J. Range Manage.
46:21-25, January 1993

Annual medic establishment and the potential for stand persistence in southern Arizona

KEBE BRAHIM AND STEVEN E. SMITH

Authors are graduate research assistant and associate professor, Department of Plant Sciences, University of Arizona, Tucson 85721.

Abstract

Few perennial legumes have been successfully introduced into western North American rangelands receiving less than 250 mm annual precipitation. Winter annual legumes in the genus *Medicago* (medics) are native to arid sites in North Africa and the Middle East and have been successfully introduced into arid and semiarid rangelands. The objective of this study was to evaluate the potential of establishing medics in areas of the southwestern U.S. receiving between 100 and 200 mm winter precipitation (November–May). Five medic accessions from 4 species (*M. laciniata* (L.) Miller, *M. littoralis* Rhode ex Loix. Delong., *M. polymorpha* L., *M. truncatula* Gaertn.) that could avoid drought were identified in a preliminary screening nursery in 1987–88. These accessions established and produced seed in 1989–90 in a field plot at Tucson, Ariz., with 125 mm winter precipitation. Less than 5% of all seed produced by these accessions germinated following summer precipitation. Plant re-establishment in the winter 1990–91 (181 mm precipitation) from pods produced in 1989–90 was observed for only 1 accession (*M. truncatula* 'Cyprus'). New plant re-establishment and seed production was observed in 1990–91 for all 5 accessions from seed produced in 1989–90 with supplemental irrigation (300 mm) in addition to precipitation. Failure to observe comparable establishment from seed produced without irrigation was attributed to the scarcity of germinable (permeable) seeds in the soil seed bank. Rapid maturing medics that exhibit breakdown of hardseededness by autumn appear to be well adapted to southern Arizona sites receiving as little as 110 mm winter precipitation. If such introductions are to be successful, initial seeding rates in excess of 115 pure live seeds/m² may be necessary to develop a large soil seed bank.

Key Words: hardseededness, legumes, precipitation, *Medicago*, soil seed bank, winter annuals

In western North America, most attempts to introduce legumes on rangelands have utilized alfalfa (*Medicago sativa* L. and *M. falcata* L.) and other perennial forbs (Rumbaugh 1983, Berdahl et al. 1986). Once introduced, these species have generally persisted only in areas receiving more than 250 mm annual precipitation (Rumbaugh 1982). There has been little success in identifying legumes able to establish and persist on more arid sites (Rumbaugh and Townsend 1985). Annual legumes may offer advantages in revegetation of arid rangelands where winter growth is possible. In addition to the N_2 fixation and forage quality attributes common to legumes, many annual legumes have characteristics that make them especially well adapted to arid environments. By growing when temperatures and evaporative rates are lower, water use efficiency may be higher than for warm-season species (Tadmor et al. 1972). Many annual legumes produce indehiscent fruits (pods) that break down slowly and prevent moisture from rapidly reaching the seeds (Small et al. 1991). This trait, along with hardseededness mechanisms, allows a proportion of a seed population to survive extended drought and promotes germination only when soil moisture is high enough to support seedling growth. Once germinated, annual legumes exhibit rapid vegetative growth and maturity, and extreme developmental plasticity. This increases the chances for seed production under conditions of erratic and low precipitation (Kemp 1989).

Winter annuals in the genus *Medicago,* commonly referred to as medics, occur naturally in portions of North Africa, southern Europe, and the Middle East with mild, rainy winters, and alkaline soils (Lesins and Lesins 1979). Medics typically germinate in late autumn with the onset of winter rains, grow vegetatively until early spring, and flower and produce seed as rainfall ceases in late spring. Weather-resistant pods and hardseededness allow natural re-establishment in succeeding years even if winter rains are insufficient in a season to permit seed production (Crawford et al. 1989). Medics provide high quality forage in many regions with Mediterranean climates and more than 300 mm winter precipitation. This includes approximately 50 million ha of land in Australia where self-reseeding medic pastures are used in crop rotations (Crawford et al. 1989). Certain medics are native to sites in North Africa receiving an average of less than 250 mm winter precipitation (Francis 1981) and may provide significant forage in these regions (Gintzburger 1986). Medics from these regions have also been successfully introduced into other arid grazing lands. Using soil pitting, accessions from a variety of medic species were established at 2 sites in Western Australia that received less than 100 mm of precipitation (Gintzburger 1987). Similar approaches have been used successfully in southern Australia (Campbell 1980). Local strains of *Medicago polymorpha* L. established and produced seed in 1 season with 78 mm precipitation at a site in Israel's Negev Desert (Tadmor et al. 1968). In a 9-year study, Tadmor et al. (1971) observed that medics established and persisted (re-established from the soil seed bank) at a site in Israel with average seasonal water application of 235 mm. In another long-term study using native stands, the annual legumes *Medicago polymorpha* and *Trigonella arabica* Delile established without water catchment only when precipitation exceeded about 210 mm (Tadmor et al. 1974).

In the desert and semidesert shrublands and grasslands of the southwestern U.S. and northern Mexico, between 35 and 60% of the annual precipitation (about 100 to 250 mm) generally occurs between November and May (here referred to as "winter" (Jordan 1981). Vegetation in much of this region has been severely altered by grazing, irrigated agriculture, and urbanization, and revegetation efforts have been numerous. Emphasis has been placed almost exclusively on perennial grasses and shrubs (Cox et al. 1982). While the native flora of this region contains many winter and summer annuals (Shreve and Wiggins 1964), the potential of intro-

Authors wish to thank Bruce A. Roundy for assistance in manuscript preparation.
Manuscript accepted 24 July 1992.

Table 1. **Total monthly precipitation (mm) and percent of 30-year mean monthly precipitation 500 m from the study site in Tucson, Arizona in the winter of 1989–90 (initial establishment), and summer of 1990, and winter of 1990–91 (re-establishment).**

		Winter season								Summer season					
Years		Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total	Jun.	Jul.	Aug.	Sep.	Oct.	Total
1989–90	(mm)	3.8	11.4	34.5	15.8	32.5	7.4	0.3	105.8	8.1	141.0	40.4	24.6	9.4	223.5
	(%)[1]	21	39	139	81	144	66	6	82	145	263	74	92	39	131
1990–91	(mm)	15.7	66.5	41.1	25.1	32.8	0	0.8	181.2	—	—	—	—	—	—
	(%)[1]	89	228	140	129	145	0	19	141						

[1]Percent of 30-year mean.

ducing exotic short-lived annuals into disturbed sites has not been investigated. Certain medics may be well adapted for this use given the similarity in winter temperature and precipitation regimes between areas where medics are native and low-elevation sites in the southwestern U.S. (Rudloff 1981). Early winter (November--December) precipitation is important for medic establishment since seedling growth is more rapid at the relatively higher temperatures in these months. In addition, seedlings that emerge with January or February precipitation may not be able to produce seed before spring drought (Crawford et al. 1989). Medics generally are not native in areas that receive significant summer precipitation. Summer rainfall, which is common in southern Airzona, may lead to the production of medic seedlings that are likely to be lost to desiccation before flowering, leading to depletion of the soil seed bank (Crawford et al. 1989).

The objective of this study was to evaluate the potential for establishing medics in rangelands or dryland pastures in the southwestern U.S. that receive between 100 and 200 mm precipitation between November and May in addition to summer precipitation. This involved: (1) selection of medic accessions preadapted to this arid environment; (2) evaluation of seedling establishment, growth and seed production in a field plot sown with nursery produced seed; and (3) assessment of plant re-establishment and seed production in the following seasons from the soil seed bank.

Materials and Methods

Medics able to establish in regions with less than 200 mm of winter precipitation would need to flower and rapidly produce viable seed to avoid spring drought. A screening nursery was established at Tucson, Ariz., in November 1987 to identify early flowering accessions that were able to produce seed under spring drought conditions. Rows 1 m long were sown with 50 pure live seeds (PLS) of 146 accessions from 20 *Medicago* species. Accessions were provided by the U.S. Regional Plant Introduction Station, Pullman, Wash., the South Australia Department of Agriculture Genetic Resource Centre, Adelaide, and by Walter Graves, University of California, Cooperative Extension, San Bernadino, Calif. The nursery was flood irrigated 4 times between 12 November and 17 March to insure establishment. Approximately 400 mm of water was applied in addition to 126 mm precipitation.

Five accessions from 4 species were selected from this nursery for use in an establishment and re-establishment trial under natural precipitation. Selection was based on: earliness of flowering, pod production, and apparent ability to tolerate drought as pods mature. Pods were collected from these accessions and seed removed. The 5 accessions were: (1) *M. littoralis* Rhode ex Lois. Delong. accession SA 21128, collected near Garian, Libya (Gorringe and Pullen 1984); (2) 'Cyprus', a cultivar of *M. truncatula* Gaertn. introduced into South Australia from Cyprus in the 1950s (Crawford et al. 1989); (3) Serena, a cultivar bred in South Australia using various sources of *M. polymorpha* (Crawford et al. 1989); (4) *M. laciniata* (L.) Miller accession PI 498891, collected in Lanzarote, Canary Islands; and (5) *M. laciniata* accession PI 498847 collected 145 km south of As-Salman, Iraq (Anon. 1985).

An establishment and re-establishment trial was conducted at the Campus Agriculture, Center, Tucson, Ariz., (elev. 757 m) from October 1989 through February 1991. Soil at the site is a Gila fine sandy loam (thermic torrifluvent) that was lightly tilled and free of vegetative residue. The effect of sowing a cool-season grass (Indian ricegrass, *Oryzopsis hymenoides* (R. & S.) Ricker. 'Nezpar') along with medics was also investigated in this study. Indian ricegrass established uniformly in all plots; however, the presence of grass did not have any significant ($P \leq 0.05$) effect on any aspect of medic performance. Therefore, all data reported are for plots sown with and without grass. The experimental design was a split-split-plot with 5 replicates. Two soil moisture treatments made up the main plot factor. Each of the moisture treatments was imposed within each replication. One main plot treatment received 300 mm of supplemental water from 15, 20-mm applications made with a hand-held sprinkler between 7 November and 9 April. The other moisture treatment received only precipitation. Presence or absence of Indian ricegrass represented the sub-plot factor, while the 5 medic accessions were the sub-sub-plot factor. Each sub-sub-plot contained 3 rows 0.75 m long.

Medic seeds were scarified using sandpaper and treated with commercial peat-base inoculant of *Rhizobium meliloti*. Seeds (43 PLS/row) of the 5 medic accessions (with or without 20 PLS of Indian ricegrass) were sown by hand on 29 October 1990 in each of the three 0.75-m rows in the plots (~ 115 PLS medics/m^2). Seeds were sown in the bottom of 4-cm deep furrows made at 0.5-m intervals and lightly covered to a depth of approximately 1 cm.

Individual live medic plants in each row were counted every 7 days beginning with the first emergence on 11 November 1989 until early June 1990. Date of first flower within each plot was also recorded. In June 1990, dry medic shoots from the outside 2 rows of each plot were cut at ground level and bagged. Pods from plants in these rows were collected separately. Pods in the central row were buried 2 to 5 cm deep to estimate re-establishment. Shoots and pods from each plot were weighed after air drying and seed yield estimated based on mean seed number and weight from a sample of 20 threshed pods. Pods harvested by 10 June 1990 were threshed and germination of unscarified seeds evaluated in a laboratory test. A total of 50 seeds for each accession source were tested in 2 replicates. The experiment was performed using sealed petri dishes containing water-saturated filter paper at 25 ± 1° C under 12 hours light and 12 hours darkness. Percent germination was recorded after 30 days.

Re-establishment from medic pods or seeds buried in the central row of each plow was evaluated under natural summer and winter precipitation in July and August 1990, and Februray 1991. Live medic seedlings in each row were counted at each date. Daily precipitation and temperature data were taken from a weather station located approximately 500 m from the field site.

Hardseededness and pod disintegration were evaluated by sowing whole pods of each of the medic accessions in 70 × 30 × 10 cm

Table 2. Seedling mortality, forage weight, and seed production of 5 medic accessions grown with 125 mm precipitation during the winter of 1989–90.

Medicago species	Accession	Premature seedling mortality[1]	Mature plants per row[2]	Dry wt mature plants[2]	Seeds per row	Seed yield[3]
		(%)	(no.)	(g row^{-1})	(no.)	(kg ha^{-1})
laciniata	PI 498891	53.5 A[4]	6.6 ± 1.1 B	3.4 ± 0.9 B	459 ± 139 C	15.9 C
laciniata	PI 498847	53.2 A	8.7 ± 1.2 B	11.1 ± 5.6 AB	1094 ± 562 A	52.5 B
littoralis	SA 21128	52.4 A	15.1 ± 3.4 A	20.6 ± 7.1 A	44.8 ± 141 B	29.9 B
truncatula	'Cyprus'	45.9 A	19.7 ± 1.3 A	16.4 ± 3.9 AB	461 ± 138 B	47.9 A
polymorpha	'Serena'	57.3 A	16.1 ± 2.3 A	8.0 ± 1.4 A	197 ± 42 C	20.5 B

[1]Seedlings that died before 1 May 1990.
[2]After all plants had dessicated, 1 May 1990.
[3]Based on seed yield on area of each row (0.5 × 0.75 m).
[4]Means within a column followed by the same letter are not significantly different ($P \leq 0.05$) using Duncan's Multiple Range Test.
Duncan's Multiple Range Test.

metal flats filled with soil from the field site. These flats were placed outside an area where they would receive all precipitation and experience natural temperatures. Each of 10 flats contained 20 pods of the 5 accessions grown in 1989–90 in plots with precipitation only or precipitation and supplementary irrigation. One flat was initially irrigated using a hand sprinkler 1 July 1990 and the soil was kept moist through Februry 1991. Every 15 days, irrigation was initiated in another flat until all flats were irrigated (13 November). Seedlings were counted in each flat on 8 and 18 August, 10 October, 6 and 18 November, and 2 and 29 December 1990 and 2 February 1991.

Results

Precipitation during the winter season (November–May) of 1989–90 was 82% of the 30-year mean for the site (Table 1). Precipitation greater than 5 mm was received on 8 days while amounts less than 5 mm were received on 17 days. Rainfall received during November and December was significantly below long-term averages for the site, with precipitation occurring on only 3 days. Seedling emergence was observed in all accessions following a 3.4 mm rainfall on 21 November (Fig. 1). January precipitation was above normal and maximum seedling populations were observed for all accessions in early February. Premature mortality (before pod maturity) due most likely to drought was first noted in late February (Fig. 1), averaged 52.5% of emerged seedlings, and did not differ among accessions (Table 2). Serena flowered first (13 February) followed by PI 498847, SA 21128, and Cyprus (16 February), and PI 498891 (2 March). The number of plants and weight of herbage harvested at maturity varied widely among accessions and was not closely associated with the number of seeds produced (Table 2).

Even though June and July precipitation was above average, (Table 1) only field-buried pods of accession SA 21128 that had been produced without supplementary irrigation showed substantial seedling emergence in the summer (Table 3). These seedlings all desiccated before flowering but this represented a loss of less than 5% of the seed produced by this accession, the balance remaining in the soil seed bank. Additional moisture during the year of seed production had a dramatic effect on seed production and germination in the following summer. The mean number of seeds produced with supplemental irrigation was over 3 times greater (mean ± SE: 1982 ± 418 seeds/row) than that produced with natural precipitation (532 ± 149 seeds/row). In 4 of the 5 accessions essentially all seeds produced with irrigation that were germinable by mid-summer did germinate by late-August (Table 3). Over 50% of the permeable seed of the fifth accession also germinated in the summer. Immediately after harvest there was no difference in germination between seeds from the 2 moisture treatments (mean % germination ± SE: 5.9 ± 2.0% in seed from plots receiving precipitation only vs. 6.0 ± 1.4% in seed from irrigated plots).

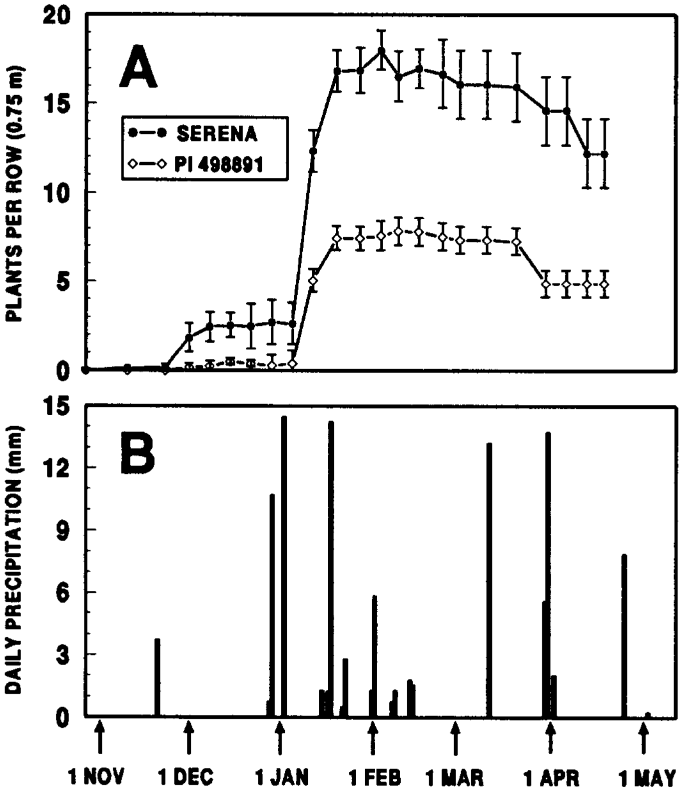

Fig. 1 Mean population of live plants (± SE) of *Medicago polymorpha* 'Serena' and *M. laciniata* PI 498891 with 125 mm precipitation at Tucson, Arizona between 29 October 1989 and 15 April 1990. These 2 accessions exhibited the highest and lowest maximum plant populations of the 5 accessions evaluated. Similar patterns of emergence and mortality were observed for other accessions. 1B. Daily precipitation recorded 500 m from the study site.

Mean seed weight did not differ between seeds from the 2 moisture treatments (2.68 ± 0.53 mg/seed with precipitation vs. 2.72 ± 0.69 mg/seed with irrigation). Supplemental moisture resulted in a slight increase in the mean number of seeds produced/pod (5.16 ± 1.01 irrigated vs. 3.82 ± 0.67 precipitation only).

During the winter season of 1990–91 precipitation was 141% of the long-term average (Table 1). Precipitation greater than 5 mm was received on 12 days while amounts less than 5 mm were received on 19 days. A total of 11 days in November and December received measurable precipitation. Nevertheless, only Cyprus seedlings emerged from buried pods in plots that had received only precipitation in 1989–90 (Table 3). As in the summer, seedling

Table 3. **Seed permiability and seed re-establishment during the Summer and Winter seasons of 1990–91 from medic pods produced in the Spring of 1990 with 125 mm precipitation only or precipitation plus 300 mm irrigation.**

		Seed produced in 0.75-m row with precipitation only				Seed produced in 0.75-m row with precipitation + irrigation				
		Summer (Jul.–Oct.)		Winter (Nov.–Feb.)		Summer (Jul.–Oct.)		Winter (Nov.–Feb.)		
Medicago species	Accession	No. seedlings		Permeable seeds[1]	No. seedlings	No. seedlings		Permeable seeds	No. seedlings	
		(% perm. seeds[1])	(% of all seeds)	(% of all seeds)	(% of perm. seeds)	(% perm. seeds)	(% of all seeds)	(% of all seeds)	(% perm. seeds)	(% of all seeds)
laciniata	PI 498891	2.3 ± 0.9		41.9 ± 15.2	0	14.8 ± 4.4		36.0 ± 19.2	6.5 ± 3.5	
		(23.2)	(0.5)	(9.1)		(>100)	(1.9)	(4.7)	(8.1)	(0.9)
laciniata	PI 498847	1.9 ± 0.9		50.6 ± 25.1	0	10.3 ± 3.0		93.6 ± 28.1	10.5 ± 5.5	
		(38.1)	(0.2)	(4.6)		(>100)	(0.4)	(3.4)	(11.2)	(0.4)
littoralis	SA 21128	18.3 ± 6.6		64.1 ± 15.4	0	24.6 ± 6.8		507.6 ± 67.8	19.5 ± 10.9	
		(>100)	(4.1)	(14.2)		(>100)	(0.8)	(17.1)	(3.8)	(0.7)
truncatula	'Cyprus'	2.0 ± 1.1		59.6 ± 22.6	1.8 ± 1.2	11.9 ± 3.9		158.0 ± 53.6	39.0 ± 12.4	
		(28.6)	(0.4)	(12.9)	(3.0)	(>100)	(0.9)	(11.8)	(24.7)	(2.9)
poly-morpha	'Serena'	0.8 ± 0.5		34.6 ± 7.4	0	0.2 ± 0.1		413.3 ± 66.6	67.0 ± 21.8	
		(>100)	(0.4)	(17.6)		(>100)	(0.1)	(20.0)	(16.2)	(3.2)

[1]Number of permeable seeds estimated from seedlings emerging from buried pods in soil-filled flats kept wet.

emergence in 1990–91 was considerably higher in plots that had received supplemental irrigation during 1989–90. This was observed even though the fraction of the seed population that was permeable did not differ significantly ($P \leq 0.05$) for individual accessions grown with or without supplementary irrigation (Table 3). For some accessions, mean seedling populations approached or exceeded those observed in the year of establishment (>20–30 plants/row). However, no more than 3.2% (mean = 1.6%) of all seeds resulted in established seedlings. Seeds were produced in the spring of 1991 by Cyprus plants in plots that received only precipitation in 1989–90 and by all accessions that had received supplemental irrigation in the year of establishment.

Discussion and Conclusions

Re-establishment of medic pastures is frequently unsuccessful if only seed produced in the previous season is available (Carter and Lake 1985). This was the case in this experiment as medics initially established and produced seed in a relatively dry winter but did not exhibit significant re-establishment in the following winter with above-average precipitation. Poor second-year establishment following favorable initial establishment was also observed in a medic establishment trial conducted in northern Utah (Rumbaugh and Johnson 1986).

Substantial re-establishment was observed in plots that received supplemental irrigation during seed development. Negligible re-establishment from plots that received only precipitation may have been due to poor seed quality associated with moisture stress during seed maturation. Andrew (1956) reported that *M. tribuloides (M. truncatula)* produced a lower percentage of mature seeds which had reduced hardseededness when plants were exposed to moisture stress following flowering. In this experiment, germination percentage initially following pod harvest (a measure of hardseededness and viability) did not differ between seeds from the 2 moisture treatments. Moreover, moisture stress during seed development did not reduce mean seed weight. This indicates that seed produced under the 2 moisture regimes did not differ physiologically.

Differences in re-establishment between the 2 moisture treatments may simply reflect the larger seed populations available in the irrigated plots. Mean seed yield produced with natural precipitation was considerably lower in all accessions than the 200 kg/ha considered necessary for re-establishment of medic pastures in Australia (Carter and Lake 1985). Assuming re-establishment rates comparable to those seen with pods from irrigated plots (3.8–24.7% of permeable seeds), a mean of approximately 6.3 ± 1.5 seedlings would be expected to emerge in 1990–91 in plots that had received only precipitation in 1989–90. Given the very low number of permeable seeds available, and the variability in emergence and seed number among plots, lack of seedling emergence should be expected.

These data indicate that rapid maturing medics could be established in southern Arizona with less than 100 mm precipitation during the period between November and May. High seed populations following initial establishment would be necessary to increase the chances for successful re-establishment. Initial seeding rates in excess of 115 PLS/m^2 could increase the probability of successful re-establishment. Considering plant populations in the year of establishment, seed production, and seed loss due to summer germination, the 2 medic cultivars Cyprus and Serena appear to represent the type of medic that could be established in southern Arizona. SA 21128 produced high plant populations and relatively large plants but may have insufficient hardseededness in summer to persist in this environment. Accessions of *M. laciniata* had insufficient breakdown of hardseededness by the onset of winter rains to provide dependable re-establishment. Future screening of medic germplasm for this environment should focus on rapid breakdown of hardseededness in autumn in addition to early flowering and drought survival.

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