Climate And Vegetation As Soil Forming Factors On The Llano Estacado[1]

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Although most of the Llano Estacado is devoted to field crop production, some of it is still used as native ranges for livestock. The floristic composition of these ranges is sensitive to small differences in soil, especially texture, and aspect associated with the large number of depressions of this featureless plain. An understanding of the native plant communities and the associated soils of these ranges assists both range and soil scientists in managing them. This paper describes the broad features of the vegetation and climate of the area and relates them to the soils.

Description Of The Area

"Llano Estacado" is Spanish for that part of the Great Plains physiographic unit south of the Canadian River bounded on the west by the Pecos valley in New Mexico, and on the east by the Rolling Plains of Texas. On the south it merges with the Edwards Plateau (Fenneman 1931). The Llano Estacado is a plateau without prominent topographic features but with elevation ranging from 2500 to 5000 feet, southeast to northwest. It is about 250 miles long, north to south and 125 miles wide with an area of about 20,000 square miles (Figure 1).

Climate

Classification

Russell (1945) supplied a detailed classification of Texas climates based on Koppen's terminology (Trewartha 1954, p. 381-383) and delineated several climatic types that were too small to be considered on a regional basis. With the possible exception of the extreme NW corner, all of the Llano Estacado falls under Russell's BScDw climatic type described as steppe, mesothermal with occasional microthermal years, with dry winters. A mesothermal year is one in which the mean temperature of the coldest month is 32-64°F; a microthermal year one in which the mean temperature of the coldest month is below 32°F.

Russell (1945) emphasized the importance of oscillating boundaries of climatic types and based his selection of boundaries on frequency of years that exceeded or were less than that set by his definition. He also stressed the distribution and wide variability of rainfall compared to temperature.

Temperature and Precipitation

Summer temperatures are high on the Llano Estacado. Most sta-

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[1] *Contribution from Soil and Water Conservation Research Division, Agricultural Research Service, and the Soil Conservation Service, USDA, Texas Agricultural Experiment Station cooperating.*

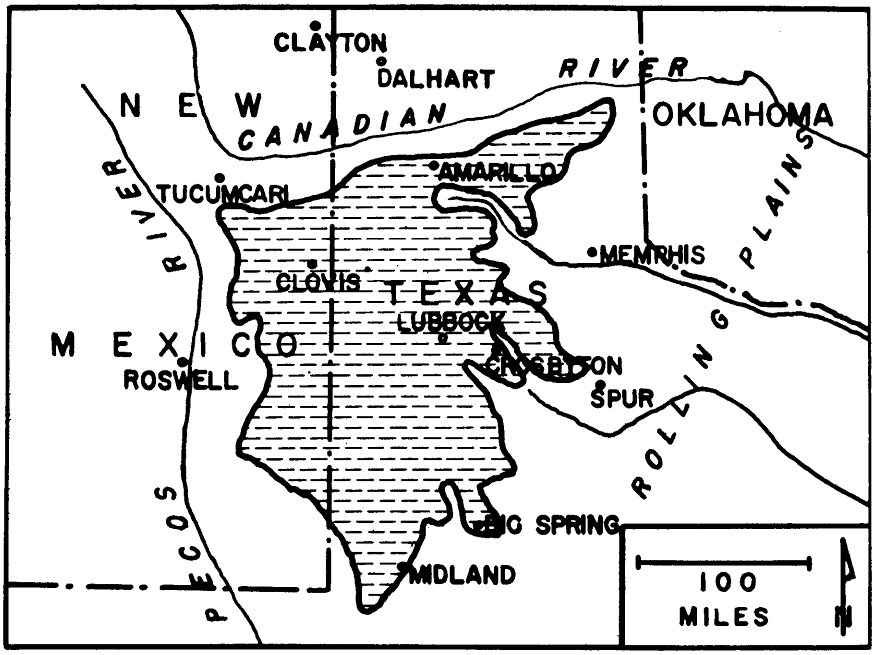

FIGURE 1. Outline map of the Llano Estacado and surrounding areas.

tions report maximums greater than 100°F during the warmer months. One feature of summer is the large diurnal temperature change; variations of 30 to 40° are common. Winter temperatures average above freezing, but short periods with below zero minimum temperatures occur nearly every year. Diurnal temperature variations are as great in winter as summer. Cold fronts may cause reductions of 40 to 50° in a few hours.

Mean monthly temperatures of 4 stations (Figure 2) indicate that temperatures are highest in the south and decrease northward with increased elevation and latitude. Big Spring has the highest mean annual temperature and Amarillo the lowest.

An important feature of the rainfall pattern of the Llano Estacado is in the summer maximum, with 70 to 80 percent of the total falling between May and October. Figure 2 shows that the rainfall occurs during the warm season; however, this distribution pattern restricts the depth to which moisture penetrates because plants extract moisture at a rapid rate.

Rainfall of the Llano Estacado varies widely from year to year (Figure 3). Although the mean annual rainfall for most stations is less than 20 inches, the maximum is usually greater than 30 inches, with minimums less than 10 inches for most stations. Clovis, with a normal precipitation of about 18 inches, received 46.91 inches in 1941 and only 7.58 inches in 1943, a variation within 4 years of more than 6 fold. Other stations show similar degrees of variation with extremes usually occurring during the same year. Areas of least rainfall have the widest variability; thus, Roswell shows a variability of about 8 fold whereas Amarillo shows variability of about 4.

Wind

Winds blow almost constantly on the Llano Estacado, and gusts exceeding 60 mph have been recorded for most stations. Average wind velocities are greater in the early spring (March totals are about 50 percent greater than for August, Figure 4), gradually diminishing to a minimum during late summer and increasing slightly toward winter. Average monthly miles of wind is never less than 1800 for Portales with most stations reporting from 2400 to 4400 miles as a minimum. Maximum miles of wind vary from 6500 for Amarillo to 4000 for Portales.

Evaporation

Total evaporation, April through September, varies from 63.39 inches at Portales to 45.53 at Spur, (Table 2). Stations having the highest mean temperatures do not necessarily have the highest evaporation rates (Figure 4); for example, although Portales has the highest evaporation rate, its mean annual temperature is lower than that of Spur, which has the lowest evaporation rate. Amarillo and Lubbock also show the effects of humidity on evaporation; Lubbock, with higher humidity, has a lower evaporation.

Mean relative humidity tends to be somewhat higher in the southeast compared to the north and northwest. Thus, Amarillo has a mean relative humidity of 53 percent whereas Lubbock has 60 percent. Moisture in the air fluctuates drastically, especially during the summer, from nearly saturation to 10 percent or less within a few days.

Figure 4 graphically shows the influence of temperature versus wind on the rate of evaporation. Evaporation for March and April, when the maximum winds occur, is considerably lower than for the warmer months of June and July, when winds are much less. However, wind movement is considerable even during the summer and contributes to the high evaporation rates on the Llano Estacado.

Insolation

High total insolation of this region influences the rate of evaporation and is an important factor contributing to the generally high summer temperatures. No station reports less than 169 clear days annually on the average; Crosbyton reports 206 and Tucumcari 234 days of clear weather (Table 1). Since, by definition, partly cloudy

Table 1. Climatological data from major weather bureau stations on and near the Llano Estacado.

Station	Temperature extremes		Precipitation extremes			Length of record (yr)		Av. Cloudiness/year	
	Maximum	Minimum	High	Low	Mean			Clear	Partly cloudy
	Degrees F	Degrees F	Inches	Inches	Inches	Temp.	Prec.	Days	Days
Amarillo, Texas	108	−14	39.75 (1923)	9.94 (1956)	21.12	66	66	160	107
Lubbock, Texas	107	− 9	40.55 (1941)	8.73 (1917)	18.89	44	46	169	94
Midland, Texas	109	− 1	30.33 (1941)	4.24 (1951)	16.20	44	51	173	93
Clayton, N. M.	102	−17	37.65 (1941)	5.54 (1936)	15.42	50	50	175	96
Roswell, N. M.	110	−15	32.92 (1941)	4.83 (1927)	12.07	61	76	184	100
Tucumcari, N. M.	108	−18	34.96 (1941)	6.13 (1934)	16.04	41	50	234	66
Clovis, N. M.	110	−17	46.91 (1941)	7.58 (1943)	18.19	38	42	207	120
Big Spring, Texas	109	− 7	29.22 (1932)	10.81 (1924)	17.39	56	60	169	104
Crosbyton, Texas	110	−10	44.42 (1941)	9.84 (1934)	21.17	47	71	206	96
Dalhart, Texas	109	−17	40.91 (1941)	9.78 (1934)	18.01	38	38	181	155
Memphis, Texas	117	−11	29.84 (1923)	11.98 (1927)	21.32	51	49	206	69

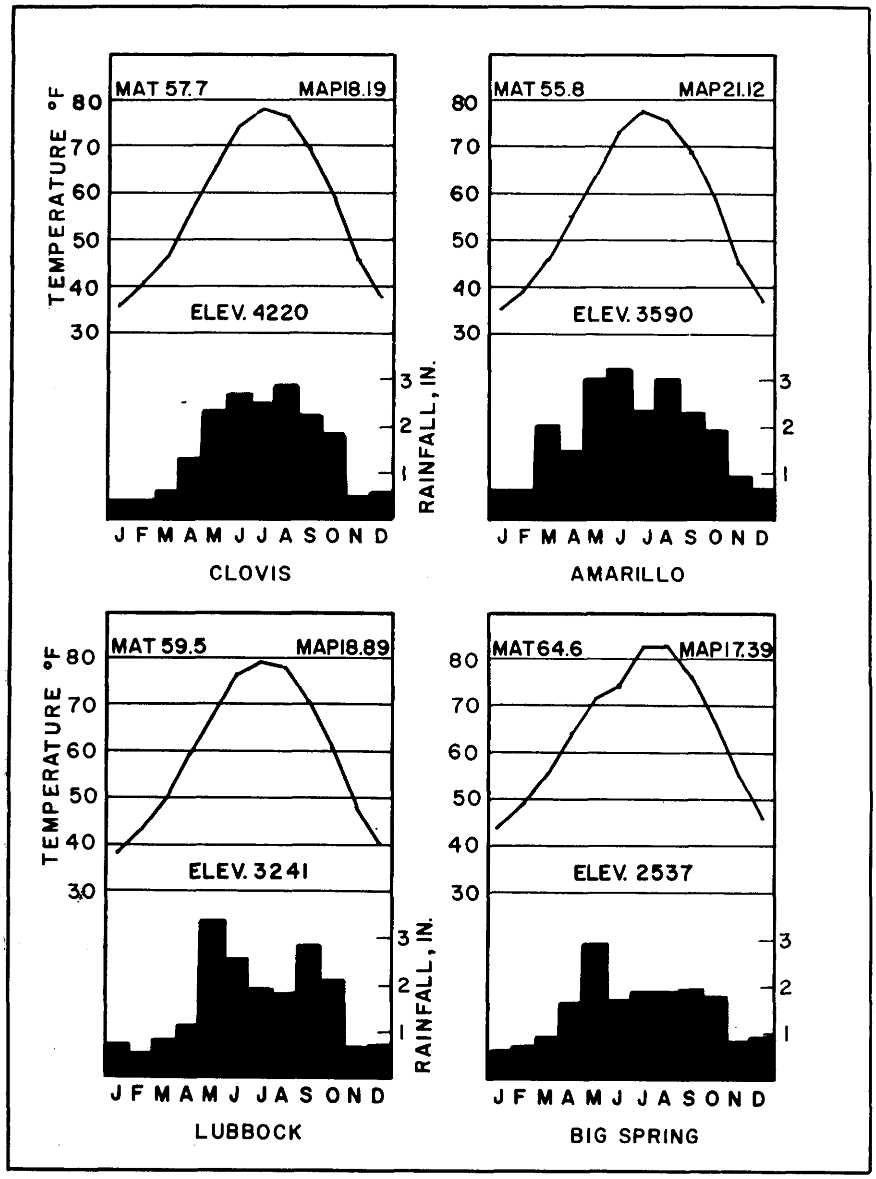

FIGURE 2. Mean monthly temperature and precipitation data for Amarillo, Lubbock, Big Spring, and Clovis.

means that 0.4 to 0.7 of the total sky is obscured during daylight, on these days a large amount of light reaches the ground surface. Clear days during winter also cause the daytime temperatures to rise above freezing during a large portion of the colder months. Daily maximum temperatures of 50 to 60°F are common during winter.

Effectiveness of Precipitation

Moisture is the critical element of the microenvironment in the area. High evaporation, temperature, and wind combine to reduce the effectiveness of the low precipitation. Finally, the yearly distribution of rainfall reduces the moisture available for soil forming processes because the vegetation is growing vigorously during the summer and draining the moisture supply.

During years of normal rainfall moisture seldom penetrates below the 3-foot level under native grass on silty clay loam soils. Unpublished studies at the Southwestern Great Plains Field Station show that a total of 28.84 inches of water (19.84 inches of rainfall plus 1.5 inches per month of added water from April through September) did not wet the soil below the 3-foot depth until October when the blue grama *(Bouteleua gracilis)* was dormant. Even 7.83 inches of rain in July failed to raise the moisture content of the soil above the wilting point at a

Table 2. Total wind and evaporation data from weather bureau stations on and near the Llano Estacado.

Station	Annual Wind	Evaporation April through October	Mean annual temperature
	Total miles	Inches	Degrees F
Amarillo, Texas	62,245	54.98	55.8
Lubbock, Texas	51,559	45.66	59.5
Big Spring, Texas	37,949	54.54	64.6
Spur, Texas[1]	58,093	45.43	61.9
Portales, N. M.	34,944	63.39	56.9
Tucumcari, N. M.[1]	41,887	55.83	57.8
Dalhart, Texas[1]	51,549	50.56	54.5

[1]These stations are not on the Llano Estacado but are in similar climatic zones. Texas stations data are from Bloodgood *et al.* (1954); Tucumcari, N. M., from Burnham (1954); and Portales from Weather Bureau records.

depth of 2 to 3 feet. Some precipitation received after the grasses become dormant remains in the profile and is available for soil forming processes and plant growth for the following season.

From moisture retention data, Taylor (1960) has calculated the depth to which a 2-inch rain will penetrate several soils of the Llano Estacado. Assuming the upper 6 inches is air dry and the rest of the profile at wilting point, these data show that 2 inches of water will only penetrate 5.4 inches of Pullman silty

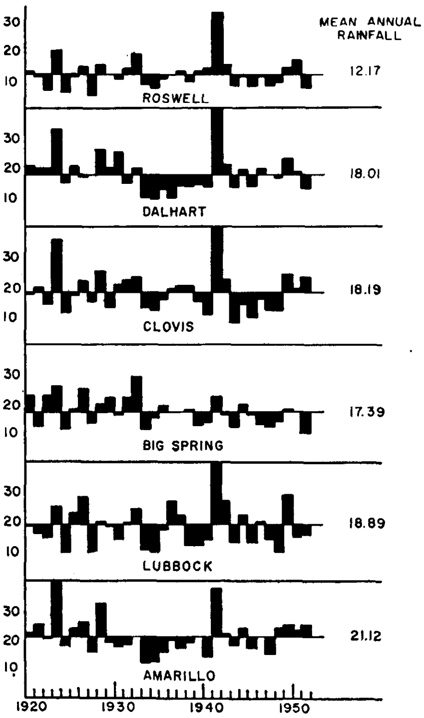

FIGURE 3. Variation from normal of precipitation (in inches) of Amarillo, Lubbock, Big Spring, Clovis, Dalhart, and Roswell.

clay loam soil. Water at this depth is lost by evapotranspiration in a short time and a similar quantity must be added to the surface layer before the deeper layers can be wetted. The same quantity of water will penetrate to greater depths for coarser soils: 14.7 inches on Amarillo fine sandy loam, 20.4 inches on Amarillo loamy fine sand, and 33.7 inches on dune sand (Tivoli sand).

From this evidence it is apparent that large areas of Llano Estacado soils are seldom wetted by a single rain much below the 0-6 inch layer where evaporation alone is effective in removing moisture. Since vegetation is also very effective in removing water from the upper 2 feet of soil it is apparent that unless heavy rains persist, these soils seldom contain moisture below this depth under native vegetation. In most years the soil is not wetted below the 2- to 3-foot zone and it is only during abnormally wet years that the deeper horizons are wetted.

Vegetational Zones

The entire Llano Estacado is covered by plant communities of the mixed prairie association of the grassland formation. These vegetational units are described by Shantz (1923), Weaver and Albertson (1956), and Moldenhauer, Coover, and Everhart (1958). Although this area is considered to belong in the mid-short grass association, certain variations include tall species. Variation in the floristic composition between the extreme northern and the southern parts of the area occurs in response to changes in climate, variations in soil texture, and minor changes in exposure associated with the playas. Under the present climate with the present stage of soil development, the plant communities growing on the various kinds of soils are those described below. Authorities for plant names are Silveus (1933), Van Dersal (1938), and Forest Service (1937).

All variations of the climax related to soils or exposure have grasses as dominants, but the composition is simple and usually consists of 2 to 4 species. Compared to the dominants, the subordinant forbs comprise many species although their total basal area is usually less than 5 percent of the total plant coverage. These forbs are prominent when flowering but are widely scattered, hence do not contribute much to the vegetational cover. West of Amarillo, galleta *(Hilaria jamesii)* comes into the climax community in response to somewhat drier conditions on the western portion of the plateau. Mesquite *(Prosopis juliflora)* is common along the north portion of the plateau next to the Canadian River, and extends completely across it in the southern part. Table 3 gives composition of vegetation occurring in the study area.

Hardland

This plant community occurs on the silty clays and silty clay loam soils on very smooth topography in the north and eastern portions of the Llano Estacado. These soils are hard when dry and, although a 4-foot profile contains about 11 inches of available water at field capacity, are difficult to wet because of low permeability owing to the high clay content.

The hardland community is

Table 3. Frequency of occurrence and basal composition of vegetation occurring in the study area. Data from a 5-year study of 10-county area north of Lubbock, Texas.

	Hardland		Mixedland		Sandyland		Sand Dune		Draws		Caliche Breaks	
Species	Frequency	Basal composition	Frequency	Basal composition	Frequency	Basal composition	Frequency	Basal composition	Frequency	Basal composition	Frequency	Basal composition
	(Percent)											
Indiangrass					66.6	13.7	16.6	20.0	37.5	16.6		
Switchgrass					66.6	16.2	16.6	15.0	62.5	33.0		
Sand bluestem					100.0	26.0	83.3	24.0	37.5	11.6	40.0	7.5
Little bluestem					83.3	22.0	66.6	46.2	25.0	15.0	80.0	25.0
Vine mesquite									37.5	40.0		
Western wheatgrass	9.0	95.0							37.5	51.6		
Alkali sacaton									12.5	10.0		
Side oats grama	3.0	10.0	80.0	42.5	66.6	31.2	50.0	13.3	62.5	15.0	100.0	53.0
Silver bluestem									62.5	13.0		
Blue grama	100.0	84.0	100.0	56.0	33.3	7.5	16.6	10.0	62.5	13.0	40.0	7.5
Buffalograss	63.6	9.3							25.0	5.0		
Canada wild rye					16.6	10.0			12.5	5.0		
Forbs	T	T	T	T	T	T	16.6	5.0	12.5	5.0	40.0	5.0
Three-awns			40.0	5.0	16.6	10.0	33.3	15.0			20.0	5.0
Sand dropseed	18.0	7.5	100.0	7.0	16.6	10.0	16.6	65.0			40.0	12.5
Hairy grama			20.0	5.0	66.6	7.5	16.6	15.0			60.0	15.0
Big sandreed					16.6	5.0	16.6	5.0				
Giant dropseed							16.6	10.0				
Galleta	11.0	40.0										
Blowout grass							16.6	5.0				
Plains bristlegrass											20.0	5.0
Shrubs											40.0	7.5

Note: The study was made of meter square quadrats by range conservationists, Soil Conservation Service. Percentages were made by visual estimates. The areas selected were relicts or properly managed ranges and represent excellent or near excellent range condition.
T = trace (0-2%)

composed primarily of 2 short grass species: blue grama and buffalograss *(Buchloe dactyloides)* and is considered to be preclimax to the mixed prairie. Under pristine conditions, or with proper range management, the grama is dominant, but with heavy grazing buffalograss becomes dominant as the grama is more available to grazing animals.

Western wheatgrass *(Agropyron smithii)* usually grows on the slopes surrounding the many depressions (playas) where somewhat more moisture is available. Along the rims of the playas, where the soil is commonly shallow and calcareous, sideoats grama *(Bouteloua curtipendula)* becomes important. Tobosa grass *(Hilaria mutica)* occurs on the southern portion of the study area and galleta occurs on the northern portion, but confined to the drier areas to the west. Although the volume of grasses is greater, forbs are by far the most diverse species.

Mixedland

Soils of this community are moderately coarse textured but range from silt loams to sandy loams; Amarillo and Dalhart fine sandy loams are common examples. They have better water relations than the hardlands because of a higher permeability rate, coarser texture, and more favorable distribution of moisture within the profile. Associated with this change in soil texture is a change in the floristic composition. Blue grama is still one of the dominants, but sideoats grama is the other important dominant replacing the buffalograss of the short grass community. The occurrence of sideoats grama is probably due to the more favorable water relations. South of Lubbock County blue grama is either completely or partially replaced by black grama *(Bouteloua eriopoda)*. Western wheatgrass is absent in this community, probably due to the coarser soil texture and the higher temperatures at this latitude. This grass is an important member of the grassland farther north.

Sandyland

Sandy textured soils such as Springer and Brownfield loamy fine sand comprise about half of the total area. Water relations of this community are superior to those of the 2 preceding ones because of the high soil permeability and coarse texture. These soils are particularly susceptible to wind erosion when the vegetational cover is removed. Sideoats grama and little bluestem *(Andropogon scoparius)* are the most important species. Small amounts of sand bluestem *(An-*

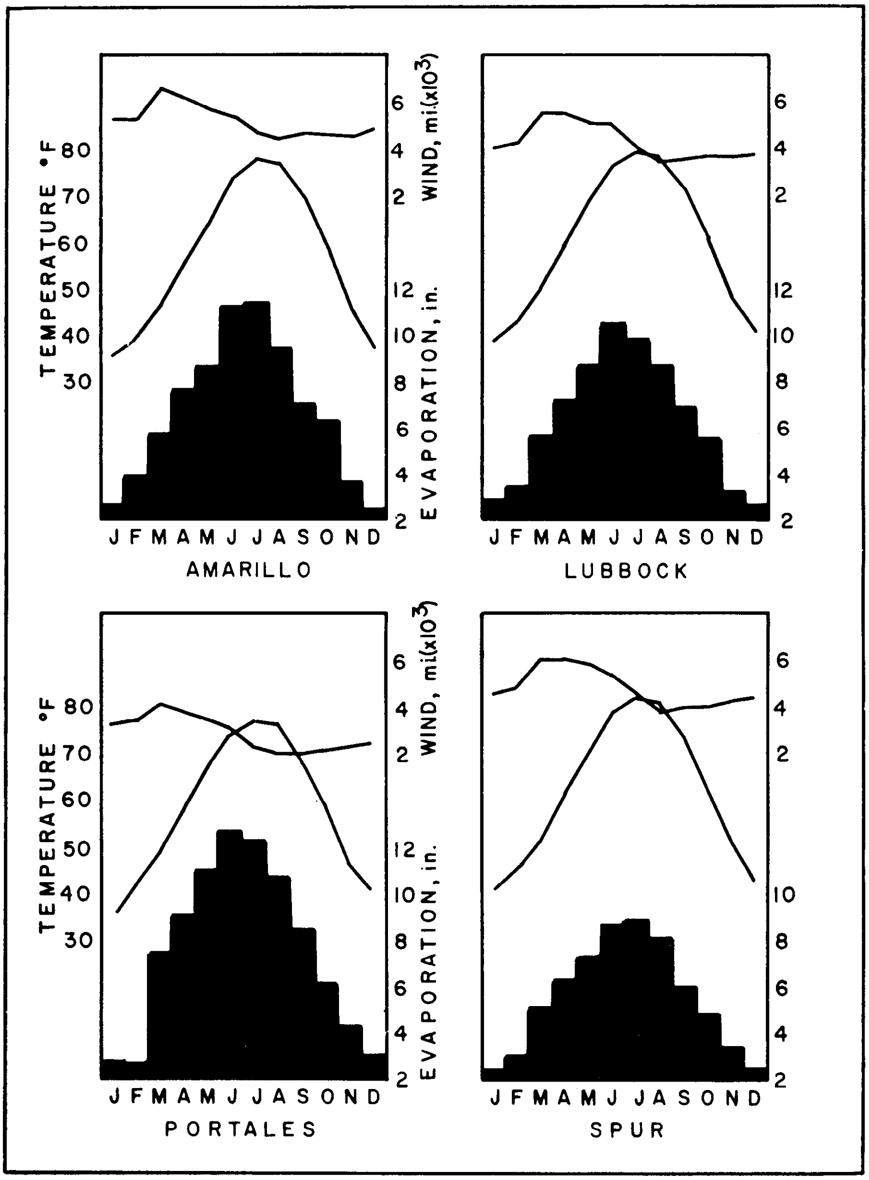

FIGURE 4. Mean monthly temperature, evaporation, and wind for Amarillo, Lubbock, Spur, and Portales.

dropogon hallii) and Canada wild rye *(Elymus canadensis)* replace blue grama. Sand dropseed *(Sporobolus cryptandrus)* and purple three-awn *(Aristida purpurea)* tend to increase with moderate to heavy grazing at the expense of the other grasses. Small soapweed *(Yucca glauca)* and sandsage *(Artemisia filifolia)* are important members here in contrast to the hardland and mixedland communities. Havard's oak *(Quercus havardii)* is important in stabilizing the more dunline portions of these soils, especially in the south. This oak is not usually found north of Portales where sandsage is the more common shrub.

Sand Dune

True stabilized sand dunes, characterized by Tivoli fine sand, occupy a relatively small percentage of the total area. These dunes have a very high infiltration rate with little or no runoff even during heavy rains. As a result of the deep moisture penetration of these soils, plant roots must reach to great depths for water, and this results in a plant assemblage different from that on finer textured soils.

Sand and little bluestems make up about 80 percent of the total grass composition. Other grasses are big sandreed *(Calamovilfa gigantea)*, giant dropseed *(Sporobolus giganteus)*, hairy grama *(Bouteloua hirsuta)*, sand paspalum *(Paspalum stramineum)*, sand dropseed, and sideoats grama. The total number of grass species is several times higher for this community than for those described earlier. Small soapweed and sandsage are the 2 most important shrubs as far south as Portales; farther south sandsage is replaced by Havard's oak.

Draws

Although their total area is minor, the draws have a more diverse floristic assemblage because of added moisture from runoff and the varying texture of the soil. Many of the grasses already described, sideoats grama, western wheatgrass, alkali sacaton *(Sporobolus airoides)*, sand bluestem, Indiangrass *(Sorghastrum mutans)*, and switchgrass *(Panicum virgatum)* occur in the draws. Buffalograss and saltgrass *(Distichlis stricta)* are present in small amounts, along with several high moisture requiring species such as rushes, sedges, willows, and cottonwood.

Caliche Breaks

Probably the most complex plant community is that associated with the escarpment and canyons of the Llano Estacado. The typical soil is Potter loam associated with miscellaneous exposed geologic material. In addition to most of the grasses that grow on the upland, several shrubs and small trees grow in the rocky soil bordering the plateau. The shrubs include mountain mahogany *(Cercocarpus montanus)*, Havard's oak, chokecherry *(Prunus demissa)*, western hackberry *(Celtus occidentalis)*, skunkbush sumac *(Rhus trilobata)*, and catclaw acacia *(Acacia greggii)*. Juniper *(Juniperus pinchotti)* grows in the rocky soil on the margins and in the breaks with some pinyon pine *(Pinus edulis)* in the extreme northwest and in some canyons along the eastern escarpment.

Pleistocene Climate And Vegetation

Geologists have produced abundant evidence for climatic changes during the Pleistocene. During the advances of the continental glaciers the general climate of the Llano Estacado was cooler and more moist than during the longer interglacial time (Leopold 1951). Frye and Leonard (1957a) cite paleontological evidence that there was increasing aridity following the Kansan advance which continued to recent time with minor oscillations. During this desiccation of the plains the aeolian sediments covering the Llano Estacado were deposited. The faunal evidence suggests that the climate was then similar to that today.

Antevs (1954) concludes that at the latitude of Santa Fe during the Carey substage of Wisconsin time, the life and climatic zones were about 4000 feet lower than they are today. This compression of life zones occurred during the last pluvial interval when the climate was both cooler and more moist than now.

More recent evidence of changing climate with attendent vegetational changes is afforded by Wendorf et al. (1961) who studied the pollen distribution of playa sediments as indicators of past environmental conditions. They found that the relative proportions of pollen grains through the lake sediments indicate a series of changes in climate and vegetation within the last 12,000 years. Pollen analyses indicate that a gallery type forest composed of pine, spruce, and fir in addition to the dominant grasses occurred on or near the Llano Estacado during pluvial cycles. During the dry periods grasses and other zeric plants were exclusive occupiers of the areas as the trees retreated because of the lack of sufficient moisture.

These findings vary with those of Frye and Leonard (1957b) who concluded that the only trees on the Llano Estacado during pluvial periods were deciduous and were restricted to narrow bands along streams. However, Frye and Leonard based their evidence on preserved seeds and did not make pollen counts; their interpretation of past climates is based on invertebrate fossil evidence.

The evidence suggests that during arid periods the Llano Estacado supported a steppe type vegetation. During pluvial intervals the same area also supported coniferous species. The forest species are believed to have invaded the area during periods of high rainfall and cooler summer temperatures and retreated to high elevations during drought. Evidence indicates several such advances and retreats during the past 12,000 years.

Discussion

Weather elements combine to cause the rigorous climate of the Llano Estacado, with rapidly changing extremes, particularly during the winter months. The climate with its moderately high summer temperature, high total windiness, and low relative humidity causes a high evapotranspiration potential and results in rapid removal of soil moisture following a rain. Under pristine conditions the climax vegetation evolved into communities that utilize the limited moisture by breaking dormancy and growing rapidly with available moisture. Moreover, the dominant species are grasses with deep, well-developed root systems that extract water from large volumes of the soil. Thus, the native vegetation uses the summer rainfall to advantage; however, removal of water by the vegetation results in limited penetration of rainfall into the soil profile. Water from one shower is removed before another wets the soil.

Zonal soils of the Llano Estacado have been placed in the Reddish Chestnut, Chestnut, or Reddish Brown great soil groups by scientists of the Soil Conservation Service. Jenny (1941) cites evidence indicating that under an arid climate the resultant Brown and Chestnut soils have a carbonate zone at a depth of 10 to 20 inches. This, it seems, holds for soils that have formed under continued aridity from loamy parent material. However, the major soils on the Llano Estacado have the carbonate accumulation from 36 to 60 inches deep, although some concretions and films and threads of calcium carbonate appear nearer the surface. This suggests that the zone of maximum accumulation of lime may not be related to the climate of today but to past, more moist climates. The moderately fine texture of much of the area would tend to prevent deep penetration of moisture and cause lime to accumulate even closer to the surface.

The shallow penetration by rainfall is illustrated by the Pullman soil which is frequently underlain by buried soil. Although it is underlain by nonindurated $CaCO_3$, this buried soil is frequently noncalcareous in the upper horizon. The modern soil has a calcareous zone within the B_2 above the buried soil. The alternation of lime zones suggests that water does not penetrate to the buried horizon often enough to deposit $CaCO_3$ within this noncalcareous zone. There is no evidence of buried profiles in the Amarillo series. The upper horizons of the Amarillo soil are noncalcareous; however, with increasing depth the soil becomes calcareous and is often highly calcareous at depths of 4 to 6 feet.

Summary

The climate of the Llano Estacado is characterized by low rainfall with a summer maximum, high wind velocities, moderately high summer temperatures, and moderate to low relative humidities. Winters may have frequent short periods of near zero temperature, but total snowfall is small and winters are open. An important feature of winter is the rapid change in temperature with the passage of cold fronts; variations of 50° from one day to another are not unusual. Precipitation effectiveness is low because of the high evapotranspiration stress and the convectional type rainfall. The soil seldom is wetted below 3 feet during years of normal rainfall.

Under pristine conditions, the area was covered by grassland communities of simple floristic composition. Evidence suggests the possibility of a coniferous forest during pluvial intervals which, in the past, have alternated with periods of aridity. Local conditions caused by soil texture and topographic control of precipitation effectiveness result in several variations of the climax vegetation. Roots penetrate to a shallower depth on the Pullman soil but to a greater depth on the sandier soils of the Amarillo series, reaching a maximum on the dune sands of the Tivoli series.

Although the aerial portions of the climax grass species seldom exceed 1½ feet in height, the roots are extensive and extract moisture from large volumes of soil. The extensive ramification of the root system tends to dry the soil to permanent wilting percentage rapidly after a rain and to improve the structure and permeability of the soil. Moreover, this thorough permeation by grass roots contributes to the deeper distribution of organic matter of the soil without actual movement of the organic matter after mineralization. Since water is lacking, the intensity of soil forming processes is reduced because of the low precipitation which falls during the time of year when climax vegetation is removing moisture at a maximum rate.

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