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Survival of Perennial Grass Transplants in the Sonoran Desert of the Southwestern U.S.A.

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Abstract *Nine week old perennial grass seedlings were transplanted to coincide with the occurrence of summer and winter precipitation during 3 years at a study site in the Sonoran Desert. Six groups of similar grasses were evaluated biannually for 32 months to compare survival. Average survival over the 3 years of this study were 73% at 2 months and 39% at 32 months after summer transplanting. Summer transplant survival after 32 months for the Lehmann (*Eragrostis lehmanniana *Nees) and Boer (*E. curvula *var.* conferta *Nees) lovegrass groups averaged 64%, the weeping lovegrasses [*E. curvula *(Schrad.) Nees] averaged 22%, the large bunchgrasses [*Anthephora pubescens *Nees,* Panicum antidotale *Retz.,* P. coloratum *L. and* Pennisetum setaceum *(Forssk) Chiov.] averaged 29%, the old world bluestems (*Bothriochloa *spp.) averaged 41%, and the gramagrasses [*Bouteloua gracilis *(Willd. ex H.B.K.) Lag. ex Griffiths and* B. curtipendula *(Michx.) Torr.] averaged 21%. Winter transplant survival of Cochise lovegrass (*Eragrostis lehmanniana × E. trichophora *Coss. & Dur.) after 32 months was 9%. It was the only grass to survive the 3 winter plantings. Grasses evaluated in this study should be transplanted after the initiation of the summer rainy season.*

Keywords: *Eragrostis* spp., *Bothriochloa* spp., *Panicum* spp., *Bouteloua* spp., *Anthephora pubescens*, *Pennisetum setaceum*, Sonoran Desert, North America.

Introduction

Often it is desirable to replace shrubs with perennial grasses in order to reduce soil erosion, increase infiltration, and provide cover and forage for wildlife and domestic livestock. However, efforts to reintroduce perennial grasses from seed during the past 90 years have generally been unsuccessful in the southwestern United States (Cox et al. 1984) because the amount and distribution of rainfall is highly variable between years (Sellers and Hill 1974) and possibly because seed were sown in summer rather than winter.

To increase the success of plant establishment foresters (Tinus 1978), landscape architects (Aratani 1976), mine land reclamationists (Howard et al. 1978), and wildlife biologists (Springfield 1972; Ferguson et al. 1975) transplant containerized greenhouse grown seedlings and provide supplemental irrigation during establishment.

Transplant survival is dependent upon a continuous supply of soil moisture for possibly 30 days (Houser 1983). Therefore, transplanting dates which follow the expected initiation of the summer and winter rainy seasons would have the greatest likelihood of success.

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The purpose of this study was to determine the long-term persistence of perennial grasses transplanted in summer and winter, and to evaluate the effects of temperature and rainfall on survival. Data were evaluated in relation to climatic and/or edaphic conditions where plant materials were collected and to the potential for plant establishment from seed in the Sonoran Desert.

Materials and Methods

Study Site

The study site, approximately 30 km south of Tucson in southeastern Arizona, is representative of the Sonoran Desert mixed shrublands in southcentral Arizona and northwestern Mexico (Soil Conservation Service 1979). Elevation is 925 m and soil is a Comoro coarse loam, mixed, thermic, Typic Torrifluvent (Richardson et al. 1979). These soils are recent alluvium, weathered from mixed rocks, moderately alkaline, greater than 2 m in depth and well drained. The site is on a broad alluvial fan with a slope of less than 3%.

Tree-shrubs such as mesquite [*Prosopis juliflora* (SW.) DC.], desert hackberry (*Celtis pallida* Torr.), and littleleaf paloverde [*Cercidium microphyllum* (Torr.) Rose & Johnst.] were common on the site. Brittlebush (*Encelia farinosa* Gray), burroweed [*Haplopappus tenuisectus* (Greene) Blake], and cactus (*Coryphantha spp.; Echinocactus spp.; Opuntia spp.*) were the predominate understory half-shrubs.

Site Preparation

Four contoured water-spreading dikes constructed 30 m apart were used to retain on-site rainfall and two herbicides were used to reduce woody plant competition in summer 1979. Twenty percent active ingredient (a.i.) tebuthiuron (Graslan 20P)[1] (*N*-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-*N,N'*-dimethylurea) pellets at 1 gram a.i. per 2.5-cm basal diameter were applied to mesquite and desert hackberry tree-shrubs. Ten percent acid equivalent (a.e.) picloram (Tordon 10K)[1] (4-amino-3,5,6-trichloro-picolinic acid) pellets were hand broadcast at 1.5 kg a.e. ha^{-1} (Jordan 1981) over the entire study area to reduce competition from the remaining shrubs and under-story shrubs.

One-half of the area between water-spreaders was designated as a summer and the remaining half as a winter transplant area. Two to four weeks prior to transplanting twenty-eight 10-m lines, spaced at 50-cm intervals, were delineated in a plot. Twenty 15 × 35-cm holes, equally spaced along each line, were prepared with a power-driven auger when soil was dry. Loose, dry soil reentered the hole after the auger was removed. Plants were transplanted in the holes on 10 July 1980–82 and 2 January 1981–83.

Plant Propagation

Comoro soil, from 0 to 30-cm depths, collected outside the study area was mixed with peat moss with a 4:1 ratio by volume, and placed in polyethylene Ray Leach Super Cell Cone-tainers.[1] Five to ten seeds of 28 cultivars (CV) or selections (SL) of 14 perennial grasses were placed on the medium surface. The grasses were (1) Lehmann lovegrass (*Eragrostis lehmanniana* Nees), 2 CV and 4 SL; (2) Boer lovegrass (*E. curvula* var.

[1] Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products that may also be suitable.

conferta Nees), 1 CV and 1 SL; (3) weeping lovegrass [*E. curvula* (Schrad.) Nees], 1 CV and 4 SL; (4) yellow bluestem (*Bothriochloa ischaemum* var. *ischaemum* Keng), 1 CV and 1 SL; (5) King Ranch bluestem [*B. ischaemum* var. *songarica* (Rupr. ex Fisch. & Mey.) Celar & Harlan], 2 SL; (6) intermediate bluestem (*B. intermedia* var. *indica* Celar. & Harlan), 1 SL; (7) intermediate bluestem (*B. intermedia* var. *montana* Celar. & Harlan), 1 SL; (8) Caucasian bluestem [*B. caucasica* (Trin.) C.E. Hubb], 1 SL; (9) bluegrama [*Bouteloua gracilis* (Willd. ex H.B.K.) Lag. ex Griffith], 1 SL; (10) sideoats grama [*B. curtipendula* (Michx.) Torr.], 2 SL; (11) bottlebrush grass (*Anthephora pubescens* Nees), 1 CV; (12) blue panic (*Panicum antidotale* Retz.), 2 SL; (13) Kleingrass (*P. coloratum* L.), 1 SL; and (14) fountaingrass [*Pennisetum setaceum* (Forssk) Chiov.], 1 SL. Seed were covered with 60-mesh silica sand and subirrigated in trays on a greenhouse bench. Twenty-five percent Hoagland's solution was added to trays and paper placed over the cone-tainers to reduce surface evaporation.

Paper was removed after 7 days and trays drained after 21 days. Tap water was applied to the medium surface daily for 10 days and trays filled with 25% Hoagland's solution on day 31. Trays were drained and top growth harvested at 10 cm above the medium surface on day 48. After harvesting we surface watered twice daily for 3 days, once daily for 6 days, and every other day until transplanting at 9 weeks of age. Top growth was harvested at 10 cm above the medium surface 48 h before transplanting.

Summer-day length was approximately 16 h and plants were grown under natural light in summer. Winter-day length was 10 h and plants were grown under natural light plus 4 h of artificial light. Photosynthetically active solar radiation during the 4 h was 600 m E . m^{-2} . s^{-1}. Greenhouse temperatures were maintained between 25 and 32°C from weeks 1 to 7 and allowed to vary between 20 and 40°C from weeks 8 to 9.

Field Planting

Grasses were randomly assigned one row in the 3 plots. A hand spade was used to remove soil from the hole and the transplant, extracted from the cone-tainer, was placed in the hole. Soil was packed around the transplant so that the transplant medium surface and the soil surface within the hole were depressed 1 to 2 cm below the soil surface. Daily precipitation and soil surface temperatures were measured on site.

Data Collection and Analysis

The number of live plants, those with green leaves and tillers, were counted in late summer (September) and late winter (March) for 3 years after transplanting. Experimental design was a split-plot with transplanting at 2 seasons within 3 years and 3 replications of each cultivar or selection at the 6 planting dates. Only one grass, Cochise Lehmann lovegrass, survived 2 months after winter transplanting; therefore, we considered the 3 summer plantings as main plots and grasses as sub-plots. Survival data of genetically similar cultivars and selections were compared by date with analysis of variance. When F values were significant ($\alpha = 0.05$) a Tukey's w-procedure was used to separate means (Steel and Torrie 1960).

Results

Summer Transplant Survival

Survival of all lovegrasses declined steadily during the first 14 months but was greatest for Boer lovegrasses and least for the weeping lovegrasses (Tables 1, 2, and 3). Survivals

Table 1
Survival of Lehmann lovegrasses
transplanted as nine-week-old seedlings
during the summers of 1980, 1981, and 1982

Cultivar or selection[1]	Years	Months after transplanting[4]: 2	8	14	20	26	32
		% Survival					
A-68[2]		85	74	56ab	51b	41b	55
L-11[2]		88	76	63ab	57ab	65ab	63
L-19[2]		85	84	53b	58ab	62ab	61
L-28[2]		95	88	69a	71a	70a	65
L-38[2]		94	81	71a	68ab	63ab	71
Cochise[3]		80	78	53b	53ab	50ab	51
Average		88	80	61	60	58	61
	1980	93a	86	79a	76a	51	64
	1981	97a	78	34b	33b	49	46
	1982	75b	78	71a	73a	74	74
Interaction		NS	NS	NS	NS	NS	NS

[1] Plant materials provided by USDA-SCS, Plant Materials Center, Tucson, AZ and L.N. Wright (deceased), USDA-ARS, Tucson, AZ.
[2] *Eragrostis lehmanniana*
[3] *Eragrostis lehmanniana* × *Eragrostis trichophora*
[4] Means within columns, for each evaluation date, followed by the same letter are not significantly different ($\alpha = 0.05$) by Tukey's w-procedure.

after 32 months were 61, 72, and 22% for Lehmann, Boer, and weeping lovegrasses, respectively. The 13 dry days which followed the 1982 summer transplanting date had a dramatic effect on weeping lovegrass (64% mortality) transplants, but a moderate to light effect on Lehmann (25% mortality), and Boer (13% mortality) transplants. Weeping

Table 2
Survival of Boer lovegrasses
transplanted as nine-week-old seedlings
during the summers of 1980, 1981, and 1982

Cultivar or selection[1]	Years	Months after transplanting[3]: 2	8	14	20	26	32
		% Survival					
A-84[2]		94	80	71	78	78	76
Catalina[2]		88	75	65	71	68	68
Average		91	77	68	74	73	72
	1980	86	71	82a	85	78	79
	1981	100	81	54b	66	69	71
	1982	87	80	68ab	72	71	67
Interaction		NS	NS	NS	NS	NS	NS

[1] Plant materials provided by USDA-SCS, Plant Materials Center, Tucson, AZ and L.N. Wright (deceased), USDA-ARS, Tucson, AZ.
[2] *Eragrostis curvula* var. *conferta*
[3] Means within columns, for each evaluation date, followed by the same letters are not significantly different ($\alpha = 0.05$) by Tukey's w-procedure.

Table 3
Survival of weeping lovegrasses planted as nine-week-old seedlings during the summers of 1980, 1981, and 1982

Cultivar or selection[1]	Years	Months after transplanting[3] 2	8	14	20	26	32
		% Survival					
Common[2]		73	65	30	25	16	18
S3-6891[2]		76	62	37	36	33	26
S3-6892[2]		79	70	43	46	33	31
S3-6893[2]		68	40	23	26	13	15
S3-6894[2]		72	46	27	29	25	21
Average		74	57	32	32	24	22
	1980	85a	76a	66a	65a	41a	39a
	1981	99a	61a	9b	12b	8b	7b
	1982	36b	32b	21b	20b	22ab	20ab
Interaction		NS	NS	NS	NS	NS	NS

[1] Plant materials provided by USDA-SCS, Plant Materials Center, Knox City, TX and P.W. Voigt, USDA-ARS, Temple, TX.
[2] *Eragrostis curvula*
[3] Means within columns, for each evaluation date, followed by the same letter are not significantly different ($\alpha = 0.05$) by Tukey's w-procedure.

lovegrasses transplanted in summer 1981 survived the summer with only 1% mortality and with 39% during winter, but survival declined to 9% by 14 months.

Sixty-nine percent of the transplanted old world bluestems survived at 2 months but only 41% at 32 months (Table 4). There were significant differences among species and varieties at 14 months but no differences at 32 months.

Survival of the grama grasses (Table 5) closely paralleled that of the weeping lovegrasses (Table 3) and old world bluestems (Table 4). Mean plant survival declined from 80% at 2 months to 21% at 32 months. Vaughn seedlings may be more sensitive to cold and drought conditions than Hachita and Niner, but all were similar by 32 months.

Survival of bottle-brushgrass, blue panicgrass (SDT and A-130), Kleingrass (S-75), and fountaingrass averaged 54% at 2 months and 26% at 32 months (Table 6). Significant interactions among grasses and years at 2, 8, and 14 months after planting indicates that these large bunchgrasses responded differently within the 3 planting years. Mortality of SDT transplants at 2 months, in all years, was greater than 85%, while A-130 mortality was 60, 82, and 40%, respectively, for 1980, 1981, and 1982. At 8 months both blue panicgrasses had died in the 1981 plantings and survival of both averaged 6% in the 1980 and 1982 plantings.

Following the cold, dry winter of 1982 (Figure 1) Kleingrass and fountaingrass populations in the 1981 plantings declined by 80%. Kleingrass transplants in the 1980 and 1982 plantings were not influenced by the cold, dry or cold, wet winters of 1982 and 1983, but older (1980) and newer (1982) fountaingrass transplants declined by 30 to 35% following both cold winters, while all remaining blue panicgrasses died.

Winter Transplant Survival

The majority of the 1981 winter transplants that survived after 26 months and all 1982 and 1983 transplants that survived after 8 months were Cochise Lehmann lovegrass.

Table 4
Survival of Old World Bluestems transplanted as nine-week-old transplants during the summers of 1980, 1981, and 1982

Cultivar or selection[1]	Years	Months after transplanting[7] 2	8	14	20	26	32
		% Survival					
Ganada[2]		69	52	28ab	21	31a	29
573[2]		70	59	28ab	44	32	31
477[2]		74	73	33ab	50	55	55
506[3]		74	64	45a	48	52	55
517[4]		68	61	51a	51	46	48
765[5]		59	48	17b	23	21	26
857[6]		70	52	49a	45	41	45
Average		69	58	37	40	40	41
	1980	69b	61ab	49	54	39	46
	1981	97a	74a	22	32	43	41
	1982	42c	40b	37	35	36	37
Interaction		NS	NS	NS	NS	NS	NS

[1] Plant materials provided by USDA-SCS, Knox City, TX and C.L. Dewald, USDA-ARS, Woodward, OK.
[2] *Bothriochloa ischaemum* var. *ischaemum*
[3] *Bothriochloa ischaemum* var. *songarica*
[4] *Bothriochloa intermedia* var. *indica*
[5] *Bothriochloa caucasica*
[6] *Bothriochloa intermedia* var. *montana*
[7] Means within columns, for each evaluation date, followed by the same letter are not significantly different ($\alpha = 0.05$) by Tukey's w-procedure.

Some Cochise transplants in the 1982 planting which were considered dead between 8 and 20 months and transplants in the 1983 planting considered dead at 20 months began to actively grow between 26 and 32 months (Table 7). The response was unexpected and it was first thought that dormant seeds planted on the growth medium surface in the greenhouse might have produced new plants. Close inspection of the new growth and excavation of crowns indicated that new growth was from the transplant crown rather than from dormant seed.

Total Transplant Survival

Climatic conditions varied considerably between July and September of 1980, 1981, and 1982 (Figure 1). Temperature extremes were similar in 1980 and 1981, but precipitation was 14% below normal (154 mm) in 1980 and 15% above normal in 1981. Greater amounts of rainfall prior to and immediately after transplanting in 1981 may explain why total transplant survival was higher 2 months after planting in that year than that measured on the same date in 1980 (Table 8). However, total survival for both years averaged 66% 8 months after planting.

Unusually cool (Figure 1) and moist conditions prevailed in summer 1982. Tempera-

Table 5
Survival of Blue and sideoats gramas transplanted as nine-week-old seedlings during the summers of 1980, 1981, and 1982

Cultivar or selection[1]	Years	Months after transplanting[4] 2	8	14	20	26	32
		% Survival					
Hachita (NM-118)[2]		78	69	38a	37	21	28
Niner (NM-28)[3]		81	61	33ab	22	28	18
Vaughn[3]		80	56	17b	21	17	18
Average		80	62	29	27	22	21
	1980	84a	73	54a	43a	32	29
	1981	95a	61	12b	13b	17	17
	1982	59b	53	22b	25ab	18	18
Interaction		NS	NS	NS	NS	NS	NS

[1] Plant materials provided by USDA-SCS, Plant Materials Center, Las Lunas, NM.
[2] *Bouteloua gracilis*
[3] *Bouteloua curtipendula*
[4] Means within columns, for each evaluation date, followed by the same letter are not significantly different ($\alpha = 0.05$) by Tukey's w-procedure.

ture extremes were 8 to 9°C cooler than in 1980 and 1981 and precipitation was 58% above normal. Such ideal growth conditions should have aided in transplant survival, however, survival at 2 and 8 months after transplanting was the least of the 3 years (Table 8). On July 5, 10 mm of precipitation was recorded at the site. This amount was adequate to moisten the soft soil in the holes, but not adequate to moisten the soil profile to greater than 3 cm in undisturbed areas. No additional precipitation was recorded until 13 days after transplanting. All cultivars and selections had rolled leaves and green tissue was no longer present on 75% of the transplants.

Total summer transplant survival declined 15% between 20 and 26 months of the 1980 plantings, and 39% between 8 and 14 months on the 1981 plantings (Table 8). The declines for both plantings occurred following winter 1982 (Figure 1). Daytime and nighttime temperature extremes in winter 1982 were 4.2 and 5.8°C, respectively, and cooler than in winter 1981 while rainfall in 1982 was 58% less than in 1981. Plant survival decreased from 50 to 40% between 8 and 14 months on the 1982 summer planting following the winter of 1983, which was more harsh than winter 1984. Plants in the 1980 and 1981 summer plantings which survived winter 1981 did not appear to be harmed during winter 1982.

Discussion

Our results demonstrate the importance of the first summer growing season on the initial survival of all transplanted perennial grasses and verifies the need for summer planting. The results clearly document the superior survival of bottle-brushgrass, Lehmann lovegrass and Boer lovegrass cultivars and selections. Interestingly, the original seed collections for all three grasses were made in the Karoo Region of South Africa where they

Table 6

Survival of bottle-brush, blue panic, Klein, and fountaingrasses (large bunchgrasses) transplanted as nine-week-old seedlings during the summers of 1980, 1981, and 1982

Cultivar or selection[1]	Years	Months after transplanting[6] 2	8	14	20	26	32
		% Survival					
Glen[2]		67	64	66	68a	64a	62a
Seedling Drought Tolerant (SDT)[3]		8	1	0	0b	0c	0c
A-130[3]		36	6	0	0b	0c	0c
S-75[4]		78	53	47	50a	48ab	39ab
USDA-ARS[5]		81	80	37	44a	34b	29b
Average		54	41	30	32	29	26
	1980	58	53	53	53a	46a	42
	1981	54	33	11	16b	18b	14
	1982	47	35	27	27ab	24ab	22
Interaction		.05	.05	.05	NS	NS	NS

[1] Plant materials provided by USDA-SCS, Plant Materials Center, Knox City, TX and Tucson, AZ and E.C. Bashaw, USDA-ARS, College Station, TX and L.N. Wright (Deceased), USDA-ARS, Tucson, AZ.

[2] *Anthephora pubescens*

[3] *Panicum antidotale*

[4] *Panicum coloratum*

[5] *Pennisetum setaceum*

[6] Means within columns, for each evaluation date, followed by the same letter are not significantly different ($\alpha = 0.05$) by Tukey's w-procedure.

share codominance in the semiarid grasslands (Roberts and Fourie 1975). Climate, soils, and elevation of the Karoo (Fourie and Roberts 1977) are similar to areas within the Sonoran Desert which were previously semidesert grasslands (Humphrey 1958; Sellers and Hill 1974; Richardson et al. 1979).

Bottle-brushgrass was recently introduced and has only been seeded at one location in the Sonoran Desert. The Lehmann and Boer lovegrass cultivars and selections, however, have been seeded at 10 or more locations within the Sonoran Desert during the past 20 years (USDA-ARS unpublished data). Only A-68 and Cochise Lehmann lovegrasses and A-84 and Catalina Boer lovegrasses have consistently emerged and persisted at the planting sites. Since no differences exist in long-term survival between the Lehmann or between the Boer lovegrass seed sources, we need only address differences between the 4 lovegrasses based on ease of establishment before recommending the ideal seed source.

A-68 Lehmann lovegrass and A-84 Boer lovegrass consistently emerge only from sandy loam soils; germination is slow (48 to 120 h), seedlings are not drought tolerant, and seed must be planted near the soil surface which dries rapidly in summer (Cox 1984; Frasier et al. 1984). Whereas, Cochise Lehmann lovegrass and Catalina Boer lovegrass consistently emerge from sandy loam and silty clay loam soils; germination is quick (12 to 24 h), seedlings are drought tolerant, and seed may be planted at greater depths than A-68 and A-84.

Cochise seed was originally collected in South Africa (Holzworth 1980) and Catalina was developed in the U.S.A. from Boer lovegrass collections made in South Africa (Wright 1971). Cochise and Catalina germination and seedling characteristics (Cox 1984)

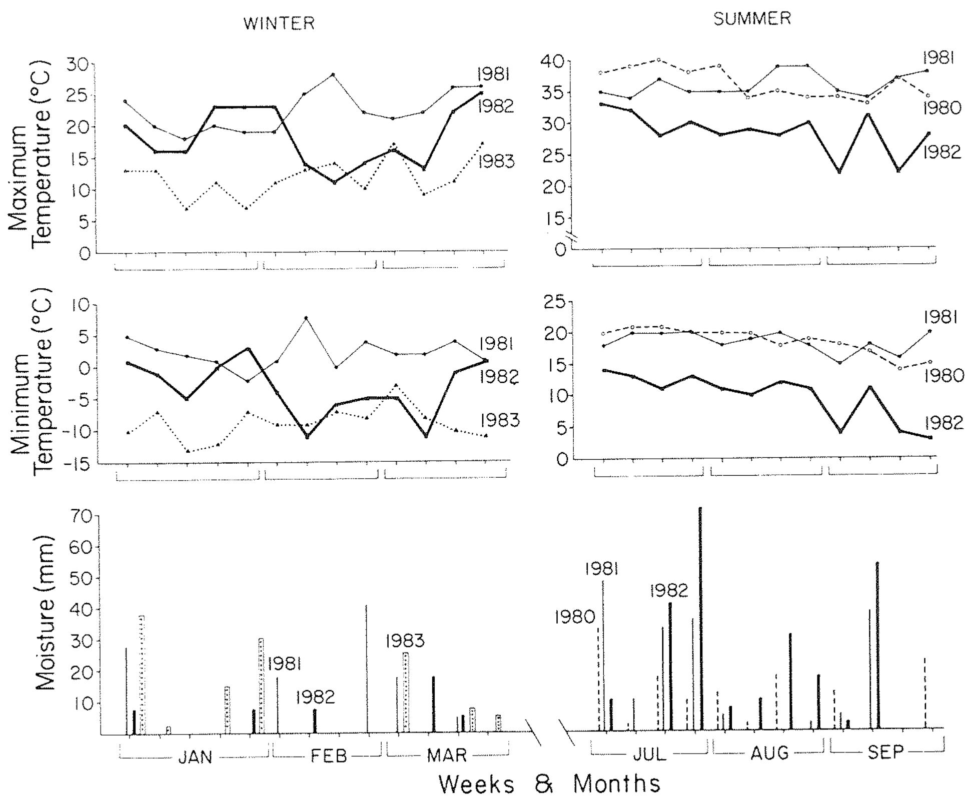

Figure 1. Weekly winter and summer maximum and minimum temperature extremes at the soil surface and precipitation at the transplant study site from 1980 to 1982.

and long-term survival within the Sonoran Desert suggests that these two grasses will establish and persist under a greater variety of climatic and edaphic conditions in semi-arid regions of the world than A-68 and A-84.

Weeping lovegrass, blue panicgrass, Kleingrass, and fountaingrass are common in the warm humid savannas of central and southeastern Africa (Grunow et al. 1980; Huntley and Walker 1982; Booysen and Tainton 1984). Some of these grasses have high nitrogen and water requirements (Wright 1970; Cox et al. 1983) and neither is abundant at the study site (Sellers and Hill 1974; Richardson et al. 1979).

Table 7
Survival of Cochise Lehmann lovegrass transplanted as nine-week-old seedlings during the winters of 1981, 1982, and 1983

	Months after transplanting					
Years	2	8	14	20	26	32
	% Survival					
1981	98	37	67	40	52	52
1982	52	0	0	0	2	8
1983	62	27	10	0	25	30

Table 8
Survival of perennial grasses at 6 dates following summer and winter transplanting during 3 years

Season	Year of transplanting	Months after transplanting					
		2	8	14	20	26	32
Summer	1980	76	68	61	60	45	47
	1981	90	64	25	27	32	31
	1982	54	50	40	41	40	39
Winter	1981	71	22	26	21	23	23
	1982	21	1	1	1	2	3
	1983	30	2	1	1	1	1

The old-world bluestems (*Bothriochloa* spp.) used in this study were collected from either cool-moist or cool-dry areas within Europe and Asia and evaluated under similar conditions in the Great Plains of North America (Sims and Dewald 1982). During late spring and summer (April–July) in the Sonoran Desert daytime temperatures often peak at 38°C or greater on an average of 41 days annually and soils are dry (Sellers and Hill 1974). During the same months in the Great Plains daytime temperatures are 5 to 10°C cooler and soils are usually moist. We can not specifically relate transplant mortality to dry soils in spring and summer, but most plants died between 8 and 14 months or during the spring-summer period (Table 4).

Blue and sideoats grama are common in the cool-dry and cool-moist short- and mid-grasslands of North America (Hitchcock 1950). As with the old-world bluestems, we suspect that transplant mortality is related to dry soils in spring.

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