,000 + $3,000) ÷ 2, or $11,500

The interest rate can either be what is charged on a machinery loan or what you could earn on that money if invested in an alternative investment. Using a 10 percent interest rate, the annual interest charge would be:

Annual Interest = Interest Rate x Average Investment

Annual Interest = .10 x $11,500, or $1,150

Again, this can be allocated on a per acre basis.

The remaining ownership costs, property taxes and insurance, can be the actual costs taken from records and allocated to the appropriate equipment, or they can be calculated costs using an insurance rate and tax rate applied to the average investment as calculated previously. While these costs can most easily be allocated equally per acre across the farm, they can also be allocated using a weighting scheme based on the relative use of equipment among crops. The trade-off in choosing between different allocation and calculation methods is often between time and precision. Try to find a method that minimizes the time involved and yet provides a reasonably accurate estimate.

Using the Enterprise Budget in Marketing

Marketing is an important function, but one given little attention by many producers. Market or price risk for most agricultural commodities is significant. While producers cannot influence the market price, they can influence the price at which they sell and the level and type of price risk they face. More information on price risk and marketing can be found in the Marketing section of this production guide.

Even though farmers are price-takers, there are two important questions they should ask themselves when they are developing enterprise budgets. First, given these costs, what yield do I need to break even? And second, given this yield, what price do I need to break even? Breakeven analysis and sensitivity analysis are two procedures that can answer these questions.

Breakeven Analysis – Calculating breakeven price or yield levels requires access to reliable enterprise budgets. Breakeven price (BeP) can be calculated as follows:

BeP = Costs ÷ Expected Yield

Breakeven prices can be calculated for just the operating costs, just the ownership costs, or for the total costs. The breakeven price needed to cover the total costs shown in Table 2 follows:

BeP = $141.06 ÷ 40 = $3.53

With an expected yield of 40 bushels per acre, it would take a selling price of $3.53 to cover all the production costs shown in Table 2. Substituting in just the operating or ownership costs per acre would result in breakeven prices of $2.22 and $1.30 per bushel, respectively. In the short run, a grower need not cover all of the production costs. But if the grower does not have a reasonable expectation of covering at least the operating costs, then production should not occur. If opportunity costs are used to insure that all resources receive a market value, then a grower can get less than a breakeven price and still be profitable. The grower would, however, be receiving less than a market return for his labor, management, or equity capital. The cost data can also be categorized as cash and non-cash. At a minimum the cash costs need to be recovered in any year. Non-cash costs such as depreciation, return on owner equity, labor, and management can be deferred.

Breakeven yields can also be calculated. Estimating a breakeven yield is especially important when the crop is contracted at a specific price. Breakeven quantity (BeQ) can be calculated as follows:

BeQ = Total Costs ÷ Contract Price

A grower signing a $3 contract would need a yield of approximately 47 bushels to cover the total costs shown in Table 2:

BeQ = $141.06 ÷ $3.00 = 47 bushels

Sensitivity Analysis — Sensitivity analysis allows you to vary two factors simultaneously, rather than just one, as in breakeven analysis. It can be useful to construct a table with a range of values for both yield and price as shown in Table 3. A range in values above and below the expected price and yield should be used, since the future often fails to meet our expectations. While the mechanics can be a little tedious, the process can be simplified by using a spreadsheet program once the enterprise budget is developed. The University of Idaho CAR estimates include a price/yield sensitivity analysis similar to that found in Table 3. Table 3 shows the net returns over operating costs, ownership costs, and total costs based off the eastern Idaho hard red winter wheat enterprise budget found in Table 2.

Summary

There is no single cost of wheat production that fits all Idaho growers or even growers in one region. Cost of production is influenced by all factors that determine the productivity of land, the quantity and type of resources used in the production process, and the alternative uses for these resources. Growers should develop and maintain cost of production estimates for all enterprises on their farms. Modifying published cost of production estimates may be a useful starting point, but growers should ultimately develop production cost estimates specific to their operation. The usefulness of any cost of production estimate depends on its accuracy, and its accuracy depends on the reliability of the underlying data.

Table 3. Sensitivity analysis of net returns to price and yield for eastern Idaho hard red winter wheat.

	Price per bushel				
Yield/Acre	$2.70	$3.00	$3.35	$3.70	$4.00
Return over operating costs					
20 bushel	-7.88	1.12	11.62	22.12	31.12
35 bushel	5.62	16.12	28.37	40.62	51.12
40 bushel	19.12	31.12	45.12	59.12	71.12
45 bushel	32.62	46.12	61.87	77.62	91.12
50 bushel	46.12	61.12	78.62	96.12	111.12
Return over ownership costs					
30 bushel	28.82	37.82	48.32	58.82	67.82
35 bushel	42.32	52.82	65.07	77.32	87.82
40 bushel	55.82	67.82	81.82	95.82	107.82
45 bushel	69.32	82.82	98.57	114.32	127.82
50 bushel	82.82	97.82	115.32	132.82	147.82
Return over total costs					
30 bushel	-60.06	-51.06	-40.56	-30.06	-21.06
35 bushel	-46.56	-36.06	-23.81	-11.56	-1.06
40 bushel	-33.06	-21.06	-7.06	6.94	18.94
45 bushel	-19.56	-6.06	9.69	25.44	38.94
50 bushel	-6.06	8.94	26.44	43.94	58.94

Additional Reading

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Marketing

P. E. Patterson, L. D. Makus

Marketing is more than just selling wheat. Marketing decisions begin before planting rather than after harvest. Deciding which market class or variety to grow is the first part of marketing. Unfortunately, marketing is also a frustrating activity for many producers. There is no one "best" or "recommended" marketing strategy that fits all growers, or even one that fits a specific grower from year to year. Marketing is a complex activity because there are many alternatives and markets change constantly.

Markets are influenced by a wide variety of economic variables that are influenced by uncertain forces like human behavior, international politics, and weather conditions around the world. Marketing should be viewed as an inexact science, and marketing activities must be adjusted as conditions change. The challenge is to approach marketing decisions with careful planning and analysis, rather than reacting with emotion, particularly in times of rapid change.

Using a Marketing Plan

A useful tool to help avoid marketing mistakes is the marketing plan. A marketing plan is a written course of action that improves your chances of selling at a time that meets your marketing goals. The plan allows quick response to changing market conditions because alternative courses of action have already been considered. The plan should be viewed as a map to help guide decision-making with flexibility for responding to a change in the market. A marketing plan will help manage the risk associated with unpredictable grain prices. The marketing plan must, however, be part of an overall farm plan that outlines the financial and personal goals of the farm manager and the manager's family.

A marketing plan is only as good as the information used in the plan's development. All the available marketing alternatives, the conditions under which each alternative tends to perform best, and how each alternative is affected by changes in market conditions need to be evaluated. Each alternative tends to have distinct advantages and disadvantages, depending on market fundamentals and the overall direction of the market. Market forces that influence prices will need to be examined. Understanding and evaluating price outlook is important when comparing marketing alternatives. Historical data on supply, demand, stocks, and price can provide insight into market behavior.

Although there is no specific format for a marketing plan, the plan should answer four basic questions:

1. What should I produce?
2. When should I sell?
3. Where should I sell?
4. How should I sell?

In addition to answering the four basic questions, a marketing plan should have the following features:

Realism: Wishful thinking can be fun at times, but it just doesn't belong in a marketing plan. Evaluating price outlook is an important way to include realism in a marketing plan.

Flexibility: The plan must be flexible enough to allow response to changing market conditions. Flexibility suggests that in marketing, change is the normal situation rather than the exception.

Specific Objectives: Clearly stated and specific objectives demand action when a certain event takes place. Marketing objectives should be evaluated based on whether they are specific enough to demand action.

Compatible with Review: The review may take place daily in volatile markets, and will always happen at least annually.

Custom Design: The marketing plan must fit within the overall goals of each operation. Each manager views risk differently, markets different commodities, and needs a plan designed to meet his or her specific situation.

Refer to *Developing a Grain Marketing Plan* by Russell and Hanson for more specific information on how to develop and use a marketing plan.

Marketing Alternatives

Successful grain marketing means selecting the best marketing alternative. Complexity, level of assumed risk, impact of major changes in the market, and expected price will vary among alternatives. Even though there may be constraints that limit the alternatives, advantages and disadvantages of all potential choices should be considered.

Cash Market Based Marketing Alternatives

Sell at Harvest:

Grain is sold for cash at harvest, minimizing handling charges and eliminating the inconvenience and cost of storage. Grain is delivered to a convenient cash market and the price at harvest is accepted.

Advantages

1. No costs or inconvenience associated with storage.
2. No accumulating interest costs.
3. Easily understood.
4. Price is known immediately and price risk is eliminated.

Disadvantages

1. Shortens marketing period to only a few weeks out of the entire year.
2. Harvest price is frequently the year's lowest.
3. Tends to limit a careful evaluation of alternative cash markets.
4. Congestion at elevators.

Storing for Later Sale:

Grain is placed in either on-farm or commercial storage after harvest. Your grain is then sold based on some guideline (for example, an acceptable market price or when there is a need for cash).

Advantages

1. Extends time period to make a pricing decision.
2. Increases delivery flexibility (stored on farm) or increases delivery convenience (stored commercially).
3. Offers some potential to obtain a return for storage.

Disadvantages

1. Quality may deteriorate.
2. If stored commercially, decreases delivery flexibility.
3. Increases costs (interest costs and commercial storage fees or on-farm storage costs).
4. Exposure to adverse price changes during the storage period.

Cash Forward Contract:

A cash forward contract is a legal agreement to deliver a fixed quantity and grade of wheat, at a specified price, and at a specified location. Premiums and discounts for grade, protein, and moisture are generally specified, as are the penalties for noncompliance.

Advantages

1. Extends time period to make a pricing decision.
2. Eliminates the risk of an adverse price or basis change.
3. Easy to understand and available in convenient quantities.
4. Not necessary to hold a futures position and maintain a margin account.

Disadvantages

1. Increases production risk since delivery is an obligation.
2. Reduces profit potential. Elevators usually hedge forward contracts with futures. There may be more profit potential if you hedge directly.
3. Reduces flexibility to change your marketing strategy if market conditions change.

Delayed (Deferred) Pricing Contract:

Grain is delivered to a commercial elevator and sold at a price to be established at some time in the future. Generally, pricing must occur by some agreed date. Price is usually tied to the local posted bid or an established differential from a terminal bid (for example, 65 cents off of Portland). A partial payment may be received at delivery and storage fees may be eliminated or reduced. Failure by the farmer to establish a price by the agreed date generally means the elevator sets a price on the termination date or as agreed to in the contract.

Advantages

1. Extends time period to make a pricing decision.
2. May eliminate or reduce commercial storage costs.
3. Cash availability if contract has an advance payment at signing.
4. Can contract in convenient quantities.

Disadvantages

1. Increased costs including interest and any storage fees.
2. Bankruptcy risk since the grower becomes an unsecured creditor.
3. Exposure to adverse price changes until the grain is actually priced.
4. Potential for repayment of some of the advance if price drops substantially.

Basis Contract:

Producer delivers grain to the elevator and agrees to sell before a specified date at a specified amount above or below a designated futures price (or basis). The contract generally specifies the relevant futures contract (for example, Kansas City December Wheat) along with the amount of the basis. A partial payment may be made on delivery and storage costs may be waived or reduced.

Advantages

1. Extends time period to make a pricing decision.
2. May reduce commercial storage costs.
3. No risk of an adverse basis change.
4. Can contract in convenient quantities.
5. Cash available if partial payment is made.

Disadvantages

1. Interest cost of holding crop and storage fees.
2. Bankruptcy risk since the grower becomes an unsecured creditor.
3. Exposure to adverse price changes until the grain is actually priced.
4. Potential for repayment of some of the advance if price drops substantially.

Futures and Options Based Marketing Alternatives

Hedging with a Futures Contract:

Grain is still sold in the traditional local cash market. An appropriate amount of futures contracts is sold (wheat futures contracts are available in 1,000- or 5,000-bushel increments) to offset the current or expected cash market position. The futures positions are "bought back" when the wheat is sold on the cash market. The initial sale in the futures market can be pre-harvest or post-harvest and can even take place before planting. The net price received by the grower is a combination of the cash market and futures market transactions. Generally, what is lost or gained in one market is offset by a gain or loss in the other market. Whether a price objective is achieved depends on one's ability to predict basis. Additional information on using futures markets in grain marketing is discussed in CIS 1089 *Understanding Commodity Futures and Options for Grain Marketing* by Makus and Patterson.

Advantages

1. Extends time period to make a pricing decision.
2. Risk of an adverse price change is eliminated.
3. Generally a very liquid market, allowing the producer to reverse positions quickly.

Disadvantages

1. Risk of an adverse change in basis.
2. Margin requirements increase interest costs and may cause cash flow problems.
3. Contracts are in fixed increments of 1,000 or 5,000 bushels.
4. Requires understanding of futures markets and basis relationships.
5. Eliminates gains from rising prices.

Using an Options Contract:

Grain is still sold in the traditional local cash market. Put options are purchased that are converted to money (if they have value) when the grain is sold on the cash market. Otherwise, the options are allowed to expire. The options are for a position in the futures market, so they are in 1,000- or 5,000-bushel increments. A put option can be exercised (giving the producer a short position in the futures market) as a means to obtain the option's value. However, if an option has potential value through exercising, the market recognizes this value and the option can just be sold. The net price the producer receives for the grain is a combination of the cash market and options market transactions. Options allow the producer to establish a minimum price without giving up all of the gain in a rising cash market. The ability to predict basis determines whether the price objective is achieved. The amount paid for the price protection (the premium) is known at the time of purchase. Unlike hedging with a futures contract, there is no margin account to maintain. Additional information on using options in grain marketing is discussed in CIS 1089 *Understanding Commodity Futures and Options for Grain Marketing*.

Advantages

1. Extends time period to make a pricing decision.
2. Risk of an adverse change in price is eliminated.
3. Producer obtains some of the gain from rising prices.
4. Eliminates margin requirements.
5. Generally a very liquid market, allowing the producer to quickly reverse positions.

Disadvantages

1. Risk of an adverse change in basis.
2. Cost of options (premium) may be greater than the value of the price protection.
3. Options sold in fixed increments of 1,000- and 5,000-bushels.
4. Requires understanding of options, futures market, and basis.
5. Data are substantial and can be confusing.

Producing Alternative Market Classes of Wheat

Keep in mind the marketing component of the decision when evaluating variety choices. Recent and anticipated future changes in the farm commodity program mean less support from the government, making the cash market more important. Producing the highest yielding wheat to increase government program benefits may not be the best alternative. Produce wheat for the market, not for the government farm program.

Comparing Historical Prices Using a Seasonal Price Index

Historical information can answer the question, "What should you have grown to make the most money?" However, past information should be used with caution in predicting the future. Markets are dynamic. Supply and demand relationships change constantly. New markets develop and established markets diminish in importance.

While domestic use of Idaho wheat has been increasing in southeastern Idaho, Idaho still exports the majority of its wheat, much of it moving overseas through ports in Washington, Oregon, and California. The local wheat price is highly dependent on these terminal market prices, less transportation and handling. Table 1 shows the average marketing year (July - June) price at Portland for soft white wheat and for different protein levels of hard red winter and hard red spring wheat for the period 1993 through 2002. While all wheat prices tend to move in the same general direction, substantial year-to-year price variation exists among different wheat classes and protein levels.

Expected price movement within the marketing year can help in developing a marketing plan. Commodity prices often follow predictable patterns known as trends, cycles, and seasonal price movements. Trends are general upward or downward price movements that occur over long periods of time. Cycles are regularly occurring price movements over several years that typically reflect supply expansion and contraction. Seasonal price movements are price changes from one month to the next, within a given marketing year.

A seasonal price index is one of the best tools to show seasonal price movements based on historical data. Figure 1 graphs a Portland seasonal price index for soft white wheat that was constructed using the average monthly price indices for the ten marketing years of 1992/93 through 2001/02. A price index is a relative value expressed as percentage of a base price or denominator. The base value (denominator) used to calculate the index should be a seasonal average price for the time frame that matches the price series. The price series could be daily, weekly, or monthly, as is the case with Figure 1. Rather than using the marketing year average price as the base seasonal value, the index graphed in Figure 1 was calculated using a 12-month centered moving average. Instead of dividing the October 2000 price by the 2000/01 marketing year average price to get the index value for that month, the October price was divided by the average of the six monthly average prices that preceded October and the six monthly average prices that followed October 2000. Using a centered or moving average as a base value, while more difficult to construct, will better identify trend factors that might be influencing price.

How many years should be used in constructing a seasonal price index? Ten years is probably the minimum and 25 or 30 years is probably the maximum. Using data too far back in time can bias the index if the market now behaves in a fundamentally different manner. Too few years in the index can also bias the index if the time period chosen represents an aberration. Another thing to consider when constructing a price index is whether to construct a "conditional" price index. In the construction

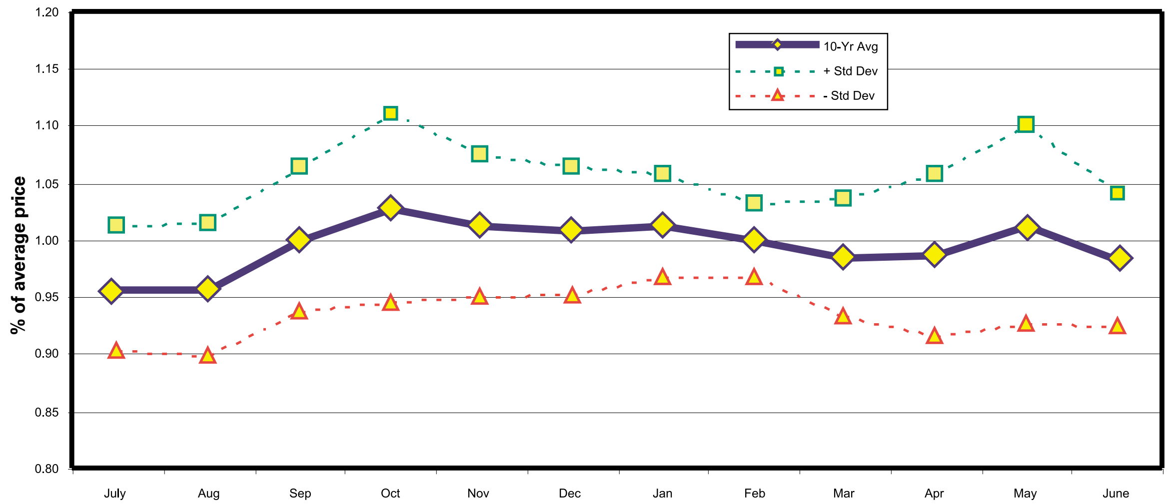

Figure 1. *Portland soft white wheat seasonal price index, 1992-2001*

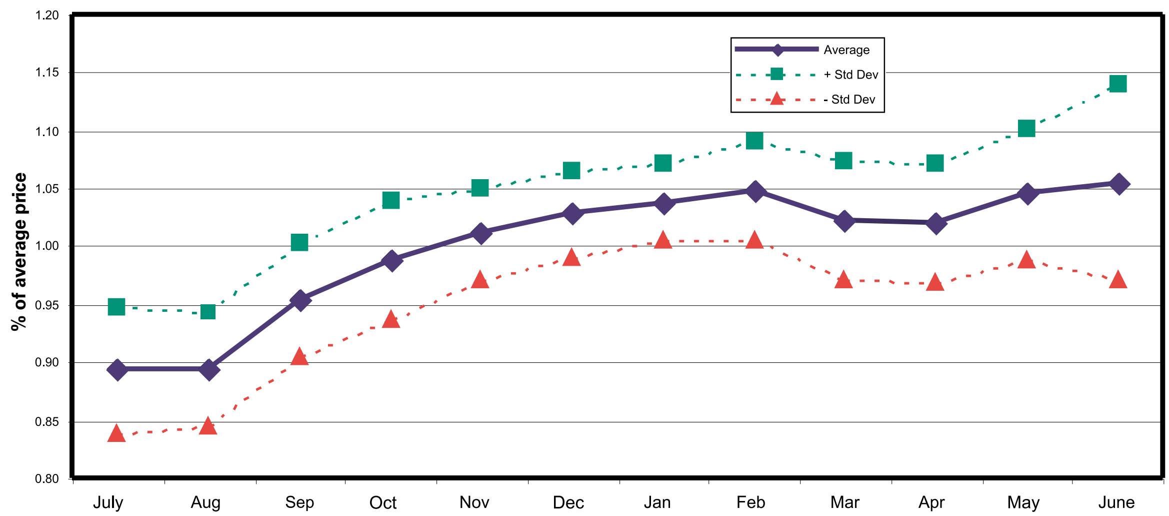

Figure 2. *Portland soft white wheat seasonal price index, short crop years: 1982, 1987, 1988, 1991, 1994, 1995, and 2000.*

of a conditional price index, each year is evaluated according to certain criteria or conditions to determine whether or not that year's data will be included in the index. Figure 1 is not a conditional index. All years from 1992/93 through 2001/02 were included. Marketing years could be classified as short crop or normal crop years, for example, and only those years meeting one of the conditions would be included in the index. In essence there would be two indices, one depicting "normal" crop years and one depicting "short" crop years. Figure 2 shows a "short crop" conditional price index for soft white wheat. Using a conditional price index may give a better indication of seasonal price behavior than combining all the years together. The price index graphed in Figure 2 was constructed using the marketing year average as the base (denominator), not with a centered average. Note that in Figure 1, price peaked in October before starting a long decline that would typically end with a price rally in May before prices again fell. But in short crop years, the price didn't hit its initial peak until February. Following several months of weaker prices, the market would typically rally in the spring and establish a new marketing year high in June. It is important to understand the data used to construct an index as well as the potential uses and limitation of any price index.

In addition to the index values, Figure 1 also graphs a plus one standard deviation and a minus one standard deviation for each monthly price index. The standard deviation is a statistic that measures the variability of the historical data from the calculated average. A small standard deviation indicates that the average index value is a good predictor of price or price behavior, while a large standard deviation indicates a poor predictor, or more variability. Graphing a plus one standard deviation and a minus one standard deviation provides a confidence interval around the average.

Most indices use a base of 100. An index below 100 indicates that the value is below the base price, while a value over 100 indicates that the price is above the base. Price indices reflect the historical data. Figure 1 indicates that on average over the period from 1992 through 2001, the price of soft white wheat peaked in October. The index also shows that if a price rally occurred in the spring, May was the month when it occurred. Figure 1 also shows that October and May have not only the highest price index, they also have the highest standard deviation, which indicates a wider range in prices during these months as well.

For more information on constructing seasonal price indices, refer to *Agricultural Price and Commodity Market Analysis or How to Construct a Seasonal Index.*

Analyzing Alternatives Using Gross Margins Analysis

Gross margin analysis is a procedure used to rank alternative crop enterprises by comparing gross margins. Since this procedure does not use the total cost of production it is only valid for short-run planning decisions. Gross margin analysis provides a relative comparison and does not indicate whether any of the alternatives are in fact profitable, only that one is better than the other. This procedure works best when comparing crops that use the same machinery, for example, barley compared to wheat or hard red compared to soft white. For a more detailed discussion of operating costs and ownership costs, refer to the section on cost of production.

Only three values are used in calculating the gross margin. These are price, yield, and the operating (variable) costs used to produce the crop. Once the gross margin is calculated, alternatives under consideration can be ranked from high to low.

The gross margin formula is shown below:

(1) $GM = GR - VC$, where:

GM = Gross Margin
GR = Gross Revenue, or Price times Yield
VC = Variable Costs

To compare two crops (A and B) and determine at what point the gross margins are equal, the following equation is used:

(2a) $GM_A = GM_B$, or

(2b) $(P_A \times Y_A) - VC_A = (P_B \times Y_B) - VC_B$

If the cost of production for the two crops is equal (a reasonable assumption when comparing different varieties or market classes of wheat), the variable costs can be eliminated from the equation. This simplified or modified gross margin analysis becomes one of comparing only gross revenues, or:

(3a) $GR_A = GR_B$, or

(3b) $(P_A \times Y_A) = (P_B \times Y_B)$

By substituting in the appropriate price and yield information, it is easy to determine which crop to grow from an economic standpoint. However, agronomic factors should not be ignored.

Table 1. Marketing year (July-June) average wheat price by market class and protein level, 1993-2002, Portland.

Market Year	Soft White	White Club	HRW Ord.	HRW 11%	HRW 12%	HRW 13%	HRS 13%	HRS 14%	HRS 15%
1993	$3.55	$3.65	$3.65	$3.75	$4.10	$4.75	$4.60	$5.50	$6.05
1994	$4.25	$4.30	$4.25	$4.30	$4.35	$4.45	$4.45	$4.80	$5.00
1995	$5.35	$5.45	$5.70	$5.75	$5.95	$6.30	$6.10	$6.30	$6.50
1996	$4.45	$4.50	$5.00	$5.00	$5.05	$5.10	$5.00	$5.25	$5.40
1997	$3.65	$3.80	$3.90	$3.90	$4.05	$4.40	$4.35	$4.65	$4.85
1998	$3.05	$3.35	$3.30	$3.35	$3.55	$3.85	$3.95	$4.20	$4.35
1999	$3.00	$3.85	$3.00	$3.15	$3.45	$3.80	$3.65	$4.00	$4.25
2000	$3.05	$3.05	$3.55	$3.65	$3.75	$3.85	$3.85	$4.15	$4.30
2001	$3.60	$3.60	$3.70	$3.70	$3.75	$3.80	$3.95	$4.05	$4.10
2002	$3.90	$3.95	$4.55	$4.60	$4.60	$4.60	$4.85	$4.95	$4.95

Source: Grain Market News, USDA. Values simple averages rounded to the nearest $.05.

Analyzing a Market Class Using Gross Margins Analysis

One of the more useful ways of using gross margin analysis is in developing breakeven prices and breakeven yields for alternative crops that are needed to match a given base crop gross margin. When price and yield for alternative crops are uncertain, breakeven analysis can at least provide the minimum values you need. It's then up to you to figure out whether or not you can reasonably expect to achieve them.

The formula for calculating breakeven price and breakeven yield are shown below. Crop B is the base crop and Crop A is the alternative crop.

$$\text{Breakeven } P_A = (GM_B + VC_A) \div Y_A$$

$$\text{Breakeven } Y_A = (GM_B + VC_A) \div P_A$$

P = Price
Y = Yield
GM = Gross Margin
VC = Variable Costs
A = Alternative Crop
B = Base Crop

Assume your base crop is irrigated soft white winter wheat where your average or expected yield is 110 bushels, your average or expected price is $3.00 per bushel and your expected variable production costs are $215 per acre. If you grow hard red spring wheat, will you generate the same gross revenue? Or another way of viewing this issue is asking what price and/or yield will you need to achieve with the hard red spring wheat to match the $115 gross margin you currently get with soft white winter wheat? Whether you calculate the breakeven price or the breakeven yield may depend on whether you have the greatest confidence in your ability to predict the price or the yield you will get on hard red spring wheat. Assume that your production costs will be $10 higher for hard red spring wheat because of higher seed costs, higher fertilizer costs, and the need to apply an additional herbicide to control weeds on spring planted wheat.

The breakeven price needed on hard red spring wheat to generate the same gross margin as soft white winter wheat, assuming a 90-bushel yield on hard red spring, is calculated as follows:

HRS Breakeven Price = ($115 + 215) ÷ 90, or

HRS Breakeven Price = $3.67

The breakeven yield needed on hard red spring wheat to generate the same gross margin as soft white winter wheat, assuming a $3.40 price per bushel on hard red spring, is calculated as follows:

HRS Breakeven Yield = ($115 + 215) ÷ $3.40, or

HRS Breakeven Yield = 97 bushels

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On-Farm Testing

S.O. Guy and R.J. Veseth

Introduction

This winter wheat production guide presents crop management information about rotation, varieties, seeding, lodging, fertility, pests, harvesting, and crop residue. This information is the current general knowledge available on these topics. However, winter wheat growers must adapt and utilize management techniques that are specific to their unique soil, climatic, management, and cropping program situation. This may necessitate the creation of new techniques and management approaches or adaptation of established practices. On-farm tests allow growers to evaluate new or adapted management practices under their unique growing conditions to make the most profitable management choices. On-farm tests are replicated, randomized evaluations using farm-scale equipment. For a more complete discussion on this topic, see EB1706 *On-Farm Testing: A Grower's Guide* available from WSU Cooperative Extension Bulletin Office (509-335-2857) for $1.00. This 20-page guide to designing and carrying out on-farm testing includes record-keeping forms.

There are two types of on-farm tests:

1) Coordinated regional on-farm tests with one replication per farm. This type of test involves at least four growers in a region. Each grower plants one set of strips of the same comparison(s). Each comparison is considered a replication when the data from all the locations are combined for statistical evaluation. The regional test gives an evaluation of relative performance under different growing conditions in one region. However, a regional test cannot evaluate whether a new technology will work under some growing conditions and not others. Growers are often tempted to look at one set of strips of a regional test and draw conclusions, but it is essential that results from multiple locations are scrutinized together. A regional test needs a coordinator, a role often taken by county extension educators.

2) Multiple replicate on-farm tests. This type of test produces reliable results in a replicated test usually conducted by one grower. This test needs four or more replications close together to minimize differences among replicates. These tests evaluate the performance of a practice for a specific site. However, this type of test is not as practical for evaluating a large number of factors, such as a multiple variety comparison. This multi-replicate test will be presented in the remainder of this chapter (Fig. 1).

Designing an On-Farm Test

In order to fairly evaluate a different production practice, the comparison between the new practice(s) and another practice (often a check or standard) must be constructed to give all practices an equal chance of performing. On-farm tests that use long, narrow side-by-side comparisons reduce variation among treatments and encounter much of the same variation along their length. This arrangement includes the field variability that the practices would ultimately encounter if adopted, but reduces side-by-side variability. Plots should be positioned to avoid biased variation among plots. Biased variation might be encountered if plots are contoured on a slope and varia-

Figure 1. *A multi-replicate test evaluates the performance of a practice for a specific site using four or more replications in the same area.*

tion runs up and down the slope. On leveled irrigated land, different topsoil depth may run parallel to the length of the test plots and give one plot an advantage over another. In this case, place plots perpendicular to soil variation to give the plots equivalent soil variation.

Because growers use their own field equipment to conduct on-farm tests, the plots need to be as narrow as possible, but wide enough to accommodate field practices and to allow harvest. It is best to cut a full combine header width down the middle of each plot. If this is not possible, then a carefully regulated plot width for harvesting is needed.

Number of practices to compare Comparing two to four practices will keep a test simple and manageable. Proper data collection and harvest capabilities dictate evaluation of a low number of practices. A simple, properly executed on-farm test gives more information than a complex but incomplete test.

Strip size Longer strips will usually provide more accurate results. Uniformity trials show that strips 1,000 feet or more in length will give very accurate results. However, in uniform field conditions, strips as short as 300 feet long have given good results. Plot width should be as narrow as practical to allow treatments and fit the equipment needed for the crop and treatments.

Replication Four replications are usually the minimum needed for accurate results from an on-farm test. While it may be tempting to use just three replications, the small added work with a fourth replication can make a large difference in test accuracy. Replications can be located side-by-side or in different locations within a field.

Randomization Treatment order needs to be randomized within each replication. Randomization helps eliminate the potential for bias from growing condition gradients, such as soil types or depth. Even a site that appears uniform has production gradients. Treatments need to be "drawn from a hat" to determine their position within each replication.

Data and records In most tests, yield differences between treatments are the most important data. However, many other conditions or factors that may influence yield should be available from an on-farm test. This necessitates good record-keeping and careful collection of data.

All relevant information about a test should be carefully compiled for later reference. This starts with a field history including previous crops, fertility, chemical applications, and soil tests for the previous three to five years. The layout of the test site is important; a good map can provide all the necessary information. For the period of the test, collect all information about soil tests, tillage, planting, crop protection chemicals, pest infestations, and weather conditions, as well as general observations about the crop.

Yield results provide the basis for production and economic comparisons. Determine yield as accurately as possible. Harvest a combine width of known length from each plot and record the weight and area harvested for each plot. Weighing grain from each plot can be done quickly and easily using truck scales or a weigh-wagon and causes little delay during harvest. Weighing devices are often available from extension educators. On-board combine yield monitors can give good results; the monitors should be calibrated and run carefully on each harvested strip. Often a subsample from each plot is collected when the grain is weighed to test grain qualities such as moisture, test weight, protein content, and impurities.

Many other types of data can be collected for each plot during the course of the test. The design of the experiment and the tester's interest are the only limits to the amount of information that can come from a test.

Analysis of results Nearly all test results will show differences between treatments. However, this variation could be due either to the treatments themselves or it could be caused by inherent test variability that was not due to the treatments. Replication and statistical analysis can help separate these sources of variation and enable the tester to come to a valid conclusion about the results. When there are small differences between treatments, it is difficult to tell if those differences come from variability across the test or from differences caused by the treatments. An aid in determining true differences is the Least Significant Different (LSD) statistic. If differences between treatments are greater than the stated LSD value (often at the 5% level) then treatments are considered "significantly different." This separation statistic shows that there is at least a nineteen in twenty chance that the apparent difference between treatments is due to the treatments themselves rather than experimental variability. However, when treatments are shown to be not significantly different, it does not prove that they are the same. This simply means that under the conditions of this test a difference was not found. Extension educators can perform statistical analysis and help with interpretation of test results. A simple computer statistics program, AGSTAT02, is available from Oregon State University. AGSTAT02 is available free of charge at the STEEP website: http://pnwsteep.wsu.edu/onfarmtesting/index.htm.

Management Considerations for Conservation Tillage Systems

R. J. Veseth, S. O. Guy, L. D. Robertson

Introduction

Selection of tillage and residue management practices for winter wheat and other crops in rotation depends on a number of considerations including production efficiency and profitability, agronomic performance, and effects on the soil resource and environment. Reducing the intensity of tillage and the number of field operations with conservation tillage systems can provide benefits in all of these production aspects.

Grower adaptation of no-till and minimum tillage systems is increasing dramatically in the Pacific Northwest and around the world. Growers, ag support personnel, and the general public share an increasing awareness and concern about soil erosion impacts on cropland productivity and environmental quality. With advances in management and equipment technologies, improved profitability and production efficiency are becoming major incentives for grower adaptation of these systems.

Intensive tillage practices dramatically increase biological decomposition rates and accelerate the loss of soil organic matter faster than it can be replaced with the additions of crop residue. In combination with soil erosion, this has resulted in the reduction of about half of the original soil organic matter content that was present under the native sod. Soil organic matter plays a critical role in soil water-holding capacity, aggregation or "tilth," aeration and internal drainage, resistance to erosion, fertility, biological activity, and many other factors affecting soil quality and productivity. In contrast to the effects of intensive tillage, no-till and other minimum tillage systems offer the potential for increasing soil organic matter content and soil productivity over time.

A few important considerations for tillage and residue management in conservation tillage systems include:

1) A systems approach to winter wheat production under conservation tillage
2) Efficient storage of precipitation for crop production
3) Controlling soil erosion
4) Crop rotation
5) Residue management starting at harvest with the combine
6) Fertilizer placement
7) Equipment considerations
8) Tillage and residue management for variable cropland

Use a Systems Approach to Winter Wheat Production under Conservation Tillage

Successful conservation tillage systems require a whole "systems" approach, that is, looking at your crop rotation and production practices as an interconnected system. Growers need to be aware of how management choices such as crop rotation, residue management, fertility, planting equipment, and many other production aspects can affect control of weeds, diseases, insects, and other environmental stresses, which in turn affect the health and yield of winter wheat and all crops in rotation under conservation tillage. Changing one part of the production system, such as tillage practices, will change other physical, biological, or chemical factors that affect all crops in rotation. The more you are aware of research findings and grower experiences on the effects of different management options for conservation tillage, the better you will be able to develop and maintain successful production systems.

In the 1970s and 1980s, Northwest growers had limited experience with adjusting other aspects of crop production when changing from intensive tillage systems to conservation tillage systems. At the same time, there was limited research-based information available for guidance in this transition. Early attempts frequently ended in failure, usually because of severe weed and/or disease problems. These problems were the result of changing one part of the cropping system—the tillage practices—without adjusting other management options in the new "cropping system puzzle."

Today, prospects for developing profitable, effective conservation tillage systems have greatly improved. Significant advances have been made in crop management and equipment technologies. STEEP (Solutions To Environmental and Economic Problems) and related research projects on conservation farming systems in Idaho, Oregon, and Washington have helped provide management options to many of the earlier production problems. However, the diversity of soils, climatic conditions, crop options, and production practices across the Northwest necessitates continued research and farmer innovation to develop and adapt conservation tillage systems for local production conditions.

Efficient Storage of Precipitation for Crop Production

Water is one of the most important factors limiting winter wheat yields in much of the Northwest, even in the higher precipitation areas. Conservation tillage practices that improve water storage can improve yield potential and profitability. Fortunately, saving water for crop production also means minimizing soil erosion potential.

About 60 to 70 percent of the annual precipitation in northern Idaho usually occurs between October and April. Soil water storage during this period is essential to make effective use of the annual precipitation for crop production. Yearly precipitation patterns are more evenly distributed in southern Idaho, but water conservation principles apply across the region.

Research in the Northwest has shown that crop residue on the soil surface increases capture of precipitation where it falls, enhances infiltration, and reduces evaporation and runoff losses. Important hydrologic processes to consider for improving soil water storage include snow trapping, water infiltration, surface runoff, and evaporation.

Snow Trapping If snow is part of the annual precipitation, maintaining at least some standing crop stubble overwinter can help retain snow. Snow trapping is particularly important on ridges and upper slopes that normally blow free of snow, and water is typically most limiting. Retention of snow would also reduce the formation of snow drifts on the leeward side of ridges. These can reduce yields of winter wheat. Snowbank melt runoff can also cause soil erosion. Snow cover can reduce soil freezing depth and frequency, thus helping maintain infiltration and reduce runoff. Snow cover, like crop stubble, also reduces the potential for winterkill and frost heaving damage.

Infiltration and Runoff One management option to improve infiltration and reduce runoff is to maintain at least a portion of the previous crop's residue on the soil surface. This protects the soil from raindrop impact that can disperse soil aggregates and result in soil surface sealing. Crop residues slow water movement across the soil surface and increase infiltration time. Like snow cover, residue also reduces soil freezing.

A second management option to improve water infiltration and reduce runoff is using tillage to roughen the surface, and fracture and loosen the soil. Surface roughness, like surface residue, slows surface water movement, allowing more time for infiltration. Tillage can also increase the number of large soil pore spaces (macroporosity), which improves water infiltration and drainage, and reduces runoff and evaporation losses.

The importance of tillage on water infiltration and runoff depends on soil compaction, texture, organic matter content, aggregation, freezing depth, and frequency of runoff events on frozen soils. These factors vary across field landscapes and locations, and with field history, and should be carefully evaluated when managing tillage and residue.

Evaporation Evaporative loss of water is relatively low over winter. However, maintaining more crop residue on the soil surface can increase overwinter soil water storage by reducing soil water evaporation and snow evaporation (sublimation). Evaporative water loss is most critical in field areas where water is most limiting.

Water Storage Examples

Soil, management, and climatic factors can influence soil water storage potential. However, understanding the principles that affect water storage – snow trapping, water infiltration into the soil, surface runoff, and evaporation – allows better evaluation of alternative tillage and residue management strategies.

Inland Northwest research projects have shown that overwinter water losses from a bare soil surface, where cereal stubble was removed or incorporated by tillage, can commonly reduce soil water storage by one to two inches or more compared to standing stubble. Fall chiseling or other tillage operations that leave a rough surface and retain surface residue can increase overwinter water storage compared to undisturbed stubble if surface runoff occurs on frozen soils. Without surface runoff on frozen soil or reduced infiltration potential due to soil compaction, tillage usually does not increase overwinter water storage compared to undisturbed residue.

Surface residue and tillage both influence soil water storage and runoff potential. Under some conditions, a combination of surface residue and tillage can increase soil water storage beyond the individual effects of either one. This is particularly important when soils have low infiltration rates due to compaction, or during rainfall or rapid snowmelt on frozen soils.

Figure 1 shows the complimentary benefits of both surface residue and tillage in a 14-inch precipitation zone. The Paratill chisel was used to leave the soil surface and stubble relatively undisturbed while loosening and fracturing the soil to a depth of about 15 inches. A standard

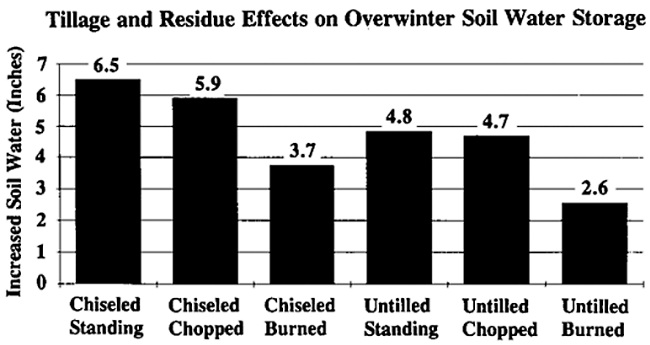

Figure 1. *Increased soil water storage from November through March, 1983-86 under standing, chopped and burned cereal stubble both with and without tillage 15 inches deep with a Paratill chisel 30 miles west of Colfax, WA (PNW Conservation Tillage Handbook Series No. 18, Chap. 3).*

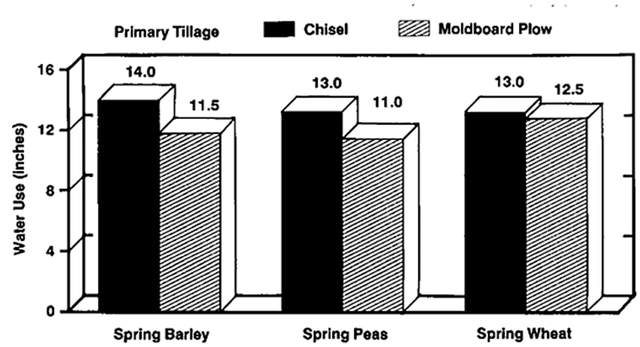

Figure 2. *Comparison of winter wheat water use from April 1 to harvest under chisel-based and plow-based tillage systems after spring crops of barley, wheat, and peas, 1988, Pullman, WA (PNW Conservation Tillage Handbook Series No. 18, Chap. 3).*

chisel with narrow straight points might create a similar water infiltration potential, although evaporative water loss may be higher because of greater soil exposure.

In the three-year study, two years were conducted on spring barley stubble and one year on winter wheat stubble. The *effect of tillage alone* without residue is the 1.1-inch increased water storage between the burned untilled treatment (2.6 inches) and chiseling after stubble burning (3.7 inches). The *effect of residue alone* without tillage is the 2.2-inch increased water storage between the untilled burned treatment and the untilled standing stubble. The *combined effect of tillage and residue* is shown in 3.9 inches increased water storage between the untilled, burned treatment and chiseled standing stubble (6.5 inches). The added benefit of chiseling with residue is shown in the 1.7-inch increased soil water in the chiseled standing stubble compared to the standing stubble. Conversely, the added benefit of residue with tillage is shown in the 2.8-inch increased soil water in the chiseled standing stubble stored compared to burning and then chiseling. Chopping stubble did not significantly change water storage in both tillage situations.

Figure 2 shows another example of the combined residue and tillage influences on soil water storage and crop use. This research was conducted in a 21-inch precipitation zone near Pullman, WA. Minimum tillage systems, with a standard chisel as the primary tillage implement, increased water use by winter wheat grown after spring barley, spring peas, and spring wheat compared to a low-residue, moldboard plow-based system. The minimum tillage system increased winter wheat yields approximately 3 to 15 bushels per acre with the added soil water.

Controlling Soil Erosion

Critical Soil Erosion Periods

A critical period for water erosion in winter wheat production systems in the Pacific Northwest is during the winter precipitation period between October and April. The worst runoff and erosion problems are usually associated with rapid snowmelt, rain on snow, or rain when soils are frozen. Damaging water erosion events can also occur from intense rainstorms in the spring and summer, before crop growth is adequate for erosion protection, and on fallow land. However, these erosion events are less frequent than in other regions of the U.S.

Wind erosion problems also typically occur when the growing crop provides little protection. Critical times for wind erosion vary across the region, but generally occur from August through May, depending on wind patterns in the area, cropping systems, precipitation zone, and other factors.

Residue and Roughness for Erosion Control

When the soil is not adequately protected by a growing crop, control of water and wind erosion is largely dependent on crop residue and soil roughness, along with other supporting conservation practices. Tillage and residue management practices that improve water storage can also minimize wind and water erosion. Management options that reduce the potential for soil erosion by surface runoff include: surface residue, shallow incorporated residue and surface roughness from tillage practices, field strip systems, cross slope or contour farming, and crop canopy cover. Wind erosion control practices include surface residue, surface roughness, crop canopy cover, field strips systems, and wind barriers.

A growing winter wheat crop can help control soil erosion overwinter depending on canopy cover extent and timing of critical erosion periods. However, the effectiveness of crop canopy cover for erosion control is often limited by pest problems associated with earlier seeding dates, and deficient seedzone soil water that delays germination and establishment.

Surface residue and surface roughness are the two most effective erosion control factors and are important components of most conservation systems.

Surface Residue Cover Northwest research has shown that surface residue is highly effective in reducing soil erosion (Figure 3). The surface cover factor on the vertical axis (from 0 to 1) provides an indication of the erosion potential relative to surface residue levels. The highest erosion potential would occur at a factor of 1, with no surface residue, and the lowest potential at 0, with 100 percent surface cover.

Even as little as 30 percent cover can reduce the surface cover factor (that approximates erosion potential) from 1.0 to about 0.2 – an 80 percent reduction in erosion. In contrast, there is limited increased erosion control with increased surface residue cover beyond about 40 to 50 percent cover. This indicates the effectiveness of moderate, manageable levels of surface residue for erosion control.

Surface Roughness Soil surface roughness and increased porosity created by tillage operations can improve soil and water management. Surface roughness slows surface water movement and increases infiltration, reducing runoff and erosion potential. For example, chiseling can improve infiltration potential and slow runoff, while only incorporating a small percentage of surface residue. Surface roughness from tillage has been classified for inclusion in erosion prediction models used by the Natural Resource Conservation Service.

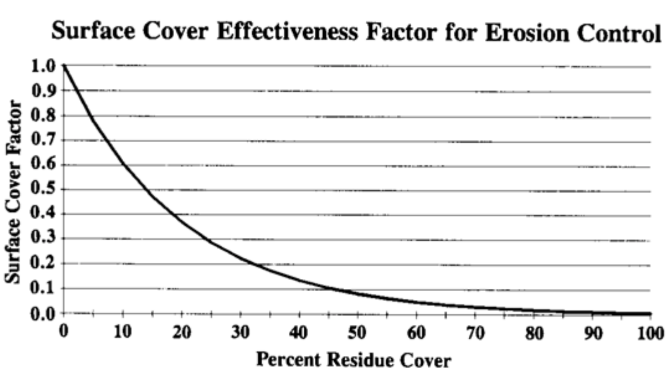

Figure 3. *Surface cover effectiveness factor for erosion control in the Inland Northwest. The surface cover factor approximates the proportionate reduction in soil erosion potential from highest (factor of 1) to lowest (factor of 0) for each percentage increase in surface residue cover. (PNW Conservation Tillage Handbook Series No. 18, Chap. 3)*

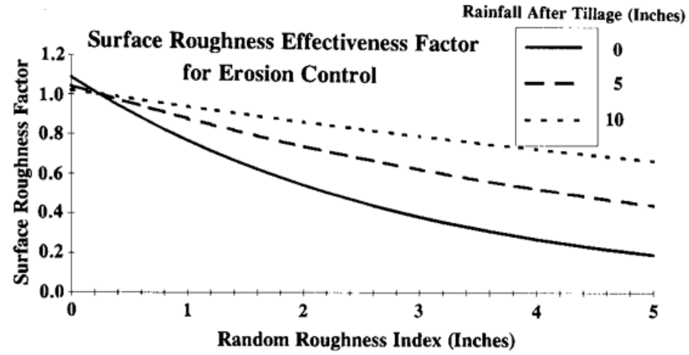

Figure 4. *Surface roughness effectiveness factor for erosion control in the Inland Northwest. The surface roughness factor approximates the proportionate reduction in soil erosion potential from highest (factor of about 1) to lowest (factor of 0) for each incremental increase in random surface roughness after 0, 5, and 10 inches of precipitation. (PNW Conservation Tillage Handbook Series No. 18, Chap. 3)*

Figure 4 shows the surface roughness factor (an approximation of the erosion potential) decreasing with increasing random roughness. Random roughness is a measure of the relative difference (standard deviation) between the average height and depth of the soil clods and the soil surface. For a reference, a random roughness of 1.5 to 2 inches would probably be about the highest roughness possible after seeding winter wheat with most double disc drills.

It is important to note that roughness is not as effective as surface residue for reducing erosion during the critical overwinter erosion period on seeded winter wheat. The effectiveness of surface roughness for reducing erosion sharply decreases during the winter as the soil clods slowly break apart or "melt down" with precipitation and freeze-thaw cycles.

For example, a random roughness of 3 inches in the fall after the last tillage gives a surface roughness factor of about 0.4, a 60 percent lower erosion potential than a smooth surface. After 10 inches of rainfall over winter, the original random roughness of 3 inches would only provide a 0.8 surface roughness factor, a 20 percent lower erosion potential. This erosion reduction potential is equivalent to a 1-inch random roughness without rainfall. Wetting-drying and freezing-thawing cycles also gradually break down soil clods.

Crop Rotation

Crop rotation has proven to be one of the most effective pest management tools in conservation tillage systems. Beginning with the 1996 Farm Bill, growers now have more flexibility to develop crop rotations that improve pest control under conservation tillage (refer to the earlier section on crop rotation in this publication for more information).

Begin Residue Management at Harvest

Residue management for successful conservation cropping systems must begin with the combine at harvest – the first opportunity to begin processing and distributing residue (Fig 5.). The health and production potential of a winter wheat crop can be influenced by crop residue management practices from the preceding crop. Likewise, management of winter wheat residue can significantly affect the following crop.

High amounts of residue in combine straw and chaff rows can seriously interfere with subsequent tillage and planting operations and create an adverse environment for plant growth. Equally or more important is uniform distribution of weed and crop seeds to minimize populations of weeds and volunteer in the combine rows. Uniform residue and seed distribution by the combine is especially advantageous for no-till or minimum tillage seeding, but also under conventional tillage systems, even when moldboard plowing. For more information about residue management in cereal production, refer to PNW 297 *Uniform Combine Residue Distribution for Successful No-till and Minimum Tillage Systems*.

Increasing Combine Residue Levels

The potential for problems with combine residue distribution has increased over the past few decades for several reasons. Average combine header widths have doubled from about 12 feet in 1950 to 24 to 30 feet today. Most standard factory-run combines are not adequately equipped to uniformly spread the large volume of residue harvested with these header widths. Higher yields from improved wheat and barley varieties have increased the amount of residue to manage at harvest. Chaff becomes a larger component of residue with increasing yields. Advances in fertility management have also increased grain production and harvest residue.

Figure 5. *Good residue management begins with uniform distribution of residue from the combine.*

Impacts of Combine Straw and Chaff Rows

Many production problems can be associated with high concentrations of residue and seeds behind the combine. Some of these include:

1. Poor drill performance: plugging, straw "tucking" in the seed row, uneven seeding depth, poor seed/soil contact, and uneven seedling emergence
2. Slower growth: less access to solar energy, cool and wet soils
3. Lower nutrient availability: immobilization of N, S, and other soil and applied fertilizer nutrients from microbial decomposition of large amounts of residue
4. Favorable disease environment: Rhizoctonia and Pythium root rots, take-all, and other diseases can dramatically increase on roots of volunteer and other host weeds concentrated in the chaff row; diseases are also favored by the cool, moist environment; prolonged disease inoculum carryover results from slower rates of residue decomposition
5. Reduced herbicide effectiveness: delayed germination of weed and volunteer seeds, higher weed and volunteer populations, herbicide interception and sorption
6. Increased crop competition: concentration of weeds and volunteers limit availability of nutrients, moisture, and light to the crop
7. Increased rodent damage : concentrated food source and cover, protection from predators

Management Options

Improved commercial chaff and straw spreaders, or modifications of existing spreading systems, can alleviate residue distribution problems. The results of a study on residue distribution from both cylinder and rotary type combines, with and without straw and chaff spreaders, are shown in Figure 6. Total wheat residue averaged 4.8 tons per acre including harvested straw and chaff (2.7 tons per acre) and uncut stubble (2.1 tons per acre). Standard cylinder combines with no alteration (factory run) had

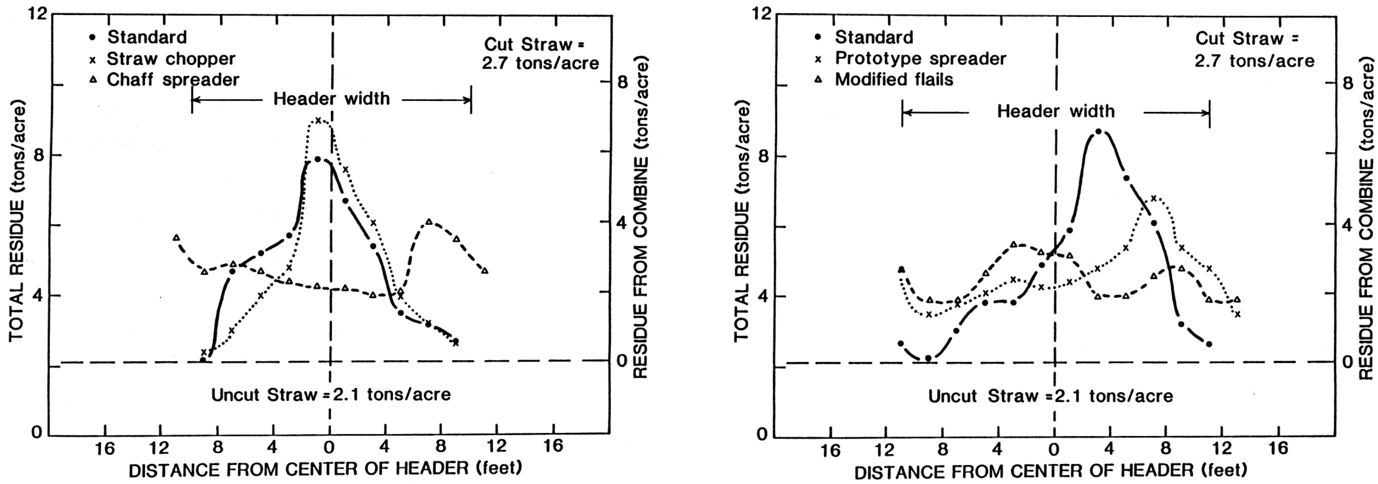

Figure 6. *Residue distribution by cylinder (left) and rotary (right) combines with and without residue spreading attachments (from PNW Extension Bulletin PNW 297).*

very uneven residue distribution (Figure 6, left) giving 2.1 tons per acre (only the uncut stubble) near the outer edges of the header to 9.0 tons per acre directly behind the combine. Chaff (anything less than 2 inches long) made up 65 percent of the 9.0 tons per acre residue behind the combine. A straw-chopper reduced straw length but did not improve residue distribution. The combine with a chaff spreader distributed straw and chaff much more uniformly. However, chaff thrown beyond the header width caused some overlap with the next pass, producing a peak in residue levels near the edge of the swaths (Figure 6, right). This can be corrected by reducing the rotation speed of the chaff spreader.

Standard rotary combines with center exits and no residue spreading attachments had a distribution pattern (Figure 6, right) similar to that of the standard cylinder combine without attachments, only shifted slightly to the right. A prototype spreader distributed the residue more uniformly, but again chaff and straw thrown beyond the header width produced a higher residue area from overlap with the adjoining swath. Residue concentrations from the prototype spreader ranged from 3.5 to 7 tons per acre. Lowering the flails, adding more and larger flail bats, and increasing flail rotation speed provided a more uniform distribution of residue, ranging from 3.9 to 5.7 tons per acre across the header width. Growers can either modify their own flail system or purchase relatively low-cost commercial attachments.

Cross-harrowing after harvest can help spread some of the larger pieces of residue from combine rows, but it does little to distribute concentrations of chaff and seeds on the ground. Harrowing, or other operations to spread residue rows, may also spread infestations of some weeds, diseases, and insects across fields.

Nutrient Tie-up in Combine Rows

Uniformly distributed combine straw and chaff can reduce nutrient tie-up in the residue rows. Nitrogen is affected the most, but the availability of sulfur and other nutrients can also be reduced. Carbon/nitrogen (C/N) ratios of 30 or more result in temporary immobilization (tie-up) of nitrogen by soil microbes during the decomposition process. Wheat residue has low concentrations of nitrogen, commonly a C/N ratio of 100 to 200. Most of the N required for microbial decomposition of wheat residue must come from the available soil N or from applied fertilizer N. Thus, uneven nitrogen fertility levels can be created from uneven crop residue distribution across the field, which can reduce yield potential of the following crop. Yellowish nitrogen-deficient strips in growing crops can indicate combine straw and chaff rows from the preceding harvest.

Uniform combine residue distribution can maintain more uniform field N levels. For example, the 24-foot rotary combine with the standard factory flail system (Figure 6, right) resulted in residue levels across the header swath from 2.4 tons per acre in the outer four feet to 7.3 tons per acre in the middle 12- to 16-foot section. Total residue from harvested straw and chaff plus uncut stubble averaged 4.8 tons per acre. Estimated N shortages (15 lb N for each ton of residue) from microbial decomposition in the 12- to 16-foot section (110 lb N/acre) were three times higher than the outer four feet (36 lb N/acre). Improved uniformity of residue distribution with the modified flail system (flail cones lowered; larger, additional flail bats added; and rotation speed increased), resulted in a small difference in residue levels and estimated N shortage across the header, 1.1 tons and 16 pounds N per acre, respectively.

If additional nitrogen fertilizer is applied to correct nitrogen shortages in straw and chaff rows, then there is excess fertilizer outside the rows. Also, additional nitrogen will generally not solve other problems of combine straw and chaff rows related to increased plant disease, cooler soils, shading, and other factors. Increased incidence of root diseases associated with the roots of volunteer and weeds concentrated in the combine row contribute significantly to this "combine row effect."

Commercial chaff spreaders or modified flail systems are now available to fit most combine models. Many growers make their own shop modifications for improving residue distribution. Contact your combine dealer or county extension agent for more information. Good combine residue distribution systems are well worth the small time and financial investment.

Nitrogen Required for Residue Decomposition

Regardless of the combine straw and chaff rows, management of the previous crop's residue can influence N availability for the following crop. The amount of N fertilizer required to compensate for N immobilization during microbial decomposition of the residue depends on several factors, including the amount of residue produced, the portion incorporated in the soil, timing of incorporation, available soil moisture, and timing and method of N fertilizer application. More information on this topic is available in University of Idaho CIS 825 *Wheat Straw Management and Nitrogen Fertilizer Requirements*.

In general, it is suggested that an additional 15 pounds of N fertilizer be added per ton of cereal residue in order to offset N immobilization during residue decomposition when wheat or barley follows another cereal crop. This additional N fertilizer application should not exceed 50 pounds N per acre.

Crop Residue Removal

Crop residue removal can have advantages and disadvantages. Advantages include ease of seedbed preparation for the following crop, less N fertilizer to offset N immobilization during microbial decomposition of incorporated residue, and reduction in some weed, disease, and pest problems. In the short term, yields of cereal crops planted after cereals with residue removed often remain the same or are higher than where residue is retained. Over time, however, research indicates that crop yields slowly decline with continued residue removal. Residue removal reduces organic plant material available to become soil organic matter. Soil organic matter, and the microbial activity associated with it, affects soil fertility and many soil physical characteristics that influence soil tilth and productivity.

In addition to lower availability of some nutrients with lower soil organic matter content, removal of residue decreases the return of nutrients that would be available for future crops. An average ton of wheat straw contains 13 lb of N, 3 lb of P_2O_5, 23 lb of K_2O, and 5 lb of S, plus other plant nutrients. In terms of fertilizer replacement costs, the nutrient value in one ton of wheat straw is worth nearly $10 based on fertilizer costs for these four nutrients alone at $0.36, $0.36, $0.15 and $0.16 per pound, respectively.

Burning Although the short-term costs and detrimental effects of field burning are often minimal, the longer-term impacts discussed above can be significant. Field burning can leave the soil more vulnerable to soil erosion. It is estimated that a majority of the N and about half of the phosphorus and sulfur are lost during burning, so fertilizer requirements increase with repeated burnings. Furthermore, yield losses from declining soil productivity will not be totally offset with additional fertilizer. Burning can potentially reduce carryover of some weed seeds and residue-borne disease inoculum.

Offsite environmental impacts of burning should also be recognized. There is an increasing public sensitivity to burning, and more restrictions could be imposed in the future.

Baling of Straw In some areas there are markets for cereal straw that can provide additional economic return from the crop. Baling straw after harvest usually removes about 50 percent of the straw and chaff produced. Consequently, detrimental effects on nutrient availability, soil organic matter, and other soil properties affecting productivity would be less than when residue is removed by burning.

Fertilizer Placement

Fertilizer placement for early root access is a good general production practice, although the crop response to different fertilizer placement options is often strongly influenced by crop rotation which, in turn, influences root disease potential and other pest problems. Northwest research has shown that fertilizer placement below or near the seed row and below seeding depth can significantly reduce the effects of root diseases when cereals are planted after cereals under conservation tillage. Conversely, fertilizer placement is less important when cereals are planted after non-cereal crops.

Northwest studies have demonstrated that, compared to surface broadcasting, deep banding of most of the crop's nitrogen fertilizer requirement can significantly reduce populations of grassy weeds, such as wild oats and

Table 1. Estimated residue production (adapted from Residue Management Guide - Small Grain Residue in the Pacific Northwest).

Crop	Pound of residue per unit of yield
Winter wheat	70-110/bushel
Spring wheat	60-100/bushel
Winter barley	1.0-1.7/pound
Spring barley	0.85-1.5/pound
Spring pea/lentil	0.85-1.5/pound
Oats	40-60/bushel

NOTE: The amount of residue produced by a crop depends on several factors. These include timing and amount of precipitation, temperature, soil water content, soil depth, soil fertility, variety, and pest problems.

downy brome, and increase crop competitiveness and yield potential of cereals in conservation tillage systems.

For more information on fertilizer placement, refer to the fertilizer management section.

Equipment Considerations

Tillage is the principal manipulator of crop residue. Almost any field operation, including seeding, will result in some residue incorporation. Improvements in water conservation and erosion control across variable cropland can be made with equipment that most growers already have. Minor changes in equipment selection, adjustment, and operation frequently give needed improvements. Some growers have made modifications of their present equipment. Others use specialized commercial implements or attachments for conservation tillage.

Before selecting a tillage system to leave a specific surface residue level, it is necessary to know the initial amount of surface residue. This can be estimated from the crop yield (Table 1). Using estimates of percent groundcover residue remaining on the surface after each tillage operation (Table 2), predict the surface residue level after seeding, then convert the predicted percent cover to pounds of residue (Table 3). It is important to consider that many environmental and production management factors can influence both residue production and surface retention.

Table 2. Estimated surface residue retention for common tillage operations (from *Residue Management Guide - Small Grain Residue in the Pacific Northwest*).

Operation	Percent residue remaining
Chaff and awn deduction	70
Overwinter residue decomposition	70 - 85
Tandem, one-way & offset disc	
4-6" deep	60 - 75
6" + deep	40 - 60
4" deep on pea, bean, lentil residue	10 - 30
Chisel plow	
straight points, 12" spacing	70 - 80
straight points, 18" spacing	75 - 85
twisted points, 18" spacing	50 - 70
Chisel-disc combinations	45 - 65
Moldboard plow	
8" deep	0 - 15
6-8" deep, no trash boards	20 - 30
uphill furrow, 6-8" deep	30 - 40
Secondary tillage	
field cultivator	75 - 85
16" sweeps w/shovels	75 - 85
field cultivator w/sweeps, 8" deep, after moldboard plow	100 - 120
rodweeder	85 - 95
rodweeder w/sweeps	75 - 85
harrow, 10-bar spike	80 - 90
harrow, 10-bar tine	85 - 95
Drills	
double disc	80 - 90
deep furrow or hoe	75 - 85
no-till light double disc	75 - 90
no-till heavy double disc	50 - 75
no-till heavy double disc in pea, bean, lentil residue	30 - 50
chisel point or air seeder	50 - 75
Shank fertilizer applicator	80 - 90
Grazing stubble	40 - 80

NOTE:
Maximum residue reduction is achieved with low residue amounts, good soil moisture, fast operating speed, and deeper tillage. Minimum residue reduction is achieved with high residue amounts, dry soils, slow operating speed, and shallow tillage. Spring grains, spring pea, and lentil residues are less resistant to tillage and disappear more rapidly. When planning tillage operations for these crop residues, select the lower residue retention value from the table.

Simple calculations can estimate residue following a wheat crop (Example 1). Using Tables 1 and 2, based on a 50 bu/A yield, an estimated 4,500 lb/A of residue was reduced through a year of summer fallow tillage and planting another wheat crop to 531 lb/A. Using Table 3, this ended as about 30 percent residue groundcover to protect the soil until the seeded crop starts to grow and adds to groundcover.

Example 1: Residue remaining from a 50 bu/acre winter wheat crop, followed by summer fallow tillage prior to winter wheat.

Initial residue:	50 bu/A x 90 lb/bu = 4,500 lb/A
chaff and awn reduction	4,500 lb/A x 70% = 3,150 lb/A
fall chisel, 18" twisted points	3,150 lb/A x 60% = 1,890 lb/A
overwinter decomposition	1,890 lb/A x 70% = 1,323 lb/A
field cultivate, tine harrow	1,323 lb/A x 85% x 90% = 1,012 lb/A
rodweed	1,012 lb/A x 90% = 911 lb/A
shank fertilizer, tine harrow	911 lb/A x 90% x 90% = 738 lb/A
rodweed	738 lb/A x 90% = 664 lb/A
deep furrow drill	664 lb/A x 80% = 531 lb/A

Table 3. Conversion of Percent Cover to Pounds Residue for Wheat, Barley, Oats, and Pea.

Percent Residue	Pounds Residue
10	164
15	252
20	346
25	446
30	554
35	669
40	793
45	928
50	1076
55	1239
60	1384
65	1629
70	1868
75	2151
80	2498
85	2944
90	3773
95	4649

The primary tillage operation can often result in the largest reduction in surface residue, so primary tillage implement selection provides the foundation for tillage systems to achieve the final residue level desired after seeding of the next crop. Inversion tillage implements, such as the moldboard plow and heavy disk, cause the most residue incorporation. However, with careful adjustment and use, they still can have application to conservation tillage systems. "Plowing uphill" (turning the plow furrow uphill) is also the only tillage operation that can move soil up slope. Tillage erosion from downhill plowing and other tillage operations has greatly reduced topsoil depth on ridgetops and upper slopes.

Subsoiling and Surface Pitting

Many types of subsoiling and surface pitting implements are now available and may provide some new management options to improve soil water storage, particularly on ridgetops, upper slope positions, and other field areas where water infiltration is limited and erosion potential is higher. These implements can potentially increase water storage and reduce erosion. Their greatest benefit would be in field areas where water infiltration is limited by soil compaction or where runoff on frozen soils is a problem.

Seeding Equipment for Direct Seeding and Other Reduced Tillage Systems

Equipment options for seeding in conservation tillage systems in the Pacific Northwest have changed extensively over the last twenty years. More than sixty models of "no-till" drills are available in the region, compared to about five in the early 1970s. None of the early drills could deep band fertilizer at planting. Nearly all of the current models have that option.

Drills vary considerably in their amount of soil disturbance and residue retention. Some important drill considerations include the capability to penetrate hard dry soil, deep band fertilizer below seeding depth and near seed rows, and penetrate crop residue to prevent "hair-pinning" of residue in the seed row, or drill plugging. The choice of crop rotation is an important factor in determining the drill features needed.

The development of heavy duty, direct-shank fertilizer applicators has eliminated the need for a primary tillage operation (commonly the disk) prior to using conventional shank-type fertilizer applicators in pea and lentil ground and after other lower residue crops, as well as after spring cereals. Many fertilizer dealers now have direct-shank fertilizer applicators available to growers. Many growers and dealers have also added fertilizer injection equipment to chisels and cultivators for the same purpose. After direct-shank fertilizer injection, growers can often use their conventional drills (without options for deep banding of fertilizer) for seeding in a minimum tillage system.

These fertilizer placement equipment options have enabled the development of what has become know as "shank (fertilizer)-and-seed" systems that are now used extensively for planting after low-residue crops in the Inland Northwest. Shank-and-seed is also being adapted for use after spring cereals and in fallow. Shank-and-seed generally means direct shanking of fertilizer followed by the use of non-selective herbicides as needed before seeding. However, a light cultivation or rodweeding is sometimes used in place of nonselective herbicides with a minor reduction in surface residue and surface roughness.

Depending on the type of fertilizer applicator shanks, depth, speed, and soil conditions, direct shanking of fertilizer can often maintain about 90 percent of the residue on the surface and create a relatively rough, cloddy surface. If the shank depth is adequate, the shanks can help fracture soil compacted during spring tillage operations. Increased surface roughness, water infiltration rate, and internal drainage resulting from soil disturbance by the applicator may sometimes provide better runoff and erosion protection than with no-till seeding using disk drills, particularly no-till drills without fertilizer shanks for deep banding.

Summer Fallow in Conservation Tillage Systems

Under past USDA farm programs, fallow-winter wheat rotations provided growers with a relatively profitable and low risk system in the low rainfall regions. In the future, however, the frequency and management of summer fallow will likely be very different. With the new flexibility of crop rotations, and decline and elimination of program payments under the 1996 farm program, growers need to revaluate the use and management of fallow in their production systems.

Intensive tillage fallow methods typically leave little or no surface residue on the soil surface to conserve soil water and control soil erosion. Fallow water storage efficiencies (% of precipitation stored in the soil) with a bare fallow are often less that 25 percent, primarily due to water loss by evaporation. Loss of water to surface runoff further reduces water storage potential and can cause significant soil erosion. Minimum tillage fallow systems with higher surface residue levels can increase water storage efficiency from 25 to 40 percent. No-till chemical fallow can achieve 40 to 55 percent efficiencies. Both also greatly improve soil erosion control.

However, growers need to closely evaluate the economics of any fallow system compared to more flexible and intensive cropping rotations now possible. With improved water conservation under no-till and minimum tillage systems, annual cropping under more diverse crop rotations will become more common even in low rainfall regions of the Northwest.

Tillage and Residue Management Strategies for Variable Cropland

Introduction

Landscapes and soil properties create high variability within fields in the Northwest cropping region. Production limitations, yield potentials, and needed production inputs vary across landscapes and soils. In the past, variable fields were usually farmed using uniform production practices. As we are entering the 21st century, however, increasing environmental concerns and a need for improved production efficiency are indicating a need for more precise management of variable fields. Changing tillage and residue management practices and production inputs through precision farming of variable cropland can offer opportunities to improve production efficiency, profitability, and resource protection.

Available water is typically most yield-limiting on shallow soil, particularly on ridgetops and upper slopes where crop residue production is low and soils have low water infiltration and storage. Management practices that improve water storage in these critical areas can improve potential yield and profitability. Tillage and residue management practices that increase water storage should also reduce soil loss by water and wind erosion, and associated pollution problems.

Bottomland and lower slope areas, in contrast, have a low erosion potential and water is not as often a yield limiting factor. Excessive residue, weed and disease problems, and wet soils are often more yield-limiting than water availability. More intensive residue incorporation with tillage, or partial residue removal, might benefit production management practices in these areas without increasing soil erosion potential.

The greatest need for management strategy change is in the use of tillage and residue management practices that increase water storage and erosion protection where it is most needed within fields. Intensive tillage practices for soil warming and drying, and for reducing weed and disease problems, are already a part of conventional tillage systems. The need for variable tillage and residue management systems vary across the region, as well as for each field and grower.

Scenarios of Variable Tillage and Residue Management

Variable tillage and residue management is increasingly being used on whole fields, within divided slopes and on field strips, and in field divisions with identified management units. The basic principles can be used across precipitation zones and topographic regions of the Northwest. However, variable tillage and residue management is specific to each field and farm situation.

In some cases, variable tillage and residue management practices within fields might apply only to the primary tillage operation. In other situations, growers might continue differences in management until planting uniformly across the whole field. Finally, individual "management zones" could be maintained within fields, such as with divided slopes, field strips, or other field divisions. The grower chooses management systems based on differences in erosion and yield potentials, special production limitations, the layout and landscape of the field, identification of the management units, travel distance between fields, equipment limitations, and many other production considerations.

The overwinter condition of a field is very important since this water storage period is critical to yield and erosion protection. Furthermore, these conditions can affect water storage and erosion potential through the growing season, and even the subsequent fall and winter, particularly if winter wheat will be planted. The following scenarios of variable tillage and residue management are presented to stimulate ideas for consideration and adaptation, and not necessarily for direct application.

Winter Wheat to Fallow

In crop-fallow regions, the most critical erosion period is usually during the fall and winter after seeding the winter wheat crop. However, there can be severe erosion from intense rain storms and wind events during the summer as well. Variable tillage and residue management practices should maintain adequate surface residue where it is most needed, beginning after harvest at the start of the fallow year. To maintain more residue in the low-yielding, erosion-prone areas in Management Zone I (Figure 7), wheat stubble could be left standing overwinter. Subsoiling, surface pitting, or other tillage operations with minimal surface residue burial might help to further increase water retention and infiltration in areas where soil compaction or runoff on frozen soils are problems.

Fall chiseling might be used in Zone II where residue production is higher, erosion potential is lower, and pest problems might be more yield-limiting than water availability. To maintain more residue over the fallow period and through winter wheat seeding, particularly on Zone I, an early application of a nonselective herbicide can substitute for early spring tillage and delay the initial fallow tillage. Timing of fallow tillage would depend on soil texture, weather conditions, weed problems, and other factors that could affect seed zone water content at fall planting time.

Spring Pea/Lentil to Winter Wheat

As one management example on variable fields, growers could fertilize the entire field with a direct-shank fertilizer applicator, then vary the next field operation according to the needs of specific management units (Figure 8). A nonselective herbicide might be used to control volunteers and weeds before seeding in Zone I in order to

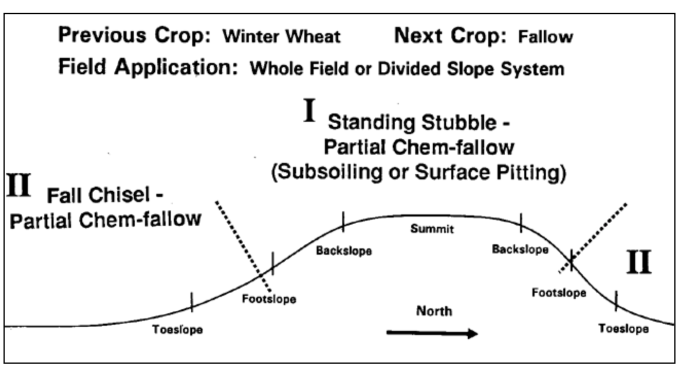

Figure 7. *Possible scenario of fall and spring management options on variable Northwest cropland after winter wheat going to fallow in low precipitation zones (PNW Conservation Tillage Handbook Series No. 18, Chap. 3).*

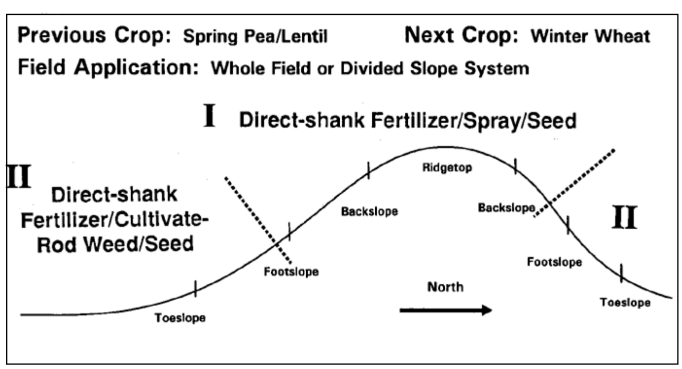

Figure 8. *Possible scenario of fall management options on variable Northwest cropland after spring dry peas, lentils, or other low residue-producing crop going to winter wheat (PNW Conservation Tillage Handbook Series No. 18, Chap. 3).*

maintain more surface residue on these erosion-prone, drier areas. A field cultivator-rod weeder operation might be used on Zone II, where residue levels are higher and erosion potential is lower.

Varying tillage and residue management practices on variable cropland should improve profitability and resource protection. The greatest benefit of increased surface residue and conservation tillage will occur in field areas where water is most limiting to yield, and where soil erosion potential is greatest.

Additional Information Resources on Conservation Tillage Systems

Wheat Health Management – This comprehensive reference book printed in 1991 is North American in scope and is the first book in a new Plant Health Management Series published by the American Phytopathological Society (APS) Press. The focus of this book is on optimizing wheat health and yield potential under conservation tillage systems.

Wheat Health Management was written to help farmers, fieldmen, farm advisors, extension, and other agricultural service and support personnel understand the basic concepts and approaches to wheat health management. This unique crop production guide integrates important aspects of wheat health management to help growers develop more productive, efficient, and environmentally-sound cropping systems. The "holistic" approach of this book considers the whole cropping system, not just the wheat crop or individual management choices apart from interactions with the overall cropping system. Although the book is about wheat production, many of the basic principles of holistic crop management apply to other crops as well. For more information on the book, call APS Press toll-free at 1-800-328-7560 between 8 a.m. and 4 p.m. CST.

PNW Conservation Tillage Handbook and Handbook Series —The Pacific Northwest Conservation Tillage Handbook is a compilation of applied research developed through PNW STEEP and related research projects on conservation tillage systems since 1975. The handbook consists of over 142 PNW Conservation Tillage Handbook Series publications. More than 40 publications have been added to the handbook since it was printed in 1990. The publications are written to show how the new research developments can fit into growers' management systems, how they interact with other management options, and where they apply in the Northwest. Contact your local county extension office to obtain a copy or call the UI Extension Ag Publications office at 208-885-7982. The handbook is also available on-line (http://pnwsteep.wsu.edu).

Northwest Direct Seed Cropping Systems Conference Proceedings and Videos

Annual Northwest Direct Seed Cropping Systems Conferences, beginning in 1998, have provided growers with opportunities to learn about the latest research and technology developments and experiences with direct seeding and more intensive crop rotations from around the Northwest and the world. If you missed the conferences, you can have the next best thing to being there: professional videos and in-depth conference proceedings.

The entire conference proceedings can be accessed on-line (http://pnwsteep.wsu.edu). Print copies are also available for $10 (including mailing) from: NW Direct Seed Conference, P.O. 2002, Pasco, WA 99320, fax 509-547-5563, phone 547-5538, e-mail (maurer@owt.com). Professional videotapes (digital-quality beginning in 1999) of the individual Conference Focus Sessions are available for purchase ($15 each) or loan (in the Northwest). Complete descriptions of the presentations and speakers on each of the videos and a copy of the video order form can be accessed through the website (above) or by calling the WSU Crop and Soil Sciences Dept. Extension office at 509-335-2915; or fax 509-335-1758.

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