CHAPTER TWO

Alfalfa

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Alfalfa (Medicago sativa L.) is a legume grown primarily as a forage to feed livestock. Approximately 32 million ha of alfalfa are grown worldwide. In North America, almost 2 million ha are grown in Canada, between 10 and 11 million ha in the United States, and less than 0.2 million ha are grown in Mexico. Alfalfa is among the highest quality of the forage crops grown in North America.

Alfalfa has been called by many common names, including medic, snail clover, median herb, Burgundy hay or clover, Chilean clover, and Bourgeois Hoy (Bolton et al., 1972). It is now most commonly known as alfalfa or lucern. The word, alfalfa, was derived from an old Persian term that meant horse fodder. The term lucern probably became associated with introductions from the Lucerne Lake region of Switzerland or from the Lucerna River Valley of Italy. Alfalfa may have been introduced into other regions of Europe from either of these areas.

TYPES OF CULTIVARS

Origin of the Cultivated Species

Centers of Origin. Alfalfa originated in central Asia in areas that surround Iran. Wild forms of alfalfa and its near relatives can be found from the center of origin to Siberia. Alfalfa evolved in a pronounced continental climate with cold winters and hot, dry summers. Alfalfa thrives in cool climates or in warm, dry climates, but it is not well adapted to warm, moist climates, a fact that is undoubtedly related to the climate in which the plant evolved.
Cultivation and Domestication. Bolton et al. (1972) stated that alfalfa, the world's most important forage crop, probably was cultivated as early as 7000 B.C. The oldest known reference to alfalfa is from Turkey and was written about 1300 B.C. The value of alfalfa as a feed for horses was described in the Greek literature in 479 B.C., when it was introduced to Greece by armies returning from battle in the Middle East.

The Romans acquired alfalfa from the Greek civilization and spread the crop through most of the northern Mediterranean region. Recommendations on seeding rates, harvest schedules, fertility, soil requirements, and other aspects of growth and culture of the crop can be found in Roman literature (Bolton et al., 1972). Alfalfa was introduced into other parts of Europe from the Roman Empire. A separate introduction into northern Africa and Spain by the Moslems may have been made in the eighth century.

Alfalfa virtually disappeared from Europe after the fall of the Roman Empire (Bolton et al., 1972). Little or no mention of the crop is found throughout the Dark Ages. Perhaps the disappearance of the crop occurred in conjunction with a number of severe cultural setbacks that occurred during this period. Alfalfa was reintroduced into Europe during the sixteenth century.

Introduction to America. Early settlers in the eastern United States attempted to grow alfalfa in the first half of the eighteenth century. Except for small areas in New York and Virginia where calcareous soils can be found, most of these attempts failed. The acid soils and humid climate of most parts of the eastern United States were not suitable for production of the alfalfa available at that time. None of the alfalfa presently grown in North America traces to the initial introductions into the eastern United States. Alfalfa germplasm that is well adapted to the infertile, acid soils of the southeastern United States still has not been developed, although great progress has been made in development of alfalfa adapted to the northeastern states.

The early Spanish and Portuguese explorers carried alfalfa with them to Mexico and Peru. From there it was taken to Texas, Arizona, New Mexico, and California by the early missionaries. These introductions made only small contributions to the alfalfa currently grown in North America.

Alfalfa was introduced into California from Chile in the mid-1800s. For a short time, it was known as Chilean clover, and the crop thrived in the warm, dry climate of the area. The crop soon became very popular with California farmers. The introduction from Chile was a major contributor to the alfalfa grown in North America today. It lacked sufficient winter hardiness, however, for much of the present alfalfa-growing region.
A German immigrant, Wendelin Grimm, brought a packet of alfalfa seed with him to Carver County, Minnesota, in 1858. He selected seed from surviving plants from his fields for several years before a population that would survive the Minnesota winters was developed. A field of alfalfa on Grimm’s farm was brought to the attention of W. M. Hays in 1900, and the first experimental field trials of ‘Grimm’ alfalfa were started in 1901 (Hanson and Davis, 1972).

Other winter-hardy introductions include ‘Ladak’ from the Ladak district of Kashmir and ‘Cossack’ from Russia (Hanson and Davis, 1972). ‘Grimm’, ‘Ladak’, and ‘Cossack’ were important sources of winter hardiness in the development of alfalfa germplasm adapted to the northern United States and Canada.

Mode of Propagation

Alfalfa is a herbaceous perennial legume. Plants have a crown at or below the soil surface and a distinct taproot. Large variation exists in alfalfa for crown and root sizes and shapes. New shoots are initiated each spring from crowns. Energy for new shoot initiation each spring comes from carbohydrates stored in the roots the previous year. Shoot initiation after cutting is from crowns or axillary stem buds, depending on cutting height and type of plant. If alfalfa is not cut during the growing season, one or more regrowths will occur.

Alfalfa is naturally cross-pollinated by bees and other insect pollinators. A very small proportion of alfalfa plants will set selfed seed in the absence of insect pollinators. Most alfalfa plants exhibit some degree of self-incompatibility, but the proportion of plants that will produce at least some selfed seed is too large to be ignored in many breeding and genetics studies.

Alfalfa has a perfect flower with five petals, the standard, two wing petals, and two fused keel petals (Fig. 2-1). The flower consists of individual florets arranged on a raceme. Three to eight seed are normally produced in a coiled seedpod. Newly produced alfalfa seeds usually have a hard seed coat, but they germinate immediately if scarified.

Most alfalfa plants can easily be vegetatively propagated by stem cuttings. Stem sections can be cut with an internode at the top end. The stem sections are placed in moist sand for about 2 weeks until roots develop. Hormone treatment usually is not required for successful rooting, but chances of successful rooting are increased if a visible bud can be seen at the internode at the top of the stem section. Vegetative propagation is common in research programs, but is not a commercial means of alfalfa propagation.
Early North American Cultivars

Some plant introductions, including 'Ladak', 'Grimm', 'Cossack', 'Hairy Peruvian', 'African', and 'Indian,' were increased and became established cultivars in the late 1800s and early 1900s (Hanson and Davis, 1972). Sizeable hectarages of these cultivars were in production as recently as 30 years ago. The climate from which these introductions came was quite different from that of the sections of North America where they were grown. These cultivars were plagued with disease and insect problems, and hectarages of these cultivars decreased drastically as improved germplasm became available.

The early introductions from Chile into California migrated eastward. Winter hardiness and adaptation of this germplasm was increased through natural selection. Seed were produced and sold as 'Common', preceded by the state in which the seed were produced, such as 'Kansas Common'. All of the common alfalfa produced in the United States traced to introductions from South America, and all of these had purple flowers. Large hectarages of these were grown but they lacked sufficient winter hardiness for successful production in much of the present alfalfa growing region.
Large amounts of Turkestan alfalfa were imported into North America in the early 1900s. Large variations were observed in winter hardiness and adaptability of germplasm from Turkey, and most of the imported seed lots were inferior to seed produced in the United States. Restrictions were placed on importation of Turkestan seed in 1926 (Hanson and Davis, 1972). Although Turkestan germplasm was highly susceptible to most foliar diseases, it has proved to be a good source of resistance to bacterial wilt \(\text{Corynebacterium insidiosum}\) (McCull), H. L. Jens., stem nematode \(\text{Ditylenchus dipsaci}\) (Kühn) Filipjev, spotted alfalfa aphid \(\text{Theroaphis maculata}\) Buckton), pea aphid \(\text{Acyrthosiphon pisum}\) (Harris), and phytophthora root rot \(\text{Phytophthora megasperma}\) Drechs.).

Current Cultivars

Tabulations from the cultivar and germplasm summary of Miller and Melton (1983) indicated that more than 250 cultivars have been named and released in North America (Table 2-1). More than 160 of these were named since 1970.

*Synthetic Cultivars.* Almost all alfalfa cultivars released in the past 30 years have been synthetics. Most of these are very broad based and can be considered to be heterogeneous populations of heterozygous individuals. Experience in alfalfa breeding has proved that broad-based synthetics are more successful, and there has been a trend in recent years for the ma-

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Public</th>
<th>Private</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before 1950</td>
<td>23</td>
<td>2</td>
</tr>
<tr>
<td>1951–1955</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>1956–1960</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>1961–1965</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td>1966–1970</td>
<td>14</td>
<td>25</td>
</tr>
<tr>
<td>1971–1975</td>
<td>17</td>
<td>38</td>
</tr>
<tr>
<td>1976–1980</td>
<td>17</td>
<td>52</td>
</tr>
<tr>
<td>1981–1982</td>
<td>12</td>
<td>26</td>
</tr>
<tr>
<td>Total</td>
<td>104</td>
<td>160</td>
</tr>
</tbody>
</table>

Data tabulated from Miller and Melton (1983).
Table 2-2  Number of Parents per Alfalfa Synthetic by Time Period

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 to 3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>4 to 8</td>
<td>1</td>
<td>14</td>
<td>2</td>
<td>10</td>
<td>1</td>
<td>28</td>
</tr>
<tr>
<td>9 to 16</td>
<td>2</td>
<td>8</td>
<td>7</td>
<td>14</td>
<td>5</td>
<td>36</td>
</tr>
<tr>
<td>17 to 40</td>
<td>3</td>
<td>6</td>
<td>8</td>
<td>11</td>
<td>7</td>
<td>35</td>
</tr>
<tr>
<td>More than 40</td>
<td>0</td>
<td>4</td>
<td>8</td>
<td>23</td>
<td>29</td>
<td>64</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>33</td>
<td>26</td>
<td>58</td>
<td>42</td>
<td>166</td>
</tr>
</tbody>
</table>

Tabulated from reports of the National Certified Variety Review Board. Some cultivars were omitted from the summary because descriptions did not give the number of parents.

The majority of alfalfa synthetics to have more than 40 parents (Table 2-2). The preference for broad-based synthetics is based on research experience and principles of alfalfa genetics, as discussed in the section on inheritance in alfalfa.

Hybrid Cultivars. Genetic and cytoplasmic male sterility have been found in alfalfa (Barnes et al., 1972). Genetic male sterility has not been used commercially because its use requires vegetative propagation of seed fields—a practice that is thought to be uneconomical. Use of cytoplasmic male sterility requires identification of two types of plants: type A, which is cytoplasmic male-sterile, and type B, the male-sterile maintainer line. Type B clones maintain cytoplasmic male sterility when used as a male with type A clones. Type A clones can be readily found in alfalfa, but type B clones that maintain sterility over a range of environmental conditions are not easily found. Hybrid alfalfa seeds are produced commercially on male-sterile female parents seeded in fields with a pollen-producing male parent. The female parent is a single cross derived by crossing a type A male sterile and a type B maintainer line. There are usually four male-sterile rows and two male-fertile rows in hybrid seed-production fields. Seed production is reduced on the female rows in seed-production fields because pollinating insects do not visit these rows as frequently as they do the male-fertile rows. Recently, Brown and Bingham (1984) discovered a male-fertile, female-sterile alfalfa plant. Interplanting the male-sterile, female-fertile seed parent with male-fertile, female-sterile plants would confuse pollinating insects enough to prevent them from consistently identifying pollenless plants of the seed parent, thereby increasing hybrid seed production. This procedure would require vegetative propagation of seed production fields. Thus, alfalfa breeders have not yet found a truly economical way of utilizing the male sterility that exists in alfalfa to produce hybrids.
**Blends.** Blends are seed mixtures of two or more cultivars and are often packaged for seed houses that want a unique product without having to support a full-scale alfalfa breeding program. Although not meeting the botanical definition of a cultivar, a number of blends are sold in the United States. The components of these blends are often eligible for certification and the identity of the components is usually a closely guarded trade secret. Blends are not eligible for certification.

**Winter Hardiness Classes.** An important factor in the classification of alfalfa cultivars is the level of winter hardiness. Lowe et al. (1972) classified alfalfa cultivars into three groups: hardy, moderately hardy, and non-hardy. The degree of winter hardiness in alfalfa is closely related to the level of fall dormancy, with more fall-dormant genotypes having a higher level of hardiness. Barnes et al. (1978) proposed a nine-point scale of rating fall dormancy and suggested that this could be reliably used to classify cultivars for winter hardiness (Table 2-3). On this scale, class 1 cultivars could be safely grown only in frost-free areas and class 9 cultivars could be grown in the northern crop-producing regions of Canada.

**Table 2-3  Fall Dormancy Classifications for Alfalfa Cultivars**

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Very nondormant</td>
</tr>
<tr>
<td>2</td>
<td>Nondormant</td>
</tr>
<tr>
<td>3</td>
<td>Moderately nondormant</td>
</tr>
<tr>
<td>4, 5, 6</td>
<td>Intermediately dormant or semi-dormant</td>
</tr>
<tr>
<td>7</td>
<td>Moderately dormant</td>
</tr>
<tr>
<td>8</td>
<td>Dormant</td>
</tr>
<tr>
<td>9</td>
<td>Very dormant</td>
</tr>
</tbody>
</table>

Adapted from Barnes et al. (1978).
in the summary. Private industry clearly carries a large portion of the alfalfa breeding effort in the United States. The ratio of public versus private support of alfalfa cultivar development in the United States is undergoing change. The emphasis on cultivar development is generally being decreased in public agencies while private industry is increasing its effort.

Private industry breeding programs usually have research stations in at least two regions of the country. One of these stations is generally in the seed-production area in one of the western states, because alfalfa seed production requires constant and professional attention. The other research stations are in areas of extensive alfalfa production and are likely to have a plant pathologist and a production agronomist to investigate disease and production problems of newly developed cultivars. The breeding effort in most private firms emphasizes germplasm development and the utilization of that germplasm for the release of new and improved cultivars. The intended market for most private alfalfa research organizations is cultivars for intensive production of hay, haylage, or silage.

The number of publicly supported alfalfa breeding programs has declined in recent years. Many of the public research programs have shifted emphasis from cultivar development to other aspects of alfalfa breeding and genetics. Problems such as improved breeding methodology, identification of sources of resistance to new disease and insect pests or those pests for which previous breeding efforts have been unsuccessful, and alfalfa for range and pasture receive attention from public programs. Organizations such as the Alfalfa Improvement Conference provide a forum for breeders from public and private firms to meet and plan research programs that minimize duplication of effort.

**BREEDING OBJECTIVES FOR CULTIVAR DEVELOPMENT**

The ultimate objective of any cultivar improvement program is the development of germplasm that will enhance production of the crop. Breeding objectives cannot be intelligently chosen without a thorough knowledge of the problems involved in crop production and a knowledge of which of these problems can be solved through plant breeding. Once an important problem that can be solved through plant breeding has been identified, methods that can be used in the breeding program and that will result in farm-level improvements must be developed.

Alfalfa use ranges from production of stored forage in intensive forage-animal production systems to a legume in pastures and ranges in extensive forage-animal systems. The goals of alfalfa breeding programs vary considerably, depending on the intended use of the germplasm under development. Nonetheless, there are some traits considered important by most alfalfa breeding programs.
Yield

Alfalfa is valued for its ability to produce high yields of high-quality forage. Although alfalfa is used in pastures and ranges, most breeding programs attempt to develop cultivars that will perform well under intensive forage production systems. Most alfalfa breeders feel that a cultivar will not be economically successful unless it is adapted to intensive forage programs.

Genetic increases in alfalfa yield have been about 3% per decade (Elliott et al., 1972; Hill and Kalton, 1976). The total increase in yields obtained by farmers has been greater than this, but part of the increase must be attributed to better management and fertility practices. Separation of genetic from nongenetic increases is difficult because some of the total increase has been the result of cultivars better adapted to intensive management and high fertility.

Several reasons can be proposed for the lower rate of genetic improvement for yield in alfalfa than for the grain crops. Evans (1980) suggested that much of the improvement in seed yield was the result of shunting photosynthetic products to organs or plant tissues of greater economic value. This route has not been available to alfalfa breeders because the entire plant is of economic value. A second possible reason for the lower rate of progress is that alfalfa is a perennial with multiple harvests per growing season. The perennial growth habit of alfalfa dictates that the same plots be observed for several years before selections are made. This increases the time per selection cycle, and under such conditions, an equal gain per cycle of selection would translate to a lower rate of gain for a given time period. A third reason for the lower rate of progress in increasing yield may be that alfalfa is an autotetraploid. The breeding methods that have been effective with diploid crop species are not as effective when applied to alfalfa.

Pest Resistance

Increased levels of pest resistance has been a major success of alfalfa breeding. Many alfalfa breeders work cooperatively with plant pathologists or entomologists, and effective techniques for increasing pest resistance have been developed. Procedures for evaluating resistance have been standardized, and susceptible and resistant lines have been identified for many of the disease and insect pests of alfalfa (Elgin, 1984).

Multiple-pest resistance is a major goal of most alfalfa breeding programs today. The most recent alfalfa cultivars usually have moderate or higher levels of resistance to bacterial wilt, fusarium wilt, [Fusarium oxysporum Schlecht. f. sp. medicaginis (Weimer) Snyd. & Hans.], anthracnose ([Colletotrichum trifolii Bain & Essary), phytophthora root rot, the pea
aphid, and the spotted alfalfa aphid. When verticillium wilt (Verticillium albo-atrum Reinke & Berth.) was first discovered in the United States, public and private agencies immediately initiated efforts to incorporate resistance into adapted germplasm. Many of the newer cultivars have moderate or higher levels of resistance to verticillium wilt. Germplasm or cultivars with resistance to a number of other alfalfa pests also have been developed (Elgin, 1984).

Increased pest resistance has been an indirect contributor to increased yields. Spectacular differences in yield can be observed when resistant and susceptible cultivars are grown on a site known to harbor a particular disease or insect pest.

Much of the breeding for pest resistance is done in greenhouse and growth-chamber facilities during the winter months when demands from field experiments are reduced. Most selections made in greenhouse and growth-chamber facilities are resistant when tested under field conditions.

Although progress in breeding for multiple-pest resistance in alfalfa has been spectacular, suitable resistance to a number of disease and insect pests has not been found, including fusarium root and crown rot [Fusarium solani (Mart.) Appel & Wr. and F. roseum Lk. ex Fr. emend. Snyd. & Hans.], the alfalfa blotch leafminer [Agromyza frontella (Rondani)], and the clover root curculio [Sitona hispidula (F)]. A degree of tolerance has been found in some cases, like the alfalfa weevil [Hypera postica (Gyllenhall)] and the potato leafhopper [Empoasca fabae (Harris)], but the level is not great enough to provide protection in severe infestations or epidemics.

The success in breeding for pest resistance depends on developing methods that permit accurate identification of resistant genotypes. Once this is done, a satisfactory level of resistance to most alfalfa pests often can be obtained in three to five cycles of selection. The inability to find resistance to some disease or insect pests can very likely be attributed to the lack of a suitable method of identifying resistance.

Quality

Alfalfa has a higher feeding value than most forage crops. Some effort is being devoted to greater improvement of alfalfa forage quality. Valid breeding objectives include increased protein concentration, decreased fiber (increased digestibility), and reduction of the bloat potential.

Alfalfa serves as an important on-farm protein source for ruminant animals. In many farm animal operations, the value of the protein from alfalfa is a major economic justification for growing the crop. Alfalfa was the most efficient of the species discussed by Heichel (1976) for production of protein. Heritability of protein concentration in alfalfa is relatively
high, and progress in breeding for higher concentrations can be expected (Hill and Barnes, 1977; Sumberg et al., 1983). Selection for increased protein concentration often indirectly improves other quality constituents (Cooper, 1973). Near-infrared reflectance spectroscopy is probably the most economical method for measuring protein concentration in alfalfa forage samples (Shenk et al., 1981).

Most forage breeding programs use in vitro dry-matter disappearance (IVDMD) as a tool for measuring fiber concentration. Both high and low estimates of heritability of IVDMD in alfalfa have been reported in the literature, and alfalfa breeders should attempt to select for greater IVDMD only after they know their technique is one that has high heritability. Alfalfa has a higher lignin concentration than forage grasses, and reduced lignin concentration has been suggested as a means of improving digestibility of alfalfa. Genetic variability is present for lignin concentration in alfalfa. Both IVDMD and lignin can be measured quite accurately with near-infrared reflectance spectroscopy.

Alfalfa is one of the bloat-causing legumes, which limits its use in pastures. Although reduced bloat potential is an important objective in improving alfalfa quality, breeders and animal scientists apparently have not identified a trait that is amenable to genetic change in a plant breeding program. Most bloat-safe legumes have higher condensed tannin concentrations than bloat-causing legumes. Alfalfa apparently has no condensed tannin (Goplen et al., 1980), and selection for increased tannin concentration does not seem to be a solution to the bloat problem of the crop. Reduced saponin concentration has been proposed as a method of reducing bloat potential in alfalfa, but high and low saponin populations did not show a difference in bloat incidence (Majak et al., 1980). Resistance to cell rupture also has been proposed as an indirect method of reducing bloat potential (Howarth et al., 1978), but the investigation is not yet complete.

There are indirect methods for improving alfalfa forage quality. One obvious approach is to develop germplasm adapted to more frequent harvests, because forage quality decreases as the plant matures. Many alfalfa breeders feel, however, that increased yield and pest resistance are more important than improvement of quality.

Other Characters

Other characters considered by alfalfa breeders include the creeping root trait for alfalfa that probably would be better adapted to range and pasture use, better establishment ability in dry environments, a greater proportion of fibrous roots for resistance to heaving and for better nutrient and water utilization, and other physiological and morphological traits. Many of these
traits are subject to large environmental variation, and successful breeding is difficult.

INHERITANCE IN ALFALFA

All cultivated alfalfa has at least partial autotetraploid inheritance. Stanford (1951) demonstrated that an extra generation is often required to distinguish between disomic and tetrasomic inheritance in genetic studies. Very few reports of disomic inheritance in alfalfa have been made since Stanford's (1951) paper was published. The full impact of autotetraploid inheritance to practical alfalfa breeding is still not completely understood.

With simple, two-allele models, the change in gene frequency under selection is slower in autotetraploid than in diploid populations with comparable gene frequencies (Hill, 1971). Autotetraploid populations have a large capacity to mask or hide recessive alleles, and populations uniform for a single dominant allele cannot be obtained without great difficulty. Fortunately, uniformity for a character is not required in alfalfa cultivars.

An extremely important consequence of autotetraploid inheritance is that parental inbreeding is partially transmitted to offspring through the diploid gamete. It has been shown that single crosses and population crosses between inbred parents have inferior yields to those between noninbred parents (Hill, 1975, 1983). Breeding procedures that involve selfing or other forms of inbreeding must be used with caution in alfalfa because the resultant inbreeding depression cannot be completely eliminated by crossing the inbred material to unrelated germplasm. Yield and seed production in alfalfa show severe inbreeding depressions.

The approach to homozygosity with inbreeding is much slower in an autotetraploid than in a diploid, and alfalfa has a much greater inbreeding depression than can be explained by a simple approach to homozygosity. The greater than expected inbreeding depression led to a theory of heterosis in alfalfa based on heterozygosity of multiple alleles (Demarly, 1963; Busbice and Wilsie, 1966). Under this theory, the relative vigor of the possible genotypes would be tetraallelic \((a_1a_1a_2a_3)\) > triallelic \((a_1a_1a_2a_k)\) > diallelic duplex \((a_1a_2a_3a_4)\) > diallelic simplex \((a_1a_2a_3a_4)\) > monoallelic \((a_1a_2a_3a_4)\), where different subscripts indicate different alleles within a zygote.

The above model for heterosis in alfalfa is similar in many aspects to early models for heterosis in maize \((\text{Zea mays L.})\). Heterozygosity is required, and an overdominance gene action is observed when different alleles are paired. It has recently been shown that heterosis in maize can be explained by linked genes and gene action no more complicated than partial to complete dominance (Sprague and Eberhart, 1977). The multiple "alleles" in alfalfa may actually be linkage blocks (Demarly, 1963;
Bingham, 1979). With only two alleles, four different chromosome segments would be present in a population as follows:

\[
\begin{array}{c|c|c|c}
A & A & a & a \\
B & b & B & b \\
\end{array}
\]

As the number of linked alleles on chromosome segments increases, the number of tetraallelic types would increase very rapidly, and a random mating population would consist primarily of tetraallelic individuals with even moderate numbers of different chromosome segments (Table 2-4).

The importance of heterosis and autotetraploid inheritance has caused alfalfa breeders to take a different route than breeders of diploid crops. With complete dominance or overdominance, the ideal diploid cultivar would be one heterozygous for a specific pair of alleles, \(aa\), or chromosome segments. The comparable ideal for an autotetraploid would be a cultivar in which each individual was tetraallelic \(a_1a_2a_3a_4\), for a specific set of four alleles or chromosome segments. The ideal cultivar for autotetraploids cannot be obtained with sexual reproduction. Single, three-way, and double-cross hybrids from noninbred parents will contain mixtures of tetraallelic genotypes, and hybrids between inbred lines will contain dianlelic and triallelic types.

Populations initiated from unrelated parents can be assumed to have different complements of chromosome segments. As the proportion of unrelated parents increases, the proportion of tetraallelic types in the populations increases (Table 2-4). Broad-based synthetics are populations initiated from a large number of unrelated parents and they have a high level of heterozygosity. Broad-based synthetics are very popular in alfalfa breeding, and the proportion of synthetics with more than 40 parents has increased in recent years (Table 2-2). Narrow-based synthetics with a small number of parents have a proven record of poor performance, and are generally not used in alfalfa breeding. The inability to concentrate a few superior tetraallelic genotypes into a cultivar is an extreme frustration for alfalfa breeders.

**Table 2-4** Genotypic Classes and Number in Each Class for an Autotetraploid Population with Multiple Alleles or Multiple Chromosome Segments

<table>
<thead>
<tr>
<th>Genotype name</th>
<th>Symbol</th>
<th>Number in group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monoallelic</td>
<td>(a_1a_2a_3)</td>
<td>(n)</td>
</tr>
<tr>
<td>Diallytic simplex</td>
<td>(a_1a_2a_3)</td>
<td>(n(n - 1))</td>
</tr>
<tr>
<td>Diallytic duplex</td>
<td>(a_1a_2a_3)</td>
<td>(n(n - 1)/2)</td>
</tr>
<tr>
<td>Triallelic</td>
<td>(a_1a_2a_3)</td>
<td>(n(n - 1)(n - 2)/2)</td>
</tr>
<tr>
<td>Tetraallelic</td>
<td>(a_1a_2a_3a_4)</td>
<td>(n(n - 1)(n - 2)(n - 3)/24)</td>
</tr>
</tbody>
</table>
STEPS CONSIDERED IN CULTIVAR DEVELOPMENT

Most alfalfa cultivars are synthetics produced through a series of seed increase generations as described in the section on seed production. The parents from which the seed increase sequence is initiated may be a collection of clones from a progeny test program or a small amount of seed from a recurrent phenotypic selection program.

Before making a decision to initiate the seed increase procedure for a new cultivar, the breeder must ensure that the parents have the desired levels of yield and pest resistance. In addition, the population must have a seed production potential suitable for a new cultivar. Some alfalfa breeders screen selected parents for a high level of self-incompatibility to reduce the level of inbreeding that might occur in advanced generations. Production of enough seed for yield evaluation at several locations involves considerable costs, and decisions to release a new cultivar often are made before certified seed is available. Alfalfa breeders cannot afford to produce seed of a large number of experimental synthetics and select the best ones. Therefore, the decision to release must be made before the final product can be tested.

Once a decision to release a new cultivar is made, the procedures described in the section on seed production are followed. A small sample of breeder seed may be used to establish plots at divergent locations in the intended market area. Samples of foundation seed will be used to establish additional tests throughout the intended market area. If satisfactory performance is observed on all these tests, certified seed-production fields will be established.

SOURCES OF GENETIC VARIABILITY

Types of Populations Used

Plant introductions, as discussed in the section on introduction of alfalfa to America, were and still are important sources of genetic variability for alfalfa breeders. Some of the current cultivars have attributes that can be traced to introductions from certain areas of the world. For example, many modern cultivars contain significant proportions of Flemish germplasm. Alfalfa germplasm collections continue to be made, and some of this material is included in new cultivars.

Selections made from old alfalfa fields represent an important source of genetic material for alfalfa breeders. Old fields are almost always examined for surviving plants in areas where new disease or insect pests develop, or in areas where a disease or insect pest is very severe.
Populations created by the breeder probably constitute the most important source of genetic variability for new alfalfa cultivars. Plant introductions, selections from old fields, selections from field evaluation trials, and plants from other sources are intercrossed to produce populations from which selections can be made. Most alfalfa breeders have several populations in which intercrosses and new selections are made and into which new germplasm from other sources is regularly introduced.

Current cultivars also represent an important source of variability. Alfalfa cultivars are very heterogeneous and contain abundant variability. Plants resistant to many disease and insect pests can be found at low frequencies in most current alfalfa cultivars.

Types of Parents

Parents of alfalfa cultivars are either clones or seed from selection programs similar to those described in the section on breeding procedures. Parents are selected and combined in ways that deliberately maintain a high level of heterozygosity in the population.

Individual plants are selected in breeding programs, but they always are crossed with other unrelated plants. Alfalfa breeders are careful to ensure that no single plant contributes a large proportion of the genes to a new cultivar. These procedures are used to avoid inbreeding, for reasons that are discussed in the section on inheritance in alfalfa.

Procedures for Artificial Hybridization

Alfalfa is naturally cross-pollinated by insect pollinators. A large proportion of alfalfa plants are at least partially self-sterile, although some plants will set seed when selfed. Controlled hybridization is accomplished by hand, by using insect pollinators, or by using male sterility.

Hand Pollination. Hand crossing of alfalfa usually is done by collecting pollen from the male parent on a folded piece of sandpaper or on a toothpick with a small piece of sandpaper attached to the end. Pollen can be collected by tripping the flowers onto the sandpaper. The pollen is applied to the stigma of the female parent by tripping the female flower into the collected pollen from the male parent. If a small proportion of selfed seed cannot be tolerated, as in genetic studies, the female parent is emasculated. Air-suction emasculation, in which the standard petal (Fig. 2-1) is cut, the flower tripped, and the pollen removed by a vacuum pump is the most popular method. Alcohol emasculation also is used. In this method,
the female flower is dipped into an alcohol solution to kill pollen. However, most alfalfa seeds from artificial hybridization are produced without emasculation.

Many population improvement programs use hand pollination for production of seed for the next cycle of selection. The breeder often goes from plant to plant tripping flowers onto a collection of pollen from the same population. The collection of pollen is assumed to be a bulk from the population in which the crossing is done.

Insect Pollination. When a greater supply of seed is needed than is feasible by hand pollination, the breeder will produce seed with insect pollinators on plants in a cage. Insect pollinators used by alfalfa breeders are discussed in the section on seed production. Except for the case when male-sterile parents are used, self-incompatibility provides the only means to prevent production of selfed seed in pollination cages. Clones should be arranged randomly instead of in rows in cages to reduce the frequency of self-pollinated seed. Some insect pollinators tend to move up and down rows rather than at random in cages. Insect pollinators should not be placed in pollination cages until all plants are in full flower.

Male Sterility. The types of male sterility available to alfalfa breeders are discussed in the section on hybrid cultivars. Procedures for commercial production of hybrids and some of the problems involved are also discussed in that section. Male-sterile plants are often used in experiments where self-pollination must be completely eliminated, such as crosses between different ploidy levels.

Mutagenesis

Induced mutation has not played an important role in alfalfa breeding. The abundant genetic variability in current cultivars and in introduced populations has made it possible for breeders to find needed traits without resorting to induced mutations.

BREEDING PROCEDURES

Historical Perspective

Strong similarities between maize and alfalfa for expression of heterosis and responses to inbreeding were observed by early alfalfa breeders (Tysdal et al., 1942). At that time, double-cross cultivars were popular in maize breeding, and schemes were proposed that simulated double
Table 2-5  Scheme for Mimicking a Double-cross Hybrid in the Production of an Alfalfa Synthetic

<table>
<thead>
<tr>
<th>Generation</th>
<th>Procedure*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syn-1</td>
<td>Increase vegetatively or through seed the four parental lines, A, B, C, and D.</td>
</tr>
<tr>
<td>Syn-2</td>
<td>Intercross in separate isolations the parental lines in sets of two to simulate single-cross production, A × B and C × D.</td>
</tr>
<tr>
<td>Syn-3</td>
<td>Blend seed of the two single crosses to establish a field for production of certified seed of a double-cross synthetic, (A × B) × (C × D).</td>
</tr>
</tbody>
</table>

*The combinations are made by open-pollination instead of hybridization with complete pollination control. The Syn 3 generation will contain advanced generation seed of each single-cross, as well as double-cross hybrid seed.

crosses in the production of seed of alfalfa synthetics (Table 2-5). Self-incompatibility, which is common in alfalfa, was proposed as a method for at least partial pollination control.

A few of the narrow-based cultivars listed in Table 2-2 were produced under the scheme shown in Table 2-5, but the method has never been very popular, and cultivars produced under this scheme were never very successful. The inbreeding that develops in the narrow-based synthetics in great enough to reduce yield beyond acceptable limits. The small amount of inbreeding that occurs during the seed-increase procedure can negate much of the potential advantage of a hybrid.

Many of the current breeding procedures used with alfalfa were patterned after methods used in maize breeding. Modifications had to be made to accommodate autotetraploid inheritance and the complete flower structure of alfalfa.

Recurrent Phenotypic Selection. This method of population improvement has been called cyclic mass selection, recurrent selection, and restricted recurrent phenotypic selection. Steps in the procedure are:

1. Evaluate a large number of plants for the trait or traits to be considered in the selection program.
2. Select the most desirable individuals from step 1.
3. Intermate the selected individuals.
4. Repeat steps 1 through 3 until the desired response is obtained.

Recurrent phenotypic selection has been very popular for increasing resistance to disease and insect pests in alfalfa. Selection is often conducted in greenhouse and growth-chamber facilities during the winter months when the work load from field plots is reduced. The method has proved to be very effective in alfalfa for traits with moderate to high heritability. It has not been used extensively in alfalfa to select for forage
yield, but Burton (1974) demonstrated that the method was successful in increasing yield of Pensacola bahiagrass (*Paspalum notatum* Flügge).

The size of the population evaluated in step 1 varies from one alfalfa breeding program to another and with the trait under selection. For disease resistance, the size of the population evaluated is limited only by the facilities available. Population size can be determined with a knowledge of the probability that a desirable individual will be found and the number of individuals desired in step 2. Research experience in alfalfa has shown that an undesirable level of inbreeding develops if fewer than 75 plants are selected in step 2, and most alfalfa breeders prefer to select 150 or more individuals. Thus, the population size must be 1500 or more if desirable individuals occur with a frequency of 0.1, and more than 15,000 plants must be evaluated if the frequency of desirable individuals is 0.01.

Intermating of the selected plants is often done by hand pollination without emasculation in the greenhouse. The selected plants also can be intermated in isolation blocks or in insect pollination cages. When recurrent phenotypic selection is conducted in the field, seed for the next cycle of selection could be harvested from the most desirable individuals. This practice is not recommended unless the undesirable plants are eliminated before pollination because pollen from unselected individuals contribute to the next generation. Response theoretically can be doubled by intermating only the selected plants.

The number of cycles required to reach a desired level of improvement varies depending on the initial gene frequencies and the heritability of the trait under selection. For most applications in selection for disease and insect resistance, the desired level of resistance often is obtained in three to five cycles of selection.

Recurrent phenotypic selection will not be very effective for traits with low heritability. The heritability of a trait can be enhanced by techniques that minimize the environmental variance. Useful techniques to control environmental variance include artificial inoculation or infestation to eliminate escapes when selection is for disease or insect resistance, and selection within small blocks when the selection program is conducted in the field.

**Backcross Breeding.** Backcross breeding as used in alfalfa differs from the classic procedure described in most plant-breeding textbooks. The recurrent parents in all cases and the donor parents in most cases in alfalfa breeding would be broad-based populations rather than inbred lines. Broad-based populations are used because it is very important to avoid inbreeding in alfalfa. The objective of backcross breeding in alfalfa would be to move genes for one or a few traits with high heritability from the donor population to the recurrent population. Steps in the procedure are:
1. Identify suitable donor and recurrent parents.
2. Cross a large number of plants from each population.
3. Evaluate progenies from the crosses in step 2. These evaluations usually will be in greenhouse, growth-chamber, or field facilities similar to those used with recurrent phenotypic selection.
4. Select the most desirable individuals from step 3 and cross these to the recurrent parent.
5. Repeat steps 2 through 4 until the desired level of the trait or traits from the donor parent is reached.

Guidelines for population sizes and numbers of plants to be selected are similar to those for recurrent phenotypic selection. Because alfalfa populations are heterogeneous, attempts usually are not made to exactly reconstitute the recurrent parent population. The large amount of variability in most adapted alfalfa cultivars also means that many desired traits, especially pest resistance, often can be found at low frequency within the adapted population. When the desired trait can be found, recurrent phenotypic selection would probably be recommended over backcross breeding.

**Progeny Test Selection.** The most popular type of progeny test in alfalfa breeding has been one based on half-sibs. These are often called open-pollination or polycross progeny tests in the alfalfa breeding literature. Polycross progeny usually come from nurseries where the parents are vegetatively replicated and spaced in such a manner as to maximize the probability that all individuals in the nursery will have more or less equal chances to intermate. Less effort is made to ensure that all parents mate with equal frequency in open-pollination progeny nurseries. Steps in the procedure are:

1. Identify or select a group of parents to be tested.
2. Intermate the parents in isolation.
3. Evaluate the progenies. Evaluations for pest resistance may be conducted in facilities similar to those used with recurrent phenotypic selection and backcross breeding. Progeny test selection often is used for yield. Progenies are evaluated at more than one location if sufficient seeds are produced.
4. Select the parents of those progenies with the best performance.

An advantage of polycross or open-pollination progeny test selection is that sufficient seed often can be produced in step 2 for plots at two or more locations. This allows the breeder to obtain information on the importance of genotype by environment interactions in the genetic material being evaluated. Progeny test selection is more effective than recurrent
phenotypic selection or backcross breeding for traits with low heritability.

Disadvantages of progeny test selection are that the procedure requires much more effort and is not as adaptable to cyclic selection as some other breeding methods. The number of progenies evaluated in step 3 cannot be large enough to permit intense selection in step 4 and still permit selection of enough individuals to avoid an inbreeding depression in the population. Thus, progeny test selection is usually reserved for evaluation of yield and other traits on potential parents that have been selected for disease and insect resistance in other types of selection procedures.

The evaluation of selfed progeny has been used to a limited extent in alfalfa breeding. Although alfalfa is partially self-incompatible, many plants will produce a few self-pollinated seed. The difficulty in obtaining sufficient seed for an adequate test limits the use of selfed progeny in alfalfa breeding.

Family Selection. Selection of the best families or superior individuals from the best families is an obvious extension of progeny test selection. The procedure would be operated the same as progeny test selection, except that all individuals or a sample of individuals from the best families would be selected. Family selection is more adaptable to cyclic selection than is progeny test selection. Despite its potential advantages, family selection has not been used extensively in alfalfa breeding. Family selection for yield would require seed production facilities beyond the scope of many alfalfa breeding and genetics projects.

FIELD-PILOT TECHNIQUES FOR GENOTYPE EVALUATION

The perennial growth habit drastically affects the evaluation of experimental cultivars. Multiple observations on the same plots cause observations to be correlated. Poor establishment of a plot will affect performance of the entry for the life of the stand. Cultivars should be evaluated in several different trials to obtain information on variations in response to stand establishment. Error terms in the analysis of variance of data from trials on perennial crops are different from those in trials where annual crops are evaluated for several years (Table 2-6).

Seeds of experimental cultivars usually are produced in cage isolation, and are submitted to germplasm trials conducted by public and private agencies throughout the intended market area. The intended market area often includes all regions for which the experimental cultivar has sufficient winter hardiness to survive. Plots in most germplasm trials usually are evaluated for 3 or 4 years.
<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>Source</th>
<th>d.f.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years (Y)</td>
<td>( y - 1 )</td>
<td>Years (Y)</td>
<td>( y - 1 )</td>
</tr>
<tr>
<td>Replications (R)</td>
<td>( r - 1 )</td>
<td>Replications in years</td>
<td>( y(r - 1) )</td>
</tr>
<tr>
<td>( Y \times R )</td>
<td>((y - 1)(r - 1))</td>
<td>Cultivars (C)</td>
<td>( c - 1 )</td>
</tr>
<tr>
<td>Cultivars (C)</td>
<td>( c - 1 )</td>
<td>R × C</td>
<td>((r - 1)(c - 1))</td>
</tr>
<tr>
<td>( Y \times C )</td>
<td>((y - 1)(c - 1))</td>
<td>Y × C</td>
<td>((y - 1)(c - 1))</td>
</tr>
<tr>
<td>R × Y × C</td>
<td>((r - 1)(y - 1)(c - 1))</td>
<td>Error</td>
<td>( y(r - 1)(c - 1) )</td>
</tr>
</tbody>
</table>

A randomized complete-block was assumed for each case. The trial of the perennial would be established once, and that for the annual each year. d.f. = degrees of freedom.
Almost all yield evaluation is done in broadcast or drilled-row plots. Broadcast plots usually are hand sown at a seeding rate recommended for the region. The plots are 1.5 m wide by 4.5 to 6.0 m long. Drilled-row plots are seeded with plot seeders made especially for experimental plots or with hand-powered single-row garden seeders. Drilled-row plots often are approximately 1 m wide by 4.5 to 6.0 m long and contain five rows. Most alfalfa germ-plasm evaluation trials are established in experimental designs with two to six replications. Lattice designs often are used when the number of entries is more than 20 or 25. Randomized complete-block designs are used for trials with less than 20 to 25 entries. Almost all trials contain current cultivars as well as experimental ones.

Management and fertility of alfalfa germplasm trials is usually that recommended for intensive alfalfa hay production in the region where the trial is conducted. Multiple harvests are made on each plot during the growing season. The number of harvests per season varies from one or two in the most northern regions of alfalfa production to more than 12 on some irrigated sites in the southwestern United States and Mexico.

When broadcast plots are used, a strip 0.7 to 1.0 m wide usually is harvested from the center of each plot. The forage on the borders of each plot is cut and discarded after yield samples are taken. It is important to cut the border forage on the same day as the yield sample so that the entire plot is subjected to the same harvest schedule. The entire plot often is harvested when drilled-row plots are used. Harvesting the entire plot eliminates the need to remove the borders after the harvesting operation. There is little or no evidence of important intergenotypic effects between adjacent plots in alfalfa.

Green weights determined on each plot usually are converted to dry matter yields or to hay equivalent at 12% moisture on the basis of moisture samples taken during the harvesting operation. Some alfalfa breeders take a moisture sample from each plot, but most breeders sample each 5 to 15 plots for moisture content. A few alfalfa breeders do not determine moisture, but instead use a conversion factor they feel is typical of the area in which the trial is conducted. This practice is not recommended because moisture content of the forage will usually vary with time of day and time of the growing season, as well as with climatic conditions at the time of harvest. Accurate estimates of yield can only be made by knowing the moisture content at the time of harvest.

The machinery used to harvest plots in alfalfa trials varies extensively. Self-propelled flail harvesters that cut the forage and blow it into a collection unit or into a weighing basket are the most popular machines for harvesting plots in alfalfa trials. There are self-propelled sickle-bar machines that cut forage and elevate it into a box or basket. The box or basket can be attached to an electronic weighing device or the forage can be taken from the basket to scales for weighing. Sickle-bar mowers or small
walking-model garden tractors are used by some breeders. When this is done, the forage is raked by hand, weighed, sampled for moisture, and discarded. Harvesting equipment for alfalfa and other forage crops has been built by several companies and by individual breeders.

PROCEDURES FOR SEED PRODUCTION

Alfalfa needs a dry climate with little probability of rain for successful seed production. For this reason, almost all commercial alfalfa seed production is done in the western states or provinces of North America. Seed production in alfalfa has evolved into a very specialized industry with cultural practices and growing conditions that are very different from those of hay and pasture production.

Seed Generations

Seed of alfalfa cultivars are produced through a series of seed increase generations that essentially are generations of random mating. Alfalfa breeders refer to these as the Syn-n generations of increase, where n is the generation of increase from the original parents.

Breeder Seed. Parental germplasm for production of breeder seed usually comes from the last step in the breeding program. The parents may be clones from a progeny test or some other selection program, a direct increase of a population that has undergone selection for resistance to one or more disease or insect pests, or an intercross of two or more populations from a pest resistance program. Breeder seed usually is the Syn 1 generation of seed increase.

Breeder seed almost always is produced in insect pollination cages or in small isolation blocks. Seed production cages are usually made of plastic screen mesh and measure approximately 2 × 2 × 8 m. Insect pollinators are placed in the cages after the plants reach full flower. If seed production is in small isolation blocks, it is almost always on spaced plants or clones. Plant spacing is usually 1 to 1.5 m in each direction. A sample of the seed or clones used to produce the breeder seed is maintained by the breeder in case there is a need to reproduce the cultivar.

Foundation Seed. Foundation seed is produced on plants grown from breeder seed. Foundation seed fields usually are seeded in rows that are 1.0 to 1.5 m apart and the seeding rate may be less than 0.5 kg/ha, or as few as 150 seeds per meter of row. The field will be managed to maximize seed production. Insect pollinators will be placed in the field after flower-
ing is well underway. Yields of 500 kg/ha or more of foundation seed are not uncommon.

Many alfalfa cultivars from private industry have only one field for foundation seed production. Seed production from one foundation seed field is expected to be enough for the life of the cultivar. Expectations are that the cultivar will be replaced with an improved one before the crop of foundation seed is depleted.

Foundation seed often is entered into germplasm evaluation trials in different regions for yield evaluation. The final decision to release or discard the cultivar is often made on the basis of performance of the foundation seed generation. Differences in performance of the foundation and certified seed generations are probably small for broad-based synthetics. Narrow-based synthetics probably would be more subject to changes in gene frequency during generations of seed increase, and differences in performance of foundation and certified generations could be expected.

Registered Seed. Registered seed is produced on plants grown from foundation seed. This generation is rarely used by alfalfa seed producers because sufficient seed for establishment of certified seed fields usually can be obtained from foundation seed production fields.

Certified Seed. Certified seed is produced on plants grown from foundation or registered seed. For some cultivars, production of certified seed from plants grown from a first-generation crop of certified seed is permitted. Seed may be harvested from a certified seed production field for no more than 6 years.

Certified seed fields usually are seeded in rows that are 1 to 1.5 m apart (Fig. 2-2). The seeding rate is usually 1.0 to 3.0 kg/ha, or approximately 200 seeds per meter of row. Certified seed-production fields are cultivated and thinned to remove volunteer seedlings from seeds dropped after each seed crop.

Seed regulations require that no more than one generation of alfalfa seed be produced outside the region of adaptation. The certified generation is often produced under irrigation in California and the other generations produced further north in the region of adaptation.

Insect Pollinators

Many insects can pollinate alfalfa flowers, but wild, natural populations of pollinator insects are not abundant enough to obtain maximum seed production. Thus, pollinator insects often are placed in alfalfa seed-production fields. The most popular insects for alfalfa pollination are the honeybee (Apis mellifera L.), the leafcutter bee [Megachile rotundata
(F.), and the alkali bee (*Nomia melanderi* Ckll.). The alkali bee is adapted to the Rocky Mountain states and westward and it cannot be easily cultivated. Honeybees and leafcutter bees can be cultivated and are used more often than are alkali bees. Alfalfa seed growers often obtain honeybees under contract from honey producers.

**Certified Alfalfa Variety Review Board**

Most, but not all, certified alfalfa cultivars are submitted to a review board before they are named and released. The review board consists of members from the Association of Official Seed Certifying Agencies, the American Seed Trade Association, the Alfalfa Improvement Conference, and an ex-officio member from the Plant Variety Protection Office. The review board reviews and evaluates information on the cultivar submitted with the application and publishes a report that becomes part of a permanent record for the cultivar. A favorable ruling from the review board insures that certification will be granted for the cultivar.

Applicants are requested to submit the proposed name, the experimental designation, genetic origin and breeding procedure, permitted steps in the seed-increase procedure, descriptive data on morphological
traits, disease and insect resistance, fall dormancy, yield, probable area of adaptation, and intended use. Applicants also state when certified seed of the cultivar will be available and whether or not plant variety protection will be requested. Applicants are requested to send a sample of seed of the cultivar to the National Seed Storage Laboratory in Ft. Collins, Colorado, and to register the cultivar in the journal, *Crop Science*.

Alfalfa cultivars must be licensed by the Food Production and Inspection Branch of Agriculture Canada before they can be sold by name in Canada. To receive a license, a cultivar must yield at least as much as current check cultivars in provincial trials. Resistance to bacterial wilt is required in most provinces, and resistance to phytophthora root rot and verticillium wilt is required in Ontario.

**Marketing and Distribution**

Alfalfa seed produced by the seed grower usually is purchased by an accumulator, who deals directly with the seed grower. The accumulator sells the seed to wholesale distributors who market to retail stores. Forage producers purchase seed from retail outlets. Very little alfalfa seed is sold by seed growers directly to forage producers because major seed production areas are distant from some of the most intensive forage production areas.

Alfalfa seed may be produced by a seed grower with or without a contract for its sale. Seed produced without a contract is referred to as open-market seed and that produced under an agreement with the purchaser is called contract seed. For open-market seed, growers use foundation seed for production of a seed crop as part of their farm enterprise. The grower sells the crop to an accumulator or wholesale distributor. The economics of open-market seed varies considerably with the supply of alfalfa seed from other sources. Much of the open-market seed is of old cultivars that probably should be removed from the market.

Contract seed is produced under terms that are agreed to by the grower and contractor. The contractor provides the foundation seed stocks and determines the hectarage to be planted. The hectarage is determined from an estimate of the amount of seed that will be sold. The use of contract seed production is an obvious means of attempting to match supply and demand for seed of a particular alfalfa cultivar. Almost all cultivars that originate from research departments of private companies are produced under contract. Public agencies that wish to maintain some control over seed supplies also use contracts for seed production.

Some cooperatives produce, accumulate, and distribute alfalfa seed produced by their growers. Others market seed of alfalfa cultivars developed by research departments supported by grower members.
FUTURE PROSPECTS FOR CULTIVAR DEVELOPMENT

The time required from initial crosses to final release of an alfalfa cultivar is often more than 10 years. Therefore, the alfalfa breeding research effort now in place will ensure that improved cultivars will be released in the future. The cultivars released in the immediate future will have higher levels of multiple-pest resistance, and some increases in forage yield are are expected. These predictions are made under the assumption that a major breakthrough in alfalfa breeding will not be made.

Scientific disciplines related to alfalfa cultivar development are changing rapidly, and it is possible that a major breakthrough will be made at some unknown time in the future. There is abundant variability within most alfalfa cultivars for yield, but current breeding methods do not effectively use that variability. Our knowledge of polyploid genetics and breeding is increasing, and some alfalfa breeder will eventually determine a way to utilize that variability to produce superior yielding cultivars. Other breeders will develop a way to utilize the male sterility now available, or a variant of it, to produce hybrids without an unacceptable reduction in seed yields.

New mechanisms of pest resistance probably will be discovered that make the task of developing multiple-pest resistant cultivars easier. Transfer of glandular hairs from wild relatives of alfalfa offers a promising mechanism for obtaining resistance to several important insect pests of alfalfa (Johnson et al., 1980).

Predictions of the contribution of genetic engineering to alfalfa cultivar development cannot be made at this time. Differences between laboratory- and commercial-scale manipulation of a biological process often are greater than expected. Techniques may be developed that permit vegetative propagation of seed-production fields, which could provide a novel method of utilization of heterosis in alfalfa (Bingham, 1979). Possibilities of creating new variability or moving desirable genes from related species with some of the new genetic techniques are almost unlimited.

REFERENCES


