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MORPHOGENESIS AND MANAGEMENT OF ANNUAL RANGE PLANTS IN THE UNITED STATES

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The annual range plant community is a dynamic aggregation of plant species which fluctuates yearly and seasonally in response to changing weather conditions. Application of various management practices such as grazing management, fertilization, burning, seeding, and chemical sprays can enhance productivity, improve species composition, and change quality tremendously in annual rangelands. The annual range is surprisingly more responsive than any other rangeland type.

The stage of plant development is equally as important as the management practices employed. By careful attention to stages of morphogenesis, including germination, vegetative growth, stem elongation, flowering, and seed production, the application of management practices can enhance the value of annual rangelands in the United States.

Location Of Annual Rangelands

Annual range plant communities predominate in two major types of climates in the United States. In California, the Mediterranean-type climate consists of moist cool winters and dry hot summers (*28*). The most favorable periods for plant growth, therefore, occur in the fall, after the onset of precipitation but before low temperatures limit plant growth and near the end of the moist season in spring, as temperatures rise after the cool winter period. Plant species that can complete their growth cycle, produce seed, and then escape the long summer drought, appear to be well adapted to the Mediterranean-type climate. Considerably fewer perennial plant species can withstand extreme drought for up to 5 or 6 months. With range deterioration, the perennial species give way to the invasion of introduced grasses and forbs from the Mediterranean region.

Annual plant species also are important in the middle-latitude desert, classified as BSK by Koppen (*28*). The northern Great Basin and Columbia Basin plains have cold winters with precipitation often occurring as snow. Spring growing conditions become favorable as temperatures increase and precipitation remains adequate for a short period. Precipitation continues at a low level through much of the summer but is often undependable, and long periods of drought prevail. Deterioration of the original vegetative cover of this region allowed the invasion of annual species which were able to germinate, grow, and mature in a short period of time or to endure the periods of summer drought.

The southern extension of middle-latitude deserts in the United States, covering large expanses of the Southwest, also have an important component of the vegetation comprised of annual species. However, in these desert areas the annual vegetation occurs as a minor understory to the dominant shrubby vegetation and, therefore, is not considered of high importance from a management or forage production standpoint. However, in an occasionally favorable year, the profuse growth of desert annual species is an interesting phenomenon and cannot be dismissed lightly (*55*). Such desert annual communities serve an important function in the ecosystem by recycling nutrients, by furnishing food and habitat to small animals, and by forming a protective plant and litter cover over the soil surface under shrubs.

The annual range plant community in California is a very dynamic aggregation of plant species that fluctuates, not only yearly but seasonally, in response to the factors and interrelation-

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ships of the ecosystem (*48*). Such predictions as "This is going to be a good clover," "filaree," or "grass year" are commonly made in recognition of the dynamic nature of the annual range plant community which may have a significantly different species composition each year. Talbot and others (*50*) reported such variations (table 1).

The date of opening rains is an important factor in determining the species composition. *Bromus mollis* L. and *Erodium botrys* (Cav.) Bertol. are likely to be abundant with early effective rains, while the initiation of rains later in the season appears to favor a greater range of species, including the annual legumes. A drought period often follows the first rain. Under such conditions, species which are more drought resistant in the seedling stage are likely to be the most abundant. Subsequent studies by many workers (*11*, *12*, *21*) on the California annual range type confirm that yearly variations in species composition are caused by weather patterns that follow the early period of germination.

Species composition changes are also subject to annual fluctuations in the upper Great Basin and Columbia Basin regions. In these regions, composition does not change as much as the density of the stand does in response to favorable or unfavorable weather conditions. Klemmedson and Smith (*26*) reported that, at Arrow Rock, Idaho, one year's cheatgrass production was 361 pounds per acre, and in the following year, it was 3,461 pounds per acre— a tenfold increase, primarily in response to favorable precipitation.

TABLE 1.—*Year to year fluctuations between plant groups. (From data published by Talbot and Biswell (50))*

Plant group	Percentage by years				
	1935	1936	1937	1938	1939
Annual broadleaved plants	74.8	53.2	43.5	61.7	52.6
Annual grasses	20.6	45.4	55.5	34.1	47.1
Annual grasslike plants	2.9	.5	.5	3.6	[1] T
Total	98.3	99.2	99.5	99.4	99.7

[1] T=trace.

Is the annual range of sufficient importance to maintain it as a type without considering conversion to perennial grass? Many of the early studies dealt with intensity of grazing, to determine the effect on stand density and whether management could favor the return of perennial grasses. Talbot and Biswell (*50*) stated that, at the San Joaquin Experimental Range in the central valley of California, the sparse perennial grasses showed no increase in response to management during a 5-year study period. Even in completely protected places the stand of annual grasses and forbs continued to predominate. A report of later work (*3*) indicated an average of 4,400 pounds per acre harvested forage in swales as compared with 1,850 pounds of air dry forage on open rolling slopes in good years. During a 12-year study period, the estimated average production of air dry herbage per acre was 1,660 pounds, with the extremes fluctuating from 1,200 pounds to almost 2,400 pounds per acre. During this time the average precipitation was about 20 inches.

Bentley and Talbot (*3*) concluded that restoring the original cover did not appear possible, nor was it necessarily a logical objective. Instead, they recommended range management that would produce a forage cover composed of the better species of introduced and native annuals and perennials. Also range management should be aimed at effective use of the annual plant forage in its most productive condition with adjustments to increase the valuable perennial plants where they are important in the stands. They hoped that it was possible to produce a forage crop superior to the original cover. These statements have proved to be true, especially in view of more recent work in which improved management practices, particularly fertilization, have produced forage yields as high as 4,400 pounds with the addition of super-phosphate and introduced annual legumes (*62*) in the foothills of the Sacramento Valley. Nitrogen fertilizers at rates of N up to 80 pounds have increased total yield more than threefold (*15*, *21*). A combination of 100 pounds of nitrogen and 88 pounds of phosphorus in the Sacramento Valley have produced yields of over 4,000 pounds per acre (*39*).

Annual cheatgrass range in the northern Great Basin and parts of the Columbia Basin are extremely important to the livestock industries in

those areas. Hall and Pechanek (*17*) stated that cheatgrass was probably the most important forage in southern Idaho. A U.S. Forest Service report (*51*) stated that cheatgrass provided the bulk of early spring grazing for all classes of stock on millions of acres in the Intermountain West. Not only is the forage abundant in good years but it also has a high nutritive value. In Montana, Hurtt (*18*) found that the condition of horses grazed on cheatgrass pasture compared very favorably with horses grazed on adjacent perennial grass pasture. In southern Idaho, the average grazing capacity of 5 to 8 acres per animal unit month (AUM) is realistic for most of the cheatgrass (*26*). However, the contrast in yields between poor and good forage years is extreme. In southern Idaho under a mean annual precipitation of 18 inches, the yield of cheatgrass in 1943 was 361 pounds per acre, while in the following year it was 3,461 pounds per acre—a tenfold increase. These data illustrate Piemeisel's observation (*46*) that forage production of cheatgrass fluctuates greatly from year to year in response to weather and is greater than that of perennial grasses.

The question may be asked, "How did the annual range plant community come into being where originally the plant cover was a mixture of perennial grasses and some annual species?" Most range ecologists will concede that in every location where cheatgrass thrives its successful establishment can be associated in some way or other with a disturbance or a deterioration of the range ecosystem. Various factors are responsible for this, including fire and abandonment of cropland. Daubenmire (*5*) considered that, inasmuch as cheatgrass does as well as the indigenous species of similar life form, it is a thoroughly naturalized alien in the *Agropyronetum*.

In the California annual type, Biswell (*4*) concluded that the kind of plant cover existing over the region before white man came can never be determined precisely, since there is no early literature that adequately describes it, and virtually no samples remain of it. However, many ecologists postulate that the original vegetation in the present California annual range type was a bunchgrass, primarily composed of *Stipa* species, plus numerous indigenous annual forbs and grasses of limited plant vigor.

Management Practices Which May Condition Or Alter Plant Development

In contrast with the opportunities available to the farmer, the range manager has fewer tools at his disposal to manipulate and manage rangeland vegetation. However, because of the more responsive nature and dynamic characteristic of annual plants, management may improve the productivity and quality of annual rangelands more than those of perennial rangelands. Results of management practices are often obtained the same year in which they are applied. Some of the more common management practices that are useful on annual ranges include grazing management, fertilization, seeding, burning, and application of herbicides. In some situations a single management practice may suffice; whereas, in others a combination of two or more may be necessary to accomplish the desired ends. In practically every case where a management practice is applied, it produces an impact on a particular stage of plant development that alters the course of subsequent growth, and often the impact radiates to the rest of the plant community

Grazing management practices involve removal of plant tissue. Too early grazing of plant tissue reduces the photosynthetic area of the plant, and cuts down the production of photosynthate to feed the growing plant and to support reproduction. Growing points may be removed; this will thwart further development of certain parts of the plant.

Range improvement by seeding involves many stages of development, but the most important ones are germination and establishment. Stands will not become established where the existing plant community is not sufficiently open to allow introduction of seeded species. Seeding operations must also give some competitive advantage, by seed placement in a favorable position in the soil or by earlier placement, to provide a time advantage against early germinating seeds.

Range fertilization is most efficient if applied when environmental conditions are most favorable for plant development. In the fall, when seedlings are just developing, root growth and top growth must proceed at a rapid rate in order to develop an adequate root system and sufficient top growth to withstand the cool winter ahead. In the spring, when precipitation and moisture

are again favorable and plants are in the rosette stage, favorable nutrition will aid rapid development towards maturity.

Fire may be used as a management tool during seed development and at the mature plant stage. The mature plant stage is not really a stage of growth but of existence in which the fire reduces dry litter and concentrates the surviving seed at the soil surface. The desired result is not to stimulate plant growth but to reduce undesirable species growth. Herbicides may be applied to reduce or eliminate seed formation of undesirable species, to retain plants in a given stage of development or to restrict other species from competing in the early seedling establishment phase.

In the following sections these management practices are described as they work specifically on developmental stages of annual range species.

Comparative Phenology

In dense populations of annual forb and grass seedlings, rapid growth results in a high demand for light, moisture, nutrients and other environmental factors (*9*). Plant survival under such circumstances will be attained only by seedlings of high vigor, or by those with different rates of morphogenesis which allows them to avoid the stress period by earlier or later development. In reporting the characteristic growth curve for the annual type, Ratliff and Heady (*47*) reported that the period of most rapid growth extended from March 28 to April 24. In 1960, growth of *Erodium botrys* and *Medicago hispida* Gaertn. was earliest, followed by *Avena barbata* Brot., *Bromus rigidus* Roth, and *Bromus mollis*, with *Lolium multiflorum* Lam. being latest. The progression of plants towards maturity reached a static period of maximum herbage weight at the time of seed development. *Medicago hispida* was an exception, in that the maximum period extended from the onset of flowering to the time of leaf shatter. After the peak of maturity, plants began to lose weight as seeds were cast, but ryegrass lost its weight only half as fast as the other species.

Species with delayed maturity often present opportunities for applying management practices. Tarweed (*Hemizonia* spp.), a summer-maturing, noxious plant, can be controlled simply by range fertilization which stimulates the growth of earlier maturing species and thus depletes the supply of soil moisture available for tarweed summer growth (*65*). *Lotus purshianus* (Benth.) Clements & Clements and *Taeniatherum asperum* (Sim.) Nevski also have late growth habit and depend on the soil moisture remaining after other range species have matured (*39, 40*).

Bromus tectorum L. is normally a winter annual, germinating in the fall when rain is sufficient and growing rapidly until cold temperatures set in, but it may act as a spring annual if there is too little fall moisture available for germination. Hulbert (*16*) noted striking variation in the phenology of plants grown at Lewiston, Idaho, from seeds obtained from several geographic locations. There was a range of about 25 days in the time of emergence of the inflorescences, and about 20 days in the time when plants turn completely brown. These ranges in dates of maturity are in striking contrast with the phenological development of the perennial grasses with which cheatgrass is a competitor in the northern Great Basin.

The implications of differences in phenological development for grazing management systems are not exactly clear. Much more knowledge is needed about the physiological status of plants in relation to morphogenesis before improved techniques, such as hormone sprays and herbicides, can be used to condition plant development.

Germination

The seemingly simple process of seed germination initiates a long series of morphogenetic changes that ultimately lead to a mature plant and reproduction of the species once again. The annual habit allows a rapid turnover of the gene pool and the annual exposure of all possible genetic combinations to environmental stresses, thus eliminating the unfit individuals from the population. Perhaps this is why annual species are so highly adaptable and vigorous; it is simply a matter of selection for such habitats.

Favorable temperature and moisture are essential for successful development of the seedling during the first critical stages of growth. Numerous management practices can be used to stimulate, retard, or eliminate plant growth during germination and seedling establishment.

A high degree of priority exists for seedlings

with a rapid growth rate during the early stages. Variability in speed of germination exists among widely differing geographic collections of *Taeniatherum asperum* seeds in the United States (*41*). Collections from areas with a higher degree of uncertainty in the first rainfall appeared to germinate at a more rapid pace than did seeds from more mesic sites in the coastal region of Oregon.

Whalley and others (*58*) showed that increasing soil fertility increased seed size and rate of germination. Soil moisture stress during seed production reduced the number of seeds, but seed quality apparently was not materially affected. Inasmuch as seed size apparently is a critical factor in promoting greater seedling vigor (*57*), any management practice which would result in improving seed size should have a correspondingly beneficial affect on seedling vigor and establishment.

Rapid mobilization of food reserves in the seed to soluble forms has been postulated as a possible index to seedling vigor (*56*). Species known for low seedling vigor apparently were slower in the mobilization of food reserves than was a species known for its higher degree of seedling vigor (fig. 1). Seed size in itself does not appear to be a sole criterion of seedling vigor but is meaningful only within a species or closely related group. Rapidity of carbohydrate mobilization varies among species. However, one of the most rapid mobilizations reported in the literature is that of *Schismus arabicus* (Nees.) (*57*). In this extremely small-seeded annual grass, mobilization of stored carbohydrate was almost complete within a 48-hour period.

Seedcoat hardness or impermeability often retards germination. This problem, however, is less common among grasses than among dicotyledonous species, particularly the annual legumes. The hard seedcoat may have an ecological advantage. Williams (*61*) demonstrated that hard seeds of *Trifolium hirtum* All. provided sufficient seed for survival of the species, when the seedlings which germinated first were eliminated by drought, following the originally favorable conditions for germination. The remaining hard

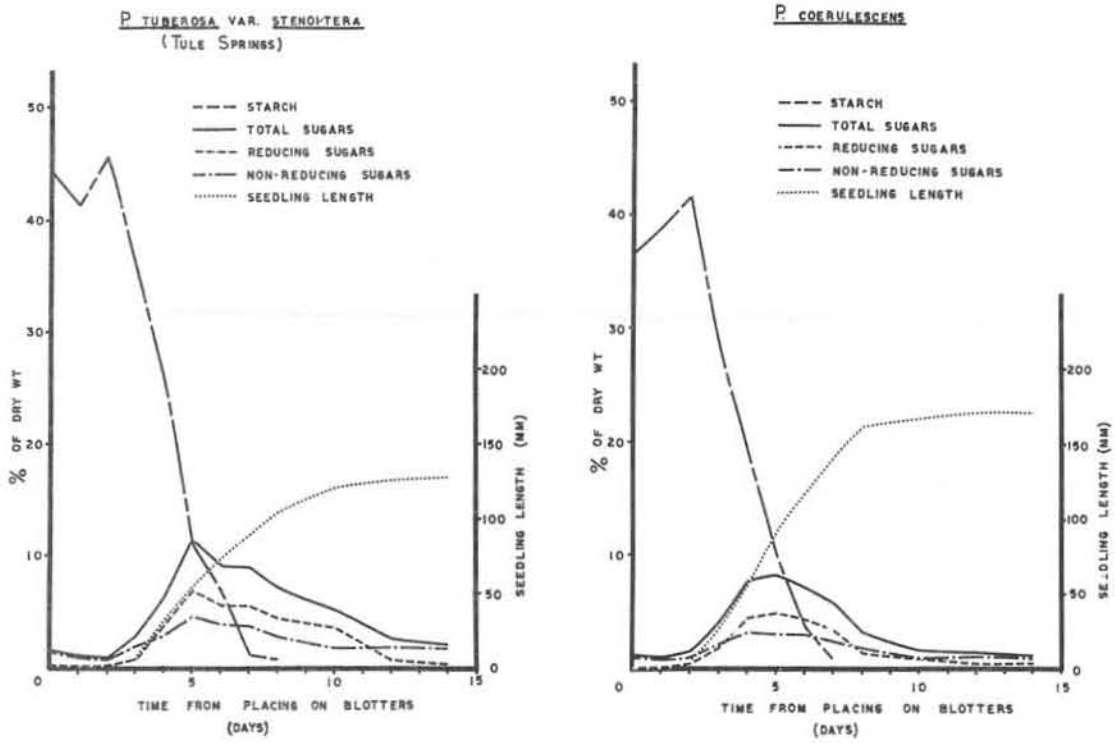

FIGURE 1.—Mobilization of carbohydrate reserves in early seed germination. (Whalley and McKell, (*58*).)

seeds in the litter provided a sufficient reserve for a second wave of germination. Seed dormancies of from 50 to 80 percent were regarded as a valuable mechanism for survival of the species.

In general, germination is reduced with increasing age of seeds. Older seeds often produce malformed seedlings, some without the appearance of a root or radical. Removal of a portion of the seed awn of *T. asperum* (*45*) appeared to increase germination of older seeds, however.

Williams (*59*) evaluated the emergence force exerted by small legumes. On the basis of differences in the force exerted, he concluded that the seedling size was not always a reliable index as to the force that the seedling was capable of exerting. In heavy soils, choosing the species with the ability to emerge under difficult conditions would be a wise management decision for seeding depleted annual rangelands. Grass species differ significantly in their ability to emerge from different planting depths. The data in table 2 show that *T. asperum* has a limited ability to emerge from soil depths greater than 2 inches.

Emergence of seedlings is often taken as an indication that establishment has fully occurred. This may be a reasonable criteria for the germination laboratory or in a humid environment, but under annual range conditions, establishment is not secure at this point. The number of plants early in the growing season has been reported (*11*) to vary from 20 to nearly 100 per square inch. Considerable reduction in this number takes place as the season progresses. In a review of seedling vigor, McKell (*36*) stated that establishment may not be fully assured until a grand rate of plant growth has been demonstrated (fig. 2).

Fertilizer may be applied in the area immediately adjacent to grass seedlings (*53*). However, *Lolium multiflorum* seedlings supplied with extra nitrogen (*1*) failed to grow roots and tops as fast as seedlings receiving no additional nitrogen. The ability to utilize nitrogen efficiently must develop later, because older *Lolium* seedlings are known to be highly efficient users of fertilizer nitrogen.

TABLE 2.—*Seedling emergence from 1-, 2-, 3-, and 4-inch planting depths. Each figure is an average of 15 observations*

Species	Number of seedlings emerging from depth of			
	1 in.	2 in.	3 in.	4 in.
Trifolium hirtum	160	91	22	1
Bromus mollis	259	42	1	0
Taeniatherum asperum	287	32	0	0

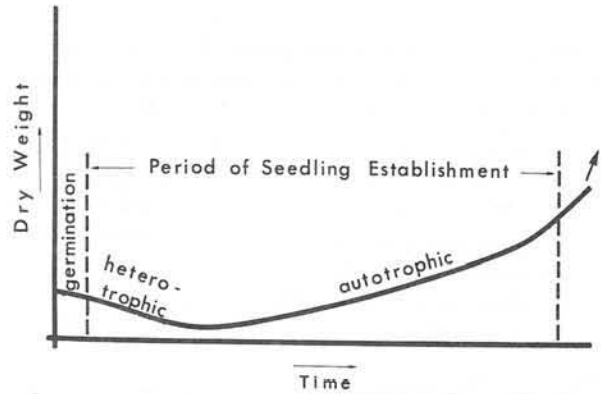

FIGURE 2.—Period of seedling establishment in relation to succeeding stages of plant growth. (After McKell, *37*.)

Artificial Seeding

The management of annual rangelands often requires that improved species be introduced to the plant community. The choice of adapted annual grasses and legumes is extremely important and has received considerable study over the past several years. Good management usually includes drill seeding, fertilization, reduction of competition by grazing management, proper depth of planting, and follow-up grazing management to assure favorable conditions for seedling establishment.

In *Bromus tectorum* areas, concern has been expressed that sites formerly dominated by perennial range grasses are almost impossible to reclaim to perennial grasses because of the intense competition offered by *B. tectorum*. Otherwise, grazing management of the existing stand of annual grasses appears to be the only solution available at the present time. Recent work by USDA's Agricultural Research Service rangeland scientists in Nevada and Washington appear to provide some answers for establishing perennial grasses in the areas dominated by *Bromus*

tectorum (*7*). These studies show that the competition for soil moisture by cheatgrass growing with *Agropyron* spp. is intense.

Herbicides have been used to manipulate plant competition during the seedling stage. Kay and McKell (*24*) used preemergence herbicides to control competing annual range species, and favor the establishment of *Trifolium hirtum* and *Phalaris tuberosa* L. var. *stenoptera* (Hack.) Hitch. Before weather conditions became favorable for seeding, an experimental area was burned to remove old litter and concentrate seeds at the soil surface. Subsequently, preemergence herbicides were applied to the surface. Two months later, after favorable moisture conditions occurred, the experimental plots were seeded with the introduced species. Competition from annual weeds was sufficiently controlled to allow successful stand establishment of the introduced species. Chemical treatments which were most effective included atrazine, simazine, and EPTC at rates from 2 to 4 pounds per acre. Subsequent refinements of the original techniques have resulted in considerable success. Kay [2] applies a 12-inch band of paraquat, then seeds introduced species below it. The seeds are protected by the soil from the effect of the chemical, which destroys the young annual grasses and forbs on the surface.

Root Growth

Rapid root growth is fundamental to establishment and development in annual rangeland communities, particularly when moisture stress is a constant threat during the period of plant establishment. Species may acquire a competitive advantage under stress conditions by (a) a faster rate of root growth, or (b) the ability to remain active in both root and top growth for a longer period. This extra growth is most important at a time when competing plants are inactive, or at the end of the growing period. Harris and Wilson (*10*) reported that rapidly elongating *B. tectorum* and *T. asperum* roots penetrated the soil ahead of *Agropyron spicatum* (Pursh) Scribn. & Smith, because they were able to continue root growth at low temperatures. Field studies indicated that *B. tectorum* roots grew well at temperatures as low as 3° C, while *A. spicatum* roots grew very slowly at temperatures below 8° to 10°. Therefore, *B. tectorum* seedlings are able to gain a competitive advantage over seedlings of *A. spicatum* by rapidly elongating their roots during winter months and using moisture through a large portion of the soil profile.

Any management practices which influence root growth are extremely important as tools in manipulating the annual plant forage resource. Fertilization has been shown to increase the overall abundance of roots in the areas normally occupied by roots of annual range species, although rooting depth was not changed much (*39*).

Grazing management also has a significant effect on root growth. Numerous studies (*19*, *20*) have shown that intense grazing decreases root growth. In general, plants which are grazed excessively will have a much shallower root system than will plants which are grazed conservatively or not at all (*31*). This favors greater root development and greater seed production of less palatable species, and of late-growing weedy species, such as tarweed and other noxious annual forbs.

Grazing management may also be used as a means of balancing competition during the establishment phase of annual and perennial seeded species. Love (*32*) recommends a moderate amount of grazing during the early spring period, when plant competition is extreme. If competition is not reduced, growth of seeded species is retarded.

Top Growth

In the developing annual seedling, expansion of leaf blades proceeds at a rapid pace. With the development of tillers upon tillers, the increase in diameter of the grass plant can be rapid; this increase may begin in the late fall and proceed into the early spring period of growth. Under extremely crowded conditions, tillers do not form, and only single stemmed grass plants result. Competition with other species is critical to the development and survival of annual range species at this point. With sufficient space, most species begin to expand the diameter of the plant. Under very dense crowding, little if any expansion takes place, and grasses continue to grow with a single upright rolled leaf sheath

[2] Personal communication, 1971.

and blade. Broadleaved species, such as *Erodium* and the annual legumes, also show the effects of crowding in the early seedling stage. Knight and Hollowell (*27*) pointed out that stand density has a marked effect on the number of vegetative stems, and later on the number of seed heads, produced by *Trifolium incarnatum* L. *Erodium* plants tend to spread out and form a mat when surface area is available. This morphological characteristic may or may not be an advantage in competition with the annual grasses.

With the onset of cool weather and lower light intensities during the winter months, many of the annual range species will maintain themselves in a rosette stage, to continue through the less favorable growing conditions. Because of a temporary plateau of the growth curve at this point, it might be appropriate to refer to the typical annual range species as a winter biennial. However, because annuals do not continue their growth through the dry summer period they actually do complete their growth in the single season typical of annual plants.

Low temperatures often stimulate the axillary buds on stems to produce additional new tillers. Davis and Laude (*6*) found that the main culm produced more shoots and more heads than did later developing tillers. Reduced light intensity at the basal tissues of closely spaced shoots, and shading by screens, reduced tillering in the annual grass, *Bromus mollis*. This would correspond to the plant response seen in the field, under less favorable environmental conditions of winter. Competition for light among species of annual clovers was also found to be a critical matter in the morphology of the seedlings. Williams (*60*) found that leaf area and leaf position in the foliage canopy of *Trifolium hirtum*, *T. incarnatum*, and *T. subterraneum* Linn. was related to the size of the cotyledonary leaves. This advantage was later extended to larger unifoliate leaves and in the higher elevation of unifoliate and first trifoliate leaves.

Some species seem to influence or interfere with the growth of other species. *Lolium multiflorum* (*37*) in a mixture of species always had a detrimental effect on the growth of these species, particularly during the seedling stage. The implications of these findings are clear for the range manager who uses a seeding mixture containing the highly competitive *L. multiflorum*.

McCowan and Williams (*35*) found that *Erodium botrys*, grown with *Bromus mollis*, acquired a disproportionate share of available sulfur, because of its more rapid root extension. However, at high sulfur levels *Bromus* became increasingly competitive and, as its population density was increased, *Erodium* was virtually eliminated. Many studies (*2*, *13*, *22*, *23*, *63*, *64*) have shown that fertilizer stimulates plant growth, even during periods of cool temperatures. Fertilized plants appear to have an increase in cold tolerance. The amount of litter left remaining on the ground from the previous season may be useful as an insulating layer (*11*).

Species of annual legumes appear to have differing abilities to take up phosphorus from the soil. Apparently, introduced legumes have a higher potential for phosphorus uptake than some of the native species (*42*). Additionally, there appears to be an advantage in phosphorus uptake to offset the effects of low temperature. Other workers (*8*, *43*, *54*) have shown that application of fertilizers during the seedling stage will accelerate growth and provide for earlier range readiness than plants which have not been fertilized.

Rapid Vegetative Development

Upon emerging from the cool winter periods, plant morphogenesis begins dramatic changes. The significant morphogenetic changes are leaf sheath and blade elongation in grasses and stem and leaf growth in forbs. Root and top growth of plants begin a rapid rate of increase, and competition for nutrients, light, water, and space again becomes extremely critical. Only those species which have been able to develop an adequate leaf area and root system will be capable of survival and development in this more active period of growth (*3*).

Under some conditions, an earlier rate of readiness can be obtained through fertilization (*34*). Fertilization, through its effect on differential species response, also has a significant impact on species composition. Evans (*18*) reported differences in nitrogen uptake among three species of the annual grassland type. Combinations of grazing with fertilization have a significant im-

pact upon species composition. Jones and Evans (*21*) reported that the percentage of *Bromus mollis* in a resident annual range was increased by nitrogen fertilization for 2 or 3 years, but increased only in the first year on ungrazed plots. Walker and William (*54*) reported a nitrogen buildup in the soil by annual legumes which had been fertilized with sulfur. The nitrogen buildup increased grass production. Most of these species composition changes occurred as a result of interspecific competition, during seedling establishment stage and the initial stages of rapid growth at the end of winter.

Removal of plant tissue at the beginning or soon after the initiation of rapid plant development, by either clipping or grazing, reduces plant vigor and encourages less palatable and competitive species to predominate. However, if grazing is not excessive in the early stages, annual vegetation has a remarkable ability to sustain a high intensity of grazing and yet to continue its growth and proceed towards maturity. It is during this period of active growth that the annual range begins its period of highest productivity.

Stem Elongation

Under continued favorable environment, the meristematic regions at the base of each internode in the compact grass stem take on new activity. Formation of new cells and cell elongation are responsible for the relatively rapid growth of the culm in the grass plant.

Competition for space is extremely intensive at this stage. Some plants, by their greater vigor or by a leaf display pattern, may have the edge in competition with other species. Again, grazing and fertilization are most important during the stem elongation stage. Grazing may remove the immature inflorescences, which grow in the protection of the rolled sheath or in the boot. Some workers (*30*, *49*) pointed out that not all species react the same to herbage removal. *B. mollis* was found to continue tillering and heading much longer than *Festuca megalura* Nutt., when clipped in a like manner. If grazing were continued to the growth terminal stage of *F. megalura*, it would depress this species, yet would still permit tillering and abundant heading in *B. mollis*.

High levels of fertilization on annual range species stimulate active growth but also accelerate the use of soil moisture. In years of inadequate rainfall, fertilization may cause the utilization of available soil moisture before the plants mature a full crop of seeds (*38*). However, under other conditions, the more efficient utilization of soil moisture will leave none for summer growing weeds (*65*). Studies in the Sacramento Valley on fertilized range indicate a 300 percent increase in efficient use of soil moisture where plots were fertilized with 100 lb./acre of nitrogen and 88 lb./acre of phosphorus (*39*).

Clipping, as opposed to grazing for clearing an area, may alter species composition. Murphy, Jones, and Love (*44*) reported that clipping encourages the summer growing forbs. Clipping appears to increase the level of soil moisture remaining for species which develop late in the summer.

To preserve the high content of protein, phosphorus, and carbohydrate, Kay and Torell (*25*) suggest using a chemical preservative, such as paraquat (1,1′-dimethyl-4,4′-bipyridinum dichloride), to stop plant development and "cure" the standing forage for use by grazing animals. With greater emphasis on forage quality in the future, and where there is no need for the replenishment of seeds for stand reestablishment, the practice of chemical curing may offer advantages to land managers.

Boot Stage To Flowering

At this stage of morphogenesis, the inflorescence is ready to emerge from the rolled leaf sheath, and to continue development towards anthesis and seed maturity. In annual grasses this is a vulnerable stage, because plants are still palatable and the immature seed heads may be subjected to grazing. In annual forbs the problem is not so critical, because many of them do not have a determinant type of flowering, but produce flowers on lateral branches, sometimes throughout the spring period. *Erodium* and *Medicago hispida* are particularly well adapted in this regard; flowers appear very early and continue until very late. Some of the annual legumes, such as *T. incarnatum* and *T. hirtum*, have a determinant flowering pattern, and are more vulnerable to grazing during these late

stages. Only through the formation of lateral flower stems is this vulnerability rendered less critical. The high density of plants growing on annual range virtually assures adequate seed production in most years, if intense grazing does not destroy the developing inflorescences. However, the number of plants which survive to the flowering stage is drastically reduced from the number of plants which germinated at the beginning of the season.

In earlier growth stages, fertilization was valuable in encouraging plant growth, but at flowering there is little benefit from fertilization. In fact, it may be detrimental if it has hastened maturity by depleting the soil moisture supply.

Palatability often changes as flowering approaches. *T. asperum* becomes much less palatable at the boot stage (*33*). Many forbs, particularly the annual legumes, take on a degree of unpalatability at this stage. Silica and fiber contents increase, and many plants become much rougher and stiffer in character.

Seed Maturity

As seeds begin to develop, carbohydrates are translocated to the seed heads of grasses and forbs. Concurrently, maturation of other plant parts proceeds rapidly. Photosynthesis is exceeded by respiration in older plant parts, and lower leaves begin to die. In the annual range, soil moisture stress is a common and prevalent environmental condition and becomes an overriding effect in hastening plant maturity and seed ripening. Management of annual rangelands at this stage may concentrate on several practices designed to manipulate the plant cover or to make continued use of the forage resource.

Range fertilization increases plant palatability, which provides excellent opportunities for continued grazing of the dry herbage. Less palatable species, when fertilized, have been observed to be consumed readily by livestock (*43*). The forage produced by fertilization is high in protein and other nutrients for the grazing animal (*52*).

Seed maturity of undesirable species can be prevented with herbicides during the period of seed maturation (*9*). Aminotriazol has effectively prevented the development of seeds of *T. asperum*, a late-maturing species. Late-maturing, weedy species have been controlled by fire, which destroys their immature seeds after the desirable forage species have matured (*14*). During a critical period of 1 or 2 weeks, the early-maturing annual forage species are dry enough to furnish fuel to support a fire which will destroy the maturing crop of medusahead seeds (*41*). Burning after the maturity of medusahead seeds is considerably less effective, because the hard seeds have been cast from the heads and lost into the litter, where they are protected by the volume of plant material and are unaffected by the passing of a fire over the area. In addition, mature seeds are less susceptible to the effects of high temperature (*29*).

Seed Dissemination

Dissemination of seeds from annual range species occurs at various times following maturity, depending on weather conditions and the structure of particular species. Seeds may be cast individually, as in *Bromus tectorum*, *Bromus mollis*, *Taeniatherum asperum*, *Avena barbata*, and *Trifolium subterraneum;* or by dehiscence of entire seed heads of *Aegilops triuncialis* L.

Seeds of annual species often have undesirable characteristics, such as spines, stout barbed awns, or coiled seed stalks, which catch in the fleece of sheep and reduce its value. These structures for attachment may provide an effective means of dissemination and even a means of transport and invasion to new range areas.

Management practices that may affect seed dissemination include removal of grazing animals (*Erodium* areas) before seed dissemination, restriction of livestock to weed-free areas, and burning. Some are ineffective; burning may actually scarify seeds, reduce litter cover and improve conditions for seedling establishment. Removal of livestock may not be realistic unless alternate feed sources are available.

Summary

Management of annual rangelands has gradually developed on a foundation of established biological principles. For example, we utilize information on nutritional requirements and phenology of plants as a basis for management decisions.

Much remains to be done to utilize existing knowledge in improving management practices. Because of their diversity, biological plasticity, and aggressive growth habits, annual species offer interesting opportunities for forage production. More information is needed on responses to manipulation by grazing and fertilization and on ways to manipulate competition during seedling establishment.

Annual forage plants have not always received the credit due them because of preconceived ideas embodied in range management practices that are based on climax concepts. Annuals are generally regarded as invaders (indeed most are) and they are listed as prime indicators of depleted or poor range conditions (which very well can be true in many cases). However, in some areas, annuals represent a tremendous grazing resource where they are relatively stable from year to year. Annuals often keep the community closed and make the most of the potential of favorable weather conditions.

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