Germination Characteristics of Range Legumes[1]

JAMES A. YOUNG, RAYMOND A. EVANS, AND BURGESS L. KAY

Range Scientists, Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture, Reno, Nevada; and Associate Specialist, Department of Agronomy, University of California, Davis.

Highlight

The germination of seeds of 19 legumes planted in range seeding exhibited considerable variability in initiation and total germination in relation to constant and alternating temperatures (0.5 to 30 C) and germination at 15 C and osmotic pressures of 0 to 16 bars. The rate of elongation of juvenile seedlings of most of the legumes was at a competitive disadvantage with weedy annual grasses.

A highly successful range improvement practice in cismontane California and western Oregon is the seeding of annual clovers to provide an abundance of nutritious forage during the spring and higher-quality dry forage during the summer and fall (Williams et al., 1957). These introduced legumes, of Mediterranean origin, represent a desirable counterpart to the many undesirable annual weeds which have colonized rangelands in the western hemisphere and Australia (Morley and Katznelson, 1965). In their native habitats, many of the clovers and the weeds were never abundant or dominant, but the inherent characteristics of the weedy species permit them to exploit heavily grazed rangelands and come to dominate millions of acres. The inherent characteristics of the legumes, on the other hand, are used by land managers in an attempt to cope with the severe competition from resident weedy annual grasses and forbs (Kay and McKell, 1963; Kay, 1964, 1968). The germination of a number of weedy annual grasses of rangelands in relation to temperature and osmotic stress was reported by Young et al. (1968a, b). The present investigation was made to provide comparable information on the germination of legumes to guide practices in range weed control and improved seeding and management.

Methods

The selections investigated were subclover (*Trifolium subterraneum* subsp. *subterranneum* L. var. Tallarook, Mt. Barker, Bacchus Marsh, Woogenellup, Dinninup, Dwalganup, and Geraldton; subsp. *brachycalycinum* Katznelson and Morley var. Clare; subsp. *yamminicum* Katznelson and Morley, var. Yarloop); rose clover (*T. hirtum* All. var. Wilton, Kondinin Hykon, and Sirint); cup clover (*T. cherleri* L. var. Beenong); bur clover (*Medicago hispida* Gaertn.); barrel medic (*M. lupulina* L. var. Cyprus and 173); alfalfa (*M. sativa* L. var. Rambler); woollypod vetch (*Vicia dasycarpa* Ten. var. Lana); milkvetch (*Astragalus cicer* L. var. Cicer), and sainfoin (*Onobrychis viciaefolia* Scop. var. Onar). Species means and groups of species were compared, rather than individual varieties.

Four replications of 25 seeds of each selections were placed on germination pads in 1-cm-deep petri dishes and kept moist with tap water containing 0.1% by volume 2,6-dichloro-4-nitroaniline. Each legume selection was tested in continuous darkness at 0.5, 5, 10, 15, 20, or 30 C. Germinated seeds were counted at 7-day intervals through 28 days.

Selections of subterranean clover, cup clover, woolypod vetch, and sainfoin were germinated in continuous darkness at alternating temperatures of 16 hr at –20 C and 8 hr at 0.5, 5, 10, 15, or 20 C. After 14 days these seeds were switched to a constant 20 C treatment for 28 days. Seeds of the same legumes were also incubated at a constant –20 C. Aqueous solutions having osmotic pressures[2] of 0, 4, 6, 8, 12, and 16 bars were prepared by dissolving, respectively, 11.8, 15.4, 18.0, 22.5, and 25.8 g of polyethylene glycol 1540 in 100 ml of distilled water, a procedure developed by Parmer & Moore (1966) and modified by Young et al. (1968b). Osmotic pressures of solutions were checked with a vapor-pressure osmometer, and concentrations were adjusted to within 0.1 bar. Four replications of 25 seeds of each legume selection were placed in plastic boxes with 5 g of ground polystyrene plastic and 50 ml of polyethylene glycol solution and germination tests were conducted in darkness at 15 C for 14 days. Seedling length was recorded as an indication of juvenile seedling vigor.

Results

Germination in Relation to Constant Temperatures.

Environmental conditions that permit germination are often of short duration on rangelands. An inherent facility for rapid germination at a wide range of temperatures should be of advantage in establishing a legume on rangelands. The subterranean clovers, alfalfa, and cup clover germinated in 7 days at all temperatures from 0.5 through 30 C (Fig. 1). The rose clovers and medics required at least 5 C for germination in 7 days. Germination of all the legumes was depressed markedly at 30 C, though the rose clovers and cup clover retained some germinability. The woolypod vetch and sainfoin selections tested germinated in 7 days only within a restricted range of temperatures; and cicer milkvetch selections did not germinate in 7 days at any temperature.

Total germination.—Total germination is difficult to establish for legumes that have a high percentage of hard seeds, such as cicer milkvetch and rose clover. Even so, the percentage germination of such legumes at 28 days of incubation generally followed the trends among selections incubated 7 days (Fig. 1 and Table 1). A notable exception were the sainfoin selections, whose germination pattern in relation to temperature was not the same at 28 days as at 7 days. No legume had a marked difference in

[1] Received February 2, 1969; accepted for publication April 28, 1969. Cooperative investigation of the Crops Research Division, Agricultural Research Service, U.S. Department of Agriculture, and the Agricultural Experiment Station, University of Nevada, Reno, Nevada. Journal Series No. 95.

[2] In this study, osmotic pressure is assumed to be equivalent in effect to matric suction or soil-water tension. One bar equals 1 atm within 1%.

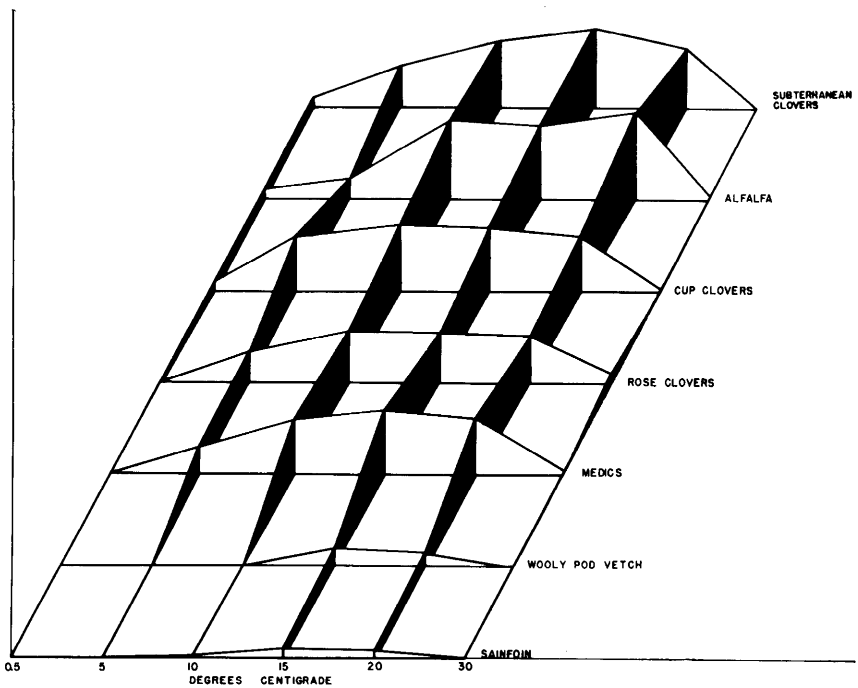

FIG. 1. Germination of legumes incubated for 7 days at 0.5 to 30 C.

Table 1. Percentage germination of legumes in relation to constant temperatures (28 day incubation period).[a]

Legumes	Selections	0–.5 C		5 C		10 C		15 C		20 C		30 C
Subterranean clovers	9	28b	w	59ab	v	71b	u	76ab	u	59ab	v	1x
Medics	3	5c	w	54b	uv	66b	u	63c	u	54b	uv	4w
Alfalfa	1	5c	w	68a	v	81a	u	83a	u	73a	uv	5w
Rose clovers	4	8c	v	54b	u	55c	u	55cd	u	51b	u	12v
Cup clovers	1	51a	v	70a	u	65b	u	61c	u	60ab	uv	2w
Woollypod vetch	1	20b	x	50b	w	67b	v	81a	u	61ab	vw	5y
Sainfoin	1	50a	vw	61ab	uv	70b	u	41e	w	29c	x	0y
Cicer milkvetch	2	0c	v	0c	v	3d	v	13f	v	20c	uv	1v
Mean		21v		52u		60u		59u		58u		4w

[a] Means are compared within and among temperatures. Means followed by the same letters (a through e) in vertical sequence or by the same letters (u through w) in horizontal sequence are not significantly different at the .01 probability as determined by Duncan's Range Test.

total germination between 5 and 20 C (Table 1). However, germination at 0.5 and 30 C was considerably lower.

Sainfoin seeds are normally covered with a pod whose presence markedly affects the rate of germination (Fig. 2). The pod greatly retarded germination at the lower incubation temperatures. Total germination at 28 days of incubation was essentially equal between selections with or without pods.

Variability within species.—A number of selections of subterranean and rose clover were investigated. The variability in germination in response to temperature of each species is compared by superimposing the means and standard deviations of both species in the same diagram (Fig. 3). At 28 days of incubation, little variability was shown at the extreme temperatures (0.5 and 30 C). The subterranean clovers exceeded the rose clovers in total germination by one standard deviation range at 0.5 C, whereas the reverse was true at 30 C. From 5 through 20 C, the selections of both species expressed a great deal of overlapping variability.

Germination in Relation to Alternating Temperatures.

Four of the legumes tested—subterranean clovers, cup clover, woolypod vetch, and sainfoin—produced considerable germination when incubated at 0.5 C for 7 days through 28 days. Selections of the four legumes that germinated appreciably at 0.5 C failed to germinate under an alternating cycle with 16 hr of –20 C. The higher the temperature of the 8-hr portion of the alternating cycle, the lower and more erratic was the germination when these seeds were switched to a constant 20 C.

Germination in Relation to Osmotic Stress.

The legumes tested, except for the rose clovers and alfalfa, showed no

Table 2. Percentage germination of subterranean clovers, cup clovers, woolypod vetch, and sainfoin after pretreatment with temperatures alternating with –20 C and constant –20 C incubation followed by 28 days at 20 C.

Species	Pretreatment of 14 days incubation at alternating temperatures					Pretreatment constant –20 C
	8 hr 20 C / 16 hr –20 C	8 hr 15 C / 16 hr –20 C	8 hr 10 C / 16 hr –20 C	8 hr 5 C / 16 hr –20 C	8 hr 0.5 C / 16 hr –20 C	
Subterranean clovers	4	3	7	9	35	61
Cup clovers	7	1	9	13	41	57
Woolypod vetch	0	1	0	1	16	64
Sainfoin	0	0	0	0	3	32

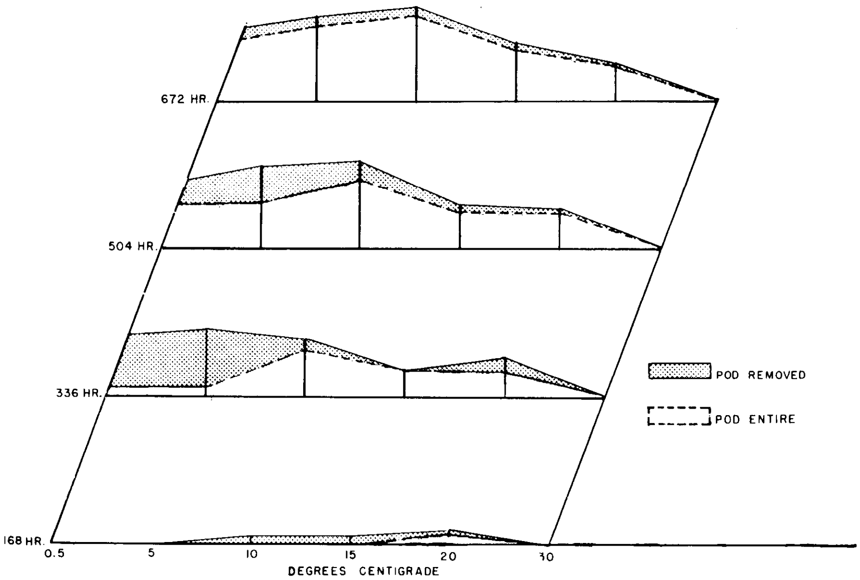

FIG. 2. Germination response of sainfoin seeds to pod presence in relation to incubation time and temperature.

marked differences in germination from 0 through 6 bars of osmotic stress. From 8 to 12 bars, however, percentage germination fell sharply, terminating at 16 bars. Seeds of many selections appeared to imbibe moisture at 16 bars of osmotic stress, but no roots or shoots emerged within the 14-day incubation period. There was still considerable germination of subterranean clovers, cup clover, and sainfoin selections at 8 and 12 bars of osmotic stress.

At 0 bars of osmotic stress, total percentage germination was lower than with the petri dish method with all selections except cicer milkvetch, which doubled. The environment of the closed boxes and the matrix of polystyrene plastic apparently was not as favorable for germination as the petri dishes and moist blotter-paper technique. However, the plastic-box method did not selectively depress germination among legumes except cicer milkvetch.

Elongation.—The seedlings of all legumes tested except woolypod vetch had a very low rate of root and shoot elongation for 14 days of incubation, in comparison with elongation figures given by Young et al. (1968b) for the weedy annual grass medusahead (*Taeniatherum asperum* (Sim.) Nevski) (Fig. 4). Woolypod vetch compares favorably with medusahead in juvenile root and shoot elongation at low osmotic stress, and exceeds medusahead at moderate to high osmotic stress.

Discussion

It is difficult to apply the classical concept of cardinal temperatures to the germination and establishment of legumes on arid rangelands. Arid rangelands in temperate portions of the world that receive winter precipitation and summer drought usually have two periods when environmental conditions permit germination.

The first germination period begins in the autumn, following sufficient precipitation to bring soil moisture within the requirements of the individual species. In cismontane California, this is in the period October through December. Environmental conditions, particularly temperature and moisture at the time of germination, largely determine which plant species will be dominant in this annual community during the ensuing growing season. Early seasons (i.e. warmer germination period) are generally referred to as "clover years," while late initial rains result in a cold germination period and a "poor clover year"—conversely, a good grass year. Any germination in the spring will bring plants into a closed community, with little likelihood of becoming established.

In transmontane California and Nevada, precipitation may not become sufficient until temperatures are too low to permit germination, or a germination period may begin for weedy grasses such as downy brome (*Bromus tectorum* L.) in late summer following thunder showers (Piemeisel, 1938). Fall germination of downy brome in Ne-

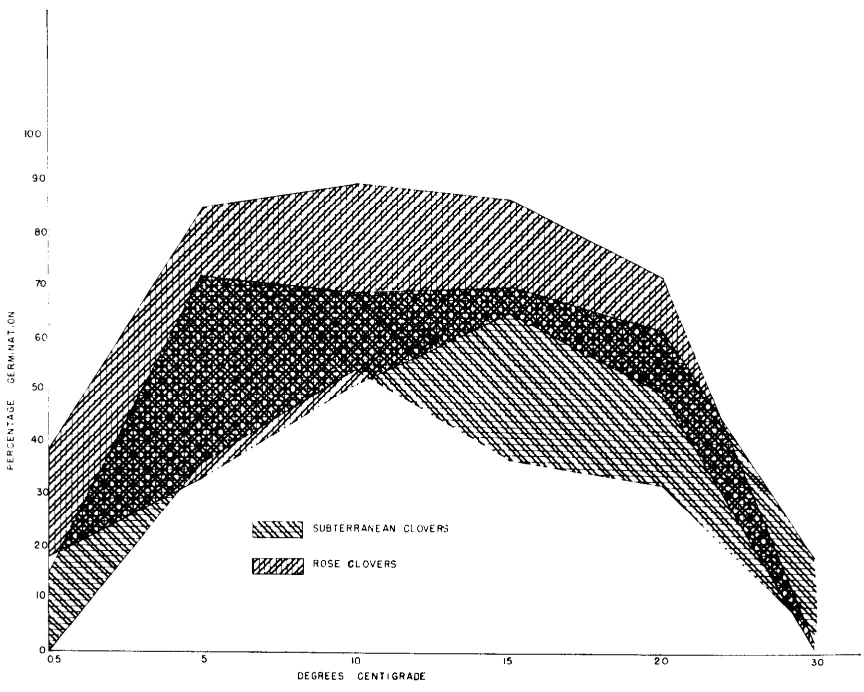

FIG. 3. Percentage germination means and one standard deviation ranges of subterranean and rose clovers, superimposed, in relation to temperature.

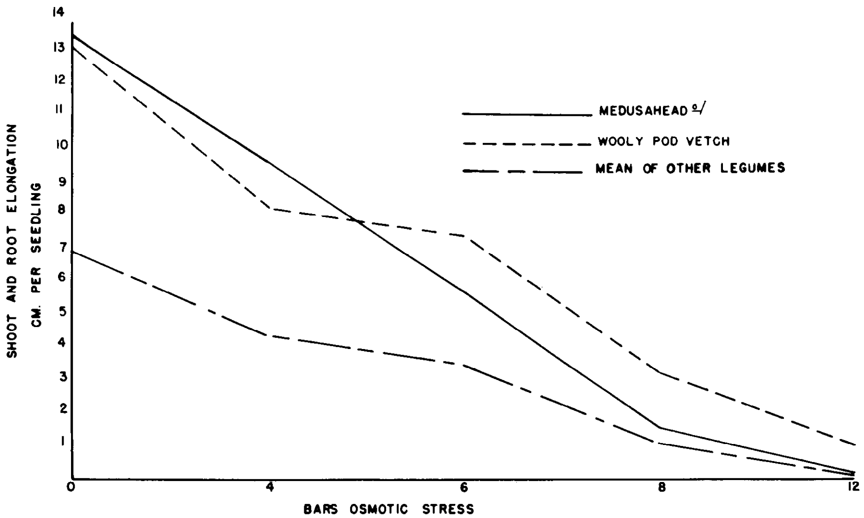

FIG. 4. Mean shoot and root elongation of woolypod vetch, medusahead, and all other legumes tested in relation to osmotic stress. ([a] Data for medusahead elongation in relation to osmotic stress from Young et al. (1968b).)

vada occurs in 1 out of 5 years.[3] For species with an after-ripening requirement, such as medusahead, the requirement must be satisfied before fall germination (Young, 1968a). The fall germination period is followed by a winter period of cold and moisture stress. Seedbed environmental conditions during the winter months do not permit germination; but studies by Young et al. (1968c) have shown that overwintering in the seedbed can have a dramatic effect on germination characteristics.

The second germination period begins in early spring, when soil moisture conditions are ideal but seedbed temperatures are very low, especially at night. As seedbed temperatures rise to the optimum for germination of desirable forage species, soil moisture is depleted by resident weedy species. The soil moisture regime may be temporarily recharged by spring precipitation, but seeded species must have enough time to become well established if they are to withstand the long summer drought. Ellern and Tadmor (1966) characterized an ideal plant for establishment on arid rangelands as one with inherent ability to germinate and develop rapidly at low temperatures, so as to withstand an early change to a hot dry climate.

The subterranean clovers, cup clover, woolypod vetch, and sainfoin selections tested showed a remarkable rate and amount of germination at 5 and 0.5 C. The rate of germination at very low temperatures greatly exceeded the inherent capabilities of most desirable or weedy range grasses (Ellern and Tadmor, 1967; Young et al., 1968a). These legumes appear to be highly adaptable to germination in late fall and early spring in cold seedbeds of arid rangelands. Although subterranean clover is well adapted to annual ranges of California, it is very difficult to establish in years with below-average temperatures during the germination period.

The low rate of elongation of juvenile seedlings of most legumes may be a disadvantage in competition with weedy grasses. The legumes have the same relative reduction of elongation in relation to osmotic stress that is found in range grasses (Young et al., 1968b). Their rate of elongation at 0 bars of tension, however, is much less than that of many grasses, especially medusahead.

A notable exception among the legumes is woolypod vetch. This species compares favorably with medusahead in rate of juvenile seedling elongation in relation to osmotic stress, which helps explain why this legume is proposed as a smother crop for medusahead.

Information on seedbed temperature on rangelands is rather limited. In the semiarid Negev region of Israel, diurnal temperature fluctuations in the seedbed zone of shallow-seeded range plants normally reach an amplitude of 20 C on bright days and about 10 C during cloudy and rainy periods (Tadmor et al., 1964). In Nevada, the daily range of air temperature may be 30 to 40 C in extreme instances (U.S.D.A., 1941).

There is little possibility of selecting strains of legumes with increased capabilities for germination at very low temperatures. The reason is that variability in germination is greatly reduced with extreme incubation temperatures, as the subterranean and rose clover selections used in this investigation show. McGinnies (1960) and Ellern and Tadmor (1966) suggested physical modification of rangeland seedbeds to provide a temperature regime more favorable to the establishment of desirable species that cannot germinate at low temperatures.

Table 3. Percentage germination of legumes in relation to osmotic stress (14 days of incubation at 15 C).[a]

Species	Bars osmotic stress 0	4	6	8	12
Subterranean clovers	59ab	68a	59ab	50b	24c
Rose clovers	33a	27ab	21b	6c	0c
Alfalfa	75a	60a	25b	20b	0c
Cup clovers	55a	55a	60a	25b	11c
Medics	40a	37a	32a	15b	3c
Sainfoin[b]	39a	42a	36ab	27b	11c
Woolypod vetch	79a	74a	72a	54b	5c
Cicer milkvetch	25a	20a	19a	5b	0b
Mean	51a	48a	41a	25b	10c

[a] Means followed by the same letter are not significantly different at the .01 probability level as determined by Duncan's Range Test. All comparisons are made horizontally.
[b] Sainfoin selections with remnant of pod removed.

[3] Evans, R. A. and J. A. Young. 1968. Effects of plant litter on establishment of introduced annual species in big sagebrush communities. Meeting of Western Section of the Ecology Society of America, Logan, Utah.

Recent investigations by Evans et al. (1967) and Eckert and Evans (1967) indicated that furrowing or herbicide-furrowing combinations greatly enhanced wheatgrass seedling establishment on arid rangelands. These treatments may benefit legumes also. Kay (1966) described the use of paraquat to control resident annual vegetation during the establishment of seeded legumes, and pointed out that seeding into the old sod provided an improved environment for germinating seedlings. The mulch of dead vegetation helps retain moisture and reduces temperature variation and the hazard of frost heaving.

The seeds of a number of plant species have been shown to respond to temperature fluctuations, germinating better (sometimes only) at alternating temperatures (Morinage, 1926; Lehmann and Aichele, 1931; Stotzky and Cox, 1962). Ellern and Tadmor (1967) reported that alternating temperatures did not stimulate the germination of species (including alfalfa, burclover, and barrel medic) suitable for seeding semiarid rangelands. Alternation cycles with temperatures unfavorable for germination retarded germination more than would be expected from their relative influence on the weighted mean. In this investigation, alternation between temperatures favorable for germination and –20 C inhibited the germination of legumes whose seeds would have germinated at a constant 0.5 C. The germination of subterranean clovers, cup clover, woolypod vetch, and sainfoin at an optimum temperature was greatly reduced by pretreatment at alternating temperatures with an unfavorable alternate of –20 C. The higher the favorable temperature in the alternation cycle with –20 C, the greater the reduction in posttreatment germination at constant temperatures. Freezing of wet seeds at a constant –20 C for 28 days did not harm germination under incubation at a constant 20 C.

The germination of the legumes in relation to osmotic stress generally followed patterns reported by Uhvits (1946) for alfalfa germination in relation to osmotic stress induced by mannitol solutions. Using the same experimental procedure as in this investigation, Young et al. (1968b) reported similar germination responses for range grasses in relation to osmotic stress. Percentage germination of most of the grasses was higher at all levels of stress, however, the subclovers maintained considerable germination at 12 bars of osmotic stress, while the rose clovers ceased germination at 8 bars. McGinnies (1960) and Chippindale (1949) pointed out that species that germinate well under a high osmotic stress are not necessarily those that survive and reproduce under severe drought conditions. They cite examples where the reverse has been true. Repeated examples of this inverse relation suggest an inherent linkage in the physiologic systems of the contrasting species. Seeds with the ability to germinate under high osmotic stress may actually be less adaptable to an arid climate since they would be more likely to sprout and die under false starts engendered by early rainfall of low volume not followed by additional moisture in time to keep the seedling alive. Such sequences are found in cismontane California in freak summer storms and early fall rains.

This investigation made no measure of the after-ripening requirement of the various legumes, for none of the seeds were freshly harvested. The after-ripening requirements and other germination characteristics of individual varieties of the legumes are being investigated with seeds obtained from common gardens.

Literature Cited

Chippindale, H. G. 1949. Environment and germination in grass seed. J. British Grassland Soc. 4:57–61.

Eckert, R. E., Jr., and R. A. Evans. 1967. A chemical-fallow technique for control of downy brome and establishment of perennial grasses on rangeland. J. Range Manage. 20: 35–41.

Ellern, S. J., and N. H. Tadmor. 1966. Germination of range plant seeds at fixed temperatures. J. Range manage. 19:341–345.

Ellern, S. J., and N. H. Tadmor. 1967. Germination of range plant seeds at alternating temperatures. J. Range Manage. 20:72–77.

Evans, R. A., R. E. Eckert, Jr., and B. L. Kay. 1967. Wheatgrass establishment with paraquat and tillage on downy brome ranges. Weeds 15:50–55.

Kay, B. L. 1964. Paraquat for selective control of range weeds. Weeds 12:192–194.

Kay, B. L. 1966. Paraquat for range seeding without cultivation. California Agr. 20:2–4.

Kay, B. L. 1968. Effect of paraquat on yield and composition of a subclover-hardinggrass pasture. Weeds 16:66–68.

Kay, B. L., and C. M. McKell. 1963. Preemergence herbicides as an aid in seeding annual rangelands. Weeds 11:260–264.

Lehmann, E., and F. Aichele. 1931. Keimungsphysiologie der gräser (Gramineau). Ferdinand Enke Publ. Co. Stuttgart.

McGinnies, W. J. 1960. Effect of moisture stress and temperature on germination of six range grasses. Agron. J. 52:159–162.

Morinage, T. 1926. Effect of alternating temperatures upon the germination of seeds. Amer. J. Bot. 13:141–158.

Morley, F. H. W., and J. Katznelson. 1965. Colonization in Australia by *Trifolium subterraneum* L. In H. G. Baker and G. L. Stebbins (ed.), The genetics of colonizing species. Academic Press, New York. 562 p.

Parmer, M. T., and R. P. Moore. 1966. Effects of simulated drought by polyethylene glycol solutions on corn (*Zea mays* L.), germination and seedling development. Agron. J. 58: 391–392.

Piemeisel, R. L. 1938. Changes in weedy plant cover on cleared sagebrush land and their probable causes. U.S. Dep. Agr. Tech. Bull. No. 654.

Stotzky, G., and E. A. Cox. 1962. Seed germination studies in Musa: II. Alternating temperature requirement for the germination of *Musa babisiana*. Amer. J. Bot. 49:763–770.

Tadmor, N. H., D. Hillel, S. Dasberg, S. J. Ellern, and Y. Harpaz. 1964. Establishment and maintenance of seeded dryland range under semiarid conditions. Project A10-CR-45. Res. Rep. for period March, 1963—March, 1964. Submitted to U.S. Dep. Agr., Volcani Inst. Agr. Res. Rehovot.

Uhvits, R. 1946. Effects of osmotic pressure on water absorption and germination of alfalfa seed. Amer. J. Bot. 33:278–285.

U.S. Department of Agriculture. 1941. Climate and Man. Yearbook of Agriculture. U.S. Government Printing Office, Wash., D.C. 1248 p.

Williams, W. A., R. M. Love, and L. J. Berry. 1957. Production of range clovers. California Agr. Exp. Sta., Ext. Ser. Circ. 458. 19 p.

Young, J. A., R. A. Evans, and R. E. Eckert, Jr. 1969. Population dynamics of downy brome. Weed Sci. 17:20–26.

Young, J. A., R. A. Evans, and R. E. Eckert, Jr. 1968a. Germination of medusahead in response to temperature and afterripening. Weed Sci. 16:92–95.

Young, J. A., R. A. Evans, R. O. Gifford, and R. E. Eckert, Jr. 1968b. Germination of medusahead in response to osmotic stress. Weed Sci. 16:364–368.