CHAPTER TWO

STAND ESTABLISHMENT

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Profitable alfalfa production is contingent upon establishment of a dense vigorous stand. Proper stand establishment is especially important in the Intermountain Region, where alfalfa fields may remain productive for 5 to 8 years or longer. Poor stand establishment can reduce the profitability of alfalfa by lowering yields, diminishing stand life, and reducing the nutritional quality of the hay. Mistakes made during stand establishment cannot usually be offset later.

SEEDBED PREPARATION

Inadequate seedbed preparation is a common cause of stand establishment failure. The objectives of seedbed preparation are to loosen the soil to remove any impediment to root growth, to level the field for drainage and ease of harvest, and to firm and smooth the soil surface for optimum crop emergence. This is accomplished through primary tillage (deep plowing or ripping); land leveling; and secondary tillage, which breaks up clods and firms the soil.

Primary Tillage

Alfalfa requires well-drained, relatively deep soil (a minimum of 3 to 4 feet) for maximum production. Physical or chemical limitations caused by hardpans, stratified soils, or salts can restrict rooting depth, which leads to decreased productivity and lower yield. Soil compaction occurs from equipment traffic, especially when it takes place on wet soils and when the crops transported are heavy, as are potatoes or sugar beets. Deep tillage can reduce compaction.

Several deep-tillage implements are used in alfalfa seedbed preparation: a ripper, or subsoiler; a moldboard plow; and a slip plow. A ripper is the most commonly used implement to alleviate compaction. For best results, work when the soil is dry and rip below the depth of the compacted layer. Ripping wet soils does not fracture compacted layers. Space the shanks no more than 3 feet apart. Ripping in one direction at half the spacing results in more of the soil being fractured than cross ripping—that is, using 20-inch centers in one direction is more effective than using 40-inch centers in two directions. The duration of the beneficial effects of ripping varies depending on the

soil type and the nature of the compaction problem, but fields should ordinarily be ripped prior to each alfalfa planting. In some cases ripping can be done well in advance of alfalfa seeding. For example, prior to a spring planting, rip fields in the fall. Rip fields in a cereals-alfalfa rotation prior to planting the grain crop. Ripping shatters compacted layers but does not mix the soil, so the beneficial effects of ripping may be short-lived in layered soils (soils with distinct changes in soil texture with depth).

A moldboard plow can also be used to alleviate compaction problems. It is particularly beneficial in layered soils, because plowing inverts and mixes the soil. Plowing can be a useful way to remove old alfalfa stands, bury weed seeds and plant debris, and incorporate fertilizer deep into the soil. However, plowing can sometimes bring less-desirable soil to the surface and is especially problematic in rocky fields. Any soil requires extra tillage or time to firm up or settle after plowing. In most Intermountain Region soils, an excellent seedbed can be prepared without plowing.

The proper type and degree of deep tillage can be difficult to ascertain. No single "recipe" is appropriate for all locations. An understanding of the soils and a knowledge of crop history are great aids in evaluating the need for deep tillage. Prior to removing a stand use a backhoe to determine the distribution of roots in the soil profile; root distribution indicates soil stratification or impermeable layers. The economics of deep tillage can be difficult to predict. Deep-tillage implements have high horsepower requirements, so deep tillage can be very expensive—in excess of $200 per acre. Fortunately, deep tillage is not necessary for most fields in the Intermountain Region. However, ripping to moderate depths, 20 to 32 inches, is usually cost-effective and recommended to reduce compaction from preceding crops.

Land Leveling

Leveling the field is important. The degree of leveling necessary depends on the irrigation system and soil type. With sprinkler irrigation, low spots need to be filled and leveled so that water does not pond and drown the alfalfa. More extensive leveling is required for fields with flood-irrigation systems.

Before the advent of laser leveling, correct cut and fill as well as the proper field slope were difficult to attain. Laser leveling is expensive, but it is by far the preferred method when flood irrigation is used. Laser leveling may be done in two stages. The rough leveling may be done after primary tillage. After irrigation borders are formed, the area between borders can be laser-leveled to attain a precise level and slope. Laser leveling between borders is also a common practice in older, previously leveled fields that are being planted to alfalfa.

Secondary Tillage

The field should be disced, harrowed, floated, and packed to form a firm, clod-free seedbed that is neither powdery nor fluffy (Figure 2.1). It should be firm enough so that a heel print in the prepared soil is not more than ½ inch deep. Poor establishment is likely if the surface is not well compacted prior to seeding. A relatively clod-free seedbed prevents excess air space, permits good seed-soil contact, allows uniform planting depth, and improves moisture availability to the seed. Take care not to overwork heavy soils: Overworking will increase their undesirable tendency for surface crusting.

COURTESY FORD NEW HOLLAND

Figure 2.1. The ideal seedbed should be firm, not powdery or fluffy, and clod-free.

PREIRRIGATION

Alfalfa can be seeded into moist soils or seeded into dry soils and then irrigated. Planting into moisture can be accomplished by either preirrigating before planting or by preparing the seedbed in the fall and taking advantage of winter precipitation to provide moisture. The advantages of planting into moist soils are that the moisture has usually melted the clods and, if the moisture is uniform, alfalfa seeds can germinate uniformly and quickly. Also, keeping up with irrigation is easier when starting with a full soil-water reservoir. Contact-type herbicides or shallow cultivation can be used to control weeds that emerge prior to planting.

Despite these advantages, the time required for seedbed preparation, irrigation, surface drying, spraying for weed control, and then planting deters many growers from preirrigation. Preparing the seedbed, planting, and irrigating is much simpler. However, a dry planting system can be less forgiving. The grower must take great care to meet the water requirements of the young crop. Weed populations are usually higher in fields that have not been preirrigated, making postemergence weed control more difficult.

SEEDING

Seeding Depth

Seed placement is critical. More stand establishment failures probably relate to seeding too deep than to any other single factor. Seeding depth should not exceed ⅜ inch, except for sandy soils, where ⅝ inch is acceptable. Seeding deeper than this can reduce seedling emergence considerably (Table 2.1).

Table 2.1. Emergence from different seeding depths.

DEPTH (IN.)	% EMERGENCE[1]
¼–½	60
1	48
2–2½	2

Source: R. Sheesley

1. Emergence from different depths can vary with soil type—that is, poorer emergence results from deeper depths with a heavy soil, in contrast to a sandy soil.

Seeding Methods

Various implements are used to plant alfalfa, but all basically involve either broadcasting or banding (drilling) the seed. Each method presents advantages and disadvantages. Factors to consider when selecting a seeding method include cost, time, equipment available, and uniformity of seed distribution. Adequate alfalfa stands can be established using either method. Firming the seedbed after planting is an important part of seeding. It ensures the seed-soil contact necessary to prevent desiccation of the emerging alfalfa seedling. Cultipacking or ring rolling once after seeding is usually sufficient in broadcast seedings; cultipacking twice can be beneficial on coarse-textured soils. Press wheels or a cultipacker works well in drilled seedings.

Broadcasting

Compared to banding, broadcast seeding is generally faster and distributes seed more uniformly. A disadvantage of broadcast seeding is that uncovered seed remains on the soil surface. However, the amount of uncovered seed is considered insignificant. Several systems are used to broadcast alfalfa seed. A cultipacker seeder such as a Brillion seeder has been used with excellent results (Figure 2.2). A Brillion seeder drops seed between double corrugated rollers. The leading roller breaks clods and firms the soil prior to seeding. The trailing roller splits the ridges made by the first roller, covering and packing the seed. Seed can also be successfully broadcast by using an air-flow ground

VERN MARBLE

Figure 2.2. A Brillion seeder is often used with excellent results to broadcast alfalfa seed.

applicator, fluid or suspension seeding techniques, aerial application, or the small seed attachment of a grain drill, which allows seed to fall out of the seed tubes and scatter on the ground. Aerial seeding is uncommon in the Intermountain Region. When used, increase the seeding rate by 2 to 4 pounds per acre to compensate for losses and nonuniformity.

Banding

A standard grain drill is typically used to band, or drill, alfalfa. Nearly all the seed is incorporated and covered when alfalfa seed is drilled. Phosphorus fertilizer can be banded with the seed at the time of seeding, another advantage of this seeding method. In addition, drilling disturbs soil less than does broadcasting, so drilling conserves soil moisture. This is particularly important when growers rely on rainfall for crop emergence. The primary disadvantage of drilling alfalfa seed relates to distribution. The distance between alfalfa seed rows is typically 6 to 7 inches. This is a particular problem when there is a planter skip, doubling the distance between rows to 12 to 14 inches. Some growers drill in two directions to overcome this problem.

Seeding Rates

A wide range of seeding rates can be acceptable provided the seedbed was properly prepared. Twenty alfalfa seedlings per square foot constitutes an adequate stand. One pound of alfalfa seed spread evenly over an acre equates to approximately 5 seeds per square foot (4 pounds per acre equals 20 seeds per square foot). Although these figures suggest extremely low seeding rates are feasible, this is not the case. Typically, only 60 percent of the seeds germinate and emerge; 60 percent of emerged seedlings may die during the first year. Under ideal conditions, adequate stands have been established with seeding rates as low as 12 to 15 pounds per acre. To compensate for less-than-ideal conditions and unforeseen weather, the seeding rate recommended for irrigated fields is 15 to 20 pounds per acre when drilling and 20 to 25 pounds per acre when broadcasting. An extra few pounds of seed is generally not too costly and is cheap insurance against less-than-optimum seedbed and weather conditions. Seeding rates higher than these are excessive. Because of self-thinning, a 1-year-old alfalfa stand seeded at an excessive rate would not likely be any different than a 1-year-old stand seeded at the recommended rate.

Seed dryland alfalfa at 8 to 10 pounds per acre. Higher seeding rates waste seed because dryland conditions cannot support as many plants per square foot as can irrigated fields.

More stand establishment failures probably relate to seeding too deep than to any other single factor.

PLANTING DATE

Factors to be considered when determining planting date include weather (primarily temperature and the likelihood of rainfall), cropping pattern, harvest date of the preceding crop, water availability, irrigation method, weed pressure, and the time of year when environmental conditions are optimum for crop emergence and seedling development. No single planting date satisfies all the criteria. Advantages and disadvantages of each time period must be weighed to decide the most appropriate date (Table 2.2). Actual seeding dates vary depending on the intermountain production area (Figure 2.3).

Spring

Spring planting dates vary considerably within the Intermountain Region. Planting can begin as early as the last week in February in areas such as Shasta Valley; they can be as late as the end of May in higher-elevation areas. The likelihood of a damaging frost delays the starting date for spring planting. Alfalfa is extremely cold tolerant at emergence. However, plants are frost sensitive when they have two trifoliolate leaves, and may be killed by 4 or more hours exposure, at 26°F (–3°C) (Figure 2.4). After plants reach the three-leaf stage, they can again withstand lower tem-

Table 2.2. Considerations in selecting a planting date.

	ADVANTAGES	DISADVANTAGES
Spring	• Rainfall may be sufficient for crop emergence. (This is especially important for flood-irrigated alfalfa fields.) • Higher yield the seeding year than that from summer planting.	• Reduced yields in seeding year (compared to fall seeding). • Chance of damaging spring frosts. • Weed competition. (Summer weeds may persist beyond first cutting and contaminate subsequent cuttings.) • Irrigation may be difficult during summer of first year (due to limited root system).
Midsummer	• Low probability of killing frost. • Rapid uniform emergence. • Improved effectiveness of some broadleaf herbicides (such as 2,4-DB).	• Frequent light irrigations required; many irrigation systems are inadequate. • Income lost from rotation crop or shorter production season for alfalfa. • Competition from summer annual weeds.
Late summer	• Nearly full production the year after seeding. • Less weed competition: Many fall-germinating annual weeds are killed by winter frosts; surviving winter annual weeds will be removed in the first cutting. • Alfalfa root and crown development over fall and spring facilitate irrigation management the first year.	• Sprinkler irrigation needed for crop emergence. • Likelihood of frost or heaving injury if planted too late. • In higher-elevation areas climate may preclude harvesting grain early enough to allow for timely alfalfa seeding.

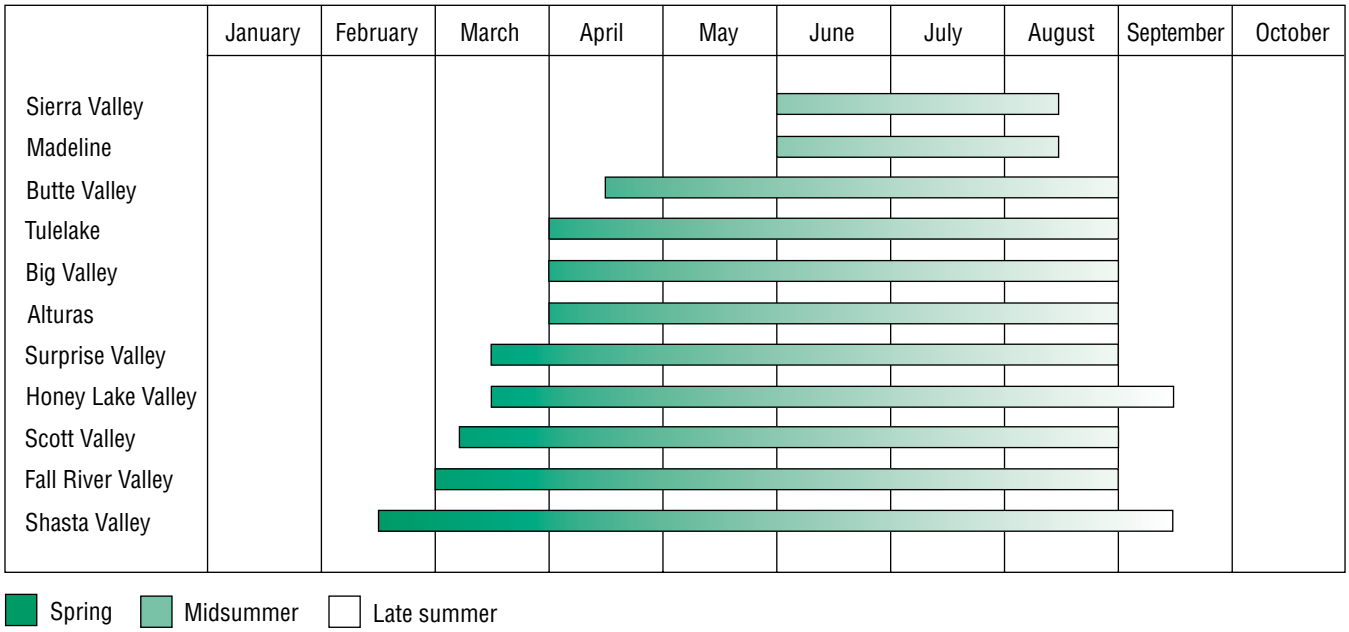

Figure 2.3. Alfalfa planting dates for areas in the Intermountain Region.

peratures. The main advantage of spring planting is that spring rains may provide sufficient moisture for crop emergence and reduce subsequent irrigation requirements. This is particularly advantageous in flood-irrigated fields. It is difficult to flood-irrigate during alfalfa establishment without causing soil erosion and washouts. (A washout is when irrigation water tears a seedling out of the soil.) The primary disadvantages of spring planting are competition from summer annual weeds and first-harvest yields lower than those from fall plantings.

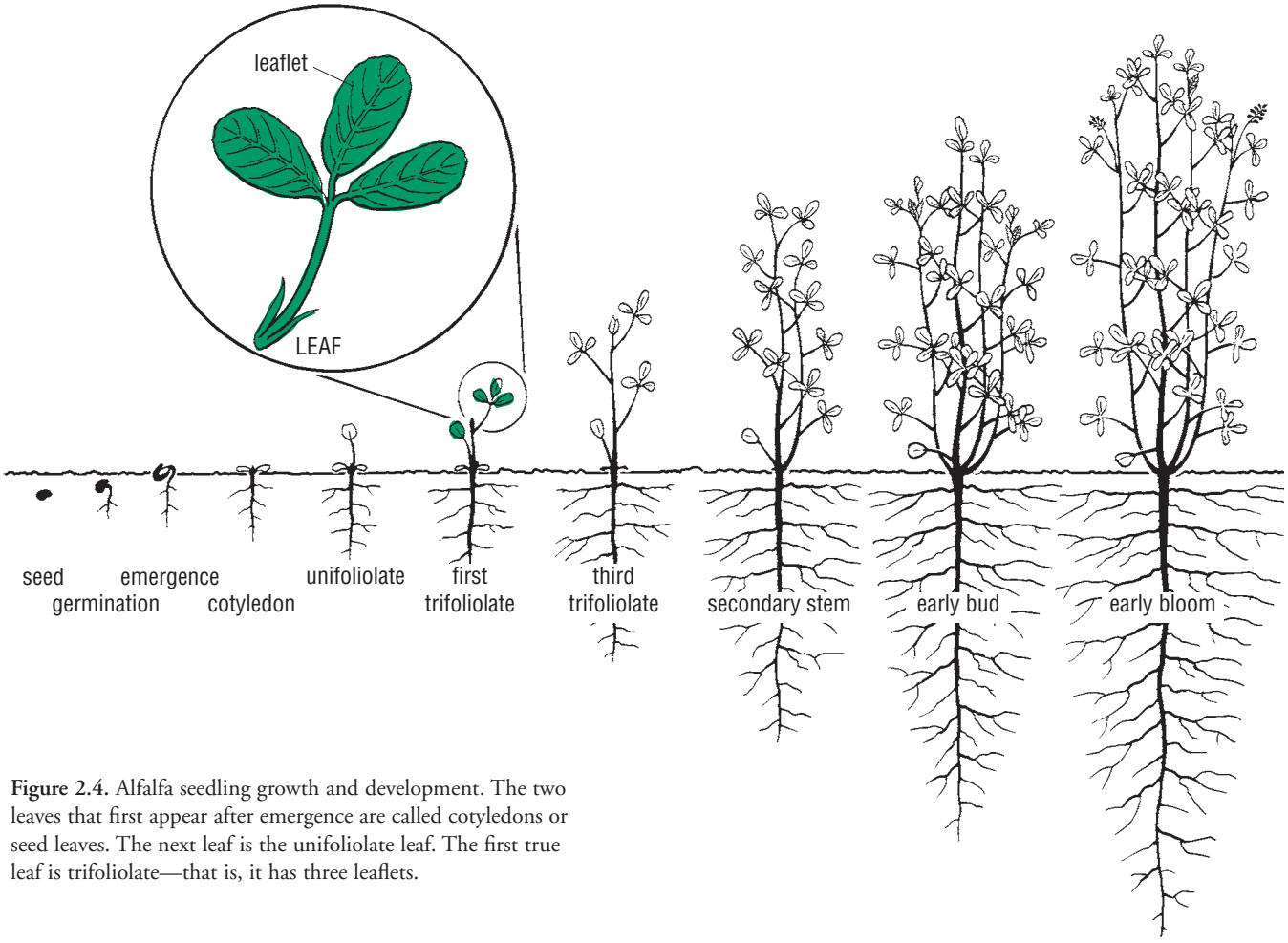

Figure 2.4. Alfalfa seedling growth and development. The two leaves that first appear after emergence are called cotyledons or seed leaves. The next leaf is the unifoliolate leaf. The first true leaf is trifoliolate—that is, it has three leaflets.

Midsummer

Summer plantings are the norm for elevations around 5,000 feet. Even in the lower valleys, planting during the warm summer months offers advantages. Warm temperatures promote rapid and uniform emergence and development of the young seedlings, and the danger of a killing frost is very low. The broadleaf herbicide 2,4-DB works well under these conditions. The major disadvantage of summer planting is that hot dry weather in midsummer can make maintaining adequate soil moisture extremely difficult, and make frequent irrigation necessary. An inadequate irrigation system or insufficient labor is an insurmountable obstacle to summer planting.

Fall

Fall planting in the Intermountain Region is more appropriately called late-summer planting. Depending on elevation, early to late August is the best time for a late-summer planting. Seeding at this time offers significant advantages. Moderate temperatures favor rapid emergence and development of alfalfa seedlings. Alfalfa plants seeded in late summer continue to grow and develop over the fall and spring. By mid-spring, alfalfa plants are well established and the result is a first-year yield similar to that from an older stand and much greater than that from a spring seeding. This is a major economic advantage. The yield advantage is not limited to the first production season; it continues for several yeears after planting.

Also, compared to spring-seeded alfalfa, alfalfa plants seeded in late summer have a much better-developed root system come summer. Consequently, it is easier to avoid moisture stress between irrigations during the hot summer months.

The risk of late-summer planting occurs when fields are planted too late (September or later in most areas). Planting should be completed at least 30 to 45 days before the first killing frost (approximately 26°F, or –3°C). Harsh winter conditions can take a toll on immature alfalfa seedlings. Freezing and ice formation causes soil heaving in fine-textured soils, uprooting and killing alfalfa seedlings that have not developed an adequate root system. Larger, more-established plants are better able to withstand these conditions.

The ability to seed alfalfa in late summer depends on the crop rotation sequence and weather. If alfalfa follows a late-harvested crop such as sugar beets or potatoes, a late summer planting is not possible. However, late-summer alfalfa plantings following a winter or spring cereal crop are feasible. Winter cereals or cereals grown for hay work best because they are harvested early enough to allow sufficient time to prepare fields for an August alfalfa planting. An August planting is also feasible following spring cereals produced for grain. Success depends on the harvest date of the grain, and the harvest date relates to the production area and weather conditions.

SEEDING STRATEGIES

Several strategies have been developed to seed alfalfa in the Intermountain Region. The best approach depends on the area, soil type, and planting date.

Tillage Prior to Seeding

The most common technique for both spring and fall plantings is to perform tillage and seedbed preparation operations just prior to planting. A technique that works well for spring plantings is to do primary tillage in the fall and final seedbed preparation in the spring. Soils are usually drier in fall than they are in spring, so ripping in the fall is more effective. An early spring planting date is possible because growers are not delayed waiting for spring soils to dry sufficiently to rip them.

Fall Tillage with Spring No-till Seeding

In spring, heavy soils are nearly impossible to prepare. An alternative in some areas is to prepare the land in fall and let winter rains and freezing create a clod-free surface (this has been done successfully in the Shasta Valley). Emerged weeds can be sprayed with Roundup (glyphosate) herbicide prior to seeding. The seedbed will generally be weed-free and the surface smooth and firm. In warmer areas growers use no-till methods to plant alfalfa in late February. These growers prefer no-till drilled seeding because tillage dries out the surface, removing needed moisture in the surface layer. This technique relies on soil moisture and spring rains for crop emergence and early seedling development. The field does not usually require irrigation until the alfalfa is a few inches tall and the threat of washouts from flood irrigation has diminished.

Stubble Seeding

Seeding into stubble is a practice used by many growers who have a crusting or wind erosion problem. It works well for late-summer seedings when there is insufficient time to cultivate the soil. Alfalfa seed is sown directly into the cereal stubble. Seedbed preparation, fertilizer application, and leveling all occur prior to cereal planting. After the grain crop is harvested, the straw is burned or it is cut, raked, and baled. For stubble seeding, oat hay may be preferable because its stubble is short—growers have no excess straw to remove. Also, volunteer grain is not usually a problem following an oat hay crop. But beware: If too much straw or stubble is left in the field, providing winter cover for meadow mice, a severe pest problem can develop (see chapter 10). When necessary, weeds can be controlled with a foliar herbicide prior to alfalfa emergence. A suitable seedbed is prepared by using a harrow or other tillage implement (such as a Rotera tiller) to loosen soil and

allow seed incorporation. For stubble seeding, alfalfa seed can be broadcast or drilled.

FERTILIZER USE

Adequately fertile soil is fundamental to successful stand establishment. Soil fertility contributes to seedling vigor, which helps alfalfa compete with weeds. Analyze soil fertility prior to planting (see chapter 5). Phosphorus is commonly deficient and is particularly important when establishing alfalfa. If soil is deficient in phosphorus, apply a 1- to 2-year supply at planting. The fertilizer can be broadcast and then disced or harrowed. Banding phosphorus with or below the seed has worked well for drilled seedings. This method places the element where it is readily available to the alfalfa, not the weeds. Furthermore, banded fertilizer is less likely to be bound in soil reactions than is broadcast fertilizer.

Plant roots grow in the presence of water, not in search of it.

The merit of applying nitrogen to alfalfa has been debated for years. Although applying small amounts of nitrogen at planting may increase seedling growth and vigor, it is not economical in most cases. As a general guideline, when soil nitrate levels are greater than 15 parts per million (ppm) and conditions favor effective nodulation (soil pH of 6.2 to 7.5 and presence of sufficient *Rhizobium* bacteria), nitrogen application does not result in economical yield increases. However, a yield increase may be expected when conditions for nodulation are poor, when soil nitrate levels are below 15 ppm, or when organic matter content is below 1.5 percent. A response to nitrogen fertilizer is more likely when soil temperatures are less than 60°F (16°C) for several weeks after planting. Under these circumstances, a small amount (10 to 50 pounds per acre) of nitrogen fertilizer is beneficial. A greater amount inhibits nodulation and delays crop development. Growers must be aware that applying nitrogen fertilizer may promote weed growth. For this and other reasons, preplanting nitrogen applications should not exceed 20 pounds per acre.

IRRIGATION

Proper irrigation of a new seeding is essential to achieving a dense healthy stand. The soil must remain moist while alfalfa is germinating and during initial seedling development. Seedling alfalfa plants are not as resilient as established plants; seedlings should not be stressed, either with too much or too little water. Some growers let seedling alfalfa fields become dry, trying to force roots to grow deeper. This is not a recommended practice; plant roots grow in the presence of water, not in search of it. Plant roots will not grow in dry soil.

The irrigation requirements of a seedling field obviously depend on planting date. Rain may suffice for an early spring seeding, but seeding after March is risky without the ability to irrigate. Growers that have to irrigate a new seeding should apply approximately 1 inch of water per irrigation (a 3- to 4-hour set for most wheeline irrigation systems). Assuming a ¼ inch per day moisture loss due to soil evaporation and crop water use, sprinkle every 4 to 5 days (for detail on irrigation scheduling, see chapter 4). Do not overirrigate; damping-off diseases (chapter 9) that attack young seedlings are greatly enhanced by excessively moist conditions.

WEED CONTROL

The consequences of inadequate weed control in the seedling year can be devastating to the alfalfa stand and the profitability of alfalfa production. Weeds compete with alfalfa for light, water, and nutrients and can reduce the vigor of seedling alfalfa. In cases of severe competition, weeds can reduce alfalfa plant density to such a degree that the field has to be replanted. Some weeds can be toxic or unpalatable to animals and make the first cutting unsalable.

Controlling weeds in the seedling year can get the alfalfa off to a fast, healthy start and reduce weed pressure in subsequent years. Deal with perennial weeds several seasons before planting alfalfa. Proper weed control in previous crops can reduce weed problems in

alfalfa. The topic of weed control in a new alfalfa seeding is covered at length in chapter 6.

COMPANION CROPS

Small grains, primarily oats, are sometimes planted with alfalfa as a companion crop (also called a nurse crop). The proported benefits of a companion crop are weed control, increased forage yields the first cutting of the seeding year, and wind and frost protection for tender alfalfa seedlings. However, the risk associated with companion crops is excessive plant competition, which can reduce alfalfa stand, vigor, and yield of subsequent alfalfa cuttings. Trials conducted several years ago in Butte Valley demonstrated that competition from a companion crop reduced alfalfa seedling root length by 3 to 4 inches. Alfalfa seedings are often stressed for lack of water during harvest of the companion crop. This reduces root growth and possibly the future productivity of the alfalfa stand.

The advisability of planting an oat companion crop depends on several factors, including planting date of the alfalfa, oat seeding rate, weed species present and their population level, cost of weed control, expected severity of wind or frost, and the hay market. If a companion crop is used, the key to success is managing the field to the advantage of the alfalfa rather than the companion crop. Oat seeding rates should not exceed 20 pounds per acre or excessive competition will occur. The field should be cut based on the maturity of the alfalfa and not the oats. However, if the companion crop is overtopping alfalfa seedlings and restricting light penetration, cut the field early; this will allow more sunlight to reach the alfalfa seedlings. The greatest damage from companion crops generally occurs when the grain crop lodges, or falls. Therefore, manage the field to avoid lodging: use a low oat-seeding rate, apply little or no nitrogen fertilizer, and choose short oat varieties that are not prone to lodging.

Cereals other than oats have been used as companion crops. Many newer varieties of wheat and barley have very large leaves that can cut off light to alfalfa seedlings. These varieties, therefore, are undesirable companion crops.

The best advice to most growers is, Do not use a companion crop. However, for cases where a companion crop is needed—where soil crusting is a problem or where blowing sand can cut off young seedlings, do not exceed a seeding rate of 20 pounds per acre. In such cases, minimize competition from the companion crop by seeding the cereal on a 12-inch row spacing perpendicular to prevailing winds. (The normal spacing would be 6 to 7 inches.) Another alternative is to use an herbicide such as Poast to control the companion crop when it is young, before it competes with the alfalfa. Whether a companion crop is used or not, remember that the primary goal when seeding alfalfa is to establish a long-lived productive stand of alfalfa. The short-term benefits of a companion crop can be nullified if the alfalfa stand and vigor suffer from excessive competition.

Benefits of a companion crop can be nullified if alfalfa stand and vigor suffer from excessive competition.

SEED INOCULATION

Nitrogen-fixing *Rhizobium* bacteria, which are found in alfalfa root nodules, usually supply the plant with nitrogen needed for growth. Existing populations of nitrogen-fixing bacteria ordinarily provide adequate nodulation in fields with a history of alfalfa production. However, there are rare fields with a history of alfalfa production that benefit from seed inoculation.

Inoculate soils without a recent history of alfalfa production. Commercial inoculum is available for seed treatment. Be sure to use fresh inoculant and do not expose it to hot, dry conditons prior to planting. If you are unsure of the history of a field, inoculum is cheap insurance.

FUNGICIDAL SEED COATINGS

There are years and field situations in which fungicide-treated seed would reduce stand loss during establishment, but these cases are believed to be rare. Seedling diseases are uncommon in the Intermountain Region.

At a given seeding rate in pounds per acre, approximately one-third fewer seeds are planted if the seeds are coated, due to the weight of the coating. Unless seedling diseases are known to be a problem, plant raw seed.

TIMING OF THE FIRST HARVEST

The last step in alfalfa stand establishment is deciding when to make the first cutting. Carbohydrates produced during photosynthesis are stored in roots. Stored carbohydrates provide the energy for regrowth after cutting. Premature cutting does not allow sufficient time for root reserves to accumulate, so it reduces alfalfa vigor and possibly the yield of subsequent cuttings. Alfalfa should be "established" prior to the first cutting. The appearance of bloom has been used as an indicator of whether the stand is established, but several factors can cause alfalfa to bloom prematurely. The number of stems per plant is a far better indicator of when to cut. Do not cut seedling alfalfa until it has developed at least three stems (Figure 2.4). Some experts recommend that the roots of alfalfa grown in sandy or sandy loam soil be at least 14 inches deep prior to the first harvest. Such roots are deep enough to avoid impedance from traffic-induced compaction layers. If you are forced to cut alfalfa prematurely, whether to remove weeds or for any other reason, lengthen the interval between the first and second cuttings. This will allow the young alfalfa plants sufficient time to recover and replenish depleted root reserves.

ADDITIONAL READING

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