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Diseases and Nutritional Disorders of Wheat, Barley, and Oats in Arizona

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INTRODUCTION

Winter cereals were the first crops cultivated by man and are responsible for the beginning of civilization. Winter cereal cultivation transformed hunting-gathering societies into stable units based on agriculture. Wheat and barley were important in the spiritual traditions of ancient people and are mentioned repeatedly throughout history. According to legend, the ancient Egyptians were cannibals until the goddess Isis returned from Lebanon with wheat and barley. The grains produced by early agriculturalists were eaten as cakes, bread, or gruel. Ancient people became expert bread makers. The Greeks, for example, produced 62 different kinds of bread.

The relationship between diseases and cereal crops has a rich and colorful history. Rust of wheat, for example, was recognized as the greatest pest of crops by the ancient Romans. Entrails of a sheep and dog were sacrificed to Robigus, the rust god, every April 25 when rust was likely to attack wheat. Bread made from grain infected with the disease ergot was responsible for hundreds of thousands of deaths in the Middle Ages. High-yielding semi-dwarf wheats, more amenable to correction of nitrogen deficiency, resulted in the Green Revolution of the 1960s. The Green Revolution is responsible for large increases in world grain production and relief from starvation for much of the world's population. Today, wheat is grown on more acreage world-wide than any other crop, and barley production ranks fourth.

Excellent publications on wheat, barley, and oats in Arizona are available from the College of Agriculture, Cooperative Extension, The University of Arizona. These publications are *Growing Wheat in Arizona* (115032) by Dennis, Thompson, Day, and Jackson, *Growing Barley in Arizona* (115015) by the same authors, and *Growing Oats in Arizona* (189028) by Ottman. The only plant disease mentioned in these publications, however, is the aphid vectored virus disease, barley yellow dwarf. The purpose of this publication is to discuss the parasitic and nonparasitic diseases that occur in Arizona on wheat, barley, and oats. It should be noted that many of the world's most significant diseases on these crops do not occur in Arizona. Others are present but they are not economically important. For example, in wheat worldwide, 31 virus diseases and 60 fungus diseases have been described. In Arizona, by contrast, only two virus diseases, barley yellow dwarf and wheat streak have been identified. Many important fungus diseases of wheat do not occur in Arizona. They include; downy mildew (*Sclerophthora macrospora*), ergot (*Claviceps purpurea*), anthracnose (*Colletotrichum graminicola*), Karnal bunt (*Tilletia indica* syn. *Neovossia indica*), flag smut (*Urocystis agropyri*), Cephalosporium stripe (*Cephalosporium gramineum*), take-all (*Gaeumannomyces graminis* var. *tritici*), and several *Septoria* and *Helminthosporium* diseases. Only one bacterial disease, bacterial streak (*Xanthomonas campestris* pv. *translucens*), is of any importance in Arizona. This disease has occurred only during unusually high winter rainfall conditions in Arizona on wheat and barley. Other bacterial diseases caused by species of *Pseudomonas* have not been identified on wheat, barley, or oats in Arizona.

There are seven viruses diseases described world-wide on barley. Only barley yellow dwarf has been reported in Arizona. Some important fungus diseases of barley not known to occur in Arizona include downy mildew, ergot, take-all, anthracnose, net blotch (*Pyrenophora teres*, syn. *Helminthosporium teres*), and scald (*Rhynchosporium secalis*). Fungal diseases of barley identified in Arizona include stem rust (*Puccinia graminis* f. sp. *hordei*), powdery mildew (*Erysiphe graminis* f. sp. *hordei*) and two smut diseases; covered smut (*Ustilago hordei*) and loose smut (*Ustilago nuda*). The rust and powdery mildew diseases of wheat, barley, and oats, because of similarities, will be discussed together. Covered smut and loose smut of barley are similar in symptoms, biology, and control to common bunt and loose smut of wheat, respectively. Thus, they will be described in the wheat section.

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Acreage of oats has ranged from 500 to 1000 acres during the last decade in Arizona. Reliable estimates of oat acreage for forage production are not available. Only four diseases, barley yellow dwarf, stem rust (*Puccinia graminis* f. sp. *avenae*), black loose smut (*Ustilago avenae*), and powdery mildew (*Erysiphe graminis* f. sp. *avenae*) are presently known to occur in Arizona on oats. The parasitic diseases of oats to be discussed in this publication include: smuts and rusts, powdery mildew, seedling diseases, barley yellow dwarf, wheat streak, and bacterial streak.

Nonparasitic diseases or disorders include frost and cold damage, water and high temperature stress, yellow berry and various mineral deficiencies. Arizona soils contain adequate amounts of most minerals for optimum growth, with the exception of nitrogen and phosphorus which are often added as fertilizer. The Russian wheat aphid will be discussed because feeding of this insect can cause virus-like symptoms on wheat and barley. Two publications, *Compendium of Wheat Diseases* 2nd Ed. 1987, and *Compendium of Barley Diseases* 1982, are available from the APS Press, the publishing arm of the American Phytopathological Society. These publications describe in detail the symptoms, causal organism and disease cycle and control of the known parasitic and nonparasitic diseases that affect wheat and barley world-wide.

PARASITIC DISEASES

WHEAT DISEASES

Diseases of wheat recorded in Arizona include the following smut diseases: common bunt or stinking smut caused by two closely related fungi, *Tilletia triticii* and *T. laevis*; dwarf bunt, *T. controversa* described earlier in Arizona as *T. brevifaciens*; and loose smut, *Ustilago tritici* (syn. *U. nuda* var *tritici*). Rust diseases of wheat identified in Arizona include leaf rust *Puccinia recondita* f. sp. *tritici*, stem rust *P. graminis* f. sp. *tritici*, and stripe rust *P. striformis*. Powdery mildew (*Erysiphe graminis* f. sp. *tritici*), and seedling diseases caused by a number of soil occurring fungi, have been noted in Arizona. Two virus diseases, barley yellow dwarf and wheat streak, and one bacterial disease, bacterial streak (*Xanthomonas campestris*) are also present.

FUNGUS DISEASES

Smut Diseases

The prevalence of smut diseases in wheat and other cereals triggered some of the earliest studies in plant pathology. For example, the Frenchman Tillet sent to the King of France in 1755 one of the first studies on a smut disease entitled "dissertation on the cause of the corruption and smutting of wheat in the head." In early texts of plant pathology, one could always find a picture of a black cloud of smut spores following a harvester. Smut diseases in our major cereal crops were widespread prior to the discovery of highly active systemic and protective seed treatment fungicides.

Also, the development of resistant varieties and certain management techniques have reduced the significance of these diseases. In Arizona, smut diseases of small grains are not serious problems. However, they occasionally occur and growers should understand that under certain situations they can be damaging. Symptoms of the barley smuts in Arizona, covered smut (*Ustilago hordei*) and loose smut (*U. nuda*) are similar to those of the smuts in wheat and oats (black loose smut *U. avenae*). A plant pathologist is needed to properly identify the smuts of the small grains.

COMMON BUNT

Symptoms: The symptoms of common bunt of wheat and loose smut of wheat are different but somewhat overlapping. In all of the smut diseases the kernels are replaced with a mass of brownish to blackish spores. Symptoms of common bunt are only noted at heading time. When wheat heads emerge from the boot they are bluish-green in contrast to the yellowish-green color of healthy heads. In place of normal kernels the affected kernels contain a mass of sooty black powder. The affected kernels are the same shape as normal kernels but are gray to brown in color and covered with a fragile membrane. Spores are released when the membrane is broken. The spores have a fishy odor which explains the naming of the disease as common bunt or stinking smut.

Biology: The black dusty powder inside the affected kernel is actually the teliospores of the fungus. The teliospores survive on seed or in the soil. The teliospores germinate in the soil or on the seed during periods of moisture and cool temperatures (40 to 57° F). Fungal hyphae penetrate coleoptiles before the seedlings emerge from the soil. Amazingly, the fungus grows internally into the growing point of the wheat seedling. The mycelium becomes established in kernel tissue and replaces normal tissue with bunt balls, thus completing the simple life cycle.

Control: Common bunt is controlled primarily through the use of seed applied, systemic and protective fungicides, and the use of resistant varieties. Common bunt is an uncommon disease in Arizona.

LOOSE SMUT OF WHEAT

Symptoms: The symptoms of loose smut differ from common bunt because the entire head, except the central axis, is replaced by the black sooty mass of teliospores. As the infected heads emerge, the teliospores are dispersed by wind or rain. Soon after emergence, only the bare stem of the fruiting structure remains. Hence the name "loose" smut as compared to "covered" smut.

***Biology*:** Although the end result is the same, the infection process with loose smut is very different from common bunt. The loose smut fungus infects healthy flowers. The teliospores, carried by wind, germinate and infect the ovaries of healthy flowers. Infection occurs only during humid, wet weather. The ovary becomes resistant to infection approximately one week after flowering. In Arizona with our typical conditions, the fungus has limited opportunities for infection. This is an advantage for growers of certified seed. In humid areas the fungus becomes established as dormant mycelium in the embryo. Infected seed is similar in appearance to uninfected seed. The loose smut fungus survives only as dormant mycelium within the embryo of the wheat seed. The fungus is activated during germination of the seed. The fungus then, as in common bunt, grows internally in the shoot apex. Eventually all of the head tissues except the rachis are invaded and turned into dark, brown teliospores.

***Control*:** Loose smut can be controlled with systemic fungicides. These fungicides translocate into the germinating seed and kill the mycelium of the fungus without damaging the seed. These products, developed in the 1970s, have revolutionized control of this once common disease. Protective fungicides, active for common bunt control, are ineffective for control of loose smut. Loose smut is not a common disease in Arizona.

DWARF BUNT

This disease is rare in Arizona and is not of any significance. Symptoms resemble those of common bunt except plants are usually stunted. Control consists of the use of certain systemic fungicides. Protective seed fungicides are ineffective. Plants are infected by soilborne teliospores when they are in the two-to-three-leaf stage. The teliospores of the dwarf bunt fungus, *Tilletia controversa*, are similar in appearance to those of the common bunt fungus. The fungus is systemic in the wheat plant. Symptoms in the heads are similar to common bunt.

KARNAL BUNT

The disease, karnal bunt and the pathogen, *Tilletia indica*, were first described by Indian plant pathologists in 1930 in experimental field plots of wheat in Karnal in the Punjab province of India. The disease was later seen in Pakistan, Afghanistan, Lebanon, and Iraq. Of interest to Arizona growers is the fact that the disease was first recognized in North America in Sonora, Mexico in 1972. Ten years later USDA inspectors intercepted karnal bunt-infected wheat seed from Mexico at Laredo, Texas. This incident initiated regulatory measures prohibiting entrance of all shipments of wheat and triticale from Mexico to the United States. The disease, as far as we know, does not presently occur in Arizona.

Because of our proximity to infested wheat areas of Mexico it is important to describe the symptoms of the disease and the biology of the pathogen.

***Symptoms*:** *Tilletia indica* is a fungus that partially infects the seed of bread wheat, durum wheat, and triticale. Developing wheat kernels are infected by fungal spores during cool, humid, wet weather. Infections lead to partial conversion of developing kernels into brown-black masses of teliospores. Normally only a few seeds are attacked per head. Blisters normally occur at the embryo end of the seed. The blisters are surrounded by a membrane that is broken during harvest. This partial infection of the kernel is in contrast to common bunt and loose smut where the kernels are completely replaced with fungal spores. The loose smut fungus, also infects seed. However, the fungus remains dormant in the seed until seed germination. The fungus then becomes systemic in the plant and replaces kernel tissue with fungal spores. In karnal bunt the fungus invades developing seed and causes disease during the same season.

***Biology*:** Teliospores, produced in infected kernels, fall into the soil at harvesting or become attached to the surface of the wheat seed as an external contaminant. Teliospores germinate the following season during wet, cool weather and produce spores that are carried by air currents or rain to the surface of developing kernels. They germinate during wet weather, infect and grow into the kernels. Fungal infection results in teliospore production and the cycle is completed.

There is currently no chemical seed treatment that can guarantee that wheat seed is not carrying viable teliospores of *Tilletia indica*. Also, presently there are no cultivars of wheat known to be immune to infection. There are different levels of resistance in wheat to the disease, but no wheat cultivars are known to be immune from infection. Our dry climate during kernel development is not favorable for karnal bunt. However, growers should be aware of this potentially serious disease.

Rust Diseases

Three rust diseases have been identified on wheat grown in Arizona. However, none of the three diseases have caused significant losses in Arizona. The lack of importance of rust diseases of small grains in Arizona undoubtedly relates to normally dry conditions during the crop cycle, our isolated production areas, and the use of resistant varieties.

Symptoms: The symptoms of the three diseases; stem rust (*P. graminis* f. sp. *tritici*), leaf rust (*P. recondita* f. sp. *tritici*), and stripe rust (*P. striformis*) can be somewhat similar. The most common symptom is the production of dry, dusty, yellow to orange red pustules that erupt through the upper leaf epidermis. These uredia are more commonly restricted to leaves with leaf rust. The uredia tend to occur in stripes along the leaves in stripe rust. In stem rust, the most common rust disease, the pustules (uredia) occur primarily on stems and leaves.

Each of the three diseases on wheat; leaf rust, stripe rust, and stem rust have overlapping symptoms. The symptoms caused by each of these three pathogens is controlled by the interaction of specific genes in each of the many physiologic races of the pathogens and resistant characteristics of each wheat cultivar. Stem rust of barley (*P. graminis* f. sp. *hordei*), and stem rust of oats (*P. graminis* f. sp. *avenae*) have symptoms that are similar to stem rust of wheat. A plant pathologist is needed for identification of these rust diseases on wheat, barley, and oats.

POWDERY MILDEW

Powdery mildew is caused by an obligately parasitic fungus, *Erysiphe graminis*. This species is parasitic on many native grasses as well as on wheat, barley, and oats. Strains of the species are host specific. For example, for all practical purposes, the strains of the species that attack wheat do not attack barley or oats. The strains found on barley and oats are specific to each of those species. Isolates of powdery mildew from oats or barley do not cause disease in wheat. For this reason, the powdery mildew pathogens of wheat, barley, and oats are referred to as *Erysiphe graminis* f. sp. *tritici*, *E. graminis* f. sp. *hordei* and *E. graminis* f. sp. *avenae*, respectively.

The powdery mildew fungi on grasses are unique in their moisture requirements for infection. In wheat, barley, and oats spore germination of each type of mildew is optimum only when relative humidities are high. Liquid water prevents spore germination. Other fungal pathogens only germinate in liquid moisture. All three of these pathogens are favored by high humidities and cool weather. In Arizona, powdery mildew is occasionally a factor in production. Our climate basically, however, is not favorable for this species of mildew because of low humidities during our winter crop cycles.

Symptoms: The symptoms of powdery mildew on wheat, barley, and oats are very similar. Seedlings may be affected. The fungus is superficial. Patches of whitish mycelium and chains of whitish conidia are easily seen with a hand lens in the field. Most infections occur on the upper surface of lower leaves. This is because the microclimate in the lower portions of the plants is more favorable for infection because of higher humidity. Distinct black dots appear almost like pepper on the leaves of maturing plants. These dots are scattered and embedded in the whitish fungal patches. They are the sexual bodies (cleistothecia) of the fungus.

Biology: Many different races of each of these form species (f. sp.) occurs. No studies have been made in Arizona. concerning pathogenic races of these fungi. *Erysiphe graminis* survives in Arizona in the absence of host plants as cleistothecia on straw and also, possibly, as mycelium and conidia on weedy grasses. Windborne ascospores or conidia initiate infection during favorable climatic conditions in the winter. Conidia are produced in large numbers. They can be disseminated by wind over several miles.

Control: Powdery mildew can be damaging if young plants are infected and cool humid weather persists through the production cycle. The disease can be very explosive because spore production regeneration cycles may occur within a five to eight day period. In humid areas of central Europe selective, systemic fungicides are used for mildew control. No fungicides are recommended for use in Arizona at this time. The use of resistant cultivars is the most feasible method for control. Dense stands of susceptible cultivars, and excessive nitrogen fertilization (which promotes rapid, lush growth), are factors that favor high disease incidence.

Seedling Diseases

Although *Rhizoctonia solani* and *Pythium* spp. have been occasionally responsible for seedling disease (pre- and post emergence damping-off) in small grains in Arizona, the diseases caused by these fungi are rare and unimportant.

SEED TREATMENTS

Fungicide treatment of small grain seed has been a very significant factor in disease control. Combinations of fungicides with systemics and surface action properties have controlled seedling pathogens such as *Rhizoctonia* spp., *Helminthosporium* spp., *Fusarium* spp., *Pythium* spp., the smut and bunt diseases, and barley stripe. Seed is treated in commercial seed treatment facilities. Growers also have the option of hopper box treatments. In some situations grain seed is treated with combinations of systemic fungicides, protective fungicides and insecticides. It should be noted that treatment of mechanically damaged seed or seed of low vigor and quality may result in reduced germination and poor seedling growth.

SEED PRODUCTION

Production of seed in Arizona has been an important commercial enterprise. Arizona is an ideal location for the production of disease-free seed.

Seed produced in Arizona is free of many diseases that occur in humid production areas. For example, more than 150 species of yeasts and fungi have been reported in cereal grains. Certain of these field fungi invade seed before harvest. A moisture content of 22 percent or higher in seed is necessary for infection. Fungi invading seeds in the field under humid conditions are found most commonly in the genera *Alternaria*, *Cladosporium*, *Fusarium*, and *Helminthosporium*.

These pathogens are of significance only when wet weather occurs before harvest. The diseases are referred to under a number of names including kernel blights, black point, head blights, and scab. Black point, a poorly understood disease of kernels of wheat, is the most important disease in this group. Symptoms consist of a discoloration and blackening of infected kernels. Infection usually occurs at the embryo end of the seed, hence the common name, black point. Black point reduces the grade and quality of seed, particularly in the durum wheats. Yields are not affected. The fungi that have been most commonly isolated from black point infected seed include a wide range of fungi that normally do not cause disease. They can be isolated from soil and from healthy plant parts including leaves, stems, and kernels. Under certain conditions of weather and plant growth these fungi (including species in the genera *Alternaria, Stemphyllium, Nigrospora, Penicillium, Helminthosporium* and *Fusarium*) are able to infect developing kernels and cause disease. Research in the Imperial Valley in California and in Arizona indicates that a number of factors seem to be involved in increased incidence of the disease including: high humidity or rainfall from anthesis through the soft dough stage, high nitrogen levels, and late season irrigation.

An important fact is that the planting of infected or contaminated seed does not increase the incidence of black point.

Stored grain and seed are susceptible to decay caused by species of fungi in several genera including *Aspergillus* and *Penicillium.* These so called, storage fungi, are responsible for decrease in seed germination, heating and mustiness, dry matter loss and mycotoxin production.

Virus Diseases

BARLEY YELLOW DWARF

The most important single disease in the production of small grains in Arizona is caused by the barley yellow dwarf virus. This aphid vectored virus disease has a number of biological characteristics that are responsible for its widespread and destructive nature. These characteristics are the large number of species of aphid vectors, the persistent nature of the virus in the vector, the large number of susceptible monocotyledonous plants (over 100 species) and the great range in variation of the virus itself.

Barley yellow dwarf virus was first identified by plant pathologists in the Sacramento Valley of California in 1951. The disease avoided identification until this time because the yellowing and stunting symptoms of the disease were non-specific and were similar to those caused by nutrient deficiencies and adverse environmental factors. The disease was first recognized in Arizona in 1956.

Plant pathologists working in the early 1950s cleverly noted that extensive yellowing and stunting of barley occurred in well managed fields growing under optimum weather conditions. They also observed high populations of aphids in these fields. These clues led to the discovery of the aphid vectored virus as cause of the disease. Barley yellow dwarf virus (BYDV) is obligately aphid transmitted. The virus is not transmitted in seed, soil, or manually. The only method of dissemination is by aphid vectors. The virus occurs primarily in phloem tissue. The aphid vectors are phloem feeders.

***Symptoms*:** Symptoms of BYD are difficult to separate from nutritional deficiencies and weather stress conditions. The best first method is to determine the field pattern of the disease. Nutritional and weather related problems usually affect large areas of the field. In contrast, because of the necessity of aphid vectors, BYD can be tentatively diagnosed in the field from the presence of aphids and the occurrence of yellowed, stunted plants in different patterns among normal plants. Diseased plants may be scattered sparsely at random in a field, clustered in spots, or be more common along the margins of adjacent grassy, weedy fields. These patterns reflect the invasion and movement of aphids that carry the virus. Massive invasion of viruliferous, winged aphids may cause almost complete infection in a field. Today, serological techniques called ELISA (for enzyme-linked immunosorbent assay) are used to identify the different strains of BYDV. The ELISA technique is based upon the binding capacity of the antiserum (antibodies) to their own specific antigen (a strain of the virus). At least five different strains of BYDV have been reported in the continental U.S.

Symptoms of BYDV on small grains is variable and dependent on the specific virus strain involved, climatic factors, and cultivar. In general, the symptoms in wheat consist of a brilliant yellowing of older leaves with flag leaves sometimes expressing a reddish or purplish discoloration. However, leaf discoloration may occur in various shades of red, purple, or yellow. Seedling infection causes plant stunting and sometimes death. In barley, the possible distribution patterns of BYDV in the field is similar to those patterns described for wheat. The discoloration of infected leaves appears, normally, as bright yellow but as with wheat the tissues may turn red or purple. Dwarfing in infected plants is variable and dependant on time of infection (early infections are the most damaging), the virulence of the virus isolate and the susceptibility of the cultivar.

In oats, BYDV is often called "red-leaf." Small, yellowish-green spots usually occur near the leaf tips. The blotches enlarge and leaves eventually become orange or red in color. Early infection causes severe stunting. Field distribution patterns of BVDV in oats are similar to those in wheat and barley.

***Biology*:** Aphid biology is the most significant factor in epidemics of BYD. Aphids only pick up the virus when they feed on plants that are infected with the BYDV. Most studies indicate that the virus is acquired by aphids in a relatively short feeding time of less than one hour. There is, however, variation between species on acquisition time. Aphids, after acquisition, are able to transmit the virus for two to three weeks. Twenty species of aphids that feed on cereals and grasses are vectors of this virus. Thus, aphids, because of their wide host range, short acquisition time, and transmission periods up to three weeks (without further feeding on diseased plants) are extremely effective vectors.

Rate and efficiency of vector transmission of the virus is, however, dependent on a number of factors, including; aphid species, temperature, strain of the virus, plant species, and age of the source plant.

***Control*:** Control of BYD in small grains revolves around planting dates that avoid, if possible, periods of high aphid activity, techniques that control or reduce aphid populations, grassy weed control and the use of tolerant cultivars of wheat, barley, and oats.

One interesting factor in explaining outbreaks of BYD is that some isolates of the BYDV can be vectored by more than one species of aphid. Other situations occur, however, where the virus is vectored by only one species of aphid. To understand the situation in the field it is necessary to identify and determine the transmission efficiency of aphids found in the affected fields, and the virulence level and identification of the virus isolate.

WHEAT STREAK MOSAIC

The only virus, other than BYD, described on small grains in Arizona is wheat streak mosaic. This disease has been seen in the lower Colorado river area in Yuma Country only on wheat. The disease is of minor importance and has not been present in this area for a number of years. The virus disease is common in the central Great Plains of the United States. The disease occurs also on barley, corn, oats, and many annual and perennial grasses.

Symptoms: Infected wheat plants, as seen under our conditions, were slightly stunted with parallel, green-yellow, discontinuous streaks on leaves.

***Biology*:** The wheat curl mite, *Aceria tulipae* is the vector of the disease. Wheat streak mosaic and the mite vector survive on many grasses.

BACTERIAL DISEASES

BACTERIAL STREAK

The only bacterial disease of small grains in Arizona presently is bacterial streak caused by *Xanthomonas campertris* pv. *translucens*. The disease has been of significance only in unusually high rainfall periods during the winter in the Salt River Valley and in the Yuma area. The disease, although seen on wheat and oats, has been more serious on barley. Bacterial streak is sometimes referred to as black chaff.

***Symptoms*:** Symptoms have only been seen in fields that have been exposed to persistent wet fronts that usually come from the Pacific coast during the winter. Symptoms are similar on wheat, barley, and oats. Small, water-soaked lesions first appear on young green leaves. These spots appear after extensive rainy and humid periods. Lesions elongate into streaks that extend down the leaf surface. The streaks are parallel and brown in appearance. Later the streaks, under wet conditions may exude a bacterial droplet. The disease is not common in Arizona because of dry conditions during our crop cycles.

***Biology*:** The pathogenicity of isolates from one small grain species to another species is complicated. *Xanthomonas campestris* pv *translucens* f. sp. *hordei* causes disease on barley but not on wheat. Isolates from wheat, under some situations, may attack barley. No studies in Arizona have been made on the pathogenicity of isolates of this bacterium to different grasses. The bacterium is seed-borne, but not soil borne. The bacterium may survive from one season to the next on barley seed and barley straw.

Control: Seed assay and certification programs have reduced the importance of this disease. Survival of the bacterium on plant residues seems unlikely under our desert summer conditions. Resistant cultivars are used in more humid production areas for control.

INSECTS

RUSSIAN WHEAT APHID

The Russian wheat aphid, (*Diuraphis noxia*) was first identified on wheat in Arizona in 1987. The insect is presently known to occur in Cochise, Graham, Greenlee, Maricopa, Pima, and Pinal counties. Recent surveys made in Arizona found that the largest infestation and most damage in small grains (wheat and barley) occurred in the high desert counties (above 3000 feet elevation) in Cochise, Graham, and Greenlee counties. This insect pest is described in this plant disease bulletin because the symptoms that result from aphid feeding can be mistaken for certain virus diseases in small grains.

***Symptoms and control*:** The Russian wheat aphid injects a toxin into leaf tissue during the feeding process. This toxin destroys chlorophyll, resulting in white or cream-colored streaks on stems and leaves. The toxin also causes a twisting and curling of leaves. Feeding also may curl the flag leaf, causing heads to become severely distorted and become "hook" like in appearance. Russian wheat aphids are small, cigar-shaped and pale green in color. They are often covered with a white powdery coating of wax. The aphids normally colonize areas deep in the whorl or beneath the leaf sheath. Without control the entire plant may be colonized. Plant death may occur under these circumstances. This aphid may be controlled with a number of systemic insecticides.

NONPARASITIC DISEASES

In Arizona the most common nonparasitic diseases are: frost and cold damage, water and high temperature stress, yellow berry, and nitrogen and phosphorus deficiencies.

COLD DAMAGE

Freezing temperatures cause most damage in wheat when cold weather occurs during tiller elongation, heading, or flowering. Frosts during elongation of tillers may cause death of growing tissue at the leaf nodes. Frosts during heading may cause flower sterility.

In barley, temperatures below 35° F after stem elongation may damage developing heads. Non-floral plant parts are usually not damaged at temperatures below freezing. Damage to barley heads reduces yield. From the seedling stage until early-boot, the head usually is sufficiently protected from cold. However, just before, during, or immediately after flowering, the head is susceptible to freezing temperatures.

After stem-elongation the greatest plant damage occurs from cold. Pollen is especially susceptible to cold temperatures.

Flower development begins at the middle of barley heads and moves toward the top and base, with complete flowering of a head requiring three to seven days. Flowering in an early planted field may continue 15 to 20 days or more, since late tillers bloom last. Occasionally, all flowers in a head are destroyed by cold but, more often, only those in the most sensitive stages of development are affected. Any factor such as wind or drought that stresses plants may cause damage to heads similar to that caused by cold.

WATER AND HIGH TEMPERATURE STRESS

Symptoms of these stress factors are similar to damage to heads caused by freezing temperatures. Drought stressed plants may appear dark blue-green in color. Leaves may show "firing" patterns from leaf tip to base and from lower to upper leaves. Kernels may be shriveled at maturity.

YELLOW BERRY

Stresses from deficient nitrogen and high temperatures during seed development are the factors that are associated with yellow berry in wheat. Excessive moisture during seed development also increases the number of kernels affected with the wholly or partially yellow-white seed (yellow berry). This yellowing is due to a high concentration of starch. Studies in Arizona indicate that excessive moisture may leach nitrogen from the root zone thus increasing the incidence of the disease. Application of approximately 30 pounds of nitrogen per acre at heading can reduce incidence of yellow berry.

NUTRIENT DEFICIENCIES

NITROGEN

Symptoms of Nitrogen Deficiency and Excess: Nitrogen deficient wheat or barley has yellowing or dead lower leaves, is pale green in color, is stunted in growth, and the leaves are very upright. Plants receiving excessive nitrogen have a blue-green cast with "floppy leaves" and excessive vegetative growth which can result in lodging. Yellowing and death of lower leaves can be caused by excessive salt or water stress as well as by nitrogen deficiency. Varieties differ in their normal shade of green at adequate nitrogen levels.

Nitrogen Requirement: Nitrogen is the main mineral nutrient required by wheat or barley. The nitrogen requirement is met primarily by fertilizer nitrogen, but nitrogen can also be provided by the soil or irrigation water.

Nitrogen requirements by wheat or barley in Arizona depend on many factors but a total of 150 to 250 pounds of nitrogen per acre is usually required for optimum production. Nitrogen fertilizer applications should coincide with or precede periods of maximum nitrogen uptake by the crop, which occur between tillering and flowering. Nitrogen uptake during the jointing stage averages 2.5 pounds of nitrogen per acre per day compared to 0.5 to 1.5 pounds at other growth stages (Figure 1). Nitrogen

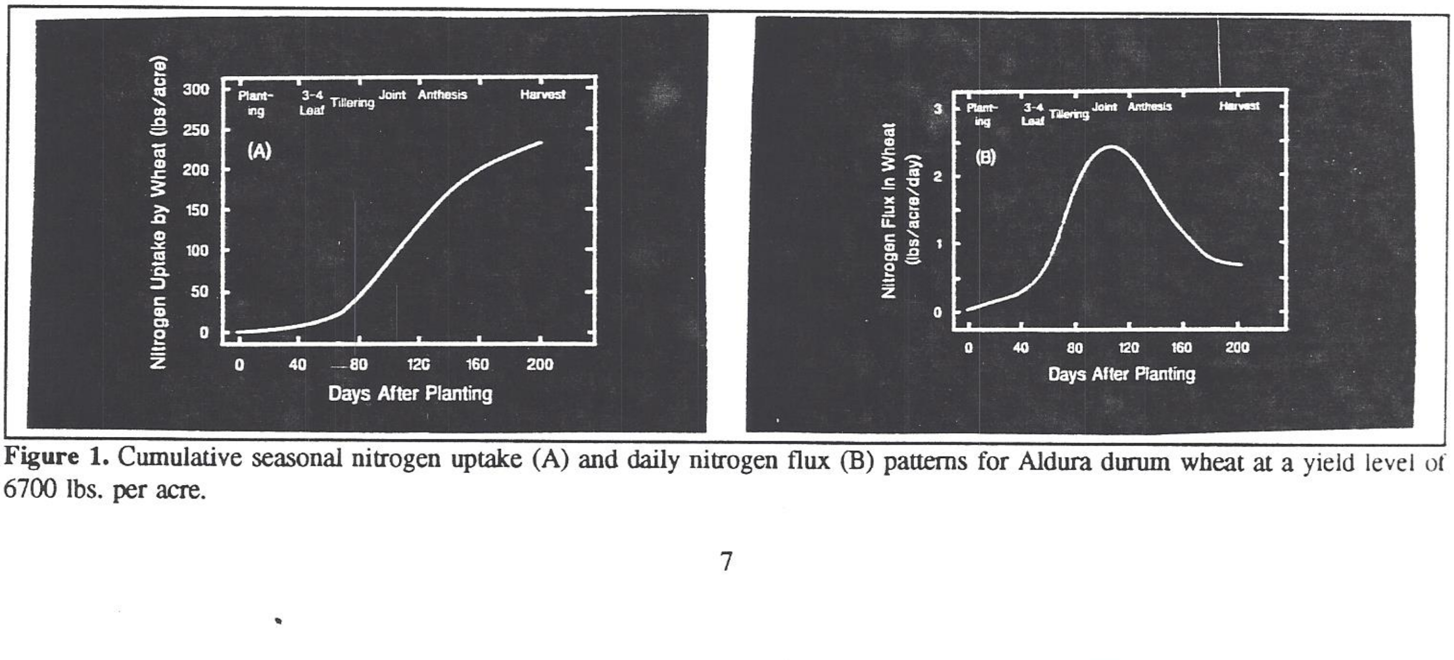

Figure 1. Cumulative seasonal nitrogen uptake (A) and daily nitrogen flux (B) patterns for Aldura durum wheat at a yield level of 6700 lbs. per acre.

applications up to the boot stage have the potential to influence yield. Applications near heading and flowering will probably not affect yield but can increase grain protein content, and applications after flowering are usually not effective. Nitrogen applications of 75 pounds nitrogen per acre pre-plant, 40 pounds at tillering, 40 pounds at early jointing, 40 pounds at boot, and 25 pounds near heading will almost always result in maximum yields and acceptable protein levels in wheat. Yields can be reduced by excessive nitrogen applications.

Factors Affecting Nitrogen Fertilizer Requirement

1. **Yield potential** – Approximately 33 pounds of nitrogen are required per 1000 pounds of grain produced.
2. **Soil nitrogen** – The average agricultural soil in Arizona about 15 ppm nitrate-nitrogen in the surface foot, which translates into 60 pounds of plant available nitrogen.
3. **Nitrogen in irrigation water** – Many wells produce water containing significant amounts of nitrates. Application of 36 inches of irrigation water containing 5 ppm nitrate-nitrogen will result in the application of approximately 41 pounds of nitrogen per acre. Most surface waters do not contain significant amounts of nitrogen.
4. **Irrigation system** – Less excess water is applied with drip and level basin irrigation systems compared to surface-flood or furrow irrigation. Excess water application is conducive to loss of nitrogen by leaching and gaseous loss through denitrification.
5. **Irrigation management** – Application of irrigation water to meet and not exceed plant water requirements results in less potential loss of nitrogen due to leaching or denitrification.
6. **Soil texture** – Sandy soils tend to contain less native soil nitrogen, be more conducive to losses of nitrogen by leaching, but less conducive to losses of nitrogen by denitrification.
7. **Variety** – Varieties can differ in nitrogen requirement due to differences in yield, nitrogen or protein content of grain or straw, or nitrogen uptake efficiency.
8. **Plant density** – Excessive seeding rates or methods (broadcast vs. drill) affect plant competition for nitrogen and can influence nitrogen requirements especially early in the season.
9. **Crop residues** – Crop residues low in nitrogen require an additional 15 pounds of nitrogen at planting per ton of residue up to a maximum of 50 pounds of nitrogen. Residues of green manure crops or legume crops such as alfalfa usually add nitrogen to the soil and lower the fertilizer requirement.
10. **Fertilizer application methods** – Banding of nitrogen (and phosphorus especially) near the seed is the most effective way to apply fertilizer at planting. Efficiency of nitrogen applied in the irrigation water is limited by the uniformity and the efficiency of the application. High irrigation water pH can lead to volatilization of ammonia from fertilizer. Urea or ammonium-containing fertilizers broadcast on the soil are subject to volatilization losses if the soil surface is wet before incorporation by tillage or irrigation.
11. **Fertilizer sources** – Nitrate-containing fertilizers are subject to greater leaching potential, but less potential for fixation by soil clays and denitrification compared to ammonium-containing fertilizers.
12. **Minimum protein requirement** – A minimum protein concentration required by the buyer forces a grower to apply more nitrogen than needed for maximum yield to ensure acceptable protein levels.

Nitrogen Application Methods: Nitrogen can be broadcast with a ground rig or airplane prior to planting and shallowly incorporated, injected into the surface soil, applied in the irrigation water, or placed with the seed at planting. Application uniformity is usually greater when fertilizer is broadcast with a ground rig rather than with an airplane. On sandy soils, ammonium-containing fertilizers such as ammonium sulfate (21-0-0), monoammonium phosphate (11-53-0), ammonium phosphate-sulfate (16-20-0), or solution ammonium polyphosphate (10-34-0) should be used rather than predominantly nitrate or urea sources due to leaching potential. Rates of banded nitrogen above 30 pounds nitrogen per acre increase the risk of injury to germinating seedlings. Placement of urea (46-0-0) or diammonium phosphate (18-46-0) with or near the seed is not recommended due to the risk of seedling damage from ammonium toxicity. Anhydrous or aqua ammonia should be injected 6 to 9 inches below the soil surface prior to planting and should never be placed near the seed zone. After planting, nitrogen can be broadcast applied and incorporated with irrigation water or applied in the irrigation water itself. Response to foliar-applied nitrogen fertilizer can be a few days quicker than nitrogen applied in irrigation water or to the soil. However, rates of foliar applied nitrogen greater than 10 pounds nitrogen per acre increase the risk of foliar burning.

Nitrogen Source: The plant is capable of taking up nitrogen in the form of nitrate, ammonium, and to a lesser extent from urea. The plant can not distinguish nitrate or ammonium supplied from fertilizer or organic sources as long as they are supplied in adequate amounts. Organic sources of nitrogen such as manure, of course, can improve the soil physical condition as well as supply nutrients. An irrigation will move ammonium a few inches in the soil, urea about one foot, and nitrate will move as far as the irrigation wetting front in the soil. Ammonium forms of nitrogen broadcast or banded with the seed at planting result in greater initial nitrogen uptake than nitrate, urea, or injected anhydrous ammonia due to proximity to the limited root system of the young plant. Nitrogen form is less important by the late tillering stage when the root system is well-established or if the plant is receiving adequate nitrogen. Generally speaking, ammonium and urea are converted to nitrate between irrigations (e.g., within four weeks in the winter and two weeks in the spring). Nitrate or urea can usually correct a nitrogen deficiency faster than ammonium sources since 1) ammonium sources remain in the surface few inches of soil until the following irrigation and may become temporarily unavailable to plants if the surface soil dries, and 2) ammonium can be fixed by the soil and become unavailable in contrast to nitrate or urea which predominantly remain in the soil solution. Caution should be used when applying aqua or anhydrous ammonia since plant injury can occur from ammonia toxicity from these sources, particularly on sandy soils. Foliar applications of nitrogen should be made using low-biuret urea (LB urea).

Producing High Quality Grain: Grain quality particularly in wheat is influenced by nitrogen fertilizer management. Adequate nitrogen fertility early in the season, an insurance application of approximately 30 pounds of nitrogen per acre near heading, and avoiding excess irrigation protects against yellow berry and low protein content. Excessive rates of nitrogen fertilizer maximize protein content, but can decrease grain yield (Table 1). Nitrogen fertilizer applied at heading can boost grain protein content (Table 2).

Predicting Nitrogen Fertilizer Requirements

1. **Past experience** – Experience is said to be the best teacher and is very useful in determining nitrogen fertilizer requirement in a particular site or situation. Experience is best put to use to provide a basis for adapting to changing conditions each year rather than to develop a "recipe" for nitrogen fertilizer application.

2. **Visual symptoms** – Nitrogen status of wheat or barley can be visually assessed by shades of green and "floppiness" of leaves. Nitrogen deficient wheat or barley is pale green, the lower leaves are yellow, and the leaves are upright. A crop receiving adequate nitrogen has a green cast, although varieties differ in the shade of green of their leaves. A crop receiving excessive nitrogen has a blue green-cast with "floppy leaves" and excessive vegetative growth. Yellowing and death of the lower leaves can be caused by factors other than nitrogen deficiency, such as excessive salt, water stress, or senescence.

3. **Soil testing** – Soil testing for nitrate is an effective tool to determine pre-plant nitrogen application rate. Soil testing has been used in other states as a guide for in-season nitrogen rates, but does not always reflect the plant nitrogen status. Pre-plant fertilizer recommendations based on soil nitrate content are presented in Table 3 below.

4. **Plant analysis** – Nitrogen fertilizer requirement after germination can be predicted from the nitrate concentration in the lower stem of wheat and barley, if used cautiously and with common sense. The stem nitrate test for small grains is not as definitive in predicting nitrogen requirements as tissue tests in other crops such as cotton. Cold temperatures or poor soil aeration from excessive irrigation or rainfall in January, for example, can inhibit nitrogen uptake even though nitrogen is available in the soil. Stem nitrate contents in wheat and barley often do not increase once at deficiency levels, even if deficiencies have been corrected by fertilizer applications, especially in sandy soils. The trend in stem nitrate concentration over time provides more information than stem nitrate at any single point in time. Fertilizer recommendations based on the stem test assume three or four post-emergence irrigations before flowering. More frequent irrigations, which exceed the consumptive use of the crop, may require increased fertilizer rates or splitting recommended fertilizer application amounts among the additional irrigations.

Collection of lower stem samples for nitrate analysis should begin at the three to four leaf stage. Stem samples should be collected 7 to 10 days before each irrigation until flowering so that laboratory results will be available to guide fertilizer application. The tissue between the ground level and the seed should be collected prior to the jointing stage, and thereafter the 2 inches of the stem above ground level should be collected. Randomly collect about 25 to 50 stems from representative, undamaged plants from a field. The samples should be placed in a paper bag and dried at 150° F (65° C) or refrigerated and submitted to a laboratory for nitrate analysis. The recommended nitrogen fertilizer rates based on the stem test are presented in Table 4. Stem test interpretation is depicted in Figure 2.

PHOSPHORUS

Phosphorus deficiency in small grains is usually expressed as stunted growth and may not be readily apparent. Phosphorus deficient plants may appear blue-green in color and leaf purpling may occur in extreme cases. Tillering is reduced and maturity is delayed. Phosphorus deficiency is most likely in cold soils due to decreased diffusion of phosphorus to the roots and decreased growth of roots to intercept the phosphorus.

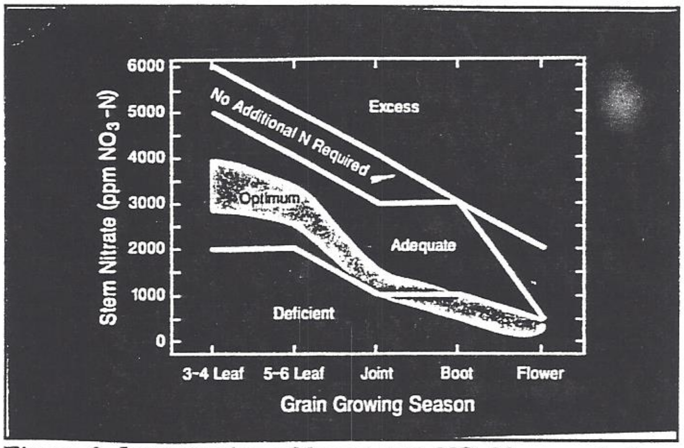

Figure 2. Interpretation of lower stem NO_3-N concentrations in small grains at various stages of growth.

Phosphorus is the only fertilizer element other than nitrogen needed by wheat or barley in Arizona in the vast majority of cases. Phosphorus fertilizer is not always required for optimum yields since some soils contain high levels of phosphorus. The phosphorus fertilizer requirement depends on the level of soil phosphorus before planting (Table 5). Phosphorus can be applied as a band near the seed, broadcast, or applied in the irrigation water at planting. Phosphorus rates can be decreased if phosphorus is applied in a band rather than broadcast or applied in the irrigation water. Phosphorus applied as solution ammonium polyphosphate may be applied at a lower rate than dry formulations, but this has not been confirmed. Triple superphosphate (0-45-0) or monoammonium phosphate (11-53-0) are recommended fertilizers when banding since ammonia toxicity can result from fertilizers such as diammonium phosphate (18-46-0) or ammonium phosphate-sulfate (16-20-0). In any case, phosphorus fertilizer that also contains nitrogen should never be banded at a rate that results in an application of more than 30 pounds of nitrogen per acre.

OTHER NUTRIENTS

Deficiencies of nutrients other than nitrogen or phosphorus have not been documented in Arizona, and presumably, application of these nutrients is rarely needed. Nevertheless, some of these elements are applied to small grains in the state.

Potassium and the secondary nutrients consisting of sulfur, calcium, and magnesium are usually plentiful in Arizona soils and many sources of irrigation water. ***Potassium*** strengthens the straw in cereals and prevents lodging. Potassium deficiency symptoms are similar to drought stress. The plants are short, the stems are weak and spindly, and the older leaves dry out starting at the tips and progressing to the margins. Potassium deficiency is most likely on sandy soils low in organic matter. ***Sulfur*** deficiency consists of leaf yellowing similar to nitrogen, but is more striking. Leaves of sulfur deficient plants are light green and the older leaves may be bright yellow. The plants are stunted and have few tillers. Sulfur deficiency can occur on sandy, acidic, cold, or low organic matter soils. ***Calcium*** deficiency is characterized by reduced or distorted growth of young tissue, withered leaf tips, brown roots and root tips, and weak stems. Calcium deficiency usually occurs on acid soils, but can occur on soils with high pH or higher sodium content. ***Magnesium*** deficiency has not be reported in North America. Deficiency symptoms include yellowing between leaf veins and a yellow mottling of the leaf, purpling of the older leaf edges, weakened stems, and stunted growth. Magnesium deficiency is most likely on soils that are acidic, sandy, low in organic matter, or high in calcium.

The plant requirement for micronutrients is many times less than other nutrients. Arizona soils generally contain a sufficient amount of micronutrients for adequate growth of small grains. Micronutrients consist of iron, zinc, copper, manganese, boron, molybdenum, and chlorine. A deficiency of ***iron*** is characterized by a sharp yellowing between veins of new leaves and stunted growth. Plants deficient in ***zinc*** develop yellowing, graying, or bronzing between veins on older leaves in contrast to development of symptoms on younger leaves with iron, manganese, and copper deficiency. ***Copper*** deficiency is expressed as stunting, leaf yellowing, wilting, dying of leaf tips, and a graying of leaves. Interveinal yellowing occurs in ***manganese*** deficiency, but not as sharply compared to iron deficiency. ***Boron*** deficiency is characterized by stunted growth. ***Molybdenum*** deficiency appears as pale, thick, brittle, withered leaves and a stunted plant. Deficiencies of iron, zinc, manganese, copper, and boron are associated with high pH soils coarse in texture and low in organic matter. Molybdenum deficiency is favored by low soil pH.

TABLE 1. Two-year summary of nitrogen fertilizer trials conducted at the Maricopa Agricultural Center with Aldura durum. Nitrogen rates were split among pre-plant, 5 to 6 leaf, boot, and heading applications. Grain yield is optimized at a lower nitrogen rate than grain protein.

Nitrogen Rate	Grain Yield	Grain Protein	Yellow Berry
(lbs/acre)	*(lbs/acre)*	*(%)*	*(%)*
0	3164	9.5	21
125	5892	11.5	1
250	6038	13.8	0
375	5275	15.1	0
500	4862	14.9	0

TABLE 2. Application of nitrogen at heading can boost grain protein levels. This data represents a three-year summary of fertilizer trials conducted at the University of Arizona Agricultural Centers with Aldura durum. Nitrogen rates before heading averaged 173 lbs/acre split among pre-plant, 5 to 6 leaf, and boot applications.

Nitrogen Rate at Heading	Grain Yield	Grain Protein	Yellow Berry
(lbs/acre)	*(lbs/acre)*	*(%)*	*(%)*
0	6718	12.3	10
15	6110	13.1	4
30	6286	13.6	2
60	6303	14.4	0

TABLE 3. Suggested pre-plant nitrogen fertilizer rates based on soil nitrate-nitrogen content.

Pre-plant Soil Nitrate-N	Recommended Nitrogen Rate*
(ppm)	*(pounds of nitrogen per acre)*
0 to 5	50 to 75
5 to 10	0 to 50
above 10	0

* Add 15 pounds of nitrogen per ton of non-legume residue recently incorporated, up to a maximum of 50 pounds of nitrogen per acre.

TABLE 4. Interpretation of lower stem nitrate levels for small grains.

Stage Sampled	Stem Nitrate-N	Recommended Nitrogen Rate*
	(ppm)	*(pounds of nitrogen per acre)*
3 to 4 leaf	>5000	None**
	2000 - 5000	25 - 50
	<2000	50 - 100
Jointing	>3000	None
	1000 - 3000	25 - 50
	<1000	50 - 75
Boot	>3000	None
	1000 - 3000	30
	<1000	30 - 60

* The recommended nitrogen rate assumes fertilizer is applied 7 to 10 days after stem sampling. Decrease nitrogen rates by 20% for barley or if expected wheat yields are less than 5400 pounds of grain per acre.

** If the pre-plant soil nitrate-N was below 10 ppm, apply at least 30 pounds of nitrogen per acre regardless of the stem nitrate concentration at the 3 to 4 leaf stage.

TABLE 5. Suggested pre-plant phosphorus fertilizer rates based on bicarbonate extractable phosphate-phosphorus.

Soil Test Phosphorus	Recommended Phosphorus Rate
(ppm phosphorus)	*(pounds P_2O_5 per acre)*
0 to 7	50 to 100
7 to 13	0 to 50
above 13	0
