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Diseases and Nutritional Disorders of Alfalfa in Arizona

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INTRODUCTION

Alfalfa, *Medicago sativa* L., originated in the mountainous regions of Asia Minor and Iran. In the 16th century alfalfa was introduced into Mexico by the Spaniards. Alfalfa was introduced into Arizona, California, Texas and New Mexico by missionaries from Mexico in the early 1800s. Nonwinter-hardy types of alfalfa with winter growth superior to the Spanish germ plasm were introduced in 1899 from Peru (Hairy Peruvian), in 1913 and 1956 from India (Indian), and in 1924 from Africa (African). Alfalfa varieties bred for multiple pest resistance first appeared in the 1950s. 'Lahontan' was released in 1954 with resistance to stem nematode, bacterial wilt, and spotted alfalfa aphid. 'Moapa' was released in 1957 and was the first non-dormant cultivar with resistance to the spotted alfalfa aphid. Nondormant alfalfa cultivars were released over the next 10 to 15 years with resistance to the various biotypes of the spotted alfalfa aphid and with improved winter growth. In 1976, 'Lew' was released with resistance to the stem nematode and 'CUF 101' was released for blue alfalfa aphid resistance. During the mid-1970s, resistance to Phytophthora root rot, anthracnose, and bacterial wilt was incorporated into nondormant cultivars. Between 1975 and 1985, breeding work concentrated on spotted alfalfa aphid and pea aphid resistance. Current breeding objectives include resistance to the Egyptian alfalfa weevil, the armyworm, various diseases, environmental stresses, and quality. Cultivation of improved varieties will continue to be a defense against plant diseases. For information concerning alfalfa cultivars (varieties) available for use in Arizona see Cooperative Extension Bulletin 8924, *Alfalfa Cultivars for Arizona, 1989* by M.J. Ottman, S.E. Smith and A.B. Simons.

Alfalfa, currently, is grown on approximately 20 percent of the total irrigated crop land in Arizona.

Between 1980-1990 harvested acreage of alfalfa varied from a low of 140,000 acres in 1984 to 165,000 acres in 1980 and 1990. Average yield in tons per acre ranged from 7.0 to 7.9 during this period. Yields in many locations, however, are in excess of 10 tons per acre per year.

The first comprehensive discussion of diseases of alfalfa in Arizona appeared in The University of Arizona, Bulletin A-16 "Alfalfa for forage production in Arizona" published in 1966. The plant disease section was written by A. D. Davison, P. D. Keener, M. R. Nelson, E. L. Nigh, and I. J. Shields. Diseases described were: Root-, Crown-, and Crown-Bud Rots; Bacterial wilt, Diseases Caused By Pathogens Attacking Leaves And Stems; and Nematodes. This bulletin was revised in 1977 and a short discussion of plant diseases, written by R. B. Hine, M. R. Nelson and E. L. Nigh, was included. The purpose of this publication is to discuss in detail the present disease situation in Arizona. It should be emphasized that many of the most serious and worldwide alfalfa diseases do not currently occur in Arizona or are rare and insignificant. These include: bacterial wilt (*Clavibacter insidiosum*); Verticillium wilt (*Verticillium albo-atrum*), Fusarium wilt (*Fusarium oxysporum* f. sp. *medicaginis*), stem and crown rot (*Sclerotium rolfsii*), stem decay (*Sclerotinia sclerotiorum*, and *S. trifoliorum*), alfalfa dwarf (*Xylella fastidiosa*), and two foliar bacterial diseases caused by *Xanthomonas alfalfae* and *Pseudomonas medicaginis*. Two virus diseases, alfalfa mosaic and pea streak, although widespread, have never been proven to cause yield reduction in Arizona.

Root and crown, foliage, seedling, and virus diseases are discussed under the "Parasitic Diseases" section. Two non-pathogenic diseases, scald and salt damage, are described under "Nonparasitic Diseases." The "Nutritional Disorders" section covers four areas for each of the most important elements including nitrogen, phosphorus, potassium, sulfur, calcium and magnesium. These areas are: 1) role of the element in plant growth, 2) symptoms caused by a deficiency of the element, 3) various forms of the element in the soil and 4) fertilization. There is also information concerning micronutrients including boron, copper, iron, manganese, molybdenum and zinc.

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PRODUCTION AREAS

Alfalfa is grown in Arizona at elevations ranging from 75 feet to 100 feet in the southwestern areas along the lower Colorado River to elevations over 5000 feet in northern parts of the state. In two southeastern counties, Graham and Greenlee, the production areas range from 3000 feet to 3500 feet. In Cochise County alfalfa is grown in some areas about 4000 feet, such as in Pearce (4375 feet) and Cochise (4212 feet). Production areas in Maricopa, Pinal and Pima counties range from approximately 1000 feet to 2400 feet, respectively. The importance of these elevation differences is that there is a correlation in Arizona between elevation and rainfall. Low elevation areas in the western part of Arizona average less than 4 inches of rain annually, whereas rainfall at Pearce is approximately 13-15 inches annually. Since alfalfa is a perennial crop, it is exposed to two rainy seasons in Arizona. The so-called "monsoon" season occurs during July, August, and September and another season during November, December and January, when cool wet fronts come from the Pacific Coast. Both of these rainy, wet periods have major impact on certain foliage diseases. Both systems are unpredictable and the amount of rainfall and length of the rainy periods vary greatly from year to year. The "monsoon" season is characterized by heavy, irregularly distributed rainfall and high humidity and high temperature. Rainfall, during this period at the higher elevations, can range as high as 10-12 inches during certain summers. Wet winter cold fronts generally persist for longer periods than the abrupt typical thunderstorms that occur during the summer monsoon season. These winter storms are occasionally severe, and rainfall of approximately 9 to 10 inches has been recorded during November, December, and January during several recent seasons. The other effect of elevation, of course, is on temperature. At elevations of 4000 feet, temperatures are approximately 12° F lower (maximum and minimum daily temperatures) than temperatures at sea level. These rainfall and temperature differences play important roles in the distribution and severity of alfalfa diseases in Arizona.

STAND PROBLEMS

Many factors are involved in stand survival and yield decline including soil and plant fertility, soil compaction, cutting frequencies, crown damage caused by equipment and grazing by sheep, scald injury, insect and weed problems, unadapted cultivars, saline and sodic soils, errors in water management, and parasitic diseases.

PARASITIC DISEASES

ROOT AND CROWN DISEASES

There are four diseases of alfalfa that are caused by plant pathogens that survive in the soil. These organisms invade and cause taproot and crown rots. They do not infect or cause upper stem or foliage diseases. These diseases are: Phymatotrichum root rot (caused by the fungus *Phymatotrichum omnivorum*), Phytophthora root rot (caused by the fungus *Phytophthora megasperma*), Rhizoctonia root, stem and crown rot (caused by the fungus *Rhizoctonia solani*) and stem nematode, (caused by *Didylenchus dipsaci*).

PHYMATOTRICHUM ROOT ROT

The most serious disease of alfalfa in Arizona currently is Phymatotrichum root rot. This disease occurs only in the alkaline, low organic matter soils of the Southwestern United States and Central and Northern Mexico. The fungus that causes the disease, *Phymatotrichum omnivorum*, has the largest host range of any known plant pathogen. It causes a root rot in over 2,300 species of dicotyledonous plants, including not only alfalfa, but also other important Arizona crops such as cotton, stonefruits, pome fruits, grapes, and many ornamental trees and shrubs. Interestingly, the first report of this disease on alfalfa in the United States was in 1889 in the annual report of the College of Agriculture, The University of Arizona.

Distribution: Heavily infested areas of Texas root rot are restricted to the flood plains and certain tributaries of the Gila River (Safford, Duncan, Solomon, Thatcher, Fort Thomas, Pima, Eden, Florence, Sacaton, Buckeye, Gila Bend, Agua Caliente, Growler, Roll, Mohawk, and Dome Valley); the Santa Cruz River (Sahuarita, Tucson, Cortaro, Avra Valley, Rillito, Marana, Red Rock and Eloy); the San Pedro River (Hereford, St. David, Benson, Pomerene, Redington, Mammoth and Winkelman); Colorado River (Parker, Poston, Ehrenberg, Yuma, Somerton, and Gadsden) and certain locations and tributaries of the Salt River and Queen Creek in areas around Scottsdale, Mesa, Higley, Magma, and Queen Creek. Other infested areas include Chandler, Aguila, San Simon, Bowie, McNeal, Douglas and Duncan. The disease is either not found or is of minor importance in areas distant from these flood plains or drainage systems.

The "mesa" (land at elevations above the influence of the Colorado River) in Yuma County seems to be free of the disease, whereas many "valley" production sites are infested. Although *Phymatotrichum* root rot occurs at elevations as high as 4,700 feet in the Elgin and Sonoita areas of Santa Cruz County, the disease has never been detected in the higher elevation farming areas that stretch south from Bonita through Willcox to Kansas Settlement. In the Sulphur Springs Valley, the disease is only found near Elfrida, McNeal, and Douglas.

In Pinal County the major infested areas are found primarily where the Santa Cruz River flood plain occurs in the western part of the county and where the Gila River flood plain bisects the northern part of the county. There are other isolated areas in the county where certain tributaries run into these two major river systems, such as Queen Creek, where the disease occurs. However, the major agricultural areas in the county are free of the disease. The same situation occurs in Maricopa, Yuma, and Pima counties. Apparently, the fungus is indigenous to areas where certain flora and soil conditions occurred in the flood plains of these major river systems. The disease does not occur in the high elevation alfalfa producing areas in Apache, Coconino and Yavapai counties.

Symptoms and Biology: Alfalfa, and also cotton, are unusual among the thousands of hosts of *Phymatotrichum omnivorum* in that both die during the first summer after planting. Alfalfa normally planted in the fall, will become infected and die during the first summer. At the lower elevations the first symptoms occur in late June or July. Circular kill patterns of varying sizes are noted. The kill patterns may be several acres in extent or they may be limited to many small patterns, less than 10 feet in diameter. The kill patterns may be restricted to certain areas in the field or scattered at random. There is no correlation between the kill patterns and soil type or low areas in the field. Severely infested fields may be adjacent to disease-free fields. Plants initially wilt during the first hot months of summer. The fungus is inactive during winter and symptoms only occur during summer. The wilting occurs in the circular patterns that were described above. Some plants are not infected and grow normally in the kill pattern area. These plants are not resistant but are merely "escapes." Under favorable conditions over 90 percent of plants are killed in infested areas. The kill pattern enlarges from year to year as the fungus grows from infected taproots to healthy roots. The reasons for varying rates of annual circle enlargement, which varies from area to area, are not understood. The disease is identified primarily by the characteristic summer kill patterns and the fact that the entire taproot is destroyed. Initially, before wilting occurs, the fungus invades and causes small lesions on the taproot. As the taproot becomes further infected, eventual wilting occurs. The fungus forms characteristic "strands" on the surface of rotted, cortical root tissue. Positive identification of the disease requires microscopic examination of the "strands" that are unique to the pathogen. *Phymatotrichum omnivorum* is restricted to localized areas in individual fields; it is not spread by irrigation or tillage. This is due to the fact that the fungus survival structures, strands and sclerotia, occur deep in the soil. Another characteristic of the fungus is that a fungal spore mat frequently occurs at the edge of the kill pattern during wet humid weather during late July and August.

The usual size of the spore mat is 4 to 8 inches in diameter and about ¼ inch thick. The spore mats appear overnight. These spores are initially white in color but become brownish in color after 2 or 3 days of growth. The powdery mass of spores produced on the surface of the mat are non-functional. They have never been germinated and they play no role in dissemination of the pathogen.

Control: There is no method of determining the presence of *P. omnivorum* in soil prior to planting a susceptible crop. The two best indicator plants are alfalfa and cotton. These two hosts are killed during the first summer after planting. Rotation and fallowing are two techniques that are usually very effective in the control of soil-borne plant pathogens. Neither technique is effective for control of Phymatotrichum root rot. Isolates of the fungus are nonspecific in their ability to cause disease in unrelated plants. For example, isolates of *P. omnivorum* from cotton or grapes or stone fruits are pathogenic to alfalfa. Alfalfa isolates are also pathogenic to unrelated plants. The fungus survives indefinitely in soil. When fields, fallowed for 10 years, are planted to alfalfa, plants die during the first summer growth cycle. All cultivars of alfalfa are susceptible to the disease.

The only recommended control measure is to reseed infested areas during the fall. This enables some winter production. There are no fumigants or chemicals recommended for control.

PHYTOPHTHORA ROOT ROT

Although this disease is no longer a major problem in Arizona it is appropriate to compare symptoms of Phytophthora root rot with Phymatotrichum root rot because the two diseases can easily be misidentified in the field.

Phytophthora root rot, caused by the soil-borne fungus *Phytophthora megasperma* was identified in 1970 in Arizona as a major factor contributing to stand and yield decline. The disease was widespread in all of the major producing areas in the counties of Maricopa, Yuma, Pinal and Pima. The disease also occurred in the higher elevation counties of northern and southeastern Arizona. All cultivars grown prior to 1980 were susceptible to the disease including the most widely planted types such as Sonora 70, Mesa Sirsa, Moapa and Hayden. Today, Phytophthora root rot is no longer a major problem in Arizona. In fact, it is difficult to find fields where this disease plays a significant role in stand decline. This situation is a result of cooperation between the U.S.D.A., the Cooperative Extension programs and research groups in the western states and private industry. The cultivars that are currently grown have high levels of resistance to the pathogen. Also, management techniques for control of the disease are greatly improved because of a better understanding of the basic biology of the pathogen.

A Comparison of Symptoms of Phymatotrichum Root Rot with Phytophthora Root Rot

Both pathogens infect the taproot of mature plants, causing extensive root decay and eventual plant death. However, *P. megasperma* is active primarily during the cooler winter months whereas *P. omnivorum* kills plants only during the hot months of summer. Neither pathogen is involved in seedling disease in Arizona. *Phytophthora* causes seedling disease in areas of the world where seeding occurs during cool weather. Seedling disease does not occur in Arizona because fields are seeded during high temperatures in the fall when the fungus is inactive. In comparison, *Phymatotrichum*, though active when soil temperatures are high, only attacks the taproot of mature plants. The fungus, for unknown reasons, is not a pathogen of seedlings of any host. Alfalfa seedlings are not susceptible to infection even when planted into infested soils during the summer months.

Field Distribution of the Two Diseases

As previously described, Phymatotrichum root rot occurs in localized areas in individual fields and there is no relation of disease incidence with soil conditions and watering practices. The distribution of Phytophthora root rot, in comparison, is normally scattered in the field and disease incidence is highest in areas of the field where soils are heavy or poorly drained.

***Biology of* Phytophthora megasperma:** This soil-borne fungus causes disease only in alfalfa, thus any rotation program will reduce the inoculum level. The fungus produces heavily walled survival spores (oospores) in infected root tissue. These structures enable the fungus to survive in the soil in absence of the host. Factors involved in survival of oospores in Arizona soils have not been studied. Other spore structures, sporangia, are produced in infected root tissue. These sporangia are produced only when soils are saturated. Motile, swimming spores called zoospores are produced in the sporangia. These spores are attracted to root tissue where they initiate infection. Infection may occur at any point on the taproot. During earlier studies on the disease in Arizona it was demonstrated that isolates of the fungus from such diverse areas as Buckeye, Laveen, Gilbert, Parker, Yuma, Snowflake, Safford, Many Farms, and Tucson were equally pathogenic to alfalfa. When these isolates from Arizona were compared with isolates from Central Mexico however, it was shown that they were biologically distinct. For example, germ plasm developed in Arizona with resistance to Arizona isolates was susceptible to isolates from Mexico.

Control: Phytophthora root rot is controlled by the use of tolerant cultivars of alfalfa in conjunction with management techniques such as: avoidance of heavy, poorly drained soils; irrigation practices that minimize the use of water; proper field leveling; and rotation.

ALFALFA STEM NEMATODE

Although a number of parasitic nematodes have been described as pathogens of alfalfa, only the alfalfa stem nematode, *Ditylenchus dipsaci*, is of significance in Arizona. The nematode currently is of principal importance primarily in Graham, Pinal and Maricopa Counties. Although the nematode has been reported to occur in the low desert areas of Western Arizona, the disease is not important in these areas because of high soil temperatures which inhibit nematode activity.

Symptoms: The easiest way to identify stem nematode infection is to examine crown buds from plants that appear stunted and stressed. Nematode infection of crown bud tissue causes these tissues to become swollen, brittle and distorted. Nematodes are easily visible when infected bud tissue is broken and examined with a hand lens. When these infected tissues are crushed and placed in water and examined under magnification in the laboratory, numerous nematodes can be seen in the infected tissue. Infected stems are shortened and thickened in appearance. During wet, cool fall and spring months the nematode is most active. High temperatures and dry conditions inhibit nematode activity. Plant death, due to nematode infection, is most common when frequent cuttings occur during cool, wet winter periods.

Biology: The alfalfa stem nematode has the unique ability to survive for long periods in a dormant stage. Hay protected from moisture could harbor a nematode population for many years. When dry, infected hay is moistened the dormancy period is broken and normal reproduction is initiated. Each female produces up to 500 eggs which hatch in 2 to 7 days after the female has deposited them in the tissue upon which she has been feeding. In alfalfa, the larvae may feed in the area where they hatch or they may move to the upper stems of the plant in a film of water.

Dissemination: The nematodes are easily spread in the field. Tail water from infested fields can carry the nematodes from infested fields to new fields. The nematode may also adhere to the feet of grazing animals or be carried by machinery.

Control: Control measures are not always effective because the nematode is protected by its habit of feeding under the leaf sheaths and in developing buds. Currently, the use of resistant cultivars is the best method of controlling this disease. For example, in 1981, a cultivar named 'Lew' was released by The University of Arizona. The distinctive feature of Lew, a nondormant cultivar adapted to the environment of the low desert areas of Southern Arizona, was its high level of resistance to the Arizona strain of the stem nematode. Currently, there are a number of cultivars developed by private seed companies that have varying levels of resistance to the disease. Winter dormant cultivars, which are adapted only to higher elevations in Arizona, are resistant to infection.

Cultural practices can help greatly in reducing infection or spread of the population throughout the entire field. Tail water from infested fields should not be used on other alfalfa fields. Manure, containing nematode infested hay, can also be a source of infection. Care should also be exercised in transferring sheep from infested fields to noninfested fields as contaminated hay may adhere to the fleece and hooves.

RHIZOCTONIA ROOT CROWN AND STEM ROT

Rhizoctonia solani was first described as a root pathogen of alfalfa in 1941. The disease was reported from the southern desert areas of California. Today, the root canker phase of the disease is described as the most serious summer alfalfa disease in the low elevation desert areas of California. However, in Arizona the disease is of minor importance. The crown and stem rot phases of the disease are more common and can be of significance.

***Biology of* R. solani:** The versatility of *Rhizoctonia solani* as a plant pathogen is beautifully illustrated in the distinct and different diseases that this fungus causes in alfalfa. The species is known to cause infections on taproots, crown tissue, lower stems, and on foliage. Although the fungus is one of the most common soil-borne fungal pathogens in Arizona, the climate and ecology of the irrigated desert areas of Southern Arizona are not conducive to some phases of the disease that occur in other areas. For example, foliar blight, which is a relatively common disease of alfalfa under higher rainfall and humidity conditions, does not occur in Arizona. The crown and stem rot diseases, however, are occasionally of economic importance.

Cotton and alfalfa constitute approximately 50 percent of all the irrigated farmland in Arizona. It is interesting to note that *R. solani*, a major cause of seedling disease in cotton, is of such limited importance in alfalfa even though the same strain of the pathogen is involved in causing disease in cotton and alfalfa. In humid areas of the world, *Rhizoctonia solani* produces a sexual air-borne stage. The air-borne basidiospores initiate infections on upper portions of the plant. In Arizona, the fungus has never been found to produce this stage. The fungus survives in the soil in organic matter and infects plant tissue when mycelial growth occurs. No aerial stage has, as yet, been identified.

Symptoms: Circular, concave, black lesions of varying sizes are seen on mature taproots. This phase of the disease is rare in Arizona.

Crown Decay: Crowns of alfalfa are invaded and damaged by a number of fungi including *R. solani* and *Colletotrichum trifolii*. Extensive mechanical damage is also a factor in death of crowns. No studies have been made in Arizona to determine the major factors (disease, insects, nutrition, and mechanical) that are involved in stand failure due to death of crowns. Crowns are rotted and dark in appearance. The cankers often extend into the lower crown and upper taproot areas. Under severe infections plant death may occur.

Stem Decay: *Rhizoctonia solani* often attacks the lower end of the stem, near the soil line. The stem is girdled and death occurs. The affected stems initially wilt and then dry. The fungus can be readily isolated from infected tissue.

FOLIAGE DISEASES

There are a number of diseases in Arizona that affect aboveground plant parts. Although these pathogens primarily infect leaves, a few also infect stem and crown tissue. They do not cause root disease. Most of the species have simple life cycles. Several of the pathogens cause somewhat similar symptoms. Diagnosis of these diseases is based on symptoms, period of time when the disease occurs, and the identification of the pathogen. Fungal inoculum for each of the belowlisted diseases is found throughout Arizona. The limiting factor for disease incidence and severity is not inoculum, but favorable weather conditions. These "wet-weather, aboveground" diseases occur only during periods when plant tissues are wet, either from dew or rainfall, for continuous periods of time in excess of approximately 18 to 24 hours. Longer wetting periods coupled with favorable temperatures trigger higher disease incidence and severity. Although these fungal pathogens have the capacity to cause defoliation and yield loss under favorable environments, it should be emphasized that during dry weather severely infected plants regrow and the incidence and severity of the disease declines rapidly.

The most important foliage diseases are downy mildew and anthracnose caused by the fungi *Peronospora trifoliorum* and *Colletotrichum trifolii*, respectively.

DOWNY MILDEW

This disease, caused by the fungus *Peronospora trifoliorum*, is probably the most important in the group. The disease occurs in all alfalfa areas but only during wet, winter periods.

Biology: The fungus produces air-borne sporangia on infected leaf tissue. These sporangia occur only during short day lengths coupled with wet, cool weather. Temperatures that are most favorable for the disease range between 55 and 75° F. Sporangia are moved by wet air currents to healthy leaves where they germinate and initiate infection. The fungus survives as mycelium in systemically infected crown buds and crown shoots of alfalfa. Thick-walled oospores are produced in infected host tissue. The role of these spores, as survival propagules has not been studied in Arizona.

Isolates of *Peronospora trifoliorum* from alfalfa are pathogenic only to alfalfa. The fungus occurs in a number of pathogenic races. These races vary in their ability to cause disease in specific cultivars of alfalfa. No studies of the races of this pathogen have been made in Arizona. The fungus, an obligate parasite, reproduces only in living alfalfa tissue.

Symptoms: The most common symptom of downy mildew occurs on leaves. Most leaf infection is in the lower canopy of the plant because the micro-climate there is more favorable for the pathogen. Infected upper leaf surfaces are bleached in appearance. During wet and humid weather the fungus sporulates on the lower leaf surface. The sporulation appears downy and violet in color. This area coincides with the bleached-yellow tissue on the upper leaf surface. Scrapings from the sporulating area reveal, under the microscope, the unique structure of the fungus. With experience, a hand lens can be used, in the field, for identification. Defoliation, caused by leaf infection, can be extensive in susceptible cultivars during wet and cool weather.

Control: No fungicides are registered for use in alfalfa. There are only 2 control methods: 1) grow resistant cultivars and 2) harvesting techniques. Harvesting is a simple management technique that can be used effectively to control this disease in Arizona. Harvesting reduces the favorable micro-climate, reduces inoculum and removes most of the young susceptible leaves.

ANTHRACNOSE

Another disease, anthracnose, caused by the fungus *Colletotrichum trifolii* is of occasional significance in Arizona during the hot summer monsoon season. The disease has recently been a problem in producing areas along the Colorado River during the monsoon season.

Symptoms: The fungus invades stem and crown tissue. Stem lesions are irregularly shaped ranging from oval to diamond. The stem lesions are sunken and straw to black in color. The fungus in wet, hot weather produces masses of fruiting structures (acervuli) that can be seen in the field with a hand lens. Stem lesions may enlarge, girdle and kill stems. Scattered death of stems in the field is a common indicator of the disease.

Biology: Conidia are produced in lesions on infected stem and crown tissue during wet, humid, high temperature conditions. The conidia are produced in disc-shaped, sunken fruiting structures called acervuli. With experience an individual can easily diagnose this disease because of the unique characteristics of these structures. The conidia are carried by rain to healthy crown and stem tissue. They germinate slowly only in a film of water. Extensive infection and disease are favored by wet periods that are in excess of 24 hours.

Control: Resistant cultivars are the only practical method for control. There are three physiological races of *C. trifolii* that have been described in the United States. Because of the erratic occurrence of this disease in Arizona no studies have been made on the susceptibility or resistance of the commonly planted cultivars to the race or races of the fungus that may occur in Arizona.

OTHER FOLIAGE DISEASES OF MINOR IMPORTANCE

There are several other foliage diseases that are occasionally seen in Arizona. They are not significant factors in production. Occasionally they occur under high rainfall conditions in scattered fields. There are no control measures recommended for any of them. They produce somewhat similar leaf-spotting symptoms. They can be diagnosed in the laboratory by examining infected host tissue and identifying the fungal pathogen. They include: common leafspot (*Pseudopeziza medicaginis*), Stemphyllium Leafspot (*Stemphyllium botryosum*) and rust (*Uromyces striatus*).

VERTICILLIUM WILT

This systemic, vascular disease is caused by the fungus *Verticillium albo-atrum*. Interestingly, the disease, which has been known in Europe for many years was first reported in North America (Canada) in 1967 and in Washington and Oregon in 1976. After this first U.S. report the disease quickly spread and was subsequently reported from several other northern states. Of concern to Arizona growers (although the disease has not been found in Arizona as of 1991) is the fact that Verticillium wilt of alfalfa was reported for the first time below 36°N latitude in 1985 in the central and north coast regions of California. Of further concern was the report in 1988 of finding the disease in Riverside, San Bernardino and Los Angeles counties and in the extreme southside of Kern County. The pathogen was isolated from infected alfalfa plants in August when air temperatures were over 95°F. Since the pathogen is known to be seed-borne, both internally and externally, and can also be introduced into wilt-free areas via infested hay and cubes, it is likely that the pathogen will eventually invade Arizona. For that reason a discussion of the disease follows.

Symptoms: The symptoms of Verticillium wilt overlap those caused by several stress factors including Phytophthora root rot, Rhizoctonia stem rot, anthracnose, certain nutrient deficiencies and insect damage. The first symptoms usually appear in scattered plants during cool weather. Presumably, in Arizona the disease would appear in the second or third year plantings during the winter in our nondormant varieties. Nondormant varieties shown to be susceptible in recent studies in California include CUF101, UC-CIBOLA and Moapa 69. Leaflets become bleached and eventually dry. The taproot may show yellow to brown discoloration in the vascular system. The only positive method of identifying the disease is to isolate and identify the pathogen from infected vascular tissue.

Biology: The fungus survives as threadlike, heavy walled mycelial strands that are produced in internally infected host tissue. Reports from other areas indicate that *V. albo-atrum* can survive in soil for 3 to 5 years. The fungus, after introduction into a field, is spread by harvest operations and wind-blown spores. Research from California indicates that the *V. albo-atrum* isolate from California is similar to alfalfa wilt isolates from Washington, Kansas, New York, Pennsylvania, Yugoslavia, U.S.S.R. and France. This information supports the thesis that alfalfa strains of *V. albo-atrum* represent a genetically homogenous clonal population with a common origin that subsequently became distributed worldwide.

Control: Both dormant and nondormant varieties of alfalfa with varying levels of resistance to the disease have been identified. This is the only practical method of controlling the disease. The alfalfa strain of *V. albo-atrum* infects other plant species. These include cantaloupe, watermelon, and potato as well as a large number of weeds such as shepardspurse, wild mustard and common lambsquarter. For that reason weed control and rotation become a part of the control strategy.

SEEDLING DISEASES

A large number of fungi, including *Fusarium* spp., *Pythium* spp., *Rhizoctonia solani*, and *Phytophthora megasperma* have been implicated in many parts of the world as causal agents of seedling disease. However, in the arid, irrigated areas in Arizona seedling diseases are not of economic importance. The common agronomic practice of overseeding may play a role in this situation. However, recent studies in Arizona indicated that beyond a certain critical level there was no correlation between seedling emergence in October and subsequent yield. These studies are typical of others that indicate that seed treatment with fungicides often reduces nodulation and is not a factor in stand survival or yield. *Phytophthora megasperma* is not a seedling disease in Arizona probably because plantings normally occur during the hot early fall months when soil temperatures inhibit pathogen activity.

VIRUS DISEASES

ALFALFA MOSAIC

In Arizona this aphid transmitted, stylet-borne (nonpersistent), easily mechanically transmitted, seed-borne and systemic virus is found in probably 80 to 90 percent of all alfalfa plantings in the state. There is no evidence that the disease causes any loss in alfalfa in our production areas. Alfalfa mosaic virus consists of many strains that differ in infectivity and symptomology. No studies have been made on the strains that occur in Arizona. Strains of this complex virus have been reported to infect over 300 plant species in 47 plant families. This disease in alfalfa is an example of a heterogenous virus in a heterogenous host. The virus is transmitted by at least 14 aphid species including three species that are important in Arizona alfalfa; the blue alfalfa aphid, the pea aphid and the spotted alfalfa aphid.

Symptoms: In Arizona the effects of AMV infection on alfalfa are variable ranging from masked infection (plants are infected but show no symptoms) to mild mottle and yellowing of leaves. Symptoms are more common during the winter. High summer temperatures mask symptoms. Most infected plants never show any symptoms.

Importance of AMV in Arizona: Although this disease appears to be of little consequence in alfalfa it is important to discuss the effects of this virus in other hosts, particularly peppers, tomatoes, potatoes and lettuce. When aphids carry the virus to these hosts the virus becomes systemic and causes stunting and a bright yellow mosaic. This disease is referred to as "calico" in lettuce and potato. In tomato there is a necrosis of stems and developing fruit. A yellow mosaic and stunting of plants occurs in infected peppers. Stand reductions in tomato have occurred in fields planted adjacent to alfalfa in the Imperial Valley of California and along the Colorado River. Symptoms in tomato plants are stunting, bronzing of foliage and necrosis of stems and fruit. Infected plants may die. The blue alfalfa aphid and the pea aphid are the major vectors in transmission of this strain of AMV from alfalfa to tomato. Occasionally, "calico" symptoms are seen in Arizona in plantings of potatoes, peppers and lettuce that are adjacent to alfalfa. Normally only scattered plants in rows closest to the alfalfa planting are affected.

PEA STREAK

Another virus disease of alfalfa in Arizona is pea streak virus. Pea streak has been known for approximately 15 years. It was first found associated with severe yellowing of alfalfa in the western part of the state. While it was never shown to be responsible for the yellowing, subsequent studies have shown it to be at least as widespread as alfalfa mosaic in western and central parts of Arizona. It does not produce distinctive symptoms in plants. It is transmitted by the pea aphid. The impact of this disease on alfalfa productivity has not been measured.

Pea streak is a *carla* (*car*nation *la*tent) virus. It is a rod-shaped virus of 630 nm and related to potato virus S, red clover vein mosaic, and eggplant mild mottle viruses.

NONPARASITIC DISEASES

Two nonparasitic diseases are of importance in Arizona. They are scald and salt.

SCALD

Scald is a major problem causing loss of stand in the summer in the low desert areas of Arizona at elevations below 2500 feet is scald. This nonparasitic disease occurs during irrigation when air temperatures are over 100°F and standing water or saturated soil conditions exist for more than 30 hours. In low areas in the field a complete loss of stand may occur. The foliage of plants wilts and death occurs. Poorly leveled, border-irrigated fields with poor sub-surface drainage are particularly susceptible to this disease. Typically, symptoms develop in the "tail end" of the field where irrigation water tends to collect. The disease does not occur in alfalfa grown in areas in Arizona above 3000 feet. The incidence of scald may be reduced by proper land leveling and preplant tillage techniques to correct drainage problems. Avoid excessive use of water and long water runs. Eliminate ponding of tailwater.

SALT

Alfalfa is considered to be moderately tolerant to saline soil conditions. At soil conductivities (millimhos per centimeter in a saturated soil extract of 6-7, 3,000-3,500 ppm salt) there is usually a slight reduction in yield. At higher concentrations seed germination is inhibited, and severe reduction in yield may occur. Since salt is a serious problem in certain producing areas there has been a long time research program to produce germ plasm with higher salt tolerance. A broad-based nondormant alfalfa germ plasm has been developed at The University of Arizona that has increased forage production under moderate salt stress. Also, salt-tolerant germ plasm has been developed that dramatically increases seed germination under high salt stress. These germ plasms have been made available to the alfalfa breeding community.

NUTRITIONAL DISORDERS

NITROGEN

ROLE IN THE PLANT

Nitrogen is the basic component of amino acids, the building blocks of protein. Chlorophyll and enzymes controlling growth processes in the plant contain nitrogen. Nitrogen is also an integral component of DNA, which contains the genetic code for the plant.

DEFICIENCY SYMPTOMS

Nitrogen deficiency in alfalfa occurs as a result of poor nodulation or inefficient nitrogen fixation due to molybdenum deficiency. Nitrogen-deficient plants are dwarfed, spindly, and are generally yellow. A pink color develops in the petioles and midrib of the oldest leaves. The oldest leaves turn yellow and die and the symptoms progress upward to younger leaves.

FORMS IN THE SOIL

Inorganic forms of nitrogen in the soil include ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), nitrous oxide (N_2O). Inorganic nitrogen can exist in soil solution, absorbed on soil particles, or fixed between clay minerals. Organic nitrogen exists in many complex and unidentified compounds. Alfalfa absorbs most of its nitrogen as nitrate but can absorb ammonium, or to a lesser extent, nitrite. Nitrate (and nitrite) are mobile in the soil and can be leached whereas ammonium is held tightly by the soil. Ammonium is usually converted to nitrate in the soil in the span of time between irrigations under Arizona conditions. Nitrite is transitory in the soil and is usually converted to other forms of nitrogen such as nitrate. Nitrous and nitric oxide are gaseous products from denitrification of soil nitrogen (usually nitrate), which occurs under waterlogged conditions, and can be lost to the atmosphere.

SOURCES

Sources of nitrogen for growth of alfalfa include that supplied by atmospheric fixation, mineralization of organic matter, release from soil minerals, irrigation water, fertilizer, and crop residues, manures, or waste products. The earth's atmosphere contains 78 percent nitrogen gas which can be converted to usable forms by free-living organisms in the soil, organisms living in a symbiotic relationship with plants, and by lightning. Alfalfa obtains an estimated one-half to three-quarters of its nitrogen through symbiotic nitrogen fixation. Thunderstorms in Arizona can contribute a few pounds of nitrogen per acre per year. Fixation by free-living organisms in the soil is thought to be a minor source of nitrogen. Most soils in Arizona contain less than 1 percent organic matter, and release of nitrogen from organic matter is minor. The exact contribution of nitrogen released from soil minerals in uncertain, but is probably of minor importance. Nitrogen added in the irrigation water can be substantial. For example, if the nitrate-N content of the irrigation water is 5 ppm and 8 acre-feet/acre of water are applied, 110 pounds of nitrogen per acre is also applied. Fertilizers are a major source of nitrogen, even in the case of some phosphorus fertilizers. For example, ammonium phosphate (11-52-0) applied at the rate of 300 pounds of P_2O_5 per acre will add 63 pounds of nitrogen per acre.

LOSSES

Nitrogen may be lost as nitrate through leaching, as nitrogen gas or nitrous oxide through denitrification, as ammonia gas, through immobilization by organic matter, by clay fixation, by erosion, via uptake by soil microorganisms, or by plant uptake.

SYMBIOTIC FIXATION

Alfalfa has the ability to interact with certain bacteria (rhizobia) to convert atmospheric nitrogen gas (N_2) to a form useful to the plant. Inoculation is initiated by these bacteria, which invade the root hairs of the plant and cause nodules to develop on the roots. The plants provide the bacteria with food (carbohydrate) and the bacteria provide the plants with nitrogen, and a symbiotic relationship is established. Nitrogen fertilizer, thus, is generally not required for alfalfa.

Effective alfalfa nodules have a pink center that is the active site of nitrogen fixation. Ineffective nodules may appear similar to effective nodules except the center is usually white or pale green instead of pink. Nitrogen fixing nodules are not firmly attached to the root system, therefore, the soil and roots need to be carefully excavated and washed to recover nodules for observation. The nodules can vary in size from one-eighth to one-half inch in diameter.

The nitrogen-fixing capability of the alfalfa plant is affected by many factors especially soil nitrogen content, pH, temperature, and cutting. High levels of soil nitrogen decrease nitrogen fixation by legumes. Soil pH values less than 6.0 can adversely affect nitrogen fixation. Soil temperatures below 50°F and above 80°F can decrease nitrogen fixation. Root nodules often shed after cutting, decreasing nitrogen fixation by 70 percent to 96 percent.

Specific strains of rhizobia may be required for optimum growth of a given cultivar. This problem may be solved by using inoculum containing a mixture of effective strains. However, even if inoculation occurs with effective strains, optimum symbiotic associations are not necessarily established. Research suggests that native populations of rhizobia present in the soil cannot be displaced by more effective strains from commercial inoculation. The indigenous strains are generally so competitive that inoculated strains form an average of only 5 percent of the nodules.

Use of commercial inoculants is usually not necessary in Arizona or other areas with soils high in calcium except possibly when establishing alfalfa on new land or on land with no history of alfalfa production. Commercial inoculants are available as a peat-based solid, a liquid, or freeze-dried. Survival of the bacteria is superior in the peat-based inoculants. Inoculants are applied directly to the soil or with the seed at planting time. Inoculants may be applied to the soil in either granular or liquid form. Applying inoculants in the granular form to the soil eliminates the concern over mixing inoculants with fungicide-treated seed and may be required if seeding with an air planter. Applying inoculants to the soil in the liquid form usually involves mixing a broth or frozen concentrated culture with water and spraying the seed furrow with conventional spray equipment. The limitation of liquid application is that the cultures must be kept refrigerated or frozen. Inoculum may be applied to the seed either in the planter box or as a seed coating. Seed may be inoculated in the planter box (in order of effectiveness) by mixing a water slurry of the inoculum with the seed without excessively wetting the seed, by sprinkling or pre-wetting the seed before mixing the seed with the peat inoculants, or by applying the inoculum dry in layers to dry seed in the planter box. Oil-based inoculum products must be used with caution to avoid clogging the planter. Inoculation of alfalfa is most commonly accomplished by pre-inoculation of the seed prior to sale with a coating of lime, acacia gum, and the bacteria. For most effective results with the inoculants, be aware of the expiration date of the product, avoid mixing inoculants with certain chemicals especially fungicides, store inoculants in a cool area or keep refrigerated, and do not leave inoculants in planting equipment overnight.

FERTILIZATION

Nitrogen fertilizer is not recommended for an established stand of alfalfa. Nitrogen is often applied in small amounts as starter fertilizer at planting time to enhance seedling growth prior to development of effective nodulation. However, application of nitrogen fertilizer may delay the development of effective nodulation and encourage weed growth. Nitrogen fertilizer rates at planting time above 50 to 100 pounds of nitrogen per acre are excessive and rates of 25 to 50 pounds per acre would most likely not negatively impact the crop.

A positive response of an established stand of alfalfa to nitrogen fertilizer is rare but may occur as a result of other problems such as ineffective nodulation. Alternatively, nitrogen fertilizer may be necessary to achieve yields above 16 tons per acre according to a study conducted on the Yuma mesa in Arizona.

PHOSPHORUS

ROLE IN THE PLANT

The phosphorus content of alfalfa is usually in the range of only 0.2 to 0.4 percent. Nevertheless, phosphorus plays a key role in many vital plant processes. The most important P-containing compounds in the plant are various energy-transferring compounds and nucleic acids, which are the building blocks of genes. Phosphorus has a direct effect on the formation and activity of nitrogen-fixing nodules in the alfalfa plant. Adequate phosphorus nutrition is important for early growth, development of a vigorous root system, maximizing water use efficiency, and maintaining protein levels.

DEFICIENCY SYMPTOMS

Phosphorus deficiency does not always produce well-defined symptoms in alfalfa, and growth reduction may occur without obvious deficiency symptoms. When symptoms do occur, phosphorus deficiency in alfalfa is characterized by stunted and barren plants. Leaves may be small and appear abnormally dark or bluish-green in color. The leaflets may fold together and the underside of the leaf may develop a purplish color. The oldest leaves may turn yellow and die.

One of the first symptoms of phosphorus deficiency is reduced respiration, which results in accumulation of carbohydrates. Carbohydrate accumulation contributes to the dark-green color of phosphorus deficient plants, and leads to accumulation of anthocyanin pigments, which are responsible for purpling associated with phosphorus deficiency. Leaf hoppers and three-cornered tree hoppers also can be responsible for purpling in alfalfa. Three-cornered tree hoppers girdle the stem leading to carbohydrate accumulation and purpling. Phosphorus is mobile in the plant, and highest concentrations are found in the new growth. Phosphorus may be remobilized from the oldest to the youngest leaves during deficiency conditions leading to death of the older leaves.

Phosphorus deficiency is most likely to occur during cool periods when diffusion and replenishment of P in the soil solution is greatly decreased. Seedling alfalfa is particularly susceptible to P deficiency since the root system is small and not established.

FORMS IN THE SOIL

Most soil phosphorus is fixed in unavailable forms. Phosphorus exists primarily as relatively insoluble calcium phosphates in most Arizona soils, although 10 percent to 30 percent of the phosphorus may be in organic form. A small amount of P exists in the soil solution as orthophosphate (HPO_4^{2-} or $H_2O_4^{-}$), which is the form taken up by plant roots. Phosphorus moves a short distance through the soil to plant roots by diffusion and is readily converted to unavailable forms. At any given point in time, the soil solution may contain only one tenth of a pound of P per acre since P is relatively insoluble in water. The P in the soil solution must be completely replenished several times each day on the average to meet plant demands. Much of the P in soil solution is "positionally unavailable" for plant uptake since plant roots occupy 1 percent or less of the soil volume. Therefore, the maintenance of adequate P concentration in the soil solution is critical for nutrition of the plant.

FERTILIZATION

Soil and plant analyses serve as a guide for phosphorus fertilizer requirements. Soil samples should be taken randomly from fields or management units before planting and submitted to a laboratory for analysis. Soil test values > 15, 11 to 15, 6 to 10, and < 6 ppm P from a bicarbonate extraction correspond to high, medium, low, and very low levels of P in the soil, and require none, 50 to 150, 140 to 250, and 200 to 300 pounds of P_2O_5 to be applied, respectively, for a 3-year crop. After planting, the phosphorus status of the field can be monitored by sampling stems at 10 percent bloom, except during the hot summer months. Total phosphorus concentrations in the plant greater than 0.20 percent indicate that top-dressing of phosphorus fertilizer is not required. A phosphorous rate of 50 to 100 pounds P_2O_5 per acre is recommended if the plant phosphorus concentration is 0.18 percent to 0.20 percent, 75 to 150 pounds P_2O_5 per acre is recommended if the plant phosphorus concentration is 0.14 percent to 0.18 percent, and 100 to 200 pounds P_2O_5per acre is recommended if the plant phosphorus concentration is less than 0.14 percent.

Phosphorus fertilizer applied at a rate sufficient for the life of the stand (assuming 3 years) is usually more economical than split applications due to cost of the application. In an experiment conducted in the Imperial Valley of California, annual applications of P resulted in a slight yield increase compared to a single application at planting, but the yield increase was not sufficient to offset the cost of application. Phosphorus applied at planting time allows incorporation of the fertilizer into the soil which is sometimes an advantage compared to top-dressing existing stands. However, top-dressing is often very effective since P is not subject to the degree of soil contact and fixation which occurs when broadcasting, root activity near the surface is high, and some P is absorbed by the crowns. The disadvantage of top-dressing, of course, is the fertilizer remains in the surface soil and may not be available to roots during drying cycles. Annual P applications may be necessary with soils low in P and at high yield levels.

Placement methods for phosphorus fertilizer include surface application, top-dress, broadcast and disc or plow, seed placed, banding, banding at various distances below and to the side of the seed, deep placement, surface strip placement, application in the irrigation water, aerial application, and combinations of the above. The most common methods of application are broadcast or banding preplant and top-dressing or application in the irrigation water for established stands. Band-placement of P fertilizer with the seed at planting time is generally more efficient than other methods of application. The amount of P_2O_5 required per acre for effective banding application is less than that required for a broadcast application. Banding can increase growth compared to broadcasting particularly during the seedling stage and for the first few cuttings.

Phosphorus fertilizer moves very little once applied to the soil. Arizona research has demonstrated that most of the P applied in a band moved less than 1 inch, and liquid phosphoric acid applied to the surface of a fine sandy loam moved less than 4 inches. Research conducted in other areas have shown that top-dressed phosphorus moves 3 inches or less in the soil after several years.

Phosphorus fertilizer sources include manure (1.15 percent P_2O_5), triple superphosphate (0-45-0), monoammonium phosphate (11-53-0), diammonium phosphate (18-46-0), ammonium phosphate sulfate (16-20-0), and liquid ammonium polyphosphate (10-34-0). Manure is a good source of phosphorus since P is released over a period of time as the manure breaks down. A manure application of 15 to 20 tons per acre should provide adequate phosphorus for soils low in P. Top-dressing manure on established stands can be a satisfactory practice. However, the disadvantages of manure include its high nitrogen content which can reduce nodulation, salt and weed seed in the material, greater mass of material that needs to be handled compared to inorganic fertilizer sources, and the inability to apply manure in a band. Triple superphosphate (0-45-0) is a preferred fertilizer for alfalfa since it does not contain nitrogen and will not adversely affect nodulation or result in injury to the seedling if applied in a band. Monoammonium phosphate (11-53-0) is an acceptable fertilizer for alfalfa although rates greater than 500 pounds of fertilizer per acre could adversely affect nodulation. Ammonium phosphate sulfate (16-20-0) contains too much nitrogen to be an effective phosphorus fertilizer for alfalfa, although it may be useful in situations where nitrogen and phosphorus are desired as components of a starter fertilizer. Liquid ammonium polyphosphate (10-34-0) is useful to apply P in surface strips, injected in bands, or in the irrigation water. Phosphate applied in the irrigation water penetrates the soil deeper than a top-dress application but the uniformity of application is no better than the uniformity of water application.

POTASSIUM

ROLE IN THE PLANT

Potassium affects nearly every aspect of plant growth. Potassium is involved in more than 60 different enzyme systems moderating the rate of plant growth processes. Potassium regulates production of high energy compounds from photosynthesis and helps in the translocation of sugar and starch. Potassium is required for the formation of protein and starch. Opening and closing of leaf pores or stomates is regulated by potassium, and efficient use of water is promoted. Potassium increases root growth and improves drought resistance. Crop quality factors such as plant protein content, feeding value, resistance to diseases, and stem strength are also affected by potassium.

DEFICIENCY SYMPTOMS

Potassium deficiency symptoms appear first as small white spots on the outer edges of the upper leaflets. The areas between the spots may turn yellow. In some cases the oldest leaves may turn yellow and a brown necrosis may develop around the margins. In severe cases, the size and number of white spots increases and the leaves become yellow and dry. The lower leaves may drop. Some alfalfa varieties exhibit a genetic disorder resulting in white spots over the entire leaf surface, in contrast to the margins as in potassium deficiency.

Potassium deficiency symptoms may also appear on older leaves as poorly defined gray spots on the upper surface near the edges opposite the midrib. These areas become pinkish cinnamon in color, and spread across the entire leaf. Secondary shoots with small leaves may continue to be produced from the base of the plant.

Alfalfa stands may be thinned and grasses become a problem in fields low in potassium.

FORMS IN THE SOIL

Calcareous soils of the irrigated valleys in Arizona contain 1.4 percent to 3.0 percent total potassium representing 56 to 120 thousand pounds of potassium per acre-foot. The potassium in the soil may occur in water-soluble, exchangeable, or fixed forms. Less than 1 percent of the potassium in the soil exists in water-soluble form. The plant extracts water-soluble potassium from the soil solution for its requirements. Exchangeable potassium comprises 6 percent or less of the total potassium in the soil. Exchangeable potassium adheres to the soil particles and becomes available for plant uptake when entering the soil solution after exchange or replacement with other cations such as calcium.

Most of the potassium in the soil exists as an integral part of the crystal structure of soil minerals, defined as the fixed form. Some fixed potassium eventually becomes available to the plant.

Most of the potassium taken up by alfalfa reaches the root surface by diffusion through the soil, rather than by mass flow through the transpiration stream. Areas of potassium deficient soil near the root surface may develop in soils unable to supply potassium at a rate to satisfy plant needs even in soils high in available potassium. Management factors, which enhance root volume and distribution, increase potassium use efficiency.

FERTILIZATION

Alfalfa has very high potassium requirements. Alfalfa removes approximately 60 pounds of K_2O per acre per ton of hay yield. However, potassium fertilization of calcareous soils in Arizona is generally not required. Native levels of potassium in the soil are usually high enough to satisfy crop needs. Potassium may be needed on certain noncalcareous sandy soils of low cation exchange capacity. Ensuring an adequate level of potassium is very important in attempting to maintain alfalfa in alfalfa-grass mixtures since grasses can outcompete alfalfa for potassium.

Potassium is rarely recommended in the United States when the concentration of exchangeable soil potassium is greater than 75 ppm. Most Arizona soils contain 2 to 20 times this threshold concentration. Concentrations of potassium in the plant greater than 2 percent are generally thought to be adequate. In Arizona, application of potassium to plants containing 1.5 percent potassium in the mature plant has failed to increase yield. Under Midwestern U.S. conditions, a sufficient potassium concentration in the upper 6 inches of the plant at early bloom is 2.5 percent. A critical level for potassium in the midstems established by the University of California is 0.80 percent. Many factors can influence the concentration of potassium in the plant tissue besides potassium level in the soil such as stage of growth, temperature, and presence of competing cations in the soil solution.

Large quantities of potassium are usually required to correct soils low in potassium. A rate of 60 pounds or more of K_2O per ton of yield goal is usually recommended. Rates above 400 pounds of K_2O as potassium chloride may result in injury from the chloride. Low rates of potassium fertilizer must be applied if banding.

The most efficient time to fertilize is thought to be before planting, but top-dressing potassium on established stands can also be very efficient. Top-dressed potassium fertilizer usually penetrates a few inches into the soil except on sandy soils. If the surface soil remains dry after top-dressing with potassium, then the fertilizer will not be available to the plant. Annual applications of potassium fertilizer to alfalfa are frequently necessary for soils low in potassium.

In the United States, potassium chloride (0-0-60) is the most common potassium fertilizer for alfalfa. Sources of potassium fertilizer other than potassium chloride may be preferable to reduce potential chloride toxicity at high rate or when application of other nutrients such as magnesium or sulfur is recommended. Additional sources of potassium fertilizer include potassium sulfate (0-0-50), potassium nitrate (13-0-45), and potassium magnesium sulfate (0-0-22).

SULFUR

Sulfur is a constituent of certain amino acids and vitamins. Low levels of sulfur result in decreased nitrogen fixation and low protein levels. Sulfur deficiency symptoms are similar to that of nitrogen. The plants are stunted and the upper leaves turn pale or yellowish. Maturity is delayed as symptoms become more severe, and leaves become long and slender, branching is abnormal, and stands become thin. In Arizona soils, sulfur is normally very plentiful and exists in organic form or as sulfates of calcium, magnesium, sodium, and potassium. The sulfate form is mobile in the soil and is readily leached.

Alfalfa removes 4 to 6 pounds of sulfur per ton of hay, which is considerably more than most other crops. Soil tests alone have not proven satisfactory as indicators of soil sulfur status. Critical soil sulfate-sulfur levels of 2 to 24 ppm have been reported for a crop response. Sulfur sufficiency levels in plants have been reported to be 0.22 to 0.30 percent total S at 10 percent bloom. Sulfate concentration of 800 ppm or greater in the leaves is considered adequate according to guidelines developed by the University of California. An optimum nitrogen to sulfur ratio of 11 has also been suggested as an indicator of plant sulfur status.

Coarse-textured soils low in organic matter are most likely to require sulfur addition. Sulfur fertilizer can be added in the form of elemental S, gypsum (calcium sulfate), potassium sulfate, or potassium magnesium sulfate. Elemental sulfur is often recommended if sulfate leaching is a potential problem. Soil incorporation of sulfur is not necessary. Required rates of sulfur application can range from 15 to 50 pounds per acre on an annual basis. The sulfur content of the irrigation water should be considered when determining a fertilizer program.

CALCIUM AND MAGNESIUM

Calcium is important in certain enzyme systems in the plant, in cell elongation, and in development of meristematic tissue. Magnesium is a constituent of the chlorophyll molecule and is essential for photosynthesis, carbohydrate and nitrogen metabolism, and synthesis of oil. Calcium deficiency seldom occurs in the field. Calcium deficiency is characterized by 1) a collapse of the petiole and reddish-purpling on the underside of the leaflets of the youngest fully developed leaves of young plants, 2) young immature leaf margins turning blue-green, gray white, then brown and the margins curling up and in to form a funnel, and 3) in older plants, the upper 1 inch of the stem collapsing suddenly. Magnesium deficient plants show interveinal chlorosis, the leaf margins turn yellow, may redden, and die. Magnesium deficiency symptoms progress from older to younger leaves. Calcium and magnesium can occur in the soil as a constituent of soil minerals, adsorbed to soil particles, or as carbonates or phosphates.

An 8-ton-per-acre alfalfa crop can remove approximately 200 to 250 pounds of calcium and 40 to 50 pounds of magnesium per acre. Arizona soils are usually well supplied with both calcium and magnesium and a response to either of these nutrients is unlikely. Magnesium deficiencies are most likely to occur on soils containing less than 50 ppm of exchangeable magnesium. Magnesium deficiency also may occur if the magnesium saturation drops below 10 percent to 15 percent of exchangeable cations in soils as reported from humid-region states. Magnesium deficiency can occur due to long-term applications of calcitic limestone to control soil acidity, high soil potassium levels, or high soil sodium levels. Calcitic limestone (calcium carbonate) and dolomitic limestone (calcium-magnesium carbonate) are the principal sources of calcium and magnesium. Gypsum (calcium sulfate), epsom salt (magnesium sulfate), potassium magnesium sulfate, and magnesium chelate foliar spray are additional sources of these elements.

MICRONUTRIENTS

BORON

Boron is involved in sugar and starch translocation, pollination and seed production, cell division, protein formation, and in sugar, starch, nitrogen, and phosphorus metabolism. Boron deficiency is most common during periods in which the surface soil dries and may be confused with drought symptoms or leafhopper yellowing. Boron deficient alfalfa sometimes is called "yellow top" or "alfalfa yellows." Plant tops become yellow and reddish. The top leaves may bunch and the growing tip die, while the lower portion of the plant remains green. Plants may fail to flower and may provide poor seed yields. When conditions improve, side branches may grow beyond the main stem. Boron exists in the soil in organic matter or as borates of sodium, calcium, or magnesium. Boron deficiency can result from drought conditions or any practice that depletes organic matter or slows its decomposition or from high or low soil pH.

An 8-ton-per-acre alfalfa crop contains approximately one-half pound of boron. Nevertheless, alfalfa is sensitive to boron availability. Soil tests for boron availability have generally not been successful. Sufficiency levels of boron have been established ranging from 20 to 40 ppm boron in the top third of the plant by the University of California and 30 to 80 ppm in the top 6 inches of the plant by the University of Wisconsin. Boron fertilizer is most often applied as borax, although other sources of boron are available such as borosilicate glasses and liquid boric acid. Boron applications of 1 to 3 pounds boron per acre are generally recommended for alfalfa. This small amount of boron can be applied mixed with other fertilizer. Boron fertilizers should always be broadcast and never banded.

COPPER

Copper is required in the plant for enzyme systems, protein synthesis, seed formation, chlorophyll formation, and nitrogen metabolism. Copper deficiency is characterized by wilting of the younger leaves. In some plants, the petioles of the younger leaves curve, causing the leaflets nearly to touch the lower part of the petiole. Pale gray to white spots typically appear near the base of each leaflet, or near the margins. The growing point may die, followed by the leaflets and petioles. Copper is present is soils primarily as a cation adsorbed to clay minerals and as a component of organic matter.

No documented cases of copper deficiency have been reported in Arizona. Some alfalfa yield responses have been reported in other areas from copper additions to high-organic-matter soils or highly weathered sandy soils. Copper deficiencies are more likely to occur at high rather than low pH since copper is less available when soil pH is high. In New Zealand, 5 ppm EDTA extractable copper from the soil is considered adequate. Copper in the plant tissue is not a good indicator of copper availability due to fluctuations resulting from growing season conditions. Copper is commonly applied as copper sulfate to the soil or as a solution to the leaves. Other copper salts and chelated copper foliar spray are available. Approximately one-fifth of a pound of copper is removed in an 8-ton alfalfa crop. However, a rate of 2 to 4 pounds of copper per acre is necessary when applying the fertilizer to the soil since copper is rapidly fixed by the soil. A much lower rate is recommended when applying copper as a foliar spray. Copper applications have a residual effect, so a single application may be sufficient for three years. Overapplication of copper can result in copper toxicities.

IRON

Iron is essential for chlorophyll and protein formation, enzyme systems, respiration, photosynthesis, and energy transfer. Iron deficiency in alfalfa is characterized by yellowing between the veins of the youngest leaves (interveinal chlorosis). The leaves progress from yellowish-green to a bleached yellow and may eventually die. Iron deficiency can occur on soils with a pH above 7.5. Deficiencies can also occur in the presence of excess carbonates and under saturated soil conditions. Cold temperatures can reduce absorption of iron by plants. A high phosphorus content or excesses of zinc, copper, manganese, and other micronutrients may aggravate an iron deficiency. Excess manganese, for example, can affect the rate of reduction of iron from unavailable to available forms in plant cells. Thus, some plants suffering from iron deficiency contain sufficient iron, but in an unavailable form. Iron exists in the soil as a component of minerals and as oxides, hydroxides, and phosphates. A relatively small amount of iron is in soil solution.

An 8-ton-per-acre alfalfa crop removes approximately 3 pounds of iron. Soil analysis has not been effective in determining crop needs for iron. A sufficiency range of 30 to 250 ppm for the top 6 inches of alfalfa sampled prior to bloom has been established by Ohio State University. Soluble inorganic iron fertilizer is not effective on the alkaline soils of Arizona. Chelated materials are effective but usually cost-prohibitive. Foliar application can correct deficient leaves, but new leaves may still be deficient due to poor translocation.

MANGANESE

Manganese is required in plants for photosynthesis, enzyme systems, nitrate assimilation, iron metabolism, and chlorophyll formation. Manganese deficiency is characterized by yellowing between veins of the younger leaves, followed by the development of small, light brown areas on the upper leaf surface. Manganese deficiencies can be produced by liming a soil to an acid reaction, burning organic soils, by certain bacteria that oxidize manganese to an unavailable form, or by excess calcium, magnesium, or iron. Manganese deficiency in alfalfa is rare, but is most common in alkaline soils, especially those high in phosphorus and those with poor drainage. Manganese exists in the soil as a component of organic matter, adsorbed to the exchange complex, or as various oxides.

The sufficiency range of manganese for the top 6 inches of the plant sampled prior to bloom is 30 to 100 ppm according to Ohio State University. An 8-ton-per-acre alfalfa crop removes approximately 2 pounds of manganese, but 15 to 20 pounds of manganese per acre is usually necessary to correct manganese deficiency. Manganese also can be applied as a foliar solution. Manganese sulfate is a common form of manganese fertilizer, although other manganese salts and chelates are available.

MOLYBDENUM

Molybdenum is essential to alfalfa for protein synthesis, atmospheric nitrogen fixation, various enzyme systems, and for nitrogen metabolism. Since molybdenum is necessary for nodulation and assimilation of nitrogen in the plant, molybdenum deficiency symptoms are similar to nitrogen deficiency symptoms of dwarfed, spindly growth with general yellowing. In addition, leaflets may show interveinal white notching, followed by complete bleaching of the tips and centers. Flowering may be reduced. Molybdenum deficiency occurs in acid soils because molybdenum is less available at low pH, in soils high in iron, and in soils where molybdenum is subject to leaching. Molybdenum is present in the soil as a component of minerals, as oxides adsorbed by clay particles, as part of organic matter, and as water soluble compounds.

Molybdenum is required in very small quantities by an alfalfa plant. An 8-ton-per-acre alfalfa crop contains one-third ounce of molybdenum. Alfalfa plants containing less than 0.5 ppm molybdenum at one-tenth bloom are considered deficient. A deficient level of 0.3 ppm molybdenum in the top one-third of the alfalfa plant has been established by the University of California. Molybdenum fertilizer can be supplied by ammonium or sodium molybdate or molybdenum trioxide mixed with other fertilizer sources or as a foliar spray. Molybdenum rates can vary from a few ounces to a few pounds per acre. Overapplication of molybdenum can result in molybdenosis disease in animals fed the forage or, at higher concentration, molybdenum toxicity to the plant itself.

ZINC

Zinc is used by alfalfa for protein synthesis, starch formation, root development, enzyme systems, growth hormones, and seed formation. Zinc deficiency is characterized by 1) small, upward curling young leaves, 2) brown to bronze spots (which eventually turn white) around the margins or randomly distributed on the top leaves of the plant, 3) retarded growth, reduced tillering, and general plant yellowing, 4) small, stiff new leaves with margins that tend to roll inward and a deep notch at the tip, and 5) a graying pattern on the middle leaves of the plant that starts at the tip and soon covers the whole leaflet. Zinc deficiency symptoms are rarely observed in the field because alfalfa has a low zinc requirement. Zinc deficiency is most likely in high pH soils with high phosphorus availability. Zinc exists in the soil as a constituent of minerals and organic matter, adsorbed to soil particles, or as carbonates of calcium and magnesium. Zinc is relatively immobile in most soils.

An 8-ton-per-acre alfalfa crop contains approximately one-third of a pound of zinc. Soil tests for zinc availability have not been successful. A deficiency level for whole alfalfa plants is 15 ppm, with a sufficiency range of 21 to 70 ppm for the top six inches of the plant sampled prior to bloom. Zinc fertilizer usually is applied at rates of 5 to 15 pounds zinc per acre as a soluble salt such as zinc sulfate. Chelated forms of zinc may be useful on soils with a high zinc-fixing capacity.

OTHER MICRONUTRIENTS

Cobalt is essential for rhizobia bacteria, which fix atmospheric nitrogen in association with the alfalfa plant. Chlorine is reported to be essential for growth, but deficiency symptoms have not been reported in the field.