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Seed Production

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CHAPTER

32

Seed Production

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Introduction

The primary objectives of most forage breeding programs are to increase forage yield and quality. Though these traits are certainly important, forage cultivars are not necessarily preferred by producers because of them alone. A successful forage cultivar must be adapted to its environment, of value to the end-user, produce an abundance of good quality seeds, and once planted have quick emergence and establishment (Harlan 1960).

In the past, when farmers needed seeds for planting, they allowed hay fields or pastures to flower and produce seeds. Seed production was a co-product of forage production. As adapted varieties became available, grazing and harvested forage systems became more specialized, and the dedicated seed trade expanded, the seeds of many forage species were produced as specialty crops in regions geographically removed from the areas where the seeds were utilized for forage production; regions where environmental conditions are more conducive to dependable yields of high-quality seeds.

Today, seed producers and the seed sales industry provide consumers with dependable quantities of high-performing seeds that add value to the production systems where used. Special rules are followed by seed producers to help ensure that the genetic quality of cultivars remains true to the genetic composition as originally developed by plant breeders. Also, specialized production and **seed conditioning** practices are needed to assure that the seeds produced are as pure as possible from physical contaminants such as weed and other crop seeds.

Most forage plants are grazed or cut frequently for hay or silage and rarely allowed to complete their life cycles to produce seeds. When forage plants are allowed to produce seeds, they are exposed to additional physiologic pressures in the field that may not normally affect performance when grown for forage. Many of the flowers produced may fail to set viable seeds as a result of disease or insect infestation or due to a lack of pollination if cross-pollination is required. Once seeds begin to mature after fertilization, environmental stresses related to weather may lower seed quality and the ability of seeds to produce vigorous plants after seeding. Numerous problems may exist during seed harvest and conditioning, the cleaning processes used to separate the forage seeds grown from other crops seeds, weed seeds, and inert materials, that reduce the actual amount of crop seed that will be eventually sold and planted.

Many of these problems can be reduced by growing forage grass and legumes species for seeds in environments that are conducive to reproduction. But even for the same species, production practices may vary greatly across the regions where they are grown for seeds (Figure 32.1).

Forages: The Science of Grassland Agriculture, Volume II, Seventh Edition.
Edited by Kenneth J. Moore, Michael Collins, C. Jerry Nelson and Daren D. Redfearn.

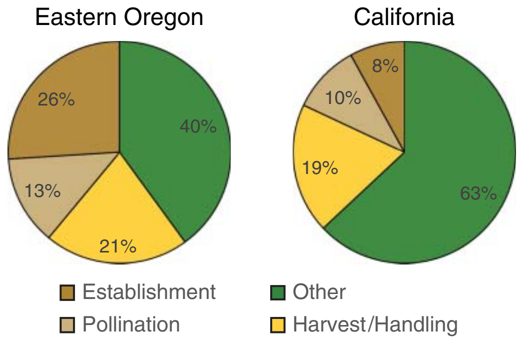

FIG. 32.1. A comparison of the relative costs of different production operations for alfalfa seed grown in eastern Oregon and central California. Notice the cost of pollination is much greater in eastern Oregon than California, but the cost of operations, including irrigation and insect management, are much greater in California than eastern Oregon. Growers also need to consider where the greatest gains in production efficiency for their operation can be achieved and consider alternative management practices to increase net income.

Regional Seed Production in North America

Most temperate grass seed production occurs in the northwestern United States with the majority of perennial ryegrass, italian ryegrass, tall fescue, red fescue, and bentgrass grown in western Oregon. Significant acreage of kentucky bluegrass seed is produced in central and eastern Oregon, eastern Washington, western Idaho, and western Canada. Some forage legume species are still grown for seed in areas other than the western United States. Seed production of most of the improved red clover cultivars occurs in the west, but uncertified red clover seed is also produced in Illinois, Indiana, Ohio, Missouri, and central Canada. Similarly, most of the production area of alfalfa seed shifted in the late 1940s from the Great Plains states to California and regions of the Pacific Northwest east of the Cascade Mountains, and the western Canadian provinces, but some acreage still remains in Nebraska, Kansas, and Oklahoma.

Most of the white clover seed is produced in California's Sacramento Valley with more limited acreage in Western Oregon and Idaho. However, much of the white clover seed used in the United States is imported from New Zealand. Most crimson clover seed is produced in the Willamette Valley of western Oregon, but some seed production of this species as well as that for korean and japanese bushclover and timothy are produced in the midwestern or southeastern United States (Wheeler and Hill 1957; Youngberg and Buker 1985).

Most birdsfoot trefoil seed is produced in Minnesota, Wisconsin, Michigan, and adjacent regions of Canada. Specialty winter-annual forage legumes such as common vetch, rose clover, subterranean clover, arrowleaf clover, and egyptian clover are produced in limited amounts in either California or western Oregon.

Most native warm-season grass seed production occurs in the central and southern Great Plains region of the United States. Native grass seed is harvested from rangeland where the "wild" harvest will consist of a mixture of important rangeland species such as big bluestem, little bluestem, indiangrass, and switchgrass. Seed production of improved cultivars of these four native species, as-well-as blue and sideoats grama, buffalograss, sand bluestem, sand lovegrass, and eastern gamagrass also occurs in this region. Seed production of most introduced warm-season grasses is typically done in the areas of major use for the species. Bahiagrass and dallisgrass seed production can be found in the southeastern United States as well as Australia, weeping lovegrass and yellow bluestem seed production mostly occurs in the southern Great Plains region, and bermudagrass seed production typically occurs in Arizona, southern California, and Oklahoma.

Native grass seeds from the Intermountain Great Basin region and those from west of the Sierra Nevada and Cascade mountains are typically produced as specialized seed crops in the California Great Central Valley including beardless wildrye, purple needlegrass, and sandberg bluegrass. Produced in western Oregon are tuffed hairgrass, blue wildrye, and roemer's fescue, and in central Oregon, Idaho, and in eastern Washington are desert wheatgrass, mountain brome, and western wheatgrass.

Seeds of annual warm-season grasses, such as forage sorghum, sudangrass, sorghum-sudangrass hybrids, and pearlmillet are primarily developed and grown by commercial seed companies in the southern High Plains and Southwest states where the growing conditions are characterized by fertile soils, hot and dry days, and adequate available irrigation water (Karper and Quinby 1947).

Environmental Variability and Seed Quality

Consistent production of high-quality forage seeds depends upon the ways cultural practices are applied to optimize the reproductive expression of each species. Since most forage seed crops are grown in regions different from where the seeds will be utilized, numerous aspects of the seed production environment must be considered in relation to plant growth and reproduction. It is critical to maintain the genetic integrity of cultivars as the volumes of seeds are increased in each successive generation of seed production. Each crop cultivar starts from a small amount of seeds developed and tested by public or private plant breeders. The original **breeder seed** is increased until enough quantity is available for the market place to meet user demand. Factors such as photoperiod and seasonal temperature ranges along with rainfall patterns

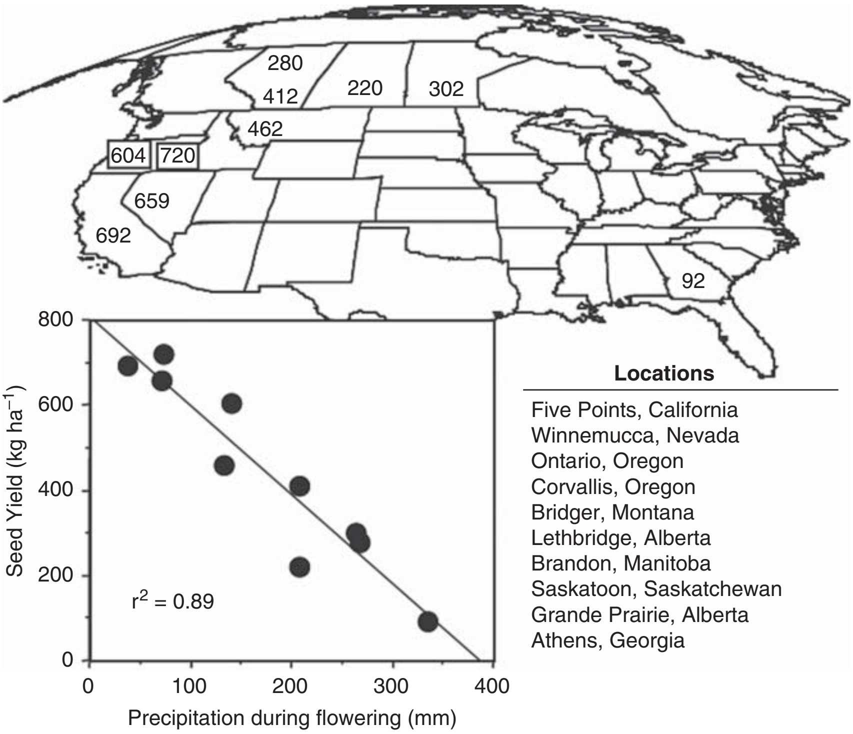

Fig. 32.2. The effect of precipitation during the reproductive period on alfalfa seed yield. Seed yields shown are based on reported average annual yields for the general production area. Precipitation amounts are the annual average amounts for the time period for alfalfa reproduction in the area.

have traditionally determined the regions where cultivars are successfully produced. However, economic and social concerns may also influence the kinds of farming practices that can be used and the capacity of the seed industry to produce consistent amounts of high-quality seeds in a given seed production environment.

The geographic shift of forage grass and legume seed production from the humid mid-western to arid western United States was due to more dependable weather conditions during seed maturation and harvest (Rincker et al. 1988). As greater amounts of seeds of improved cultivars from specialized seed production were available in the marketplace, farmers used less on-farm produced seeds. The climatic conditions of the west are best characterized by relatively warm summer temperatures and low humidity, as well as dry periods during harvest time in late-summer (Youngberg and Buker 1985). Frequent or untimely rainfall in the Midwestern states contributed to reduced seed yields and frequent crop failures. For example, alfalfa seed yield is reduced as the amount of precipitation received during the seed production period increases, so summer arid environments are best for seed production (Figure 32.2). However, even in the western United States, some specific regional climates may be more favorable to seed production than others. High ambient air temperatures during reproduction may reduce seed yields by decreasing the number of seeds successfully formed in each flower. Furthermore, the number of alfalfa florets setting pods decreases when the air temperature exceeds 38 °C, with 27 °C being the optimal temperature for seed production. Seed production usually increases as the relative humidity decreases, but low humidity associated with high temperatures can make easy-to-shatter seed crops more difficult to harvest because pods can dehisce with shattered seeds falling to the ground at late crop maturation time or during harvest. High-light intensity is also essential for good seed production as well as clear skies and warm temperatures that can favor insect pollinator activity that is needed for cross-pollinated species such as the clovers and alfalfa.

Care must be taken when choosing a region for seed production to fit the reproductive physiology of the cultivar, as well as maintenance of genetic quality. The differential effects of environmental factors such as temperature and photoperiod length may shift the genetic composition of a cultivar during seed production. For example, the temperatures in the southern California and Arizona seed production regions are characteristically mild in winter and hot in summer, compared to the cold winter weather characteristic of the mid-western or upper Great Lakes regions. When cold-resistant alfalfa cultivars are grown for seed in mild climates, the plants produced from those seeds of those populations are shifted to taller ones than the original parent material, with greater autumn plant growth and greater susceptibility to winter injury than plants grown from seeds produced in climates more like those where the cultivar was developed (Garrison and Bula 1961). As the number of seed production generations increases in regions different from the regions of adaptation, the resulting **genetic shift** is toward plants more similar to cultivars adapted to the seed production region. A reverse genetic shift may occur if warm climate southern cultivars are increased for several generations in much colder regions.

Another type of genetic shift may occur from the different flowering responses to photoperiod length of individual plants in a population (Garrison and Bula 1961; Bula et al. 1964; Taylor et al. 1990). Seed production of red clover cultivars adapted to northern regions at southern latitudes may result in a disproportionate production of non-winter-hardy genotypes that are not adapted to cold continental winter climates. This phenomenon can be useful for producing cultivars that are strongly vegetative at southern latitudes. Some cultivars of white clover and birdsfoot trefoil may produce more seeds when grown at northern latitudes where longer daylengths induce more flowering than when grown for seed at southern latitudes.

There has been increasing demand for native grass species to meet conservation planting needs, including vegetation restoration following wildfires. Depending upon the location of the restoration site, planting specifications may require the use of locally grown ecotypes or plant materials from similar ecoregions. The reasoning behind this is to ensure the reestablished plants will perform similarly to those that were established before the fire, and the community will have a similar natural ecologic function.

Specialized Management for Reproduction and Quality

The cultural practices employed for seed production are different from those used for conventional forage production and serve the purpose of optimizing the yield of pure, high-quality seeds. These may include special planting methods and plant population configurations, soil fertility requirements, and other management operations that benefit seed production. Forage seed crops may have irrigation requirements, weed control methods, and insect and disease pest management practices very different than those when grown for forage. In addition, special practices not used for forage production, such as pre-bloom herbage removal and pollinator management may be required to enhance reproductive development and seed yield. As the seed plant changes throughout the season, so various growth factors need to be considered and the timing of different practices be applied to optimize seed yield (Figure 32.3).

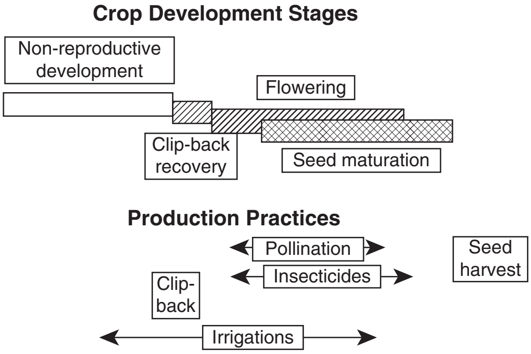

FIG. 32.3. The relationship of alfalfa seed crop-development stages with the timing of seed production practices. Notice how multiple management practices must be considered at the same time. Improper irrigation timing or amount influences the balance of vegetative and reproductive development, and improperly managed insect pests can affect the effectiveness of pollinators that significantly impact final seed yield.

Stand Establishment

Most forage crops grown for seed are planted in rows 15–122 cm apart and at very low seeding rates. Conventional grain drills are typically used to place seed in rows of less than 30 cm, whereas, single-row, box-type, planters are used to plant seed in rows of greater than 30 cm. Spaced plantings similar to those used for vegetable crops have been utilized in alfalfa to increase seed production by minimizing intra-row plant competition, while aerial broadcast seedings are used in large white clover seed fields in California.

Soil-Nutrient Management

Grass seed crops generally need supplemental nitrogen (N) fertilization (Youngberg and Buker 1985). The optimal time of N application depends upon the growth habit of the crop and local soil conditions where grown (Young et al. 1995a,b). Some grasses primarily produce their flower buds during the summer and thus respond to one N application in spring. Other species, such as some cool-season grasses, initiate their flower primordia during the fall or winter and respond when N applications are split between the autumn and spring. However, the optimal amounts and application times of N for cool-season grasses vary for different species. The total amount of applied N depends upon residual amounts of soil N from previous fertilizer applications or from previous crops in the rotation cycle, such as following legume crops.

Legume seed crops should have specific **rhizobia** inoculant applied to seeds at the time of planting to ensure that adequate N fixation occurs for plant growth. Legumes need adequate levels of phosphorus, potassium, calcium, and other nutrients to ensure proper growth. The amount of each nutrient required for seed production may be less than that needed for maximal forage production. High phosphorus levels in white clover seed fields may reduce seed yield because **vegetative growth** is favored over reproductive development (Clifford 1987). Low levels of the micronutrient boron in the soil may reduce seed yields in legumes such as white clover (Johnson and Wear 1967).

Local soil tests used in conjunction with local extension service or crop consultant recommendations can help determine the amounts of each nutrient needed for adequate plant growth. Soil pH may greatly influence legume seed crop success. Many legume seed crops are very sensitive to acid soil conditions (Steiner and Alderman 2003). For example, crimson clover is very sensitive to low pH conditions and will not adequately fix atmospheric N unless excessive soil acidity is modified with lime. Strawberry clover is better adapted to alkaline than to acid soils. These factors should be considered when choosing a suitable region or soil series for forage legume seed crops such as these.

Spring Growth Herbage Management

Removal of early spring plant growth by grazing or haying prior to or during early flowering is a common practice for some annual and perennial forage legumes species grown for seed (Rincker and Rampton 1985; Rincker et al. 1988). Herbage removal helps synchronize uniform flowering in early summer when insect pollinators are most active, disrupts the life cycles of some insect pests that attack the flowers, and provides the seed grower additional income from the sale of the herbage as hay or from grazing fees. White clover and subterranean clover are commonly grazed by sheep (*Ovis aies* L.), while alfalfa and red clover herbage is removed mechanically. Crimson clover and kura clover do not typically have herbage removed, or seed yields could be greatly reduced.

The optimal time for herbage clip-back in California alfalfa seed fields is between late-March and mid-May when new crown buds are about one-half centimeter long (Jones and Pomeroy 1962). Red clover seed fields in western Oregon have herbage removed around late-May, but the amount of available soil water, number of accumulated heat units during spring, and root health of stands greatly affects optimal timing for maximal seed yield (Steiner et al. 1995).

Some temperate grass seed crops such as annual and perennial ryegrass are grazed with sheep during the autumn and winter before **reproductive primordium** have elongated. The timing of herbage removal is critical, and must be performed before the inflorescences begin rapid development or seed yield will be reduced (Young et al. 1995a,b). Plant growth regulator use on forage grass seed crops has been investigated but, in general, has not produced beneficial results.

Soil-Water Management

In general, it is important that plant growth be balanced with active floral development to achieve good seed production. Specific water requirements vary greatly by species and depend upon soil water holding capacity and soil depth, amount and pattern of natural precipitation, air temperature, and wind speed that can affect evapotranspiration and growing season length.

Excessive non-reproductive vegetative growth of some forage legume species can reduce seed yields, so properly managed water application timing and amount applied is important to favor reproduction (Figure 32.4). If alfalfa, white clover, and birdsfoot trefoil are over-watered, **vegetative growth** will be unrestricted and seed yields will either be greatly reduced or unimproved compared to plants grown without irrigation (Taylor et al. 1959; Steiner et al. 1992; Oliva et al. 1994; Garcia-Diaz and Steiner 2000). Shallow-rooted white clover plants need more frequent applications of water than deep-rooted

FIG. 32.4. Surface irrigation for alfalfa seed production. Siphon pipes direct water into furrows between the planted rows of alfalfa plants that are grown on low raised beds. Forage legume seed crops must be managed to favor reproduction over herbage growth. Most forage legume seed crops have reduced seed yields if they are overwatered.

alfalfa plants when grown in California. White clover grown with supplemental irrigation is best adapted to soils with low water holding capacities in order to reduce excessive plant vegetative growth. Alfalfa with a long taproot may utilize water from deep within the soil profile and survive much longer dry periods than either white or red clover. Red clover responds well to large water application amounts at early bloom in western Oregon, while birdsfoot trefoil does not require irrigation.

Pollination and Pollinator Management

Most forage crops require some form of pollination and fertilization for seed set to occur. After a pollen grain reaches a receptive **stigma**, it germinates. The germinating pollen grain produces a pollen tube that grows down the **style** to the ovule entering the embryo sac. Within the embryo sac, one of the two sperm nuclei fuses with the egg nucleus forming the first cell of the new plant, the second sperm nucleus fuses with one or more polar nuclei forming the endosperm, thus completing double fertilization (Dumas and Gaude 1993).

Most grass species such as tall fescue, perennial ryegrass, and crested wheatgrass are cross-pollinated by wind. Vast clouds of pollen can be seen in spring blowing from seed fields making physical isolation distances between different cultivars within a species necessary to reduce genetic contamination between cultivars (Figure 32.5). Research has shown that pollen from domestic creeping bentgrass can be transferred to plants of the same species 21 km away and plants of wild *Agrostis* species as far as 14 km (Watrud et al. 2004). As transgenic forage varieties are developed, concerns have been raised about transgenes being spread to non-genetically modified plants, such as with alfalfa (Greene et al. 2015).

Some important grasses such as kentucky bluegrass, dallisgrass, buffelgrass, yellow bluestem, and eastern gamagrass reproduce by apomixis from which seeds are produced without fertilization of the egg nucleus. There is no pollen-mediated transfer of genetic material between different cultivars within these species, so genetic contamination during seed production in this manner is not generally a concern.

Cross-pollinated forage legumes require an insect pollinator to manipulate the flower so fertilization can be accomplished (McGregor 1976). In alfalfa, the pistil of the flower is held under pressure within the keel and fertilization cannot occur until the keel is opened, releasing the reproductive column and allowing it to strike the standard flower in an action called tripping. Other common forage legume flowers do not have this mechanism and therefore are not tripped. Instead, bees force the reproductive column out of the keel in a piston-like, reversible action that brings the pollen in contact with the insect. When a pollinator visits a flower, pollen from that flower either adheres to small hairs or sticks to its body and is transferred between flowers of different plants as the insect forages. The amount of forage legume seed produced is directly related to pollinator activity (McGregor 1976).

The western honeybee (*Apis mellifera* L.) is an important domesticated pollinator of many forage legume seed crops that require cross-pollination. A high percentage of the pollinating insects used in California alfalfa and white clover seed fields are honeybees. Honeybees are also used for most clover, vetch, and birdsfoot trefoil seed production. A general recommendation is to use an average of 3.7–5 two-story high honeybee hives per hectare for adequate pollination. Some situations may require the use of more than five hives per hectare, but the cost of additional hives may prevent an economic return. When using honeybees in large fields, it is best to have the hives spread no more than 160 m apart with groups of 12–18 colonies

Fig. 32.5. A pollen cloud released from crested wheatgrass. *Source:* Image provided by Ken Moore.

at each apiary site. Each hive should have about one-half square meters of brood covered with adult bees and an actively laying queen for adequate pollination.

In eastern Oregon and Washington, Idaho, Nevada, and Canada, the leafcutter bee (*Megachile rotundata* L.) is used for alfalfa seed production. Leafcutter bees have also been used in combination with honeybees in California. Leafcutter bees nest in grooved, laminated boards composed of wood, particle board, or polystyrene plastic or other solid materials with drilled holes that serve as nests. The blocks or nesting boards are placed in portable shelters that can be moved from field to field to facilitate pollination. A unique characteristic of the leafcutter bee is that it collects pollen or nectar to provision the brood cell. The egg is laid on the mixture of nectar and pollen in each individual cell. Because the leafcutter bee forages for pollen, it is a very effective pollinator of alfalfa (Rincker et al. 1988). Approximately one female leafcutter bee is required per four square meters of alfalfa flowers (Bohart 1967). Approximately 20 000 healthy prepupae cells of leafcutter bees are adequate for pollinating alfalfa seed fields.

The alkali bee (*Nomia melanderi* L.) is a native pollinator that has been used in alfalfa seed production in California and south-central Washington. These bees nest in the soil and have been cultured in gravel and soil beds lined with plastic so that bed moisture can be controlled (Frick et al. 1960). Salt is often added to the surface of the soil to maintain proper soil moisture by reducing evaporation and to control weeds (Rincker et al. 1988). Alkali bee beds are difficult to move and are expensive to establish. Approximately $10\,m^2$ of well-populated nesting sites is required per hectare of alfalfa seed field (McGregor 1976).

Bumblebees (*Bombus* spp.) are also very effective pollinators in alfalfa and all other forage legume seed crops. Bumblebees are very difficult to culture but are abundant in seed fields that are adjacent to wild areas along roadsides, ditches, and wooded areas. They nest primarily in undisturbed soil, but also in abandoned rodent holes. Only impregnated female bumblebees over-winter and they are very particular about nesting conditions. The solitary nature of bumblebees makes them difficult to domesticate, but nesting can be encouraged (Heinrich 1979). All bees, and especially the wild bees, are very sensitive to insecticides so pest management plans must consider how to avoid seriously damaging pollinators.

Weed Management

Weed control methods vary for different seed crops and the kinds of weeds found in specific fields. Weeds may be a serious problem when stands are thin because the competitive nature of weeds lowers crop seed yields and can delay harvest. Also, depending on weed seed shape and size, weed seeds that cannot be easily removed by **seed conditioning** (the cleaning of seeds after harvest) may render the crop unsaleable.

Depending on planting method, appropriate strategies must be employed to control weeds. Effective crop rotations, properly prepared seed beds, and planting at a time that allows rapid and uniform establishment of the seed crop stand can increase the effectiveness of herbicides. When seed crops are planted in wide rows such as with alfalfa, mechanical cultivation methods can be employed to physically control weeds or help the crop plants to gain a competitive advantage over the weeds. Many fall-planted temperate grass seed crops are seeded under a narrow band of activated charcoal sprayed over the planting row at planting time (Lee 1973). Herbicides that adsorb to charcoal are then sprayed over the field and activated by precipitation or irrigation. Weeds and volunteer crop seeds between the treated rows are killed by the herbicide, but the crop emerges unharmed from under the charcoal-treated row because the herbicide is bound to the charcoal and rendered inactive. Early-maturing weeds in several perennial legume seed crops can be controlled by removal of winter and early-spring herbage by grazing, mowing, or hay harvest. Mowing is also an effective method to reduce weed competition. Different combinations of management practices including rotation crops and establishment methods affect the kinds of weeds that grow in grass seeds fields, and can influence the reservoir of weed seeds that are found in the soil weed seed bank (Medeiros and Steiner 2002).

Preemergence herbicides are often important management tools for achieving good initial crop stands after planting. Postemergence herbicides are effective when specific sensitive weeds are selectively controlled by applications to establish seed crop stands. Herbicide effectiveness for controlling weeds can be greatly enhanced when used in combination with other control methods to significantly reduce weed establishment (Lee 1965).

Dodder, a parasitic plant, is one of the most serious weeds to control in legume seed production fields. Since this weed is classified as a primary noxious weed, there is no tolerance for dodder seeds found in seed lots that are to be sold. This weed must be aggressively eradicated from seed fields. Seed fields are monitored from the ground and air to identify infested areas that are then sprayed locally and burned before the dodder plants produce seeds. There are specific herbicides that can reduce dodder infestations if properly applied. Most of the few remaining dodder seeds harvested with the seed crop can be removed during **seed conditioning** using special separation equipment. However, each additional conditioning procedure reduces the amount of clean seed produced and adds to the final cost of production (Purdy et al. 1961; Youngberg and Buker 1985).

There are problems associated with relying on herbicides as the only means of controlling weeds, particularly in perennial seed crops. These include the danger of induced herbicide resistance in weed populations and shifts in weed populations toward those species that are not susceptible to commonly used herbicides. Resistant populations of annual ryegrass have developed in wheat fields where selective grass herbicides have been continually used to control grassy weeds in wheat. Due to shifts in the predominate kinds of weeds found in grass seed fields, cheatgrass and smooth bromegrass have become the predominate competitors in some seed fields.

The judicious use of those herbicides that continue to be registered in combination with cultural practices that reduce weed establishment, such as crop rotation and alternating the kinds of herbicides used, offer the best possibilities for effective control in seed fields. There are some cases where effective herbicides are no longer available because of human and wildlife health risks. In addition, due to the relatively small acreage of seed crops grown, the expense to chemical companies to register new chemicals is often not warranted compared to major crops such as corn, soybean, and cotton. The USDA Minor Crop Pest Management IR-4 Program provides assistance to help ensure new and more effective crop protection products are developed and made available to minor and specialty crop producers, including forage crops grown for seed.

Insect Pest Management

For both grass and legume seed crops, cultural practices can often be employed to control certain insect pests or reduce the need for insecticides. Shorter perennial grass seed rotations have reduced the incidence of bluegrass billbug (*Sphenophorus parvulus* Gyllenhal) damage as was also found in older orchardgrass seed stands. The subterranean sod webworm (*Chrysoteuchia topiaria* Zeller) can attack kentucky bluegrass and reduce stand longevity, but the use of deep-rooted cultivars reduces crop damage compared to those cultivars with shallow root systems.

In the Pacific Northwest, burning of grass seed field crop residues (Figure 32.6) after harvest often controlled some insect pests in long rotation stands, but the accumulation of charcoal on the soil surface also bound insecticides making them ineffective when applied at labeled application rates (Kamm and Montgomery 1990). The market change from public cultivars grown in long rotations to a far greater number of privately developed cultivars grown in shorter rotations has mitigated the negative impact of perennial grass seed crop pests, regardless of the reduction in grass seed crops burned after harvest in the Pacific Northwest. With the reduction in field burning of post-harvest straw, the increase in soil organic matter and earth worm populations has reduced the effectiveness of chemically treated baits used to control invertebrate slugs (*Derocerus reticulatum* Mueller). Earthworms are immune to the pesticide and carry the bate carrier into their burrows at night where it is out of reach of the slugs (Gavin et al. 2012).

Fig. 32.6. Open field burning was once a common practice in the Pacific Northwest for disposing of grass straw after seed harvest. Burning effectively controlled some disease, insect, and weed pests when perennial grass seed stands were kept in production for 10 years or more. Growers have changed their postharvest straw management and weed control practices since legislation to restrict field burning was enacted in the 1990s. Shorter rotations have greatly reduced the threat of some disease and insect pests.

In the past, organophosphate insecticides were frequently used in legume seed production. Depending on the seed production region and crop, one-to-as-many as four applications were required to adequately control pests such as Western tarnished plant bug (lygus) (*Lygus hesperus* (Hemiptera: Miridae)), aphids (*Aphis* spp.), and leaf-hoppers (*Erythroneura* spp.). More recently, pyretheroid-type insecticides are widely used and are replacing the organophosphates. Special care must be taken to use pyretheroid-type insecticides properly because some insect pests can quickly develop resistance to these types of chemicals. When utilizing herbage from seed fields for livestock feed, careful attention must be given to product registrations to be sure such use is allowed.

Certain insect pests are not controlled by available insecticides, so other methods need to be used. There are no chemicals available to control the clover seed midge (*Dasineura leguminicola* Lintner, Cecidomyiidae) in red clover, but its life cycle can be disrupted by herbage removal during the early bloom period in spring. Alfalfa seed chalcid (*Bruchophagus roddi*, Eurytomidae) damage in alfalfa can be reduced by incorporating residues into the soil after seed harvest using cultivation and irrigation to rot infested seeds; performing spring clip-back of herbage in early spring delays initial crop flowering time that, in turn, removes available host sites to females trying to oviposit. Also, not extending the pollination period into late-summer reduces the build-up of chalcid populations in later flower cycles. This pest has become a more significant pest in California since pyrethroid insecticides have replaced organophosphates.

Control of alternate nesting sites in weeds can also be used to control some insect pests. A dogfennel weed control program in winter and early-spring, both alongside and within red clover seed fields, removes feeding and oviposition sites for lygus and thus reduces pest pressure later in the season (Kamm 1987). This combined weed and insect control practice can probably be used for other legume seed crops where lygus is a problem.

Insect control must be carefully planned and done in a manner that optimizes pest control, minimizes harm to insect pollinators and beneficial insects, and avoids chemical trespass from the field where the product is applied. Similar as the situation with herbicides, forage seed growers have a diminishing number of insecticides available for insect pest management. Decline in honeybee populations have reached a critical juncture, so care must be exerted to help reduce any stress that could be due to insecticide use, particularly since these insects are critical to legume seed production.

Additionally, significant changes in climate may influence the distribution and abundance of insects (Cannon 1998). For example, it has been suggested that some aphids may cause more severe damage to plants due to increased settling times and reproduction under elevated CO_2 concentrations (Awmack et al. 1996; Smith 1996), and other aphid species may not be affected at all by elevated CO_2 concentrations (Salt et al. 1996). Regardless of these facts, seed producers need to be aware of changing environmental conditions and adjust their seed production practices to meet new challenges.

Diseases and Their Management

The best way to control diseases in forages is by using disease-resistant cultivars. However, most cultivars are genetically selected for their performance in the region where they will be grown for forage, and not necessarily where grown for seed. Such cultivars are often exposed to different kinds of disease organisms or amounts of severity in the seed production regions, compared to where they are grown for forage.

Plant pathogens that affect grass seed production can attack both foliar and reproductive plant parts. Important inflorescence diseases include ergot (*Claviceps purpurea* (Fr. Tul.)), blind seed (*Phialea temulenta* Prill. & Delacr.), and the nematode seed gall (*Anguina* spp.) (Hardison 1963). The epidemiology of these diseases has become better understood, but there are no completely effective chemical controls (Alderman 1991). Blind seed disease is controlled through cultural practices including timely harvesting to avoid seed shatter, removal of lightweight (including infected) seed from the field, planting seed at least 1 cm deep, plowing, rotation with a non-susceptible crop, and the use of late-maturing cultivars (Alderman 2001). Seed conditioning is important because it can mechanically remove ergot and seed galls. Choke disease (*Epichloë typhina* (Pers.) Tul. & C. Tul) is more problematic since plants are systemically infected (Pfender and Alderman 2003). However, most inflorescence diseases can be managed though crop rotation with a non-susceptible host.

Stem rust (*Puccinia graminis subsp. graminicola* Urban) is a devastating disease in perennial ryegrass and tall fescue seed production (Pfender 2001). Typically, several fungicide applications are required annually to control this disease. Epidemic development is strongly dependent on weather conditions (Pfender 2003), so optimal timing for fungicide applications differs among years and locations. Seed fields must be carefully monitored to assess when the disease is present. Fungicides must be applied before disease severity reaches damaging levels because after symptoms are obvious, infections become less responsive to fungicides. Weather-based plant growth models have been developed to determine the time of optimal fungicide applications to improve disease control with minimized fungicide use (Pfender and Upper 2015).

The kinds of diseases that impact forage legume seed crops are primarily the same as those that attack forage crops. Most important are the root rotting diseases caused by (*Fusarium* ssp.) and (*Phytophthora* spp.) that affect stand persistence. The resistance of improved red clover cultivars to *Fusarium oxysporum* Schlecht. Emend. Snyder and Hansen grown in mid-western state forage fields does not reduce the impact of *Fusarium solani* (Mart.) Sacc. that is prominent in Oregon seed production fields (Steiner et al. 1997). Wilt caused by *Verticillium albo-atrum* Reinke and Berthold has become an important problem in some alfalfa seed producing regions because it can be seed-borne. When red clover and other legume seed fields are not properly rotated, *Sclerotinia* spp. can become a serious problem with long-term implications. Northern anthracnose (*Kabatiella caulivora* (Kirchn) Karak.), a seed-borne disease of crimson clover and red clover, can be controlled by seed treatment and proper planting time in the autumn (Leach 1962).

Seed Harvest

Many forage species have a tendency to shatter before all seeds on a plant are mature or produce flowers in an indeterminate fashion so that seeds of different stages of maturity are present on the same plant at the same time. Legume seed produced in naked pods, such as birdsfoot trefoil and vetches, tend to dehisce when ripe, propelling seeds in all directions. Most all forage legumes and grasses are susceptible to **seed shattering** once the seeds have dried.

Forage seed crops are harvested with a combine, either by direct combining of the standing mature crop or by first windrowing the crop before shattering begins and then combining the windrowed material at a later time (Rincker et al. 1988). The windrow method is chiefly used for temperate grass, clover, and other forage legumes because it allows cutting the crop when the foliage is slightly green and before shattering has begun. Once the mature inflorescences with seed have dried adequately for proper threshing, a special continuous belt attachment mounted to a combine gently picks up the cut windrow with minimal shaking that greatly reduces shatter loss. When direct combining is involved, a chemical desiccant may be used to aid plant drying without windrowing. Monitoring of seed moisture content during maturation can help determine the proper time to harvest forage seed crops by maximizing seed maturity and minimizing seed shattering (Klein and Harmond 1971).

There are also specialty harvest machines for forage seed crops with unique growing features. Subclover produces flowers near the ground and its pods often develop below the soil surface, similar to peanut. Once the seeds have matured, special harvesters developed in Australia vacuum up the pods and loose soil, separate the pods from soil, and then thresh the seeds.

Unlike temperate grass and legume species, the inflorescences of many native warm-season grass species not only have indeterminate ripening, but the seeds are also chaffy which makes harvest and cleaning difficult. Specialized harvesting equipment like the Woodward Flail-Vac seed harvester (Figure 32.7) was designed to harvest native and introduced chaffy-seeded grasses (Dewald and Beisel 1983; Dewald et al. 1985, 1993), and the crop stripping combine header that was designed to harvest a variety of crop seeds has been used successfully to harvest native grass seeds (Shelbourne and McCredie 1995).

Fig. 32.7. Stripper harvesters are designed to make multiple harvests from the same native grass stand in the same year. These machines come in widths from 1 to 8 m to fit different kinds of terrain. They can be powered by hydraulic motors, combustion engines, or tractor power take-off systems and can be mounted on a combine, tractors, jeeps, and all-terrain vehicles, as well as hand-held units. This technology greatly increases the ease of harvest of chaffy native seeds.

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