The influence of climate and soils on the distribution of four African grasses

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Abstract

Around 1900 temperate and semidesert grassland productivity declined, soil erosion increased, and drought destabilized the livestock industry in the northern and southern hemispheres. As government leaders throughout the world began to recognize the importance of grassland productivity and soil conservation, a massive experiment began to evolve. Government and private individuals collected seed from every continent, and planted seed at experimental stations and ranches in their respective countries. Hundreds of individuals who conducted thousands of seeding trials observed that buffelgrass (*Cenchrus ciliaris* L.), weeping lovegrass [*Eragrostis curvula* (Schrad.) Nees], kleingrass (*Panicum coloratum* L.), and Lehmann lovegrass (*Eragrostis lehmanniana* Nees) plants from seed collected in Africa were easier to establish and persisted longer than other grasses. Between 1930 and 1986 scientists in many countries evaluated the establishment and persistence of these grasses, but no attempt was made to synthesize the data base and determine the effects of climate and soil on plant establishment and persistence. Our objective was to: (1) determine the climatic and edaphic characteristics of areas where the seed of each grass was collected in Africa, and where each grass has been successfully established in both hemispheres, and (2) identify characteristics which influence long-term persistence. Where buffelgrass predominates and spreads, summer rainfall varies from 150 to 550 mm, winter rainfall is less than 400 mm, mean miminum winter temperatures rarely fall below 5° C, and soil texture is loamy. Weeping lovegrass can be established and plants persist when spring, summer, and fall rainfall varies from 400 to 1,000 mm on deep sandy soil and mean minimum winter temperatures rarely fall below -5° C. The invasion of adjacent nonplanted sites occurs only in Africa where growing season rainfall infrequently cycles between 750 and 1,000 mm and soils remain wet in mid-summer. Kleingrass can be established where mean maximum daily summer temperatures are above 30° C, mean minimum daily winter temperatures rarely fall below 0° C, summer growing season rainfall varies from 400 to 990 mm, and soils are clayey or silty. Kleingrass, like weeping lovegrass, spreads to nonplanted sites only in Africa where a mid-summer drought does not occur. Lehmann lovegrass predominates and spreads only in southern Africa, southeastern Arizona, and northern Mexico when summer rainfall in 30 to 40 days exceeds 150 mm, and soil textures are sandy or sandy loam.

Key Words: buffelgrass, kleingrass, Lehmann lovegrass, weeping lovegrass, rangeland seeding, Northern and Southern hemispheres

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Commercial and religious rivalries among the Dutch, English, Portuguese, and Spanish between 1450 and 1550 resulted in the establishment of shipping lanes and exploration of continental land boundaries. Coastal exploration was followed by colonization, and by 1900 European settlers and their livestock had occupied the seemingly endless temperate and semiarid grasslands of Africa, Australia, North America, and South America. As European man and domestic livestock numbers increased, there was a corresponding increase in weed and woody shrub densities, and grassland productivity declined (Sellers and Hill 1974, Cooke and Reeves 1976).

Between 1880 and 1930, frequent droughts occurred in Africa, Australia, and North America, and livestock numbers declined (Brooks 1929, Bogdan 1961, Cox et al. 1983a). In an attempt to stabilize livestock populations, botanists, ranchers, and military personnel from Australia, England, South Africa, and the United States travelled throughout the world searching for a "miracle grass" that could produce an abundance of good quality forage with limited precipitation. Attempts were also made to develop high-producing varieties through plant breeding that would surpass native species (Thornber 1905). Their approach was to: (1) collect seed from plants growing in harsh environments, (2) plant seed at experimental stations or ranches in their respective countries, (3) increase seed from species that appeared to be drought tolerant, and (4) plant seed under extreme climatic and edaphic conditions (Griffith 1901). From thousands of seeding trials conducted throughout the world, 4 warm-season African grasses were recognized for their ease of establishment, persistence, and forage production. The grasses were buffelgrass (*Cenchrus ciliaris* L.), weeping lovegrass [*Eragrostis curvula* (Schrad.) Nees], kleingrass (*Panicum coloratum* L.), and Lehmann lovegrass (*Eragrostis lehmanniana* Nees). The purpose of this paper is: (1) to determine where the original seed sources were collected, and by whom; (2) to determine where the 4 grasses have been successfully established from sown seed, where mature plants have persisted for more than 20 years, and where seed from mature plants has colonized new areas; (3) to discuss relationships between climate, soils, and pests which may influence the long-term persistence of the 4 grasses; and (4) to evaluate the results as they may apply to future seedings throughout the northern and southern hemispheres.

Materials and Methods

Historical records and journals were examined to determine (1) where seed were originally collected and (2) countries where each grass had been successfully established. Rangeland conservationists in each country provided estimations of the area sown to each grass as well as adjacent colonized areas.

Climatic and edaphic data were collected at or from nearby areas where seed were originally collected and where mature plants established from seed persisted for 20 or more years. Climatic reporting stations were selected based upon (1) topographic similarities between reporting stations and the area where seed were collected or established, and (2) having 10 or more years of continuous records which corresponded with actual planting or invasion years.

Climatic data are summarized in the following mean monthly categories: (1) maximum temperatures, (2) minimum tempera-

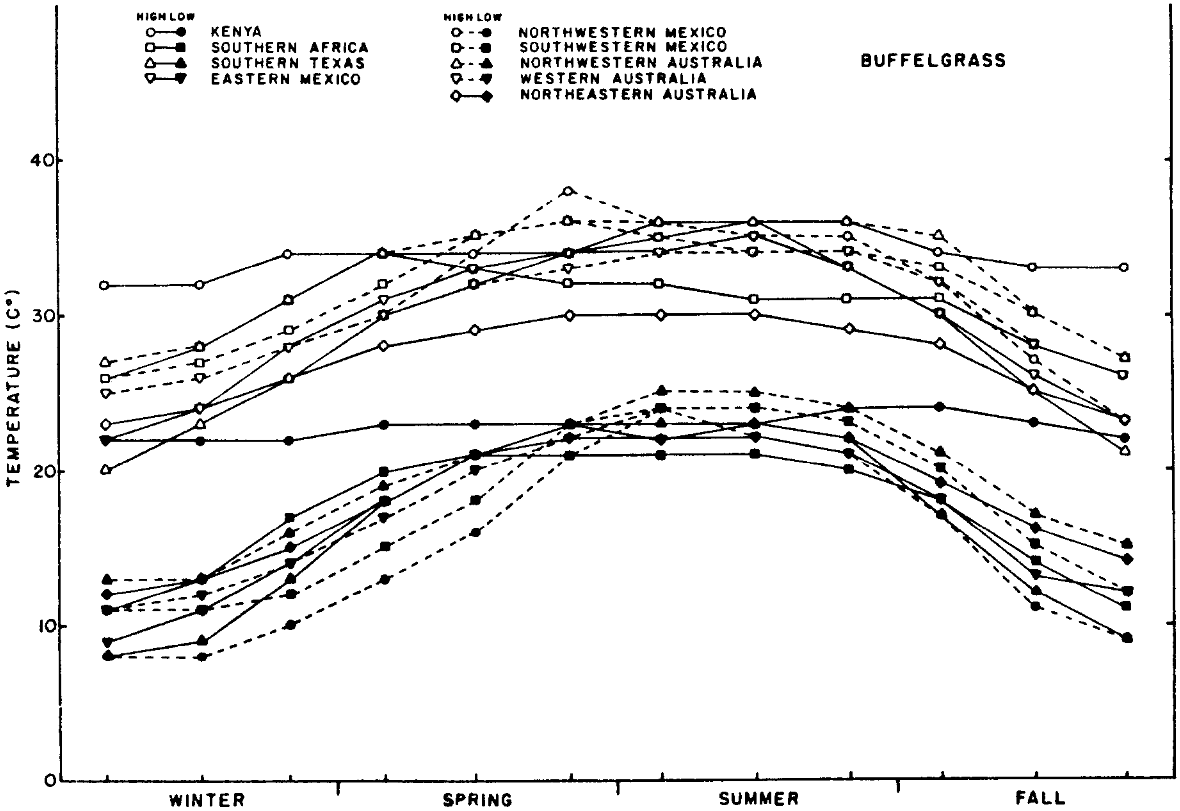

Fig. 1. *Mean monthly maximum and minimum temperatures during winter, spring, summer, and fall where buffelgrass has been successfully established in the northern and southern hemispheres.*

tures, and (3) precipitation. Data from stations in the northern and southern hemispheres are adjusted by month so that winter, spring, summer, and fall seasons correspond.

Results

Initial plant establishment from seed was documented in 31 countries for buffelgrass, 15 for weeping lovegrass, 9 for kleingrass, and 5 for Lehmann lovegrass. Long-term persistence and colonization, however, occurred only in 6 countries for buffelgrass, 3 for weeping lovegrass, 2 for kleingrass and 1 for Lehmann lovegrass.

Buffelgrass

C.J.J. van Rensburg, Department of Agriculture, South Africa, collected buffelgrass seed at many semiarid northeast African locations between 1940 and 1945. Seed were sown at Rietvlei Plant Introduction Station near Pretoria and evaluated for establishment, persistence, and forage production. Plants from seed collected in the Turkana Desert of northcentral Kenya and southern Ethiopia in 1940 survived a drought in 1942, and a seed production program was initiated in 1945.

Seed from the Turkana Desert collection were shipped to the United States in 1946 (Holt 1985). Plants were successfully established and persisted in southern Texas, and the U.S. Department of Agriculture, Soil Conservation Service (USDA-SCS) informally released T-4464 buffelgrass in 1949. Between 1949 and 1985, Texas seed producers sold 7 million kg of T-4464 seed, and ranchers in southern Texas established the grass on over 4 million ha. Seed were transported south into Mexico and successfully established on 6 million ha along the eastern coast, and on 300,000 ha along the western coast. T-4464 as well as seed from other buffelgrass collections made in Pakistan and southern Africa (Ivory et al. 1974) were shipped to Australia and successfully established on 7.5 million ha in the western and northern territories (Humphreys 1967).

Various buffelgrass accessions have been selected for production and cold tolerance (Das et al. 1978, Ivory and Whiteman 1978, Khan and Zarif 1982). Neither factor, however, can be repeatedly shown to differ among accessions when tests were conducted under the same or similar climatic and edaphic conditions.

Where buffelgrass occurs in northcentral Kenya and southern Ethiopia, elevations vary from 150 to 700 m, and mean monthly minimum and maximum temperatures annually vary from 21 to 24° C and 31 to 36° C (Fig. 1), respectively. Rainfall is bimodally distributed in 2 summer growing seasons, and annually varies from 200 to 400 mm. Buffelgrass is generally found growing in loam and sandy clay loam soils, and growth occurs whenever soil moisture is available (National Animal Husbandry Research Station Annual Report from Naivasha, Kenya 1979).

Where buffelgrass has been successfully established from seed, elevations vary from 6 to 830 m; but mean minimum winter temperatures at these locations are 10 to 15° C colder than in the Turkana Desert (Fig. 1). Leaf growth begins when mean minimum temperatures rise above 10° C. but active growth occurs only in summer when mean minimum temperatures are between 15 and 20° C and mean maximum temperatures are below 40° C in southern Africa (du Toit et al. 1973, Dye and Walker 1980), northeastern and northwestern Australia (Humphreys 1967, Sweeney and Hopkinson 1975, Harsh et al. 1981), eastern and western Mexico (Cota and Johnson 1975, Molina et al. 1976), and the southcentral United States (Hanselka 1985). Annual rainfall varies from 200 mm in the Turkana Desert and northwestern Mexico to 1,250 mm in northeastern Australia, and may be distributed in

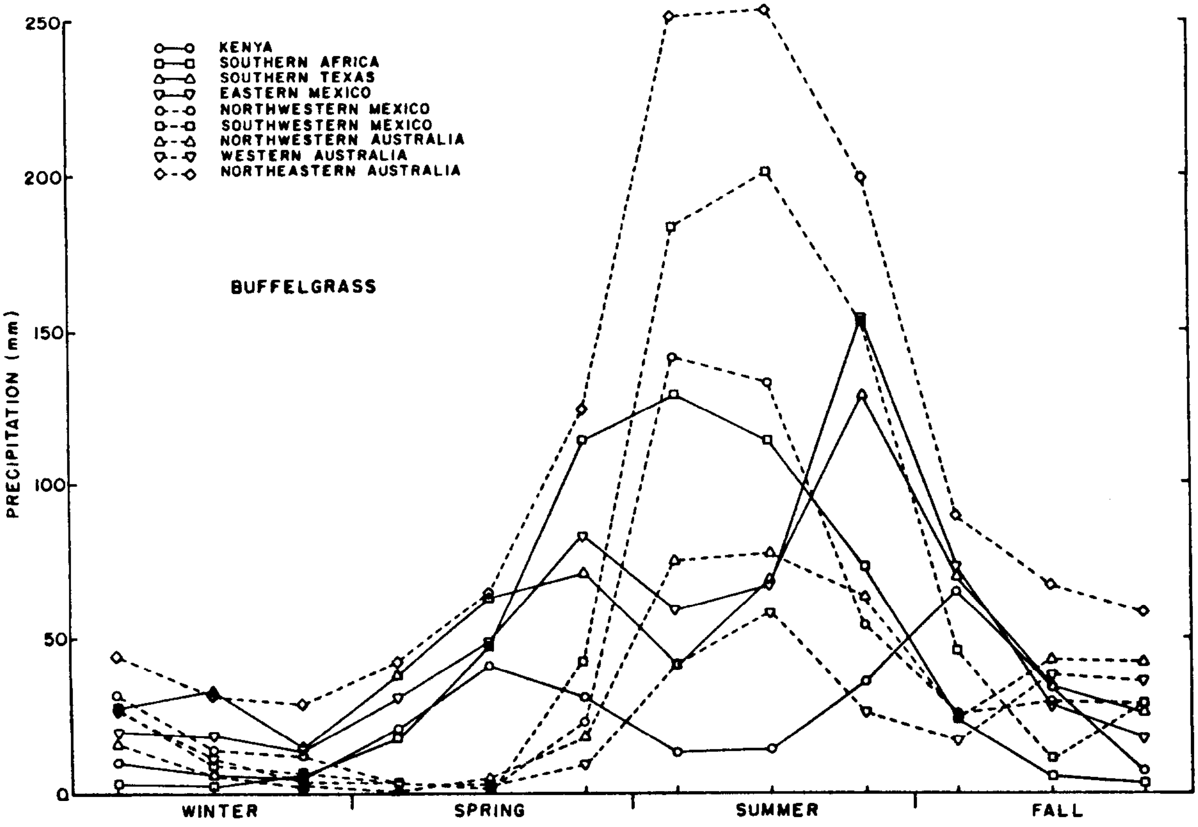

Fig. 2. *Mean monthly precipitation during winter, spring, summer, and fall where buffelgrass has been successfully established in the northern and southern hemispheres.*

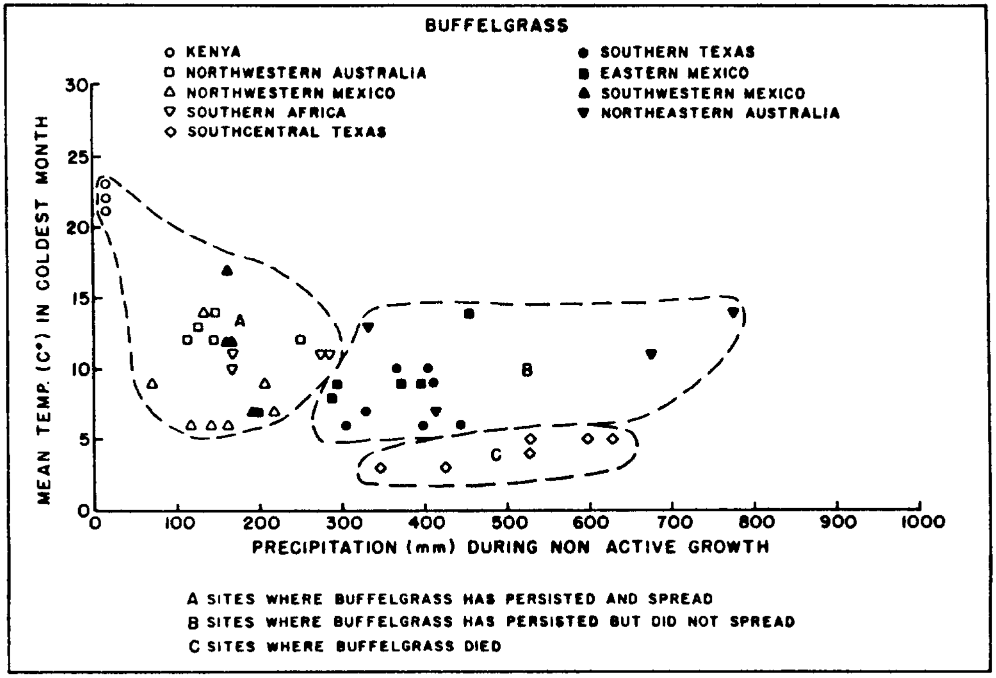

Fig. 3. *The effect of mean winter temperature and winter precipitation on the long-term persistence of buffelgrass in the northern and southern hemispheres.*

either a summer peak, bimodally in summer, bimodally in summer and fall or bimodally in summer and winter.

Buffelgrass seed, from plants established on planted sites, actively colonize adjacent nonplanted sites in Kenya, southern Africa, northwestern Australia, and northwestern Mexico. At all locations, summer rainfall during active plant growth varies from 170 to 400 mm while rainfall during dormancy varies from 10 to 285 mm (Fig. 2); dry periods totalling 150 to 210 days occur in either winter or in fall and spring; and mean minimum temperatures in the coldest month range between 0 and 23° C. Under such conditions, buffelgrass seed in soil may remain viable for 3 years (Winkworth 1963).

Established stands persist but do not actively colonize adjacent nonplanted sites in northeastern Australia, southwestern Mexico, eastern Mexico, and southern Texas. Summer rainfall exceeds 440 mm in northeastern Australia and southwestern Mexico, while rainfall during dormancy generally exceeds 300 mm in northeastern Australia, eastern Mexico and southern Texas (Fig. 2). Plant distribution under these environmental conditions is limited by allelopathy (Hussain and Ilahi 1982), competition with more productive forbs and grasses (Sweeney and Hopkinson 1975), insects which reduce plant vigor (Reis et al. 1984), and pathogens (Azmi and Singh 1985) which reduce seed germination during extended wet periods in either summer or winter.

In southcentral Texas, mean minimum temperatures in the coldest month are below 6° C, rainfall during dormancy generally exceeds 400 mm (Fig. 3), and an extended dry period does not occur. Stands established under these conditions fail to persist because seed produced in summer is destroyed during wet winters (Amzi and Singh 1985) and established plants die during cold winters (Holt 1985).

Weeping Lovegrass

L.W. Kephart and R.L. Piemeisel, Bureau of Plant Industry, U.S. Department of Agriculture, collected weeping lovegrass seed in northcentral Tanzania in 1927 (Crider 1945). Seed were collected from plants growing in black, waxy, sun-cracked soil on an escarpment between Mbula and Ngorongoro Craters, where elevation varied from 1,300 to 1,800 m.

Seed were shipped to Arizona in 1932 and numbered A-67 (Crider 1945). Weeping lovegrass was initially thought to be adapted in the semiarid southwestern United States, but mature plants were unable to survive spring and summer droughts (Bridges 1941, Judd and Judd 1976). Mature plants from seed planted in Oklahoma and northwestern Texas, however, did persist and between 1940 and 1980 A-67 weeping lovegrass was established on 800,000 ha.

In 1947 and 1953 seed from collections in Oklahoma were transported to Argentina and plants were established on 800,000 ha (Covas and Carinie 1985). Seed were also transported and established in southeastern Australia (Lloyd et al. 1983, Watt 1983), southern Africa (Kruger and Grunow 1983, Kategile 1985), Japan (Nada 1985), and Spain (Nieto 1985).

Three major weeping lovegrass types, selected for leafiness and cold tolerance, have been and are currently being compared to A-67. 'Morpa' (more palatable) was collected by R.K. Godfrey, Bureau of Plant Industry, U.S. Department of Agriculture, at Rietvlei Plant Introduction Station near Pretoria, South Africa in 1953. Seed were planted at Woodward, Oklahoma, in 1954, and seed from mature plants that survived in harsh winter in 1955–1956 were increased (Voigt 1971). 'Morpa' is taller, leaves are wider, and plants mature earlier than A-67 (Novosad et al. 1983). Beef cattle and sheep prefer 'Morpa' and gain weight faster than when grazing A-67 (Shoop et al. 1976).

'Ermelo', a leafy weeping lovegrass type was collected 200 km southeast of Pretoria at Nooitgedacht Research Station in 1944. Elevation is 1,750 m and nighttime temperatures are frequently below freezing in fall, winter, and spring. 'Ermelo' was introduced into the United States in 1948, and a second ecotype from an 'Ermelo' seeding in Zimbabwe was introduced in 1964.

Weeping lovegrass seeds collected from 54 sites in Basutoland (currently Lesotho) were increased by the Department of Agriculture and Technical Services in Pretoria and shipped to the United States in 1964. One selection, Renner, was more palatable and vigorous than the others. Renner has blue-green leaves and leaves are broader than A-67, 'Ermelo' and 'Morpa'. Renner was released in 1972 by the Texas Research Foundation (Read et al. 1980).

Differences among the 4 weeping lovegrass types, which do not include all African types, are related to leaf size, vigor, palatability

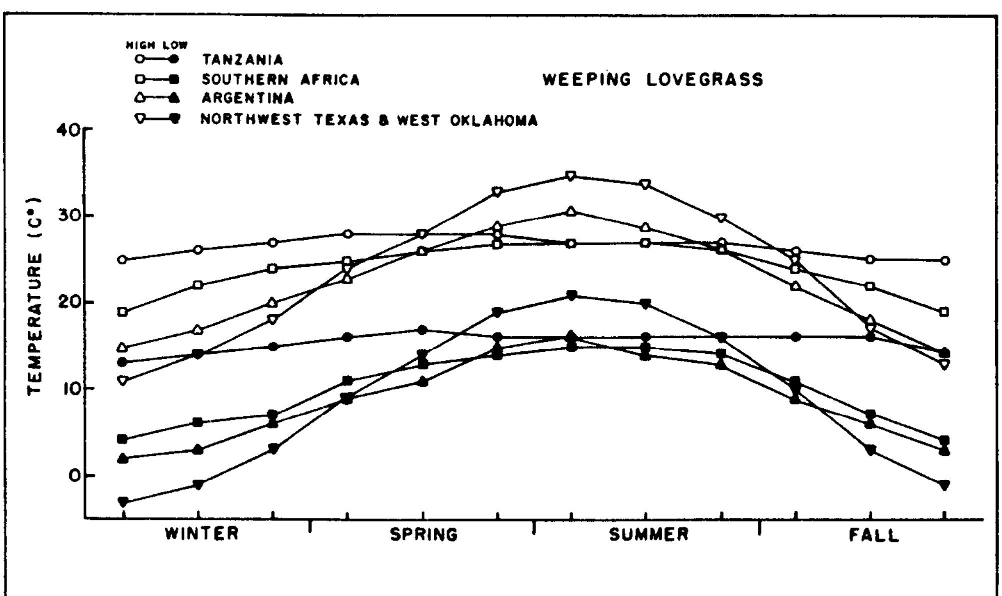

Fig. 4. *Mean monthly maximum and minimum temperatures during winter, spring, summer and fall where weeping lovegrass has been successfully established in the northern and southern hemispheres.*

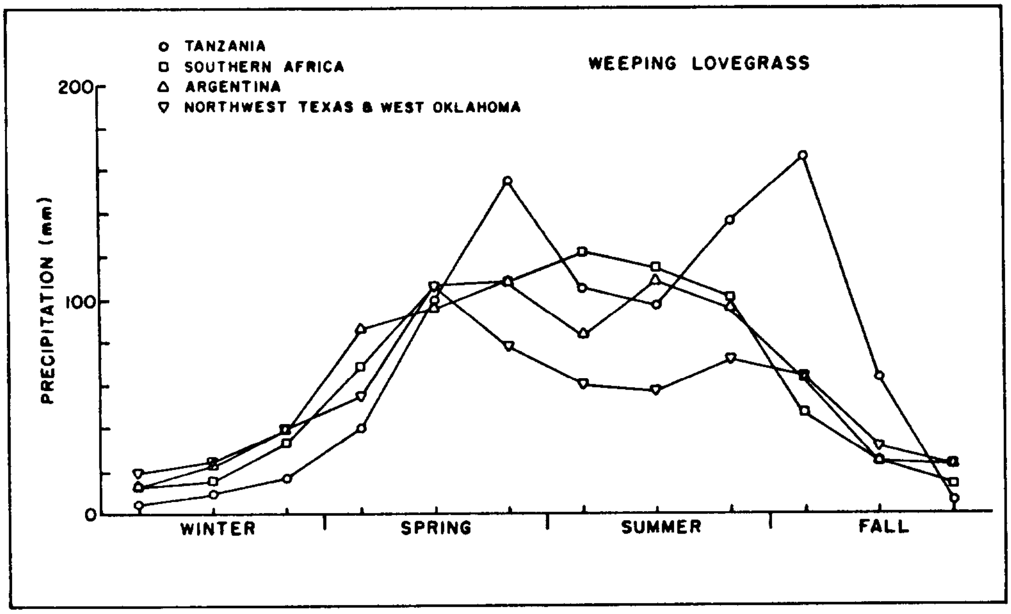

Fig. 5. *Mean monthly precipitation during winter, spring, summer, and fall where weeping lovegrass has been successfully established in the northern and southern hemispheres.*

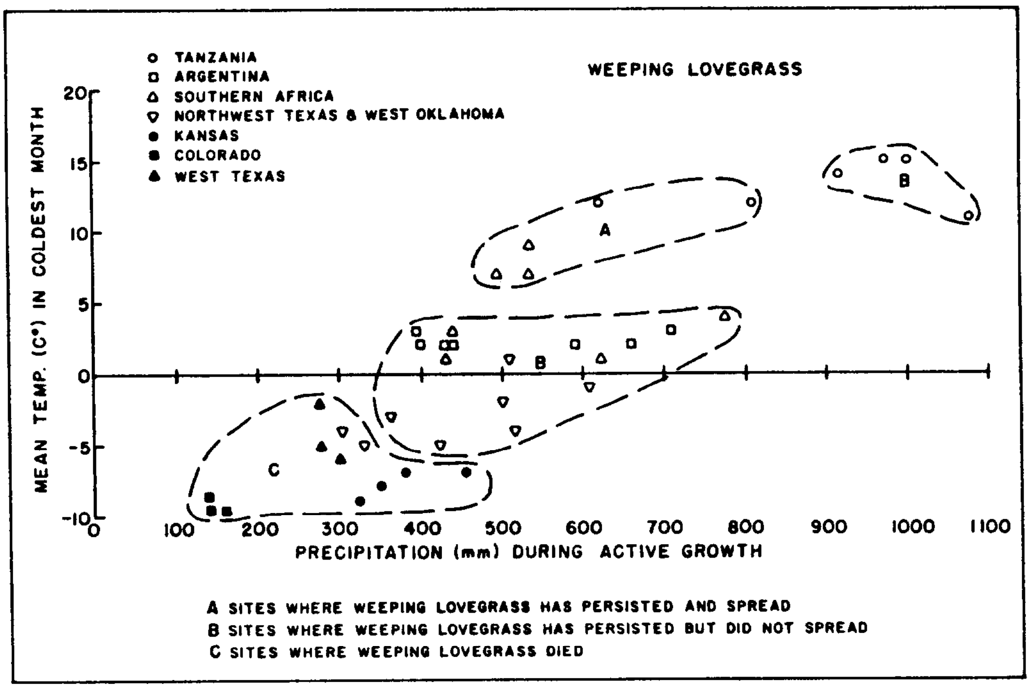

Fig. 6. *The effect of mean winter temperature and summer precipitation on the long-term persistence of weeping lovegrass in the northern and southern hemispheres.*

and possibly cold tolerance. The 4 types, however, represent most of the potential variability within the weeping lovegrass complex (Kruger and Grunow 1983). Thus, all types will be considered as 1 in our discussion.

In northcentral Tanzania where weeping lovegrass occurs, elevations vary from 1,190 to 1,530 m. Mean monthly minimum and maximum temperatures range from 10 to 18° C and 25 to 30° C, respectively (Fig. 4). Rainfall is bimodally distributed in summer and fall, and annually varies from 625 to 1,075 mm. More than 80% of the annual rainfall (765 to 965 mm) occurs when mean minimum daily temperatures are above 15° C, and winter and spring are typically cool and dry. Weeping lovegrass generally grows in deep sand or loamy sand. Leaf growth occurs when early summer rains begin, productivity peaks in mid-summer just prior to or during a moderate dry period, and regrowth occurs in fall (Mukurasi 1984).

Weeping lovegrass has been successfully established from seed in southern Africa, southcentral Argentina, and southcentral United States, but the species does not actively colonize adjacent non-planted sites. In South Africa, on the Natal Highlands and northern Transvaal Plains, weeping lovegrass has been established at 700 to 1,750 m elevations, while in Argentina plants are most often established at 80 to 310 m elevations. Winters in Tanzania, South Africa, and Argentina are cold and dry (Fig. 4), but mean minimum winter temperatures in Tanzania are 8 to 10° C warmer than in South Africa and Argentina.

Rainfall in South Africa peaks in mid-summer and annually varies from 500 to 1,200 mm, while rainfall in Argentina peaks in early and late summer and annually varies from 640 to 955 mm (Fig. 5). Rainfall in the growing season ranges from 400 to 775 mm, at both locations, and mean maximum summer temperatures rarely exceed 30° C. Plant growth occurs when soil moisture is available and mean minimum temperatures rise above 10° C, and productivity peaks in mid-summer when mean minimum and maximum temperatures vary between 15 and 30° C (Kruger and Grunow 1983, Rethman and de Witt 1984, Covas and Cairnie 1985).

In the United States, weeping lovegrass has been established from southern Colorado to southern Arizona and from Maryland to Georgia (Crider 1945, Denman et al. 1953). Plant persistence, however, is limited to 300 to 1,000 m elevations in western Oklahoma, and northwestern and northcentral Texas. Plant growth begins in late spring when mean minimum temperatures rise above 10° C; productivity peaks when mean minimum and maximum temperatures range between 15 and 30° C; growth declines in mid-summer when mean maximum temperatures exceed 30° C and soils dry (Shoop and McIlvain 1970).

In western Oklahoma and northwestern and northcentral Texas, mean minimum daily temperatures in the coldest month vary from -1 to -5° C (Fig. 6) and minimum daily temperatures in winter are below 0° C for 60 to 90 days. Under such conditions established weeping lovegrass stands will persist if they are not fertilized and defoliated prior to freezing winter temperatures (Rommann and McMurphy 1974). To the north in southern Kansas and west in southeastern Colorado, mean minimum temperatures in the coldest month vary from -7 to -10° C and daily minimum temperatures are below 0° C for 120 to 160 days. Weeping lovegrass can be established during summer in Kansas and during atypically wet summers in Colorado, but plants die in winter (Dwyer et al. 1974, Dalrymple 1976, Shoop et al. 1976, Read et al. 1980, Novosad et al. 1983). Stands can also be established during atypically wet summers and they persist for 10 or more years in southern Arizona, eastern New Mexico, and west Texas; but mature plants die when summer rainfall declines to 350 mm (Bridges 1941, Judd and Judd 1976).

Weeping lovegrass has been used throughout the world to revegetate mine spoils and steep slopes (Cresswell 1973, Farrington 1973, Wang et al. 1975, Voigt et al. 1982). Established stands persist where summer rainfall varies from 400 to 1,000 mm, and mean minimum and maximum temperatures annually vary from 0 to 30° C. Plant production, however, declines where summer rainfall exceeds 7[illegible] mm because of allelopathy (Dalrymple and Rogers 1983), competition with other forbs and grasses (Giraudo et al. 1984), fungal infections (van der Merwe et al. 1979), mites (Ehara 1985), and nematodes (Gnanapragasam 1981, van den Berg 1985).

Kleingrass

Dr. Mildred Wilman, Director of the McGregor Museum, Kimberley, South Africa, collected kleingrass seed between Kimberley in the Orange Free State and Potchefstroom in the Transvaal in 1949. Seed from the collections were planted throughout Texas between 1954 and 1968. Plants were successfully established in central Texas, and in 1968 the USDA-SCS and the Texas Agricultural Experiment Station jointly released Selection 75 (Holt 1969).

Between 1975 and 1985, commercial seed producers in Texas sold over 2 million kg of Selection 75 seed, and seed were planted on 2.8 million ha of degraded rangeland. Seed were transported and established on small acreages in eastern Australia (Rees 1972), Brazil (Alberto and Barreto 1983), Cuba (Oquendo et al. 1983), India (Mukherjee 1972), Japan (Inosaka et al. 1975), Venezuala (Gallardo and Leone 1983) and Zimbabwe (Mills 1977).

Kleingrass variety *makarikariense*, originally collected in Botswana, has a bluish color and wider leaves than Selection 75 (Holt et al. 1985). *Makarikariense* has been successfully established on small acreages in eastern Australia (Lloyd et al. 1983), Brazil (Alberto and Barreto 1983), and Japan (Inosaka et al. 1975).

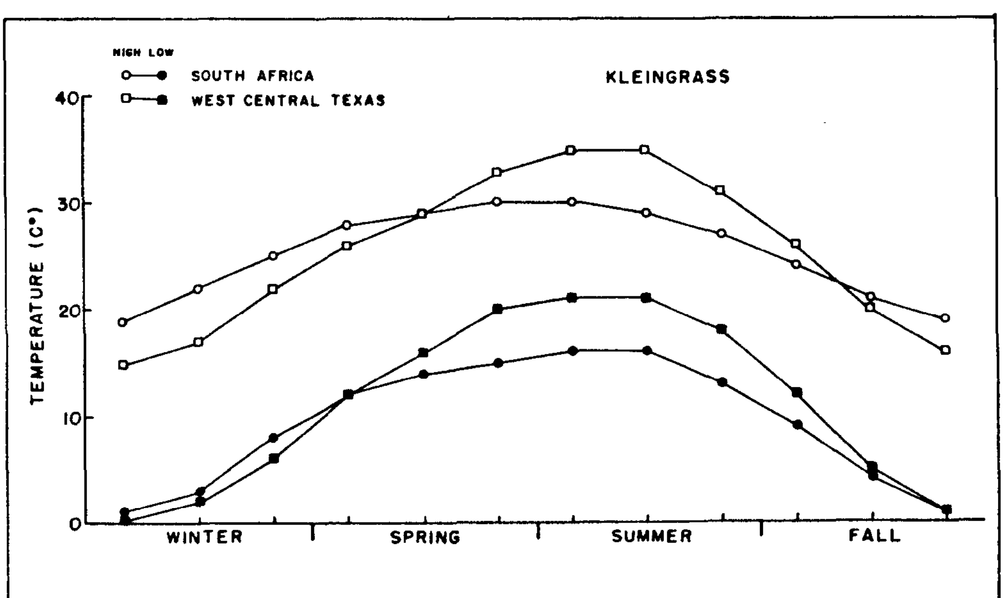

Fig. 7. *Mean monthly maximum and minimum temperatures during winter, spring, summer, and fall where kleingrass has been successfully established in the northern and southern hemispheres.*

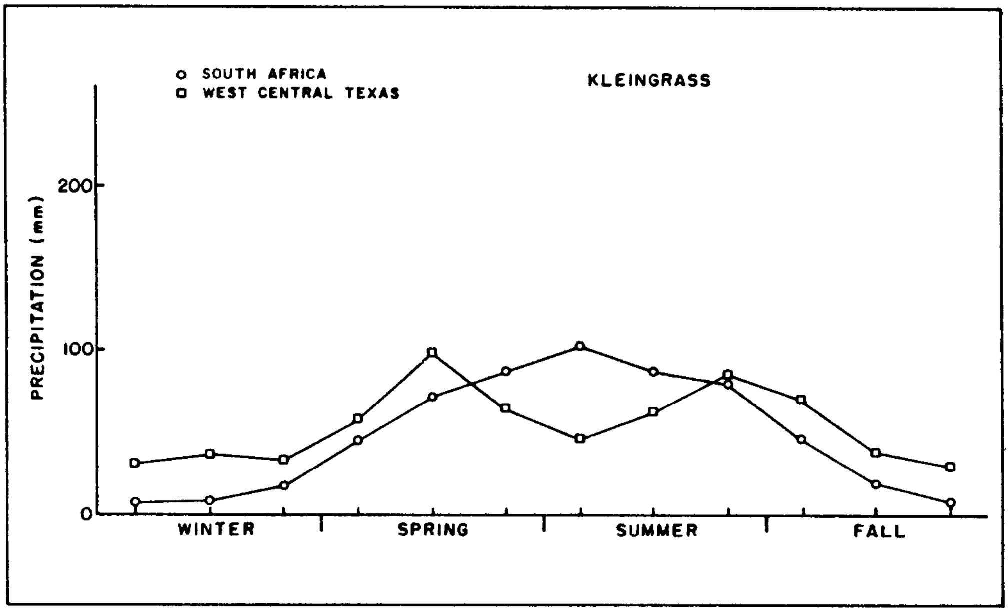

Fig. 8. *Mean monthly precipitation during winter, spring, summer, and fall where kleingrass has been successfully established in the northern and southern hemispheres.*

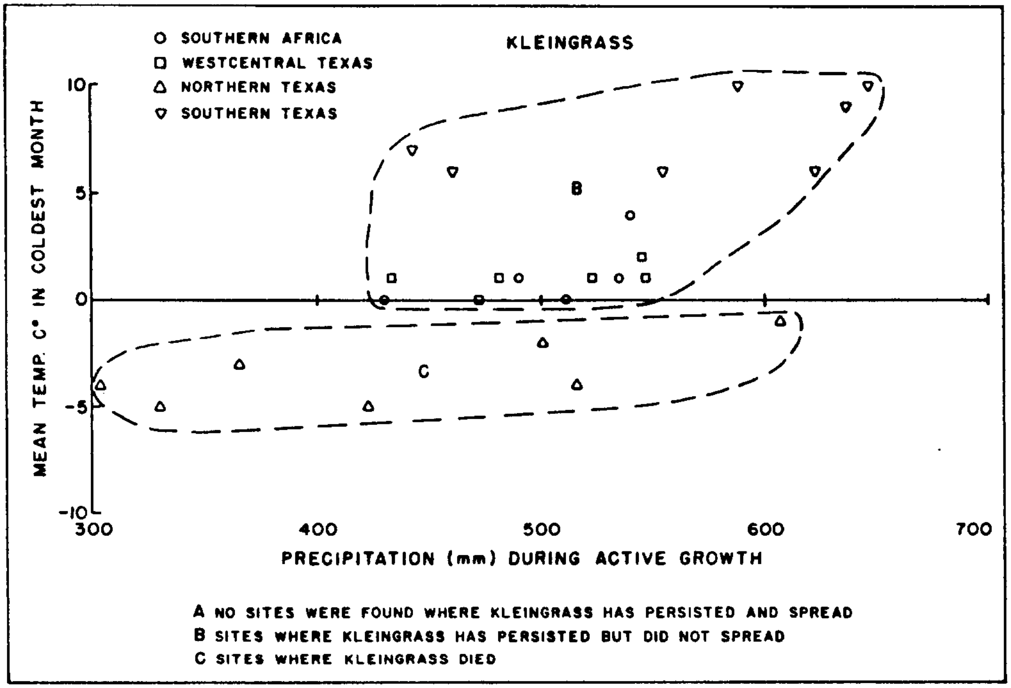

Fig. 9. *The effect of mean winter temperature and summer precipitation on the long-term persistence of kleingrass in the northern and southern hemispheres.*

Selection 75 is apparently more cold tolerant than *makarikariense*, but their establishment, productivity, and digestibility characteristics under moisture stress are similar (Kobayashi et al. 1978, MacKenzie et al. 1982, Bade et al. 1985). Thus, both selections are considered as one in our discussion.

Elevations in the western Transvaal of South Africa range from 1,000 to 1,450 m, and mean monthly minimum and maximum temperatures annually vary from -2 to 17° C and 16 to 31° C (Fig. 7), respectively. Rainfall peaks in summer, and annually varies from 425 mm at Kimberley to 610 mm at Potchefstroom. Winters are dry, and mean minimum daily temperatures in the coldest month vary from -5 to 4° C. In Zimbabwe, 200 to 300 km north, kleingrass grown under a similar climatic regime initiated growth in spring when temperatures approached 10° C and moisture in the soil was available (Rodel and Boultwood 1981). Plant productivity peaked when mean daily minimum and maximum temperatures ranged from 15 to 30° C, and seedlings and mature plants were most often found where fine soil particles and water accumulated (Rodel 1972).

Kleingrass has been successfully established from seed in Australia (Rees 1972), Brazil (Alberto and Barreto 1983), Japan (Kobayashi et al. 1978), United States (Holt 1969), Venezuela (Gallardo and Leone 1983) and Zimbabwe (Rodel 1972), but the species does not actively colonize adjacent nonplanted sites. The species can be expected to survive extreme fall defoliation only in west central Texas (Holt et al. 1985) and southern Africa (Rodel and Boultwood 1981).

In west central Texas, elevations range from 440 to 540 m, and mean minimum and maximum temperatures annually vary from 0 to 22° C and 12 to 36° C (Fig. 7), respectively. Winters are dry in some years while wet in others, and mean minimum daily temperatures in the coldest month vary from 0 to 2° C. Rainfall is bimodally distributed, and peaks occur in late spring and early fall (Fig. 8). If soil moisture is available kleingrass grows from spring to fall when mean minimum daily temperatures are above 10° C. Plant productivity peaks throughout summer when mean maximum temperatures range from 30 to 36° C (Stubbendieck et al. 1973, Pitman and Holt 1983, Bade et al. 1985, Bedunah and Sosebee 1985). Weeping lovegrass productivity, under similar temperature extremes, rapidly declines even when soil moisture is available (Farrington 1973, Mills 1977, Covas and Cairnie 1985).

Kleingrass persistence is limited by temperature to the north and by precipitation west of west-central Texas (Taliaferro et al. 1983), while production is limited by competition to the east and south (Holt et al. 1985). Established kleingrass stands in northern Texas and Oklahoma die (Holt 1969) where mean minimum daily temperatures in the coldest month vary from -1 to -5° C (Fig. 9) and minimum daily temperatures in winter are below 0° C for 30 to 60 days; whereas in west Texas, stands die if total precipitation in the growing season (April to October) is less than 400 mm (Pratt et al. 1971). Kleingrass can be successfully established and will persist in high rainfall (700 to 990 mm) areas of east and south Texas, but competition with other seeded grasses reduces kleingrass forage production (Hussey and Holt 1982). Production in high rainfall areas may also be limited by nematodes (Rodel et al. 1976).

Toxins accumulate in kleingrass foliage, and goats and sheep may die after consuming large quantities during fall in southern Africa (Rodel 1972) and summer and fall in central Texas (Dollahite et al. 1977, Muchiri et al. 1980). The distribution of kleingrass, as a potential pasture grass, may be limited because of its toxic characteristics.

Lehmann Lovegrass

Dr. Mildred Wilman, Director of the McGregor Museum, Kimberley, South Africa, sent Lehmann lovegrass seed collected in the Griqualand West Region of South Africa to F.J. Crider at Superior, Arizona, in 1932 (Crider 1945). In 1935, Crider organized a series of irrigated screening tests at Tucson, Arizona, and selected plants that matured quickly and produced seed in the first growing season. Seeds from established plants were numbered A-68.

Between 1937 and 1950, approximately 135 kg of Lehmann lovegrass seed, produced at Tucson, was planted in small plots from west Texas to Arizona. Many of the seedings were successful, and between 1951 and 1985, commercial seed growers produced more than 75,000 kg of Lehmann lovegrass seed. Approximately 70% of the seed was sown on rangelands in Arizona, New Mexico, and Texas. The majority of the remaining seed was transported into Mexico and planted in the northern frontier states of Chihuahua, Coahuila, and Sonora (Cota and Johnson 1975, Sanchez 1976, Cox et al. 1984). Between 1940 and 1980, ranchers and government agencies successfully established Lehmann lovegrass on more than 70,000 ha and the species spread by seed to an additional 70,000 ha in the southwestern United States and northern Mexico (Cox and Ruyle 1986).

Elevations in west-central South Africa where Lehmann lovegrass occurs naturally, range from 1,175 to 1,350 m and mean minimum and maximum temperatures annually vary from 0 to 19° C and 18 to 34° C (Fig. 10), respectively. Annual rainfall peaks in late summer, and approximately 80% (225 to 395 mm) is distributed in late spring, summer and early fall when mean minimum daily temperatures are above 15° C. Rainfall amounts are low and storms are widely distributed in late spring and summer, and

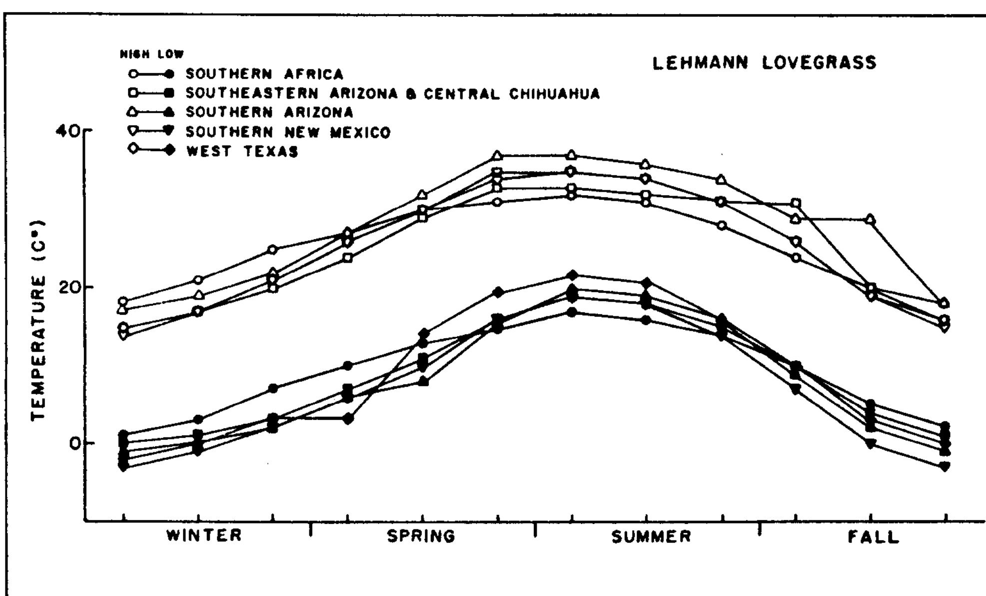

Fig. 10. *Mean monthly maximum and minimum temperatures during winter, spring, summer and fall where Lehmann lovegrass has been successfully established in the northern and southern hemispheres.*

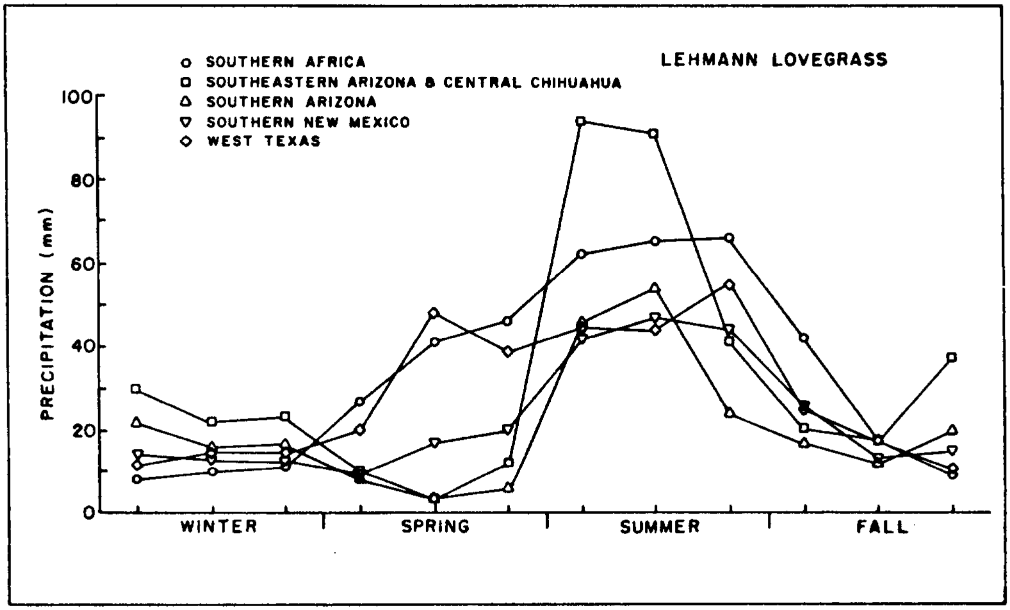

Fig. 11. *Mean monthly precipitation during winter, spring, summer and fall where weeping lovegrass has been successfully established in the northern and southern hemispheres.*

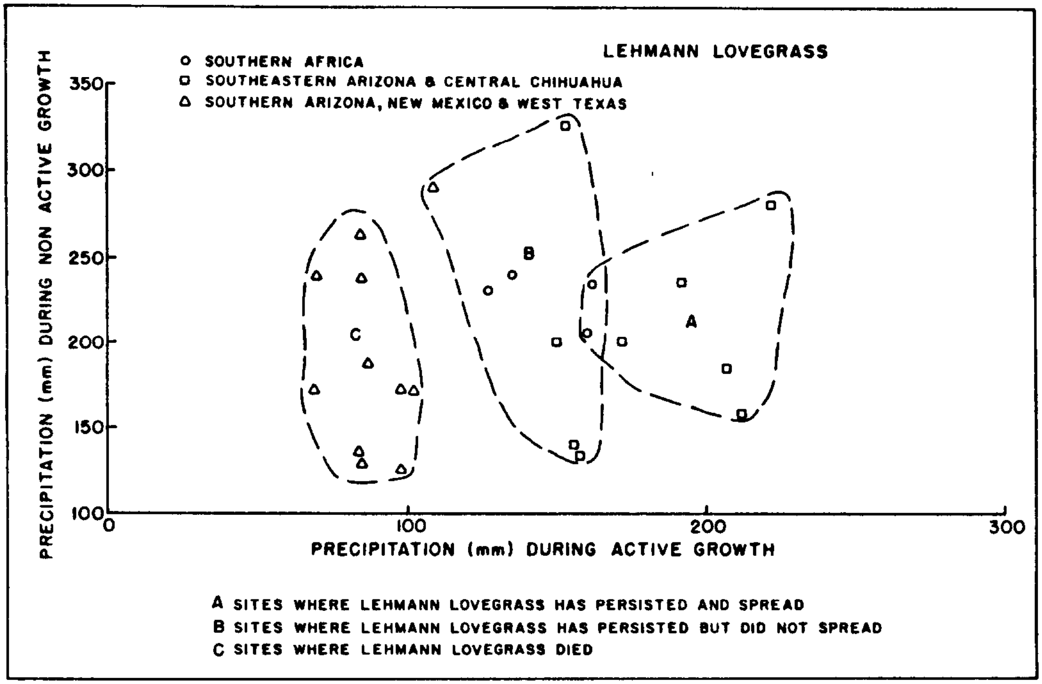

Fig. 12. *The effect of winter and summer precipitation on the long-term persistence of Lehmann lovegrass in the northern and southern hemispheres.*

Lehmann lovegrass normally remains semidormant. As rainfall amount and distribution increase in late summer, Lehmann lovegrass initiates growth and productivity peaks in 30 to 40 days (Fourie and Roberts 1976). Precipitation during active growth ranges from 130 to 160 mm (Fig. 11) while mean minimum and maximum temperatures vary from 15 to 32° C.

Where Lehmann lovegrass has been successfully established and has spread in the southwestern United States and northern Mexico, elevations range between 775 and 1,540 m, and daily mean minimum and maximum temperatures vary annually from –4 to 20° C and 13 to 38° C, respectively (Fig. 10). Annual rainfall varies from 275 to 500 mm, and may be distributed in a summer peak or bimodally in summer and winter (Fig. 11).

Lehmann lovegrass seed, from plants established on planted

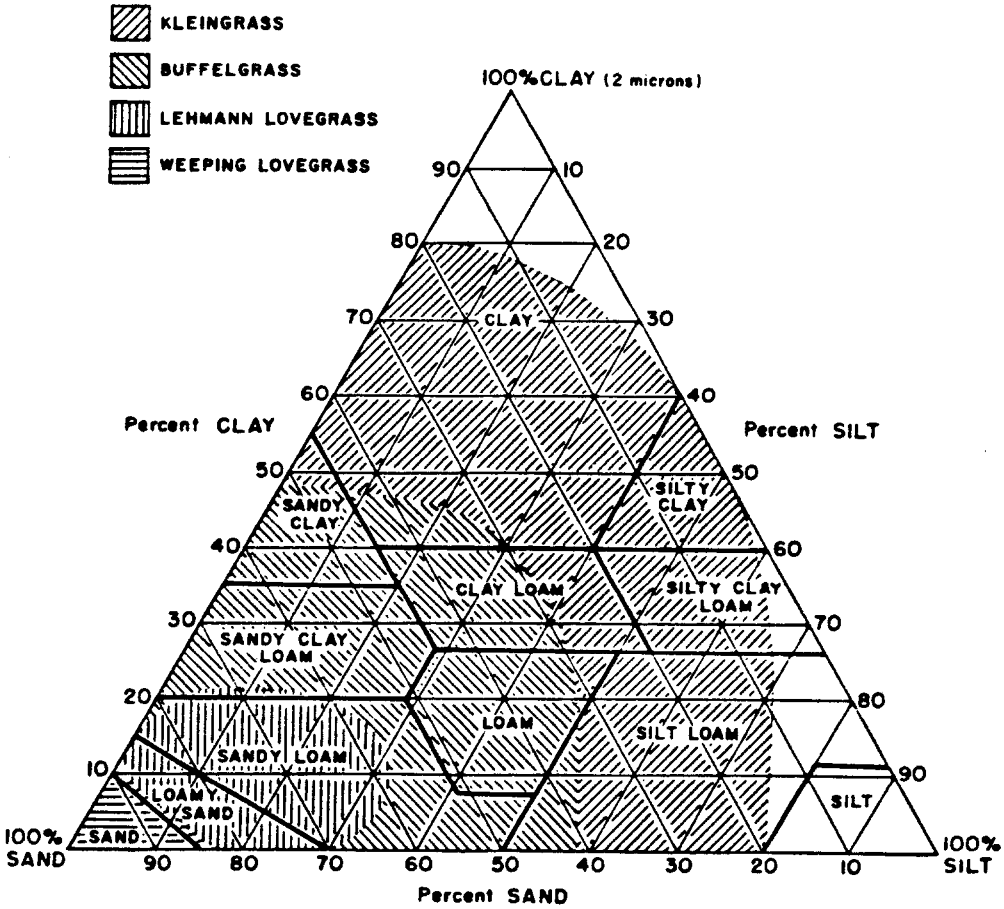

Fig. 13. *The effect of soil texture on the long-term persistence of four warm-season African grasses.*

sites, actively colonize adjacent nonplanted sites in southeastern Arizona (Cox and Ruyle 1986) and northcentral Mexico. At all locations, summer rainfall during active plant growth ranges from 150 to 220 mm (Fig. 12), and elevations vary from 1,100 to 1,540 m (Anderson et al. 1957, Cable 1971). Where Lehmann lovegrass has persisted but has not spread in southeastern Arizona, southern New Mexico, west Texas, and northern Mexico, summer rainfall during active growth is about 100 mm. Established Lehmann lovegrass stands in the area die when summer rainfall during active growth ranges between 70 and 85 mm.

Effects of Soil Texture

Buffelgrass, kleingrass, weeping and Lehmann lovegrasses have been initially established in almost all soil textural types; but long-term persistence of each grass is dependent on specific textural types (Fig. 13). Buffelgrass and kleingrass seedlings emerge when seed are sown in sandy, silty, and clayey soils, but buffelgrass emergence declines as either sand, silt, or clay content approaches 100% (Mutz and Scifres 1975, Agostini et al. 1981). Buffelgrass seedlings gradually lose vigor and die when established in silt, silt loam, silty clay loam, silt clay and clay soils; whereas, kleingrass seedlings persist in the same soils (Sweeney and Hopkins 1975, Watt 1976, Christie 1978, Pitman et al. 1981, Rodel et al. 1981, Hanselka 1985). Buffelgrass persists in well-drained loam, sandy loam, clay loam, and sandy clay loam soils, and actively spreads by seed in northwestern Australia and northwestern Mexico in sandy loam soils (Humphreys 1967, Cota and Johnson 1975).

Weeping lovegrass seedlings emerge from sand, loamy sand, sandy loam, and loam soils, but long-term persistence in southern Africa is normally, but not always, limited to deep sandy soils (Rethman and de Witt 1984). Sand depth may vary from 1 to 5 m (Farrington 1973, Wang et al. 1975, Kruger and Grunow 1983), and the soil profile may be saturated seasonally (Covas and Cairnie 1985).

In the eastern and southern United States weeping lovegrass can be established and will persist in sandy soil (Dalrymple 1976, Haferkamp and Mutz 1982). Plant distribution in this area, however, is limited by soil texture which is predominantly silt loam, clay, and clay loam. Chemical and physical characteristics of these soil types either reduce or inhibit weeping lovegrass germination (Stubbendieck 1974), seedling emergence (Cox et al. 1986), shoot growth (Chichester 1981, Lavin et al. 1981), and root growth (Tischler and Voigt 1983).

Lehmann lovegrass seedlings emerge when seeds are planted near the surface in sand, loamy sand, and sandy loam soils; seedlings, however, do not emerge in silt loam, loam, and clay loam soils, regardless of planting depth (Cox et al. 1983b). In southeastern Arizona and northcentral Mexico long-term persistence and spread is limited to loamy sand and sandy loam soils (Cox and Ruyle 1986).

Discussion

Attempts to artificially revegetate degraded rangelands in the northern and southern hemispheres have been going on for approximately 100 years (Humphreys 1967, Cox et al. 1986). The method most widely used to establish grasses was to: (1) mechanically reduce unwanted competition, (2) prepare a seedbed, (3) plant seeds of as many species, accessions, and cultivars in as many soil types as possible, and (4) pray for rain. In 1 of every 10 planting attempts grasses were successfully established, but climatic and edaphic data were not collected and it was impossible to determine why plantings were either successes or failures.

When grasses were successfully established there was a tendency to extrapolate, because successes occurred infrequently, and imply that a species was adapted over a broad geographic region. Lehmann lovegrass can be established on most soils in the southwestern United States and northern Mexico in an atypically wet summer (Cox et al. 1984), but the species persists and spreads only on sandy or sandy loam soils where summer precipitation in 30 to 40 days varies from 150 to 220 mm (Cox and Ruyle 1986). Hence, Lehmann lovegrass is adapted at a few localized areas, rather than throughout the southwestern United States and northern Mexico.

The identification of climatic and edaphic factors which influence the persistence (Fig. 1-13) of the 4 African grasses can be used to predict where each grass is adapted. For example, the distribution of buffelgrass, kleingrass, and weeping lovegrass is limited when mean minimum temperatures in the coldest month are 5° C or less, or 0° C or less and -5° C or less, respectively, whereas, the distribution of Lehmann lovegrass appears to be limited by the amount and distribution of summer rainfall and soil texture rather than cold temperatures. Buffelgrass requires approximately 90 growth days in summer and relatively warm, dry winters to colonize loam soils, while Lehmann lovegrass requires 30 to 40 growth days in summer to colonize sandy loam soils. Kleingrass and weeping lovegrass can be established and mature plants will persist where the summer growing season varies from 120 to 150 days, but neither actively invades nonplanted sites except in Africa where the growing season approaches 180 days.

Prior to 1975 it was economically feasible to seed degraded rangeland because petroleum was inexpensive. After 1975 the cost of petroleum dramatically increased and a successful seeding in 1 of every 10 attempts was no longer a worthwhile investment. If mechanical treatment and seeding is to remain a range improvement practice the probability of success must be improved. Thus, information which defines the relationships among climate and soils, and plant germination, emergence, persistence and reproduction is essential. A successful range seeding cannot be guaranteed if climate and soil are considered when selecting grasses for revegetation, but it will reduce the probability of failure.

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