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Variations in Vegetation and Microclimate on North- and South-Facing Slopes in the Mixed Prairie near Hays, Kansas

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VARIATIONS IN VEGETATION AND MICROCLIMATE

ON NORTH- AND SOUTH-FACING SLOPES

IN THE MIXED PRAIRIE NEAR HAYS, KANSAS

being

A thesis presented to the Graduate Faculty

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by

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THESIS ABSTRACT

Nichols, James T. 1961. Variations in vegetation and microclimate on north- and south-facing slopes in the mixed prairie near Hays, Kansas.

North-and south-facing slopes were studied to determine differences in vegetation and microclimate. Vegetation was analyzed by line transects. The study on microclimate included soil and air temperatures, evaporation, light intensities, and wind velocities. Appropriate instruments were used for each microclimatic factor, and were identical on both slopes.

The microclimate on north-facing slopes was less intense and severe than on south-facing slopes, resulting in a difference in vegetation. The protected position of the north-facing slope has provided a habitat which is favorable to more mesophytic plants. In contrast, the exposed position of the south-facing slope has limited the vegetation to more xerophytic species.

Big bluestem (Andropogon gerardi) and little bluestem (A. scoparius) were the dominant grasses on the north-facing slope, whereas, buffalo grass (Buchloe dactyloides), blue grama (Bouteloua gracilis), and side-oats grama (B. curtipendula) were dominant on the south-facing slope. Several species of forbs were restricted to, or were much more abundant on one slope or the other. Woody species were common on north-facing slopes, but were seldom found on south-facing slopes.

Seasonal averages of microclimatic conditions are as follows: Evaporation rates were 88.51 ml. per week more on the south-facing

slope. Wind velocities were 3.33 MPH faster on south exposures and were closely correlated with evaporation.

Soil temperatures on the north-facing slope averaged 11.23° F. cooler at 1-inch depth, and 10.20° F. cooler at 6-inch depth. Maximum air temperatures were 88.25° F. for the south-facing slope and 85.77° F. for the north-facing slope. Minimum air temperatures were 61.65° F. for south exposures, and 60.04° F. for north exposures. Light intensities averaged 4068.86 foot candles at ground level, and 4693.15 foot candles above the vegetation on the south-facing slope, compared to 2927.60 foot candles at ground level and 3632.2 foot candles above the vegetation on the north-facing slope.

Yields of forage on the north-facing slope were 1,727.7 pounds per acre, compared to 838.1 pounds per acre on the south-facing slope. Mid grasses contributed most to yields on the north-facing slope, whereas, short grasses provided the largest part of the yield on the south-facing slope.

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INTRODUCTION

Variations in vegetation because of different slope exposures are evident in many areas of uneven topography. Vegetative variations are more pronounced in timbered, mountainous areas than in rolling grasslands. Even so, the differences shown by grassland vegetation is great enough to be of ecological importance.

The greatest variation in vegetation is most commonly on north- and south-facing slopes. North-facing slopes support a more mesic type of vegetation, while the south-facing slopes support more xeric vegetation. In certain areas, trees and tall grasses may be dominant on north-facing slopes, while the south-facing slopes may be sparsely covered with short grasses and other xeric plants. Growth habit and seasonal aspect of certain species are other differences which may be observed.

Variations in vegetation due to different slope exposures are often a result of the effect of microclimate. Microclimate refers to the strictly local combination of atmospheric factors which are caused by differences in topography and plant cover. Within each area of climatic conditions (macroclimate), there exists numerous microclimatic variations. The microclimate on south-facing slopes is often more severe than north-facing slopes and may be a controlling factor in the variations in vegetation.

This study was initiated for two purposes: (1) to determine the variations in vegetation in the mixed prairie on north- and south-facing slopes, and (2) to measure the differences in microclimate in respect to north- and south-facing slopes.

RELATED LITERATURE

Various studies have been made which indicate that different slope exposures show variations in vegetation and microclimate. Shreve (1915) as indicated by Weaver and Clements (1938) stated that lodgepole pine (Pinus contorta murrayana) is generally found between elevations of 8,000 to 10,000 feet, but on warm, south-facing slopes it may extend as high as 11,000 feet and as low as 7,500 feet on cold, north-facing slopes.

Azzi (1956), working in the Apennines of Europe, indicated that microclimate may be sufficiently different to have olive trees on the south side of the watershed and chestnut trees on the north side, both at the same altitude.

Shanks and Norris (1950), using unpublished data from Jackson (1949), stated that north- and south-facing slopes at the University of Tennessee Experiment Station are sufficiently different to warrant recognition of two contrasting association-segments within an inter-related mixed mesic to sub-xeric complex. Ridge tops and south-facing slopes were characterized by one of these segments, and north-facing slopes and valley bottoms were characterized by a contrasting association-segregate--each having a definite different complex of species.

Oosting and Hess (1956) concluded that survival of hemlock (Tsuga canadensis) 200 miles from its normal range was due to the microclimate of steep slopes. Hemlock was able to survive on more xeric slopes, whereas, more mesophytic species were excluded.

Gardner (1950), working in the desert grasslands of New Mexico, found a definite difference in species and basal cover in respect to slope exposure. Since the areas studied were protected from grazing, variations were considered to be due to differences in micro-environment and not to disturbances such as grazing.

Dix (1958) conducted a study in the Little Missouri badlands of North Dakota, and indicated that slope and exposure have a definite influence on soil moisture, which in turn regulates the type of vegetation present. Behavior of the dominant species was based on a moisture gradient. Blue grama and western wheatgrass, species of the more xeric Great Plains, were more important at the low end of the moisture gradient; whereas, little bluestem, side-oats grama, and plains muhly, species of the more mesic midwestern prairies, were more important at the opposite end of the moisture gradient (high moisture content).

In the Big Bend country of Southwestern Texas, Cottle (1932) stated that trees and tall grasses grow along north-facing slopes of the mountains, while south-facing slopes are sparsely covered with short grass and other xeric vegetation. North-facing slopes exhibited a different type of vegetation due to its protection from the south wind and heat. Environmental conditions on the south-facing slope were much less favorable to plant growth.

Weaver (1917), working in Southeastern Washington and adjacent Idaho, stated that spring growth is often 10 to 17 days earlier on the warmer exposed south-facing slopes. Weaver also stated that the density was much less on south exposures, 115 plants per square meter, as compared to more than 200 plants per square meter on the north-facing slope. The most pronounced difference indicated by Weaver's study was the smaller number or total absence of more mesophytic-plant-forms on south-facing slopes. Mesophytic plants were located on the more moist, better protected north-facing slopes.

Albertson (1937) studied the mixed prairie near Hays, Kansas, and indicated that roots of plants located on south-facing slopes were more shallow than those of plants on north-facing slopes. Dominant grasses on the south-facing slope were blue and hairy grama, whose roots were usually confined to the surface 18 inches. These grasses were not dominant on the north-facing slope, but were replaced by big bluestem (Andropogon gerardi), switch grass (Panicum virgatum), and indian grass (Sorghastrum nutans). Roots of these grasses reached depths of 6 to 8 feet.

Daubenmire (1959) stated that a slope of as little as 5° towards the pole reduces soil temperatures approximately as much as 300 miles latitude in the same direction. Oosting (1958) indicated that maximum effectiveness of insolation occurs only when striking a surface at right angles. Therefore, in the Northern Hemisphere, a south-facing slope receives more insolation per unit area than a flat surface, and a north-facing slope receives even less. Shanks and Norris (1950) found that south-facing slopes had consistently higher maxima temperatures than north-facing slopes, reaching a difference of 11° in October. North-facing slopes had a lower minima than south-facing slopes, not exceeding 2° and usually less than 1°.

McMinn (1952) indicated that slope exposure influenced the amount of available soil moisture. The north-facing slopes had a decreased rate of evaporation, lower temperatures, and a different type of vegetation, therefore, soil drouth was not as serious as on more exposed south-facing slopes.

The dwarfing effect of consistent high wind velocities has been experimentally demonstrated by Whitehead (1957). Kucera (1954) studied the statistical relationship of evaporation rates to vapor pressure deficit and wind velocity, and indicated that increased wind velocities increased the rate of evaporation substantially.

METHODS OF STUDY

Three different areas were selected for study, each having a north- and south-facing slope of approximately the same inclination. Vegetational analysis and yields were taken on both slopes in all three areas, however, the study on microclimate was made only on the College Pasture.

Analysis of the vegetation included grasses, forbs, and woody species. Grasses were sampled by the point transect method (Levy and Madden, 1933). Line transects were established by using a string stretched from top to bottom of each slope. Along these lines, point transects were placed consecutively so that a continuous sample was taken. The point transect used in this study was 24 inches long and contained 10 points (Fig. 1), thus enabling a point sample to be taken every 2 inches. Data were recorded on mimeographed sheets and later calculated as to percentage basal cover, percentage composition, and percentage frequency (Levy and Madden, 1933, and Coupland, 1950).

Scientific names of grasses used in this study are those of Hitchcock and Chase (1950).

Fig. 1. Point transect used in sampling grasses.

Forbs and woody vegetation were sampled by using one- by three-foot rectangles (Fig. 2). Samples were taken along the same lines used for point transects. The one- by three-rectangles were placed end to end from top to bottom of each slope, thus making continuous belt transects one foot wide. Each species was recorded as to numbers per sample, and later calculated as plants per square foot. Nomenclature for scientific names of forbs follows Rydberg (1932).

Yields were determined by clipping areas 3.1 feet square at the end of the growing season. Forbs, short grasses, and mid grasses were weighed separately. Weights, in grams, were multiplied by 10 to convert to pounds per acre.

Soil profiles were described at three positions on both slopes of the College Pasture. Descriptions were made according to standard Soil Conservation service procedure (Soil Survey Staff, 1951).

The portion of the study concerned with microclimate covered the major part of the growing season of 1960. Exclosures 15 feet wide and extending from top to bottom of each slope were fenced to protect the instruments. Identical studies were conducted on both slopes for determination of air temperatures, soil temperatures, rates of evaporation, wind velocities, and light intensities (Fig. 3).

Air temperatures were recorded by using Bendix-Friez hygrothermographs. Maximum and minimum daily air temperatures were averaged to obtain maximum and minimum weekly averages.

Soil temperatures were taken at one-inch and six-inch depths. Standard mercury-bulb thermometers were permanently placed at the de-

Fig. 2. One-by-three foot rectangles used for forb count.

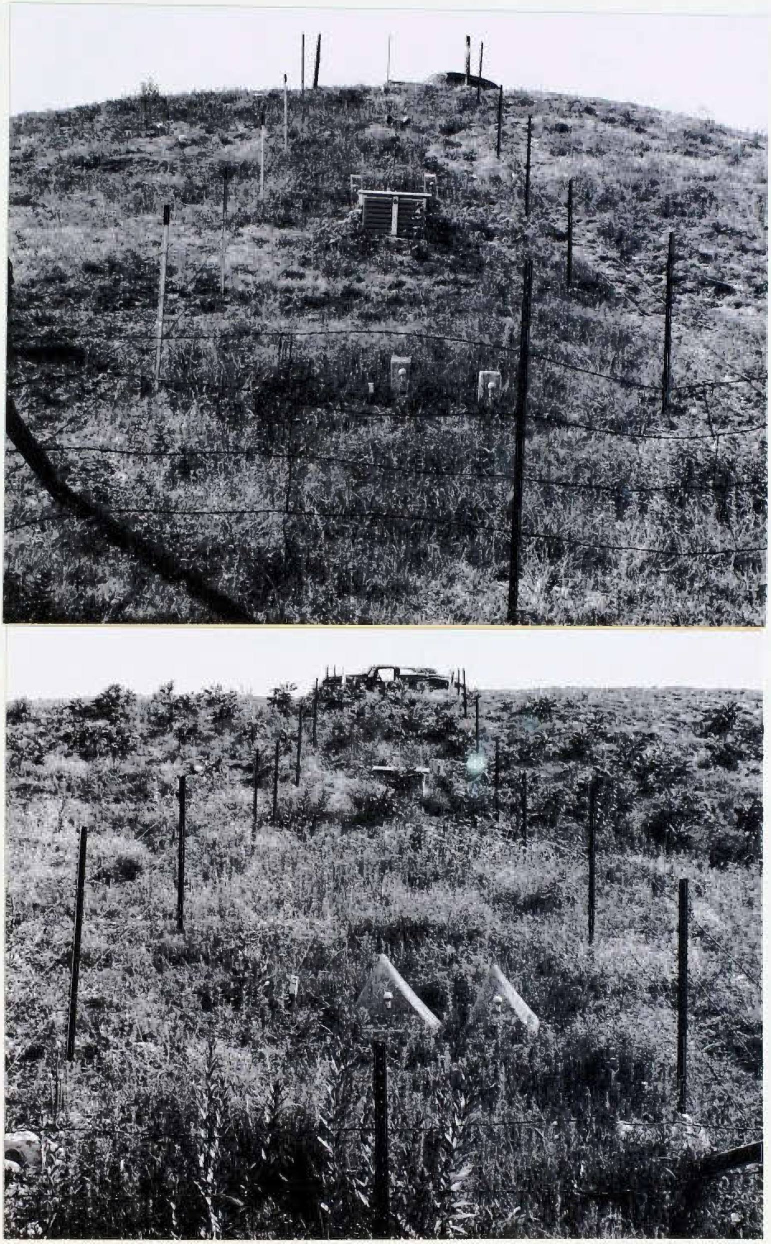

Fig. 3. Instruments in exclosures for measuring micro-climate on south-facing (top) and north-facing slopes (bottom). College Pasture, 1960.

sired depth by first making a hole with a steel rod. Readings were recorded once a week at 1:30 p.m.

Evaporation rates were measured by using Livingston-type, clay atmometer bulbs (Livingston, 1935). Duplicate pairs of atmometers were placed at the top, center, and bottom positions of each slope at a height of 9 inches above the soil surface. Distilled water was used to minimize the accumulation of mineral salts deposited by evaporation. Each atmometer was refilled once a week, and the amount of water used recorded as ml. per week.

Bendix totalizing anemometers were used for recording wind velocities. An anemometer was permanently placed at the center position three feet above the soil surface. Readings were taken once a week and recorded as total miles of wind. Later these readings were converted to average weekly miles per hour.

Light intensities were measured by using a Weston quartz-filter light meter. Readings were recorded once a week at 8:30 a.m., 1:30 p.m., and 6:30 p.m. All readings were taken parallel with the soil surface, both above the vegetation, and at the ground surface. Readings were averaged for all 3 daily recordings, and all 3 positions on each slope to give an average light intensity for each month.

DESCRIPTION AND LOCATION OF STUDY AREA

This study was conducted in the mixed prairie of west-central Kansas. Numerous studies have been made on the mixed prairie by Albertson (1937, 1938, 1939, 1941, 1942, 1943, 1945), Tomanek and Albertson (1953, 1957), Tomanek _et al._, (1958), and Weaver and Albertson (1956).

The three areas selected for study were all located within a 30 mile radius of Hays. All three areas were typical of the mixed prairie near Hays, Kansas.

Climatic conditions in the Hays area are often variable and quite extreme. The average frost-free period extends from the latter part of April to the early part of October, thus making a growing season of approximately 165 days. Normal precipitation is from 20 to 24 inches annually, but extremes have varied from 43.34 inches in 1951 to 9.21 inches in 1956. Air temperatures and relative humidity are also quite variable. During periods of drought, air temperatures may exceed 100° F., and relative humidity may decrease to 15 to 25 per cent. Effect of drought on vegetation is often quite pronounced and has been studied in detail by Weaver and Albertson (1936, 1939, 1940, 1940a, 1943, 1946), Albertson and Weaver (1936), Albertson (1942a), Weaver (1944, 1944a), Weaver and Mueller (1942), and Albertson et al. (1957).

Vegetation of the mixed prairie near Hays is typically a mixture of short and tall grasses. Short and tall grasses are not always intermixed and dispersed uniformly, but are often limited in distribution by variations in environmental factors. Short grasses commonly express their dominance on sites of limited available water, such as upland areas. South-facing slopes often support this type of vegetation. In contrast, tall grasses are dominant on sites of greater water availability, such as lowlands and north-facing slopes.

The topography of the mixed prairie is rolling, and is often broken in appearance along tributaries of many of the streams (Fig. 4). Uneven

Fig. 4. Bemis Pool area showing typical rolling, broken topography of the mixed prairie. South-facing slope in foreground, and north-facing slope in the center.

topography may vary the environmental conditions of an area sufficiently for distinct differences in plant communities to exist.

Soils of the mixed prairie near Hays have been described by Albertson (1937). Most of the soils are of a residual type developed from Fort Hays Limestone. The tops of many of the hills are capped with loessial material which is often quite deep. The ravines have alluvial soil which is not mature because of run-off and deposition from surrounding hills. Soils of the upland are silty, clay loam with a well developed, mature profile. A calcium carbonate layer often exists at a depth of about 3 feet. Soils of the hillsides are often very rocky and shallow. Limestone bedrock is exposed in many places, especially on the brows of hills. Percolation rates are often higher on the hillsides than on the upland or lowland.

The first study area was the College Pasture, located approximately 2.5 miles west of Hays. This area is part of the Fort Hays Kansas State College Farm. The College Pasture is approximately 750 acres of rolling, native grassland. It has been moderately grazed since its acquisition in 1902.

The second area studied was near Cedar Bluff Reservoir, 30 miles west of Hays. This area is composed of approximately 95 acres of native grassland, and owned by the Kansas Fish and Game Commission. Fort Hays Kansas State College has a lease on this area for research purposes. The Cedar Bluff study area has been protected from grazing since 1950 when construction started on the Cedar Bluff Dam.

The third study area was an area of native grassland located approximately 16 miles northeast of Hays. This area is situated in what is known as the Bemis Pool. Light grazing has been practiced in past years, but the vegetation is near relict condition.

RESULTS

Vegetation

Grasses. Tall grasses were dominant on the north-facing slope, whereas, short grasses were dominant on the south-facing slope (Fig. 5). Fig. 6 illustrates the differences in percent composition between north- and south-facing slopes. Little bluestem (*Andropogon scoparius*) and big bluestem (*Andropogon gerardi*) on the north-facing slope comprised 57.08 and 21.81 percent of the vegetation, respectively (Table I). Thus, they made up 79.89 percent of the total vegetation on the north-facing slope but contributed only 14.35 percent to the vegetation on the south-facing slope.

Dominant species on the south-facing slopes were buffalo grass (*Buchloe dactyloides*), blue grama (*Bouteloua gracilis*), and side-oats grama (*Bouteloua curtipendula*) (Table II). These three grasses furnished 70.21 percent of the total grasses. Of this total, buffalo grass contributed 24.38 percent, blue grama 18.93 percent, and side-oats grama 26.90 percent. On the north-facing slope, these three grasses made up only 18.76 percent of the total vegetation, most of which was side-oats grama. Blue grama and buffalo grass contributed less than 1 percent to the grasses on the north-facing slope. Side-oats grama was found abundantly on both north- and south-facing exposures and did not show preference for either slope.

Fig. 5. Variations in vegetation on a north-facing slope (top), and a south-facing slope (bottom). Note taller grasses on north-facing slope.

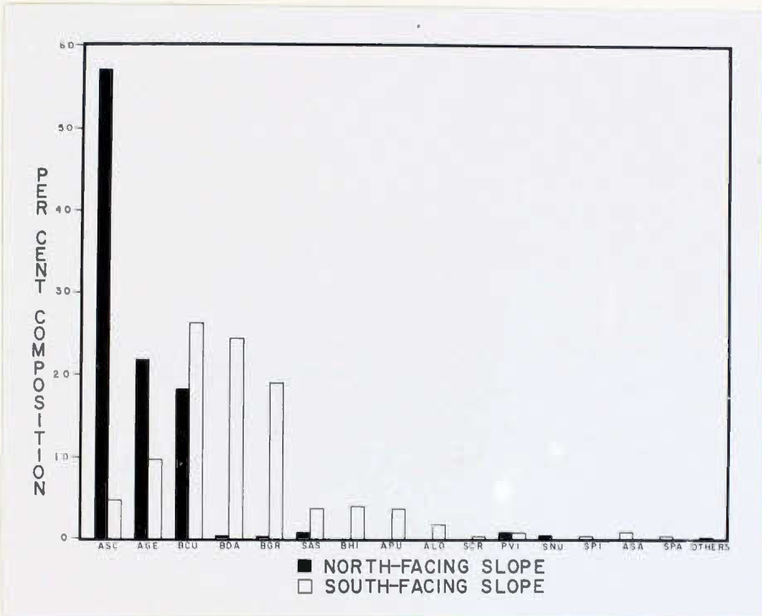

Fig. 6. Variations in percent composition of grasses on north- and south-facing slopes. Average of three different areas. Asc, *Andropogon scoparius*; Asa, *A. saccharoides*; Age, *A. gerardi*; Bcu, *Bouteloua curtipendula*; Bhi, *B. hirsuta*; Bgr, *B. gracilis*; Bda, *Buchloe dactyloides*; Sas, *Sporobolus asper*; Spi, *S. pilosus*; Scr, *S. cryptandrus*; Apu, *Aristida purpurea*; Alo, *Aristida longiseta*; Pvi, *Panicum virgatum*; Snu, *Sorghastrum nutans*; Spa, *Schedonnardus paniculatus*.

Table I. Average percentage composition and percentage frequency of grasses on north-facing slopes. Average of all three areas

Species	Percentage composition	Percentage frequency
Little bluestem	57.08	55.09
Big bluestem	21.81	30.27
Side-oats grama	18.16	21.19
Tall dropseed	.88	1.11
Switch grass	.85	1.00
Indian grass	.35	.56
Buffalo grass	.35	.42
Blue grama	.25	.55
Canada wildrye	.27	.42

Table II. Average percentage composition and percentage frequency of grasses on south-facing slopes

Species	Percentage composition	Percentage frequency
Side-oats grama	26.90	29.17
Buffalo grass	24.38	20.97
Blue grama	18.93	20.16
Big bluestem	9.75	8.04
Little bluestem	4.60	2.56
Hairy grama	3.97	5.70
Purple three-awn	3.67	5.60
Tall dropseed	3.58	4.84
Red three-awn	1.73	2.61
Silver beard grass	.91	1.61
Switch grass	.78	.57
Sand dropseed	.38	.45
Hairy dropseed	.28	.52
Texas crabgrass	.28	.52

A larger number of grass species were found on the south-facing slopes than north-facing slopes, 14 and 9, respectively.

Certain species were restricted to one slope or the other. Indian grass (Sorghastrum nutans) and Canada wildrye (Elymus canadensis) were found only on the north-facing slopes. These grasses are characteristic of mesic habitats. Numerous other species were restricted only to south-facing slopes. Included in this list were hairy grama (Bouteloua hirsuta), purple three-awn (Aristida purpurea), red three-awn (A. longiseta), sand dropseed (Sporobolus cryptandrus), hairy dropseed (S. pilosus), silver beard grass (Andropogon saccharoides), and texas crabgrass (Shedonnardus paniculatus). These grasses occupy more xeric habitats.

Forbs and woody plants. Several species of forbs were restricted to, or were much more abundant on one slope than the other. Characteristic plants of the south-facing slope, which were very sparse or totally absent on the north-facing slope, are as follows:

Common Name	Scientific Name
Broom snakeweed	Gutierrezia sarothrae
Heath aster	Aster ericoides
Mule's tail	Leptilon canadense
Narrow-leaf-four-o'clock	Allionia linearis
Prickly pear cactus	Opuntia macrorrhiza
Venus's looking glass	Specularia leptocarpa
Green thread	Thelesperma gracile
Scarlet gaura	Gaura coccinea
Blazing star	Liatris punctata
Hairy evolvulus	Evolvulus nuttallianus

Common Name	Scientific Name
Green violet	Calceolaria verticillata
Missouri loco	Xylophocos missouriensis
Spiny sideranthus	Sideranthus spinulosus
Soap weed	Yucca glauca
Stinging spurge	Tragia ramosa
False pennyroyal	Hedeoma hispida
Pennyroyal	Hedeoma camporum
Salmon colored mallow	Sphaeralcea coccinea

Typical forbs of the south-facing slope are characteristic of more xeric habitats of the Great Plains. In contrast, the north-facing slopes were dominated by more mesic-type forbs, including several species of woody or shrubby plants. Shrubs were seldom found on south exposures. The following is a list of forbs and shrubs typical of north-facing slopes:

Common Name	Scientific Name
*Lead plant	Amorpha canescens
Maxmillian sunflower	Helianthus maximiliani
Missouri goldenrod	Solidago glaberrima
*Smooth sumac	Rhus glabra
Compass plant	Silphium laciniatum
Arkansas spurge	Galarrhoeus arkansanus
*Wild rose	Rosa suffulta
Freemont's leather plant	Viorna fremontii
Mat spurge	Chamaesyce geyeri

Common Name	Scientific Name
Rigid-leafed goldenrod	Oligoneuron rigidum
*Bessy's plum	Prunus besseyi
*Buck brush	Rhus trilobata
Poison ivy	Toxicodendron radicans

*Shrubs or woody plants

Density of forbs was not significantly different between north- and south-facing slopes. Density on the north-facing slope was slightly higher, 4.55 plants per square foot, compared to 4.29 plants per square foot for the south-facing slope. Many of the plants on the north-facing slope were taller, making them much more conspicuous.

The brow of each slope was characterized by shallow soil interspersed with fragmented limestone. Several species of forbs were common to both slopes on this position and type of soil. The principal plants found here were Aster fenderii, A. oblongifolius, Scutellaria resinosa, Petalostemon purpureus, Paronychia jamesii, Echinacea angustifolia, Sabulina texana, Tetraneuris fastigiata, Lesquerella ovalifolia, and Houstonia angustifolia.

Other forbs which were found on deeper soil and were abundant on both north- and south-facing slopes were Helianthus annuus, Psoralidium tenuiflorum, Ambrosia coronopifolia, Verbena stricta, and Aster multiflorous. Of these Ambrosia coronopifolia was the most abundant for both slopes.

Phenological development. Initiation of growth at the beginning of the growing season was considerably earlier on the south-facing slope.

By the middle of April, numerous species were 2 to 4 inches tall, whereas, on the north-facing slope, most of the plants were just emerging.

Time of flowering was also considerably different with respect to slope exposure. By June 1, 22 species had flowered on the south-facing slope, compared to 15 for the north-facing slope. Later in the growing season, the north exposure had more flowering species than the south exposure. Blue grama and buffalo grass, two of the dominant grasses on the south-facing slope, were both flowering by the second week of July. In contrast, the dominant grasses of big and little bluestem on the north-facing slope were not in flower until the latter part of August. Side-oats grama flowered approximately the same time on both slopes.

Seasonal growth of big bluestem and side-oats grama were noticeably different on north- and south-facing slopes (Table III). In the early part of the growing season side-oats grama maintained a taller height on the south-facing slope, but by the middle of July droughy conditions became more severe and the reverse was true. Throughout the growing season, big bluestem was taller on the north-facing slope, and was over twice as tall by September. A reduction in height was noticeable during periods of dry weather because of drying and breaking of leaf tips. This was much more pronounced on the south-facing slope.

Average height of flowering stalks of big bluestem and side-oats grama was 13.3 and 15.3 inches, respectively, on the south-facing slope, compared to 21.2 inches for big bluestem and 17 inches for side-oats grama on the north-facing slope.

Table III. Average height in inchesof big bluestem and side-oats grama on north- and south-facing slopes for different dates of the growing season of 1960

Date	Big Bluestem		Side-oats Grama	
	North-facing Slope	South-facing Slope	North-facing Slope	South-facing Slope
May 24	5.8	3.8	3.6	4.9
June 1	7.7	4.0	3.8	5.4
June 10	8.6	4.2	3.9	5.7
June 15	7.7	4.4	4.0	5.9
June 28	11.4	5.5	6.7	6.7
July 8	11.7	5.7	6.9	5.9
July 23	10.8	6.3	7.4	6.2
Aug. 12	11.4	5.3	7.3	6.05
Aug. 20	11.8	5.4	7.2	5.2
Aug. 30	12.0	5.6	7.1	4.7
Sept.11	11.8	5.3	7.1	4.5

Soils

Soils of both north- and south-facing slopes were shallow and intermixed with fragments of limestone varying from minute to large rocks. Deep soils were not developed because of erosion. Erosion was somewhat less on the north-facing slope due to denser vegetation and mulch which has resulted in a slightly deeper A_1 horizon. Parent material of the upper horizons on both slopes was Fort Hays Limestone, but at deeper depths, shale was often encountered. This was especially noticeable at the center position on the south-facing slope where the profile was composed of different parent materials. Color of the soil on the south-facing slope was often lighter than on north-facing slopes. Streaks of iron precipitates in the lower horizons were common on both slopes. Both north- and south-facing slopes were calcareous and were sufficiently permeable for good root penetration. A complete description of soil profiles in the College Pasture at the top, center, and bottom of both north- and south-facing slopes is as follows:

South-facing Slope

Position	Horizon	Depth	Description
	A_1	0-2"	Loam; weak fine granular; numerous worm casts; limestone fragments 2" in diameter to minute; plentiful fine roots; calcareous; abrupt smooth boundary.
Top	AC	2-8"	Fragmentary loam; granular structure due to numerous worm casts; limestone fragments 3" in diameter to minute; abundant fine roots; calcareous; clear boundary.
	Dr	8"+	Fractured Fort Hays Limestone

Position	Horizon	Depth	Description
	A_1	0-3"	Gray (10YR 5/1.5 dry) to very dark gray (10YR 3/1.5 moist); gravely loam; moderate fine granular; numerous worm casts; limestone fragments ¼ to ½" in diameter to minute; abundant fine roots; calcareous.
	AC	3-8"	Grayish brown (1Y 4.5/2 moist) to light gray (1Y 5/2 dry); gravely clay loam; moderate medium fine granular structure; numerous roots; strongly calcareous; numerous worm casts.
Center	C_1	8-15"	Gray brown (2.5Y 4.5/2 moist) to light grayish brown (2.5Y 5/2 dry); silty clay loam; weak to moderate fine granular; numerous worm casts; very fine limestone fragments; small fragments of precipitated iron.
	C_{2b}	15-25"	Light olive brown (2.5Y 5/3 moist) to light yellowish brown (2.5Y 6/4 dry); weak to moderate fine subangular blocky; calcareous; streaks of iron in lower portion of weathered shale.
	D	25-42"+	Gray (5Y 5.5/1 moist) to light gray (5Y 6/1 dry); partially weathered shale; strongly calcareous; few fine roots; weak course subangular blocky; lower portion platy.
	A_1	0-5"	Light silty clay; moderate medium granular; numerous worm casts; plentiful fine roots; some linestone fragments ½" to ¼" in diameter; neutral; clear boundary.
Bottom	B_2	5-12"	Clay; moderate medium subangular blocky fracturing to medium granular; few fine roots; sandstone fragments; some worm casts; thin continuous clay skins; some rust brown stains present; neutral-gradual boundary.
	C	12-60"+	Carlile shale, upper portion partially weathered.

North-facing Slope

Position	Horizon	Depth	Description
Top	A_1	0-3"	Loam texture; weak fine granular; numerous worm casts; limestone fragments 1 inch in diameter to minute; abundant fine roots; calcareous; abrupt smooth boundary.
	AC	3-18"	Fragmentary loam; granular; numerous worm casts; limestone fragments 6" in diameter to minute; plentiful fine roots; calcareous; gradual wavy boundary.
	Dr	18"+	Fractured Fort Hays Limestone
Center	A_1	0-12"	Gray (10YR 5/1 dry) to very dark gray (10YR 3/1 moist); loam; weak fine granular; numerous worm casts; limestone fragments 1" in diameter to minute; plentiful fine roots; calcareous; abrupt smooth boundary.
	AC	12-20"	Grayish brown (10YR 5/2 dry) to dark grayish brown (10YR 4/1.5 moist); gravely clay loam; moderate fine granular; numerous worm casts; limestone fragments 8" in diameter to minute; plentiful fine roots; calcareous; gradual boundary.
	C	20-28"	Light yellowish brown (10YR 6/5 moist); gravely clay loam; weak fine medium subangular blocky; few worm castings; strong calcareous.
	Dr	28-42"+	Weathered shale; gray (5Y 5/1 moist); iron stains of (5YR 4/4 moist).

Position	Horizon	Depth	Description
	A_1	0-2"	Loam; weak fine granular; numerous worm casts; limestone fragments 1" in diameter to minute; plentiful fine roots; calcareous; abrupt smooth boundary.
Bottom	A_{12}	2-14"	Loam; granular; numerous worm casts; limestone fragments 1½" in diameter to minute; abundant fine roots; calcareous; gradual boundary.
	AC	14-22"	Fragmentary loam; granular structure due to numerous worm casts; limestone fragments 6" in diameter to minute; plentiful fine roots; calcareous; gradual boundary.
	Dr	22"+	Fractured Fort Hays Limestone

Microclimate

Evaporation. Differences in water lost by evaporation may be influential in determining the vegetation which is present on different slope exposures.

Evaporation rates were considerably higher on the south-facing than on the north-facing slope (Fig. 7). Exceptions are the weeks of May 3 to 10, and June 28 to July 5, when evaporation on the north exposure exceeded the south exposure by 13.38 and 43.58 ml., respectively. June 28 to July 5 was also the period of highest evaporation (312,78 ml.) for the north-facing slope. The highest rate of evaporation for the south-facing slope was 577.60 ml. per week, April 19 to 26.

Average evaporation rates for the entire season at the center position indicated that the south-facing slopes lost 285.43 ml. per week, as compared to the north-facing slope which lost 196.92 ml. per week. This

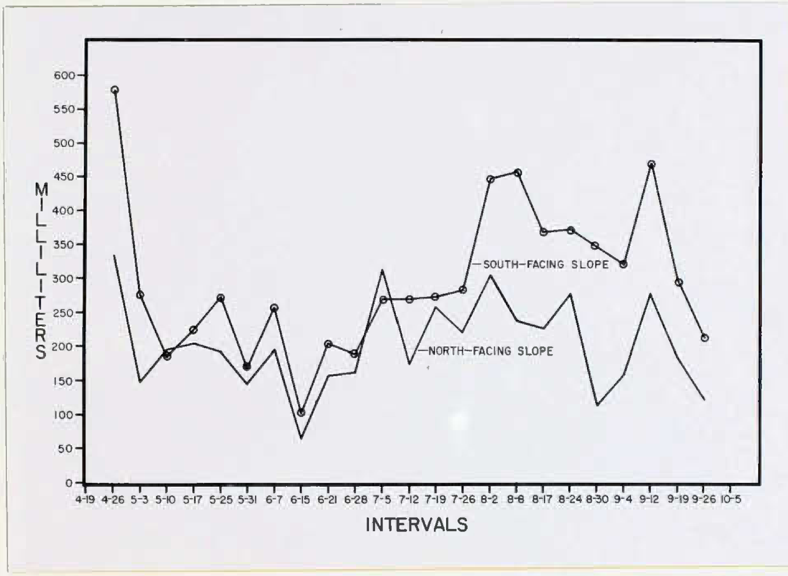

Fig. 7. Seasonal variations in evaporation rates on north- and south-facing slopes at the center position.

This difference of 88.51 ml. could contribute appreciably to the more xeric condition on the south-facing slope.

Evaporation rates and wind velocities were closely correlated. When wind velocities were high, evaporation rates increased. The widest difference in evaporation rates between the two slopes was usually during weeks when the largest difference in wind velocities occurred.

Evaporation rates were also different in respect to position on the same slope (Table IV). The top position on both slopes had the highest evaporation rate, followed, in order, by the center and bottom position on the south-facing slope. However, on the north-facing slope, the bottom location had a higher rate of evaporation than the center position. The differences in evaporation rates on the same slope seemed to be a result of differences in wind velocities. The top positions on each slope were more exposed to the full force of the wind. The bottom position on the north-facing slope was exposed to more wind than the center position because of denser vegetation at the center position.

July was the highest month of evaporation for both slopes, followed by September and August, respectively (Table IV).

Wind velocities. Prevailing winds in west-central Kansas are from a southerly direction. South-facing slopes catch the full force of these winds, whereas, the north-facing slopes are in a protected position. Wind velocities on south-facing slopes were consistently higher throughout the growing season, except during the week of May 3-10 (Fig. 8).

The highest average weekly wind velocity recorded for the north-facing slope was 6.6 MPH (May 3-10), compared to 11.9 MPH (April 14-26)

Table IV. Average monthly evaporation rates for three positions on north- and south-facing slopes

	North-facing Slope			South-facing Slope		
Month	Top	Center	Bottom	Top	Center	Bottom
April		225.86			342.00	
May	192.9	180.1	173.7	284.18	219.64	185.32
June	225.71	143.71	146.54	242.19	186.05	175.81
July	352.48	239.22	261.38	403.42	307.66	297.78
Aug.	280.83	208.15	221.33	383.36	332.05	295.02
Sept.	293.67	184.47	204.17	392.15	325.15	282.48
Average	269.12	196.92	201.42	341.06	285.43	247.28

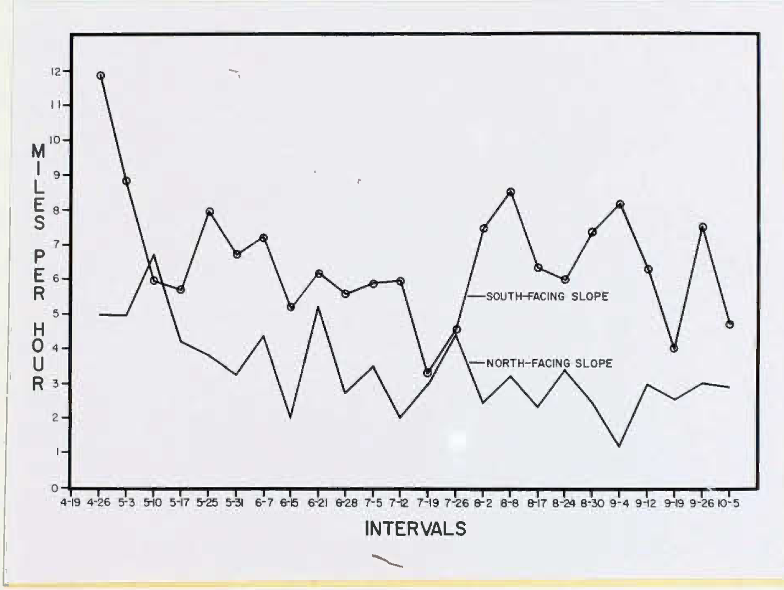

Fig. 8. Seasonal variations in wind velocities on north- and south-facing slopes.

for the south-facing slope. Other high velocities were 8.5 and 8.2 MPH for the south-facing slope during July and August.

April showed the largest difference in wind velocities between the two slopes (Table V). The succeeding months of May, June, and July maintained a significant difference, but differences between slopes were not as great. Differences increased again in August and September.

For the entire growing season, the south-facing slope maintained an average wind velocity of 6.90 MPH compared to 3.57 MPH for the north-facing slope.

Soil temperatures. Soil temperatures were consistently higher on the south-facing slope than on the north-facing slope. This was true both at 1-inch and 6-inch depths (Fig. 9). Both north- and south-facing slopes consistently maintained higher temperatures at the 1-inch depth than at the 6-inch depth. Near the end of the growing season soil temperatures on the south-facing slope at the 6-inch depth exceeded temperatures at the 1-inch depth on the north-facing slope. On both slopes, differences in temperatures between 1- and 6-inch depths were less at the start of the growing season than near the end.

The maximum temperature recorded at 1:30 p.m. on the south-facing slope was 110.3^{o} during July. On the same day, the maximum temperature on the north-facing slope was 99.5^{o}. Monthly averages indicated that July maintained the highest soil temperatures for both slopes (Table VI). At the 6-inch depth, soil temperatures on the south-facing slope steadily became higher throughout the season, whereas, on the north-facing slope a peak was reached in July and then a decline was noted.

Table V. Average wind velocities by months for south- and north-facing slopes

Month	South-facing Slope	North-facing Slope	Difference
April	10.30	4.99	5.31
May	6.55	4.46	2.09
June	6.02	3.56	2.46
July	5.40	3.05	2.35
August	7.03	2.82	4.21
September	6.12	2.51	3.61

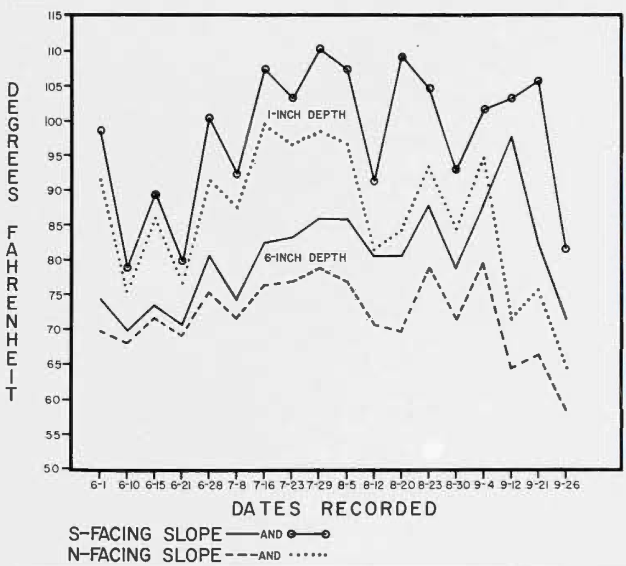

Fig. 9. Seasonal variations in soil temperatures at 1- and 6-inch depths on north- and south-facing slopes.

Table VI. Average monthly soil temperatures at 1- and 6-inch depths on north- and south-facing slopes

	South-facing Slope		North-facing Slope	
Months	1-inch	6-inch	1-inch	6-inch
June	89.48	73.82	84.20	70.72
July	102.2	81.50	97.05	76.00
August	101.26	82.74	87.98	73.58
September	98.35	87.35	76.65	67.18

Average temperatures for the entire growing season were considerably higher at both depths on the south-facing slope. The average temperature for the south-facing slope at 1-inch was 97.55° F. compared with 86.32° F. for the north-facing slope. At the 6-inch depth, the south-facing slope averaged 81.01° F. and the north-facing slope 71.81° F. Thus, the soil of the north-facing slope was 11.23 degrees cooler at 1-inch, and 10.20 degrees cooler at the 6-inch depth. Readings were recorded at 1:30 p.m., and should be close to the maximum average attained.

The higher temperatures recorded on south exposures can be attributed to the more perpendicular angle at which the sun's rays strike the soil surface. Also, the shading effect of taller vegetation on the north-facing slopes would retard the amount of sunlight reaching the soil surface.

Air temperatures. Air temperatures did not show as wide a variation between north- and south-facing slopes as soil temperatures. Maximum and minimum readings often varied less than 1 degree with respect to different slope exposures, but extreme differences of 7.86 degrees F. were recorded.

Maximum and minimum temperatures were higher throughout the growing season on the south-facing slope than on the north-facing slope (Fig. 10). Exceptions were during July when temperatures were slightly higher on the north exposure.

Average weekly maximum temperatures ranged from 78.21 to 101.8° F. on the south-facing slope, compared to 75.57 to 99.79 on the north-facing slope.

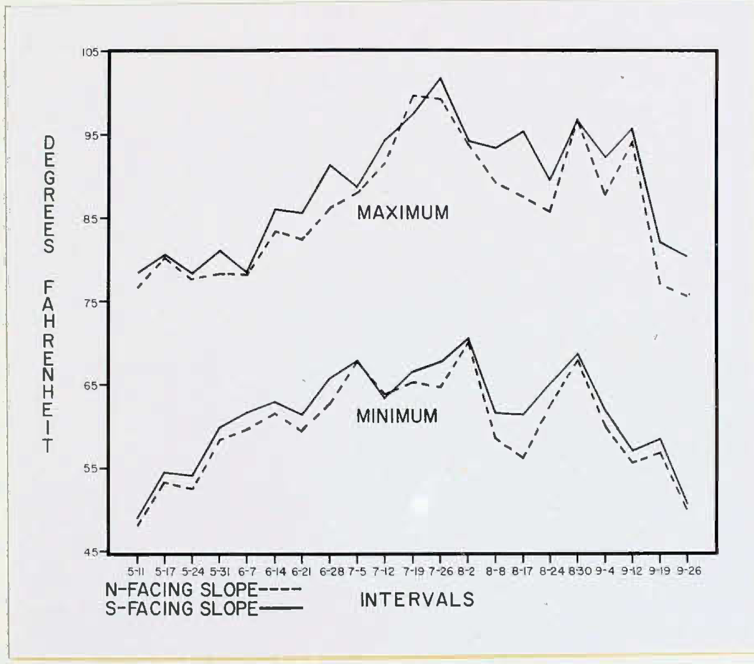

Fig. 10. Seasonal variations in maximum and minimum air temperatures on north- and south-facing slopes.

The smallest difference in temperatures with respect to different exposures existed during July when the highest maximum and minimum temperatures were recorded (Table VII).

The average maximum temperatures for the entire growing season were 88.23° F. for the south-facing slope, compared to 85.77° F. for the north-facing slope. Minimum temperatures averaged 61.65 for the south-facing slope, and 60.04 for the north-facing slope.

Light intensities. Light intensities were also considerably different due to direction of slope exposure. The south-facing slope had higher intensities throughout the season, both above the vegetation and at ground level (Table VIII).

Light intensities were considerably less on both slopes at ground level than above the vegetation due to the shading effect of vegetation.

Widest variations in light between the north- and south-facing slope occurred during September when the difference was 1933.4 foot candles at ground level and 2588.9 above the vegetation.

Average light intensity for the entire season on the south-facing slope was 4068.86 foot candles at ground level, and 4693.15 above the vegetation. This is considerably higher than the north-facing slope which averaged 2927.60 foot candles at ground level, and 3632.2 foot candles above the vegetation. The differences in light intensities in respect to exposure, indicated that the south-facing slope received approximately 29 percent more direct sunlight than the north-facing slope.

Table VII. Average maximum and minimum air temperatures by months for north- and south-facing slopes

Months	S-facing Slope	N-facing Slope	Difference	S-facing Slope	N-facing Slope	Difference
May	79.24	78.2	1.04	54.39	53.15	1.24
June	85.26	82.51	2.75	62.88	60.90	1.98
July	95.20	94.5	.70	67.14	66.36	.78
Aug.	93.77	89.91	3.86	63.91	61.45	2.46
Sept.	84.46	80.19	4.27	57.08	55.7	1.37

Table VIII. Average light intensities by months on north- and south-facing slopes at 1:30 p.m.

	Ground Level			Above Vegetation		
Month	South-facing Slope	North-facing Slope	Difference	South-facing Slope	North-facing Slope	Difference
June	3608.3	3341.6	266.7	4133.2	2908.3	224.9
July	4258.3	3215.0	1043.3	4675.0	4158.3	516.7
Aug.	4186.66	2865.0	1321.66	4586.6	3673.3	713.3
Spt.	4222.2	2288.8	1933.4	5377.8	2788.9	2588.9

Yields

Effect of microclimate on the vegetation was emphasized by differences in forage yields on different exposures. The north-facing slope produced more than twice as much forage per acre as the south-facing slope, 1,727.7 and 838.1 pounds per acre, respectively (Table IX). Mid grasses contributed most to yields on north exposures, whereas, short grasses made up the largest part of the yield on the south-facing slope. Yield of forbs was similar for both slopes.

Differences in yields were a result of variations in species composition as well as differences in environment affecting their growth potential. More favorable growth conditions shown by the north-facing slope provided a more favorable habitat for higher yielding species of plants, and also to more nearly realize production potential of the species.

Table IX. Yield of forage in pounds per acre on north- and south-facing slopes

	North-facing slope	South-facing slope
Mid grass	1488.0	203.8
Short grass	30.7	391.9
Forbs	204.0	242.4
Total	1722.7	838.1

SUMMARY

North- and south-facing slopes in the mixed prairie near Hays, Kansas, have a distinctly different microclimate, with a resulting difference in vegetation. The protected position of north-facing slopes has provided a habitat which is favorable to more mesophytic plants. In contrast, the exposed position of south-facing slopes has limited the vegetation to more xerophytic species.

Big bluestem and little bluestem were the dominant species on the north-facing slope, comprising 79.89 percent of the total grasses; whereas, buffalo grass, blue grama, and side-oats grama dominated the south-facing slope, contributing 70.21 percent to the total grasses.

Several species of forbs were restricted to, or were much more abundant on one slope or the other. Woody species were common on north exposures but were seldom found on south exposures. Density of forbs was 4.55 plants per square foot on the north-facing slope, and 4.29 on the south-facing slope.

Earlier initiation of growth and earlier flowering species were characteristic of the south-facing slope.

Flowering stalks of big bluestem and side-oats grama were considerably taller on the north-facing slope indicating a more favorable habitat.

Soils of both slopes were developed from Fort Hays Limestone with an underlying layer of shale. Soils of the north-facing slope had a deeper A_1 horizon, and were darker in color. Soils of both slopes were intermixed with limestone fragments and were sufficiently permeable for good root penetration.

Average evaporation rates for the entire growing season were 285.43 ml. per week for the south-facing slope compared to 196.92 ml. per week for the north-facing slope.

Average seasonal wind velocities for north- and south-facing slopes were 6.90 and 3.57 MPH, respectively. Evaporation rates and wind velocities were closely correlated.

Soil temperatures averaged 97.55° F., at the 1-inch depth on the south-facing slope and 86.32° F. on the north-facing slope. At the 6-inch depth, the south-facing slope averaged 81.01° F., and the north-facing slope 71.81° F. Thus, the soil of the north-facing slope was 11.23 degrees cooler at 1-inch and 10.20 degrees cooler at the 6-inch depth.

Average maximum air temperatures for the growing season were 88.23° F. for the south-facing slope and 85.77° F. for the north-facing slope. Minimum temperatures averaged 61.65° F. for the south exposure and 60.04° F. for the north exposure.

The average light intensity for the south-facing slope was 4068.86 foot candles at ground level and 4693.15 above the vegetation. This was considerably higher than the north-facing slope which averaged 2927.60 foot candles at ground level and 3632.2 foot candles above the vegetation.

The effect of microclimate on vegetation was emphasized by differences in forage yields on different exposures. The north-facing slope produced 1,727.7 pounds per acre, compared to 838.1 pounds per acre on the south-facing slope. Mid grasses contributed most to yields on north-facing slopes, whereas, short grasses made up the largest part of the yield on the south-facing slope. Differences in yields were a result of variations in species composition and differences in environmental factors affecting their growth potential.

LITERATURE CITED

Albertson, F. W. 1937. Ecology of the mixed prairie. Ecol. Monographs 7:484-547.

__________. 1938. Prairie studies in west-central Kansas. Trans. Kansas Acad. Sci. 41:77-83.

__________. 1939. Prairie studies in west-central Kansas. Trans. Kansas Acad. Sci. 42:97-107.

__________. 1941. Prairie studies in west-central Kansas: 1940. Trans. Kansas Acad. Sci. 44:48-57.

__________. 1942. Prairie studies in west-central Kansas: 1941. Trans. Kansas Acad. Sci. 45:47-54.

__________. 1942a. History of the native vegetation of western Kansas during seven years of continuous drought. Ecol. Monographs 12:23-51.

__________. 1943. Prairie studies in west-central Kansas. Trans. Kansas Acad. Sci. 46:81-84.

__________. 1945. Prairie studies in west-central Kansas. Trans. Kansas Acad. Sci. 47:405-414.

__________ and J. E. Weaver. 1946. Reduction of ungrazed mixed prairie to short grass as a result of drought and dust. Ecol. Monographs 16:449-463.

__________, G. W. Tomanek, and A. Riegel. 1957. Ecology of drought cycles and grazing intensity of grasslands of central Great Plains. Ecol. Monographs 27:27-44.

Azzi, Girolamo. 1956. Agricultural ecology. Constable and Company, Ltd., London: Essential Books, Inc., Fair Lawn, New Jersey. 427 pp.

Cottle, H. J. 1932. Vegetation on north and south slopes of mountains in southwestern Texas. Ecology 13:121-134.

Coupland, R. T. 1950. Ecology of mixed prairie in Canada. Ecol. Monographs 20:271-315.

Daubenmire, R. F. 1959. Plants and environment. John Wiley and Sons, Inc., New York. 422 pp.

Dix, R. R. 1958. Some slope-plant relationships in the grasslands of the Little Missouri Badlands of North Dakota. J. Range Mgmt. 11:88-92.

Gardner, J. L. 1950. Effects of thirty years of protection from grazing in desert grassland. Ecology 31:44-50.

Hitchcock, A. S. 1950. Manual of the grasses of the United States. U. S. Government Printing Office, Washington. 1051 pp.

Kucera, C. L. 1954. Some relationships of evaporation rate to vapor pressure deficit and low wind velocity. Ecology 35:71-75.

Levy, E. B. and E. A. Madden. 1933. The point method of pasture analysis. New Zealand J. Agric. 46:267-279.

Livingston, B. E. 1935. Atmometers of porous porcelain and paper, their use in physiological ecology. Ecology 16:438-472.

McMinn, R. G. 1952. Soil drought and distribution of vegetation. Ecology 33:1-15.

Oosting, H. J. and D. W. Hess. 1956. Microclimate and a relict stand of Tsuga canadensis in the lower piedmont of North Carolina. Ecology 37:29-39.

__________. 1958. The study of plant communities. W. H. Freeman and Company, San Francisco. 440 pp.

Rydberg, Per Axel. 1932. Flora of the prairies and plains of central North America. Science Press Printing Co., Lancaster, Pa. 969 pp.

Shanks, R. E. and F. H. Norris. 1950. Microclimate variations in a small valley ineastern Tennessee. Ecology 31:532-539.

Shreve, F. 1915. The vegetation of a desert mountain range as conditioned by climatic factors. Carnegie Inst., Wash., Pub. 217.

Soil Survey Staff. 1951. Soil survey manual, U. S. Dept. Agric. Handbook No. 18. U. S. Government Printing Office, Washington. 503 pp.

Tomanek, G. W. and F. W. Albertson. 1953. Some effects of different intensities of grazing on mixed prairie near Hays, Kansas. J. Range Mgmt. 6:299-306.

__________ and __________. 1957. Variations in cover, composition, production, and roots of vegetation on two prairies in western Kansas. Ecol. Monographs 27:267-281.

__________, E. P. Martin, and F. W. Albertson. 1958. Grazing preference comparisons of six native grass species in the mixed prairie. J. Range Mgmt. 11:191-193.

Weaver, J. E. 1917. A study of the vegetation of southwestern Washington and adjacent Idaho. University Studies, University of Neb., 17:53-54.

__________ and F. W. Albertson. 1936. Effects of the great drought on the prairies of Iowa, Nebraska, and Kansas. Ecology 17:567-639.

__________ and F. E. Clements. 1938. Plant ecology, 2nd ed. McGraw-Hill Book Co., New York. 601 pp.

__________ and F. W. Albertson. 1939. Major changes in grassland as a result of continued drought. Botan. Gaz. 100:576-591.

__________ and __________. 1940. Deterioration of midwestern ranges. Ecology 21:216-236.

__________ and __________. 1940a. Deterioration of grassland from stability to denudation with decrease in soil moisture. Botan. Gaz. 101:599-624.

__________ and I. M. Mueller. 1942. Role of seedlings in recovery of midwestern ranges from drought. Ecology 23:276-294.

__________ and F. W. Albertson. 1943. Resurvey of grasses, forbs, and underground plant parts at the end of the great drought. Ecol. Monographs 13:64-117.

__________. 1944. Recovery of midwestern prairies from drought. Proc. Am. Philosoph. Soc. 88:126-131.

__________. 1944a. Nature and degree of recovery of grassland from the great drought of 1933 to 1940. Ecol. Monographs 14:397-479.

__________ and F. W. Albertson. 1956. Grasslands of the Great Plains, their nature and use. Johnsen Pub. Co., Lincoln, Neb. 395 pp.

Whitehead, F. H. 1957. Productivity in alpine vegetation (abstract). J. of Animal Ecolgy 26:241.