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HABITAT OF *YUCCA GLAUCA* NUTT. IN SOUTHERN ALBERTA

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Habitat of *Yucca glauca* Nutt. in Southern Alberta" submitted by Bruce J. Milner in partial fulfilment of the requirements for the degree of Master of Science.

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Date. August 15, 1977

I dedicate this thesis to my wife, Margaret, who offered strength and encouragement throughout its preparation.

ABSTRACT

The habitat of Yucca glauca was examined along the Lost and Milk River coulee faces in southern Alberta. The two populations represent the most northern extent of this species.

The microclimate at the Lost River site was characterized by high solar radiation (range 144-1181 cal cm^{-2} day^{-1}, summer mean 697 cal cm^{-2} day^{-1}), high temperatures (range 2-26^{o}C, summer mean 18^{o}C), low precipitation (range from 4.3 mm in June to 10.3 mm in May, summer mean 40 mm), moderate wind speeds (range 2-13 km hr^{-1}, summer mean 8 km hr^{-1}), moderate relative humidity (range 35-100%, summer mean 61%), and a high percent of sunny days (53% of summer season). Air and soil temperature profiles were uniform (±1^{o}C) along the coulee face. The prevailing southwest winds were higher on southwest to west-facing slopes corresponding to non-yucca sites. They were lower on south to east facing slopes where Yucca occurred.

Soil differences are associated with yucca and non-yucca sites. This can be explained by the movement and deposition of soil from exposed slopes, to leeward ones, by the prevailing southwest winds. and by water erosion on the more exposed slopes. The soil of yucca sites have a sandier texture and a lower water holding capacity, but a larger soil rooting volume than non-yucca areas. Significant differences were found in depth to hardpan layer which occurred at greater than 100 cm on yucca sites, less than 50 cm on the margin of these areas, and 20-30 cm on non-yucca sites. The hardpan is very dense and is impenetrable for yucca rhizomes. Significant reduction in rhizome penetration was found for plants growing on the margin compared to the centre of yucca areas. Uprooting and dessication by wind of a shallow

underground system, in relation to the hardpan layer, is considered a major limiting factor for further expansion of Yucca glauca along the coulee slopes.

Yucca glauca is adapted to the region in several ways. Its clumped growth form can act to accumulate snow and soil. Clumped shoots, a long horizontal rhizome and plant longevity are characteristic of the species. Seeds of the species tend to germinate throughout the summer season whenever moisture is available. They germinate at a lower temperature than reported for more southern populations, but at relatively high temperatures (20°C) for this area. The species is able to tolerate a range of moisture conditions from a high of -2 bars in June to a low of -25 to -27 bars in mid-July.

It is uncertain what limits the distribution of the species beyond its northern range. Low winter temperature, agriculture including cultivation, and the distribution of the plants only known pollinator, the yucca moth, are some factors considered.

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INTRODUCTION

Throughout the mixed prairie region of North America, vegetation is patterned in relation to certain tolerance differences. These difference enable species to exist and reproduce successfully within a complex of climatic, edaphic, and biotic conditions (Hanson and Whitman 1938, Coupland 1958, Cooper 1961, Weaver 1968, McMillan 1959 a, Whitman 1969, Redmann 1975). The spreading of a species toward its areal limits is often facilitated when one or more factors are compensated for by others so that the new environment resembles that of the distribution centre (Cowles 1901, Good 1931, Rubel 1935, Mason 1936, Billings 1952).

Yucca glauca* reaches the northern limit of its range within the mixed prairie in southern Alberta. Near the species' centre of distribution in mid-United States, suitable growing conditions are met on all aspects, but in Alberta a south to east exposure is preferred (Webber 1953).

A study at the limits of the range of a species reveals information about the minimum requirements of light, temperature, precipitation, and other climatic and edaphic factors needed by that plant to survive. This information is necessary prior to successful cultivation, protection, or a general understanding of the particular species in question.

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*Nomenclature follows Moss (1959)

It was the purpose of this study to investigate *Yucca glauca* at the most northern extent of its range in southern Alberta by: 1) examining its habitat; 2) determining factors (climatic and edaphic) which may limit the species from expanding its population beyond the present limit, and 3) describing certain morphological and physiological characteristics of *Yucca glauca* in Alberta and making comparisons, when possible, with individuals growing near the distribution centre. No such studies are known to exist although the species has a wide range within the western grasslands.

DESCRIPTION OF STUDY AREA

Mixed Prairie of Alberta

General

Moss (1944, 1955) and Coupland (1950, 1953) discuss the mixed prairie region of Alberta. This region is part of the Great Plains region of North America. The mixed prairie of North America extends west to the Rocky Mountain foothills, east to about 98°30'W. longitude, south to the Rio Grande River and northward to central Alberta and Saskatchewan. In Canada, the mixed prairie extends from the foothills at the base of the Rocky Mountains eastward along the International Boundary to the vicinity of the boundary between Saskatchewan and Manitoba (Coupland 1950).

Geomorphology and Geology

The general topography of the mixed prairie in Alberta and northern Montana consists of undulating to gently rolling lands, dissected by deeply eroded coulees (Fig. 1). Two uplands occur within the area; the Cypress Hills to the northeast, and Sweetgrass Hills of Montana which rise 1,500 m to the southwest (Fig. 4).

The subsurface geology consists of Late Cretaceous age, light coloured sandstone and shale strata with clayey shales predominating. Crossbedding of course sandstones occur indicating shallow water deposition. Beds of iron-stone are frequent, but discontinuous. The soft nature of the shales and sandstone have been influenced by the movement of advancing ice sheets and melt water. Thin coal seams and coaly shales often occur near the top of the formation throughout the area. The stratum is about 60-180 m thick (Russell and Landes 1940).

Figure 1. Mixed prairie region of southern Alberta showing gently rolling topography, dissected by deeply eroded coulees.

The surface material is mainly of glacial origin, deposited during the Pleistocene when Laurentide continental glaciers advanced and retreated over the area several times. Glacial activity caused some erosion of the Cretaceous bedrock and incorporated it in drifts together with material from Precambrium rocks and Paleozoic limestone. The resultant material is generally medium textured, calcareous, and contains stones and boulders of various sizes. The resultant landform is the present undulating to strongly rolling landscape, low knolls, long smooth intermediate slopes and shallow, undrained depressions (Dowling 1917, Wyatt and Newton 1941, Webb 1954, Meyboom 1960).

Few naturally occurring lakes and marshes exist within the area. Rivers are rather shallow. The Milk River which drains into the Missouri River and the Lost River which drains into the Milk River are the two important ones involved in this study (Fig. 3). The number of deep coulees suggests that large volumes of water were transported across the landscape in comparatively recent times (Russell and Landes 1940, Wyatt and Newton 1941).

Macroclimate

Climate for the area was described by Wyatt and Newton (1941), Borchert (1950), Coupland (1958), Weaver (1966), and Longley (1967), as being characteristic of a mixed prairie region. In general the summers have long warm days and the winters are cold and bright. Climatic data for the region as recorded at the Manyberries Climatological Station at Onefour (49°07'N., 110°28'W.), about 19 km north of the study on the Lost River, are summarized in Table 1. Mean daily temperature over a 13 year period from 1962-75 reached a low of -13°C in January and a high

Table 1. Mean daily, maximum, and minimum temperature, sunlight hours, total precipitation and mean wind speeds expressed monthly from 1962-75 and 1976 for Onefour, Alberta (Atmospheric Environment Service, Canada Department of Environment, 1962-76).

Climatic Factor	J	F	M	A	M	J	J	A	S	O	N	D
Mean Daily Temp. (^{o}C)												
1962-1975	-13	-7	-4	5	11	16	20	19	12	6	-2	-5
1976	-9	-3	-4	8	15	13	15	12*				
Mean Daily Max. Temp. (^{o}C)												
1962-1975	-6	-2	2	10	17	22	27	26	19	13	4	-4
1976	-2	3	3	14	21	20	27	27*				
Mean Daily Min. Temp. (^{o}C)												
1962-1975	-19	-14	-10	-2	4	9	12	11	5	-1	-8	-14
1976	-14	-8	-11	1	6	7	12	12*				
Mean Sunlight Hrs.												
1962-1975	86	111	169	188	248	255	338	290	213	169	111	82
1976	131	159	206	241	353	261	378	270*				
Mean Total Precip. (cm)												
1962-1975	2.9	1.8	2.6	3.7	3.9	6.0	2.6	3.0	2.3	1.3	.9	2.5
1976	.73	.03	3.1	.94	.76	11.6	1.7	3.0*				
Mean Wind Speeds (km/hr)												
1976				11	12	12	10	10*				

* August, 1976 readings include 26 days.

in July of 20°C. Mean daily minimum temperatures of -19°C are reached in January and mean daily maximum temperatures of 27°C occur in July.

The region receives relatively high amounts of sunshine. From 1962-75, the area received an average of 2,260 hr of sunlight annually; about 6 hr of sunshine for each day of the year. July is the month of greatest sunshine with December and January being the lowest.

Annual precipitation is low (33 cm), with most occurring in spring. During mid-summer, precipitation results mainly from thunder showers (Wyatt and Newton 1941).

Vegetation

The mixed prairie vegetation of southern Alberta has been described by Moss (1944, 1955), Coupland (1950, 1953), and Ayyad and Dix (1964). The upland prairie is dominated by a Stipa-Bouteloua-Agropyron community with the major components being Stipa comata and Bouteloua gracilis. Associated with these species in more mesic areas are Agropyron dasystachyum, A. smithii, Muhlenbergia cuspidata, and Koeleria cristata. Calmovilfa longifolia occurs in isolated circles throughout. Carex obtusata, C. eleocharis, and C. filifolia are the dominant sedges. Scattered throughout the prairie, but mostly in more protected mesic areas are Artemisia cana, A. frigida, and Eurotia lanata.

Phlox hoodii, Lygodesmia juncea, Liatris punctata, and Solidago missouriensis are important forbs. [illegible]s include Astragalis pectinatus, Sphaeralcea coccinea, Oxytropis macou[illegible]. campestris, Pentstemon gracilis, Cirsium undulatum, Campanula [illegible]ndifolia, and Antennaria nitida are fairly common. The two cact[illegible] [illegible]tia [illegible]olyacantha and Mamillaria vivipara are in the drier o[illegible] dis[illegible]d ar[illegible]as. Rosa woodsii occurs throughout.

Some different species are found on the rocky ridges of the coulees. Here Hymenoxys richardsonii and H. acaulis make a colourful appearance in spring. The cactii are more numerous as are Eurotia lanata and Artemisia frigida. Stipa comata and Bouteloua gracilis are the major grasses.

The wetlands and flood plains are dominated by species which are able to grow under saline conditions. Sarcobatus vermiculatus is the common shrub; grasses include Spartina gracilis, Distichlis stricta, Juncus balticus, and Deschampsia caespitosa. In some areas, mostly in uplands, Hordeum jubatum and H. chenopodium occur.

Yucca glauca

General Description

The genus Yucca is within the Liliaceae. It includes species which are xerophytes, being well adapted to long periods of little soil moisture. Their large stems and rhizomes store considerable moisture and the presence of abundant endosperm indicates an adaption to dry regions (Webber 1953, Odishariya 1962).

In North America there are twelve dehiscent-fruited species, including Yucca glauca (Fig. 2), and nine indehiscent-fruited ones. The genus is distributed throughout the southwestern plains, mountains, and valleys, from near sea level in southern California to more than 2,400 m in elevation in the Rocky Mountains of Colorado. As a result, they are subject to many extremes in temperature, precipitation, and length of growing season (Trelease 1902, 1907, McKelvey 1938, 1947, Webber 1953, 1960).

The general habitat preferred by yuccas (including Yucca glauca) is well-drained soils on sunny slopes. Soils can vary from sandy to rocky slopes, dry gravelly plains, flood plains, weathered limestone,

Figure 2. Yucca glauca in southern Alberta.

finely decomposed slates, and red or calcareous clays.

Leaf longevity and length are related to sufficient precipitation. When rainfall is insufficient, the outer leaves tend to die until only those imbricated around the inner buds remain alive. With sufficient moisture, leaves reach a larger size. This is common in plants of gardens, along roadsides or in fields where cattle have worn trenches around their base (McKelvey 1947).

Yucca glauca occurs mainly on the plains and "bad lands" east of the Rocky Mountains, although its range extends into the mountains, often to high elevations on warm slopes (McKelvey 1947). It has a wide range, occurring east to the Mississippi River, south to Texas, west into Arizona and Utah, and north into Alberta where it occurs at two locations (Fig. 3). The type locality is in northern North Dakota or in northeastern Montana (McKelvey 1947).

Location of the Species in Alberta

Two populations of _Yucca glauca_ occur in the mixed prairie region of southeastern Alberta. The largest of the two is located in Section 2, Township 1, Range 4, West 4th Meridian. The second population is in Section 35, Township 1, Range 7, West 4th Meridian.

The larger of the two populations consists of over 55,000 individuals occupying ca. 2 km along the Lost River coulee face. The second yucca population, about 29 km west, is much smaller, consisting of about 450 individuals and occupying about a 150 m length of a coulee branch of the main Milk River valley (Fig. 4).

The elevation of the Lost River site is ca. 870 m while the yucca population on the branch of the Milk River is at 1,000 m.

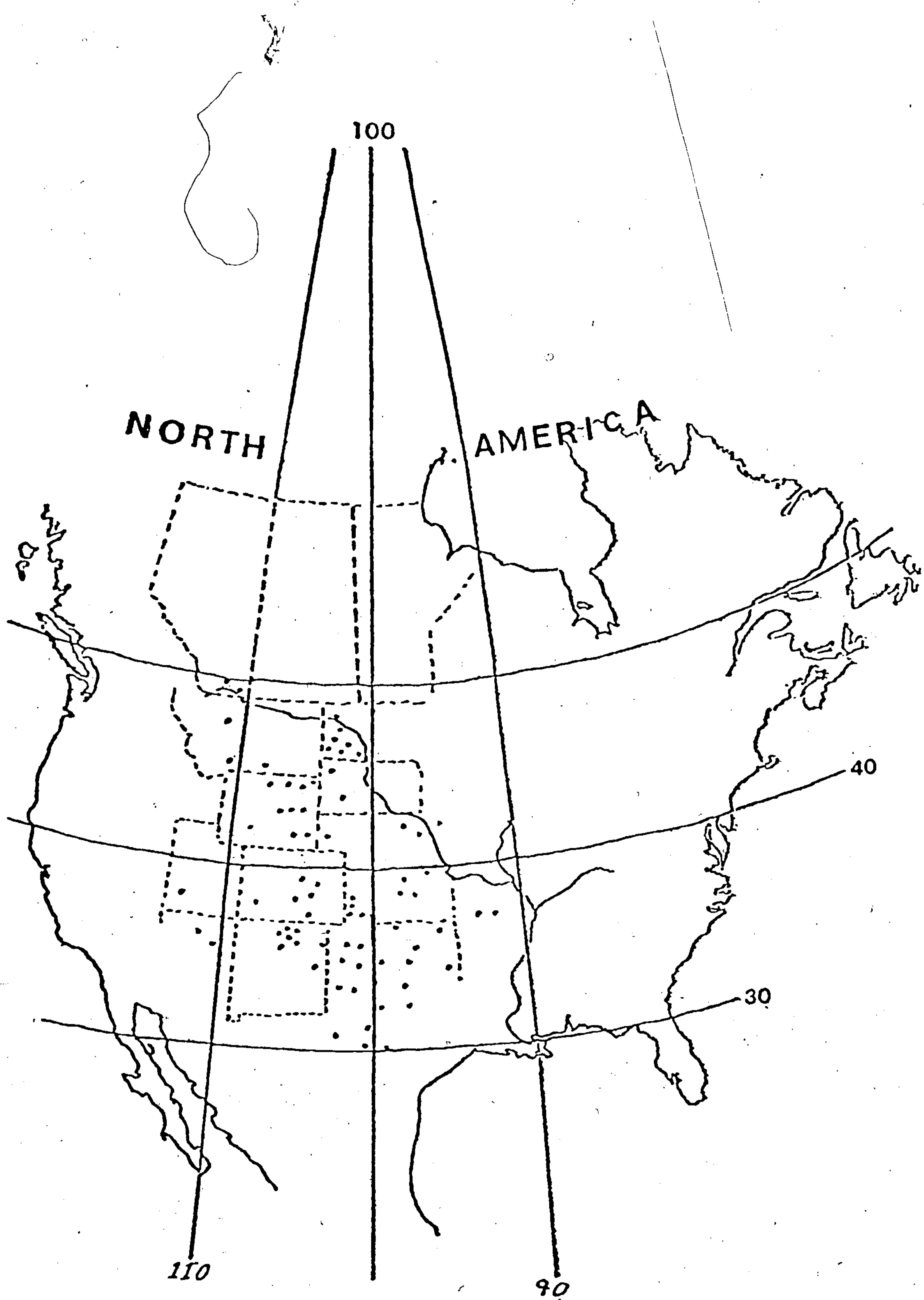


Figure 3. Range of Yucca glauca throughout North America. Dots (·) represent known populations of the species.

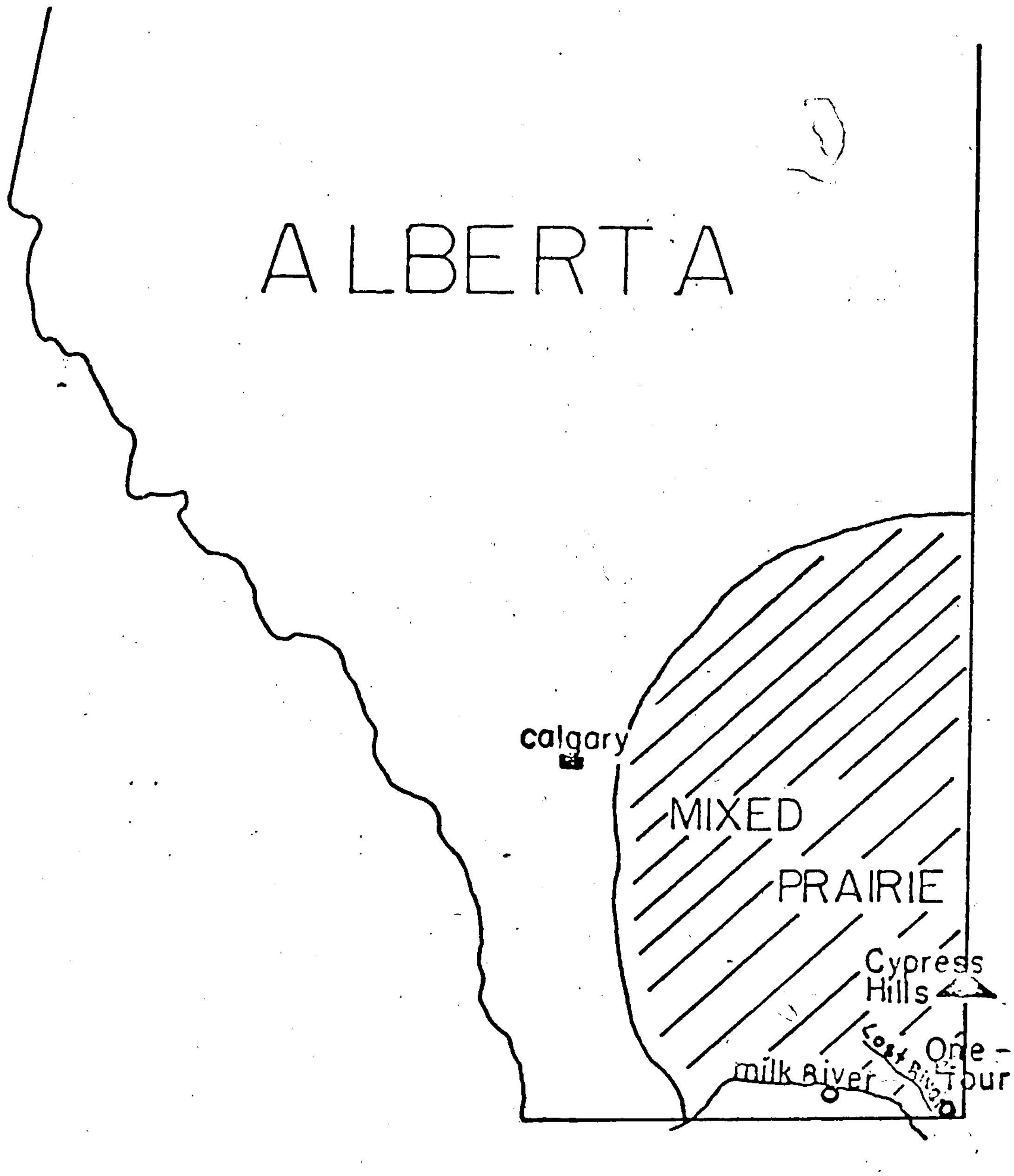


Figure 4. Mixed prairie region of Alberta showing the Lost and Milk River populations of Yucca glauca (o).

METHODS

Site Selection

The study was primarily confined to the Lost River yucca site. General site description was made including aspect, and mapping of the yucca population as it occurred along the Lost River coulee. It was found that in the western portion of the population, there were distinct yucca (Y) and non-yucca (NY) areas. A comparison of aspect, soils, and vegetation on these areas was used to select two yucca and two non-yucca plots, each 25 X 25 m. The yucca and non-yucca sites were adjacent to one another. The two yucca plots faced 180^{o} to 200^{o} to 220^{o} with the latter being protected from direct southwest exposure by the coulee face. The two non-yucca sites were more southwest in exposure having aspects of 250^{o} and 240^{o}.

Microclimate

Certain climatic parameters were measured in adjacent yucca and non-yucca plots. A Belfort hygrothermograph was placed in a white louvered shelter on the ground from May 15 until August 26, 1[illegible]. The hygrothermographs were calibrated in a controlled environmental chamber against a standard mercury thermometer. The sensors (5-10 cm above the surface) were recalibrated at least weekly. Because temperature and relative humidity readings were the same for both yucca and non-yucca sites, the instrument on the non-yucca plot was discontinued in June.

Air and soil temperature profiles were made from May through August on each yucca and non-yucca site. Two stations were positioned on each plot. At weekly intervals temperature was recorded using copper-constantan thermocouples connected to a Weston microvolt meter.

The readings were taken at 0900 and 1430 hr at 0, 2, 5, 10, 20, 50, and 100 cm above and below the surface.

Soil temperature was recorded continuously with two Moeller distance recording thermographs at -2, -10, -40, and -60 cm placed on one yucca and an adjacent non-yucca plot. It was found that the soil temperatures were the same on both plots thus only one set of readings was used for data analysis.

Wind speed was recorded throughout the summer on only the yucca site with a Belfort 3-cup totalizing anemometer; the cups were located 60 cm above ground level. Wind profiles were determined for both yucca and non-yucca areas. The measurements were taken with a Hastings hot-wire anemometer at 2, 5, 10, 20, 50, 100, and 150 cm. The sensor was held for 3 min at each position and data recorded every 30 sec to get an average reading at each site. Wind direction was also determined.

Rainfall was collected in a Tru Chek rain gauge which had been checked against a calibrated cylinder prior to use. This was positioned 1 m above ground surface.

Soils

A detailed soil investigation was made for the yucca and non-yucca habitats along the Lost River and minor sampling was done at the Milk River site. At the Lost River site, soil pits were dug, the profiles were described and composite samples collected for laboratory analyses. Texture was determined by the hydrometer method (Bouyouces 1936, 1951). Soil pH was determined on a 1:1 paste with a Sargent-Welch Scientific meter (Model, S-30009). $CaCO_3$ equivalents were determined by measuring the volume of CO_2 gas produced by a known weight of soil reacting with

HCl. Organic matter was determined by first obtaining a measure of total carbon from an induction furnace, then subtracting carbonate C and multiplying by 1.73 (Donahue 1971, Canada Soil Survey Committee on Methods of Analysis 1976).

At weekly to twice weekly intervals soil moisture was sampled gravimetrically at the two sites with duplicate samples taken at the 2, 5, 10, 20, 50, and 100 cm depths.

Soil moisture tension lines were prepared by determining moisture content at 1/3 and 15 bars in ceramic plate extractors (Soil Moisture Equipment Co.).

Plant Communities

Plant cover and frequency of species occurring on each yucca and non-yucca plot were determined. Plot location and size have been previously described under Site Selection. By a series of lines, each plot was divided into 5 X 5 m subplots. Eighteen quadrat samples (0.5 X 0.5 m) were taken randomly in each of the five rows. Cover classes used were after Braun-Blanquet (Poore 1955) and the results [illegible] calculate relative values.

Morphological Studies

The total number of yucca plants was determined for the Lost River and Milk River populations. Plant height and width, leaf length and width, floral parts, capsules, and seeds were measured and described for over 1,000 plants. These values were compared to reports for individuals occurring further south. Rhizome measurements were made for plants within and on the margin of yucca habitats. A non-destructive method for observing rhizomes consisted of carefully digging down one side of the plant making sure only a minimal portion of the rhizome was exposed. Digging was limited to early morning and evening to prevent unnecessary dessication. After measurements, rhizomes were immediately covered with soil.

Leaf Water Potential

Water potentials of leaves were measured on a weekly or more frequent basis from May through August. A leaf disc was placed in a thermocouple psychrometer chamber as described by Mayo (1974). This chamber was used in conjunction with a Wescor Microvoltmeter. The method used to obtain standard readings and eliminate any meter drift was to cool the junctions for 5 sec and take the reading after 30 sec. Three readings taken 3 min apart were averaged. The samples were equilibrated 6 hr in a water bath sunk into the slope of a south-facing coulee face. The diurnal range of the temperature bath remained constant ($\pm 1^{o}C$) for any one set of determinations. Psychrometer chambers were calibrated with saline solutions of known water potential prior to field use and rechecked on a monthly or more frequent basis through the season.

Seed Germination

Capsules of *Yucca glauca* were collected from the Lost River yucca site in August and December, 1976. Seeds were extracted from the capsules and treated with mercurial fungicide. They were placed on #2 filter paper disks in 5 cm disposable petri dishes.

A temperature gradient bar was used similar to that reported by

Barbour and Racine (1967). This was placed in an Environmental Growth Chamber (model M-13, Chagrin Falls, Ohio) at 20°C. Three replicate plates, each containing 30 seeds, were placed at 0, 5, 10, 14, 16, 18, 20, 24, 28, 37, and 43°C, with good thermal contact made between plate and bar by a thin layer of vaseline. No illumination was used during germination. Temperature of the water bath was monitored with a Grant Instruments temperature recorder and thermistor probes. Periodic checks of the temperature gradient on the bar were made with thermocouples and a Wescor microvoltmeter. Temperature differences between the germinating surface and the bar were checked periodically with thermocouples.

The filter paper was moistened as needed with distilled water. Germination was recorded daily for 3 weeks. To check release from inhibition, after termination of the experiment, 3 replicates from 0, 5, and 10°C which showed no germination, were moved to regions on the bar where maximum germination had occurred.

Statistical analysis consisted of a one-way analysis of variance followed by a Duncan's New Multiple Range test to compare differences between germination over the temperature gradient.

RESULTS

General Site Description

For the western portion of the population, the coulee face has a westerly exposure (Fig. 5). Here the yucca population is discontinuous, consisting of distinct yucca (Y) and non-yucca (NY) areas. The non-yucca areas have the same degree of slope, but aspect is more southwest (Table 2). The vegetation is more sparse on these non-yucca sites (See Associated Vegetation Results), and eroded areas do occur. The yucca population becomes more continuous toward the eastern part of the site, being broken where the slope becomes too steep and/or where erosion is too extensive. Yucca generally occurs when areas are protected from a direct southwest exposure by either a knoll, coulee face, or other feature. The population is bordered on either end by expansive eroded areas, above by mixed prairie grassland, and below by the Lost River. A number of plants occur on the prairie where protection is offered from direct exposure to southwest winds.

The second population further west along the Milk River has a general west to southwest exposure, but there is considerable protection by surrounding ridges from direct southwest winds. The majority of plants occupy the west-southwest coulee face or have migrated onto the prairie in restricted areas, but do not occur on the opposite east-facing side. Eroded areas are common and mixed prairie borders the top of the coulee.

FIGURE 5
LOST RIVER YUCCA SITE

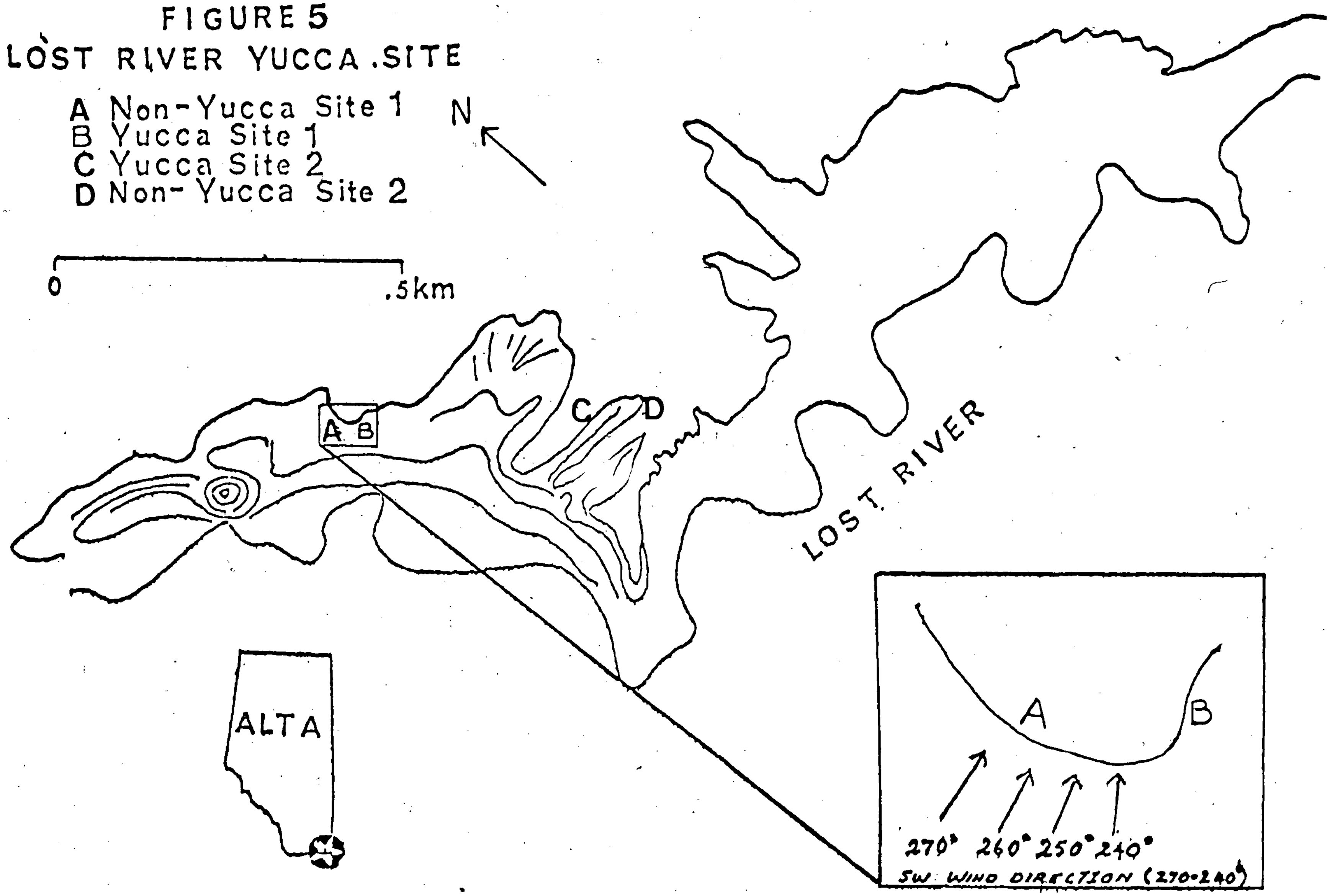


Table 2. Aspect comparisons of some yucca and non-yucca sites which occur along the Lost River coulee face.

Non-yucca		Yucca	
240	SW	34	NE
242	SW	56	NE
250	SW	90	NE
255	SW	100	E
270	W	135	SE
280	NW	140	SE
300	NW	160	SE
318	NW	165	SE
320	NW	175	SE
324	NW	180	S
334	NW	190	SSW
340	NW	200	SSW
360	N	210	SSW
		220	SSW
$\bar{X}$ = 294		147	

Microclimate

July was the month of highest mean monthly solar radiation with the maximum 5-day mean of 1030 cal cm^{-2} day^{-1} and the highest single day value of 1181 cam cm^{-2} day^{-1} (Table 3 and Fig. 6). The low of 144 cal cm^{-2} day^{-1} was recorded on June 7. These results correspond to sky observations (Table 4) which show that July had the greatest number of clear days (24) and June had the greatest number of cloudy or overcast ones (20).

Mean daily temperature reached a peak in July (Table 3). The highest mean daily temperature of 26°C was recorded in August; the highest in July was 25°C. The absolute maximum temperature of 36°C was recorded for several days in July. The absolute minimum temperature of 2°C was reached in June. From May through August, 90% of the days had temperatures of 20°C or higher.

Precipitation was greatest in June (Table 3). Most rain in July and August was from thunder showers which were intense for short periods of time. In contrast, the June rain often fell continuously for several days. Some hail occurred during August.

Maximum humidity was recorded in June corresponding to the period of greatest precipitation (Fig. 7). Five-day means show that relative humidity was highest in late June (Fig. 7) and that atmospheric moisture remained relatively high in July and August.

Table 3. Mean daily, maximum, and minimum temperature and sunlight hours, total precipitation and mean wind speed expressed monthly for the Lost River yucca site, 1976.

Climatic Factor	Months: May	June	July	August
Mean Daily Temperature (^{o}C)	15	16	21	20
Mean Daily Maximum Temperature (^{o}C)	24	23	32	32
Mean Daily Minimum Temperature (^{o}C)	6	10	13	13
Mean Radiation Intensity (cal cm^{-2} day^{-1})	306	783	891	810
Total Precipitation (cm)	.43	10.3	2.2	3.0
Mean Wind Speed (km/hr)	-	9	7	9

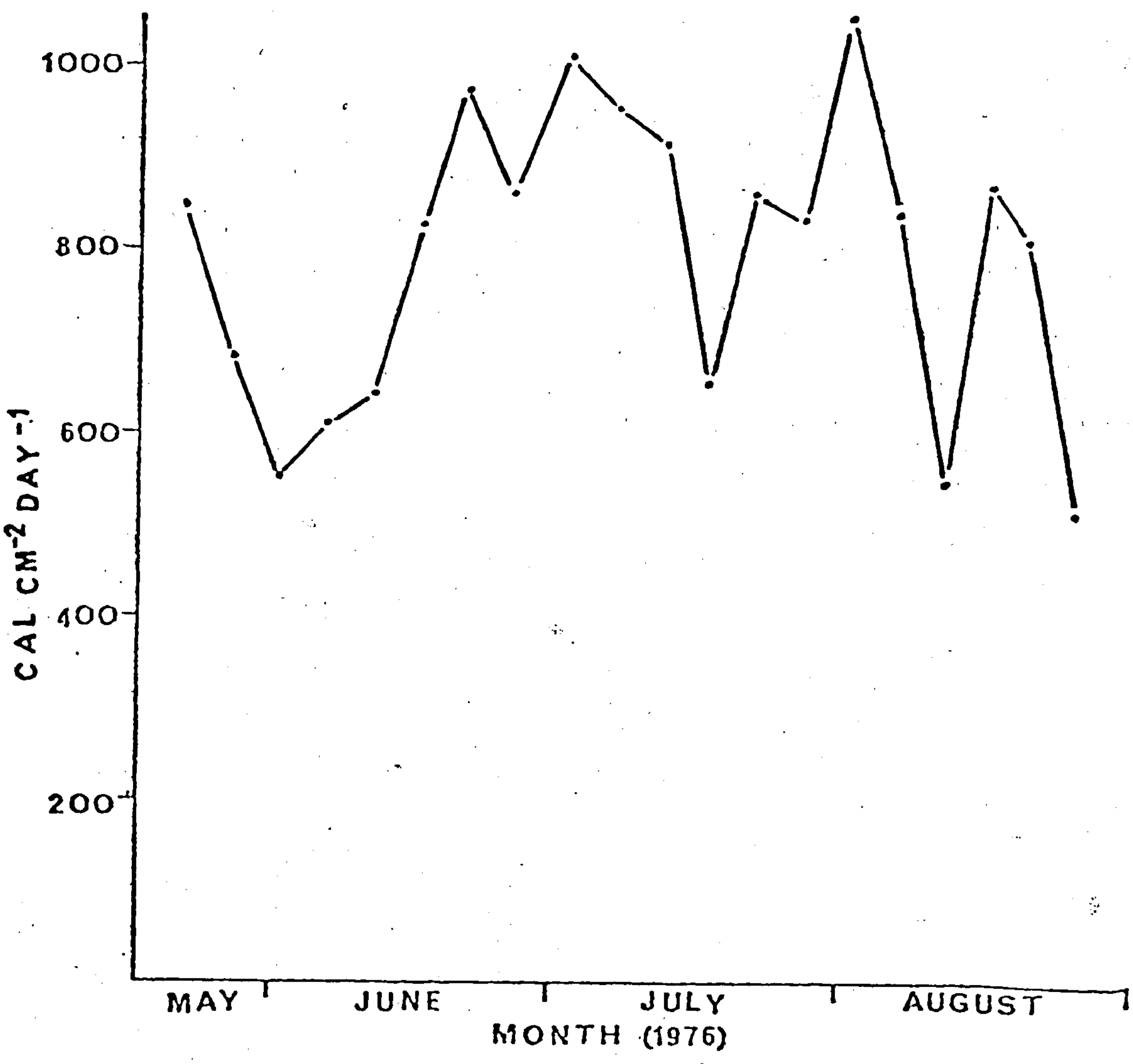


Figure 6. Solar radiation (cal $cm^{-2}day^{-1}$) from May 18-August 25, 1976, for the Lost River yucca site. Values are 5-day means.

Table 4. Sky conditions (days per month) for the Lost River yucca site, May-August, 1976.

Month	Cloudy and Overcast	Clear
May	8	4
June	20	10
July	6	24
August	8	14

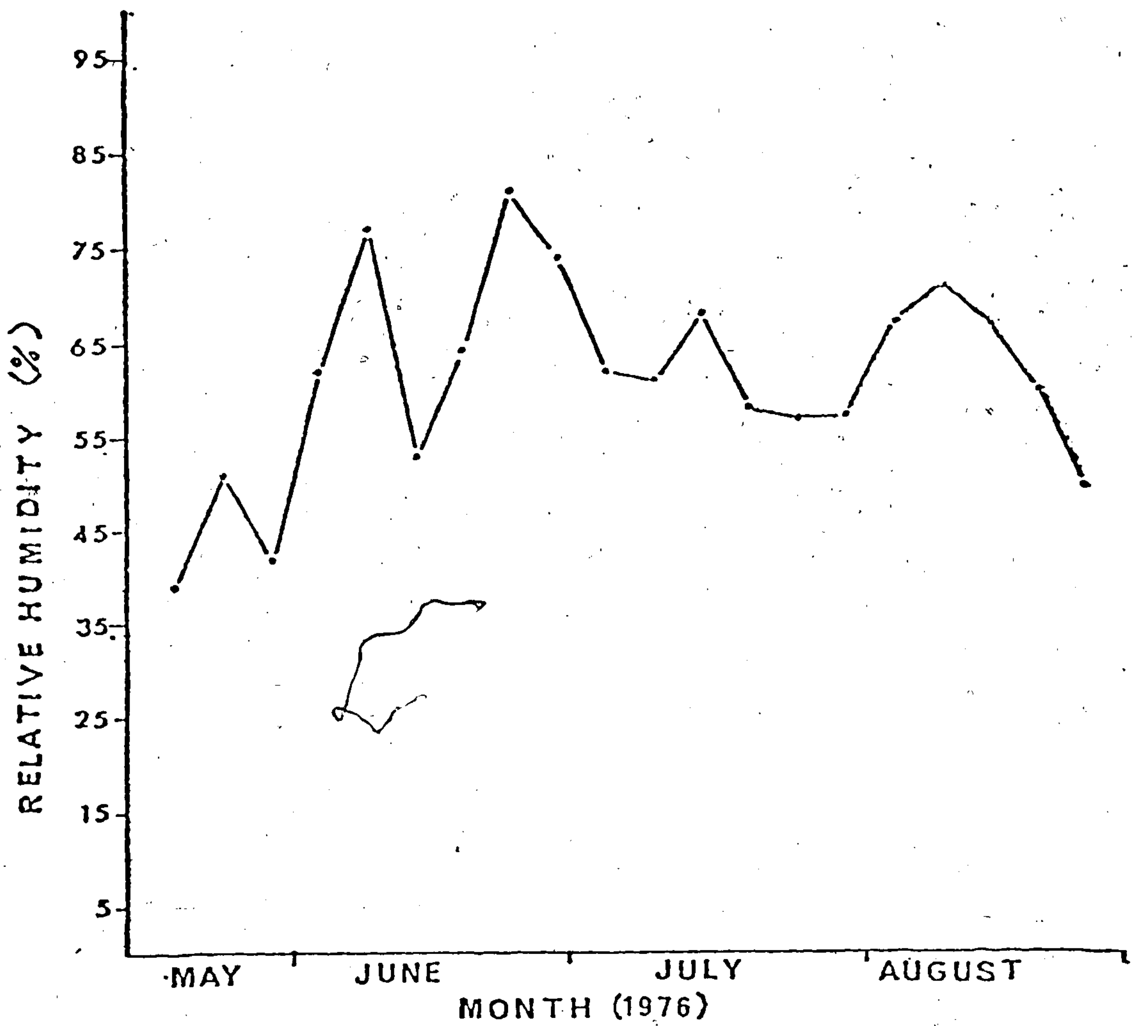


Figure 7. Relative humidity from May 15-August 26, 1976, for the Lost River yucca site at 5-10 cm. Values are 5-day means.

The diurnal pattern of temperature and relative humidity (based upon 20-day means) is shown in Fig. 8. Temperature increased from a low at 0300 hr to a high at 1500 hr. The diurnal cycle (inverse relationship) for relative humidity followed this closely. It was not uncommon for relative humidity to have a range of 50%, nor for temperature to range 15^{O}C over 24 hr.

Winds are consistently high in this prairie region, with those from the southwest predominating (89%) (Table 5). The Lost River yucca site was consistent with these results with 63% of the winds being from the southwest (Table 6). The seasonal high wind speed of 13 km hr^{-1} and low of 2 km hr^{-1} was recorded from the southwest during July and June respectively. Long term records show that winds in excess of 50 km hr^{-1} are common and occasional winds to 100 km hr^{-1} occur.

Short and Long Term Comparison of Mesoclimate

The climate of the Lost River yucca site was compared to short (1976) and long term (1962-75) data, at Onefour. Accessibility to climatic data was the main criteria used to select the 1962-75 results.

In 1976, both the mean daily and mean maximum temperatures were generally higher on the coulee face than recorded further inland at Onefour (Table 7). The mean daily temperature was 3^{O}C higher in June, 6^{O}C higher in July and 8^{O}C higher in August at the yucca site compared to Onefour. This results in part from the slope exposure and position of the sensors (10 cm at the Lost River Site and 1.5 m at Onefour). Only slight variation in mean minimum temperature and precipitation occurred at the two stations. In June, mean minimum temperature was 3^{O}C higher and precipitation 1.3 cm greater at the yucca site. Winds were generally

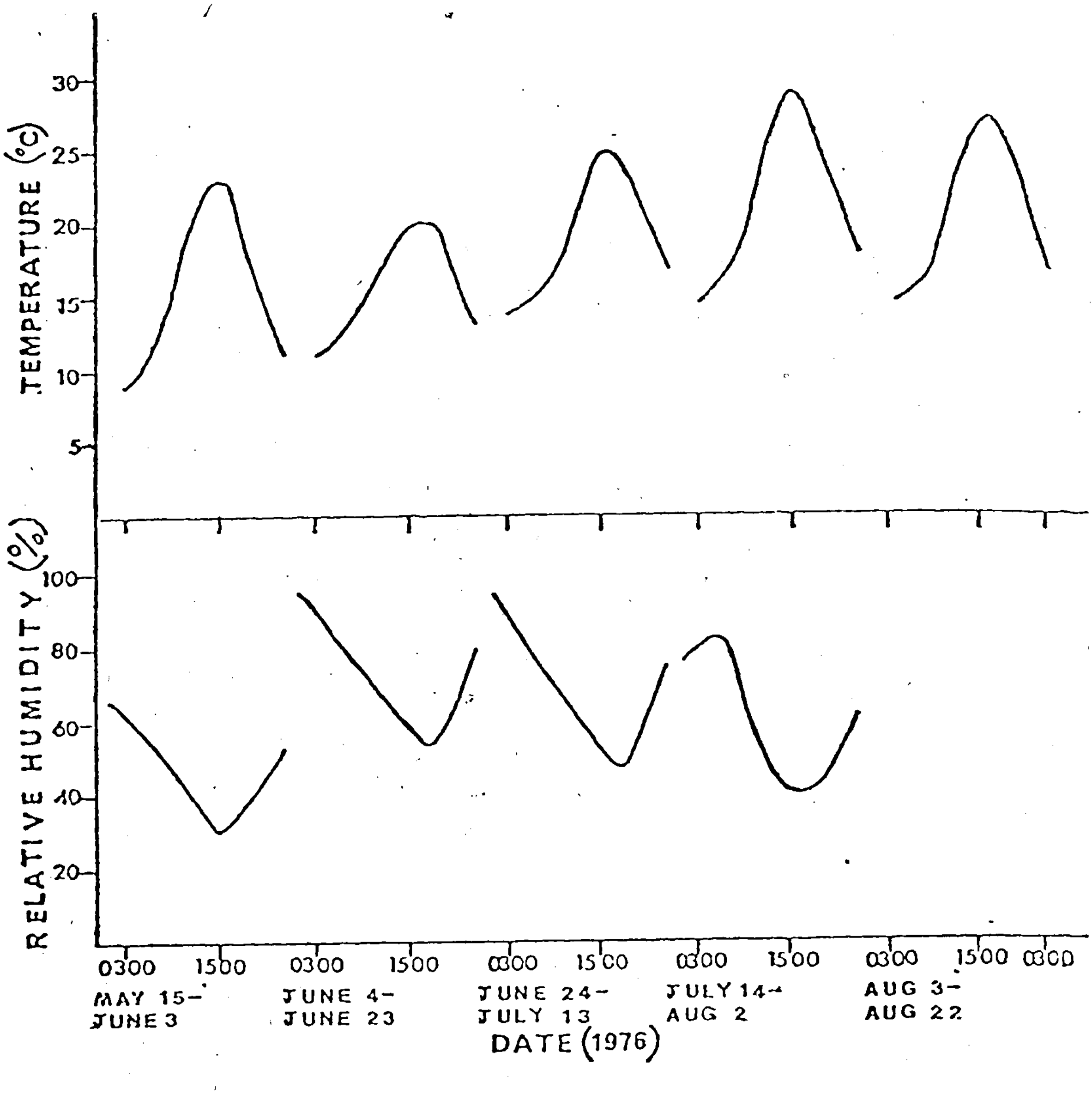


Figure 8. Diurnal temperature and relative humidity regimes at 5-10 cm for Lost River yucca site. Hourly measurements are based on 20-day means.

Table 5. Mean annual wind speed and direction (10 m) for the period 1962-1975, for Medicine Hat Weather Station (Atmospheric Environment Service, Canada Department of Environment, 1962-75).

	Wind Direction					
	SW	WSW	W	E	N	NNE
Medicine Hat mean wind speed ($km\ hr^{-1}$)	17	16	16	17	15	13
Total months for mean wind speed	161	8	6	2	3	1
Total wind direction (%)	89	4	3	1	2	.5

Table 6. Mean daily wind speed and direction (60 cm) for Lost River yucca site, June-August, 1976.

	SW	W	S	SE	E	NW
Lost River site mean wind speed (km hr^{-1})	11	10	8	8	5	7.1
Days for wind direction (%)	63	6	3	23	23	6

Table 7. Comparison of 1976 mean climatic factors from Lost River yucca site and Onefour. Differences were calculated with the Student t-test where P<0.05*, P<0.01**, and P<0.001***

	Month			
	May	June	July	August
Mean Daily Temperature (°C)				
Onefour	15	13	15	12
Lost River	15	16**	21***	20***
Mean Daily Maximum Temperature (°C)				
Onefour	21	20	27	27
Lost River	24***	23***	32***	32***
Mean Daily Minimum Temperature (°C)				
Onefour	6	7	12	12
Lost River	6	10***	13	13
Precipitation (cm)				
Onefour	.76	11.6	1.7	3.0
Lost River	.43	10.3**	2.2	3.0
Mean Wind Speed (km hr^{-1})				
Onefour	-	12	10	10
Lost River	-	9**	7**	9*

higher further inland (3-10 km hr^{-1}). The anemometers were at different heights above the ground (0.6 m at the Lost River Site vs 10 m at Onefour) which may have contributed to this difference.

Comparison was made between the Onefour 1976 summer climatic data and that from 1962-75 (Table 8). In general, the summer was cooler in 1976, although a greater number of sunlight hours was recorded. In June, precipitation results showed a 2-fold increase compared to past years. Until June, less than average precipitation fell.

Microclimatic Profiles for Yucca and Non-Yucca Sites

Air Temperature

Monthly mean temperature data taken at 0900 and 1430 hr show that profiles for yucca and non-yucca sites were similar, varying ±1°C between 0 and 100 cm. Temperature was fairly uniform from 2 to 100 cm at 0900 hr, but tended to decrease with height above the ground by 1430 hr (Fig. 9). This compares with other grassland studies which reveal how heat tends to be absorbed and accumulated in the soil during the day so that by mid-afternoon the region nearest the ground is warmer than the above layers (Baum 1949, Ayyd and Dix 1964, Geiger 1966, Whitman 1969).

Soil Temperature

Mean monthly soil temperature profiles were similar for yucca and non-yucca sites, varying by not more than 1°C between 2 and 60 cm. A diurnal range of 30°C often occurred at -2 cm (Fig. 10). Peak soil temperature at all depths was reached in July (Fig. 11). The high of 48°C was reached at -2 cm during July and the low of 14°C was reached

Table 8. Comparison of 1962-75 with 1976 climatic data from Onefour. Differences were calculated with the Student t-test where $P<0.05$*, $P<0.01$** and $P<0.001$***

Climatic Factor	Month May	June	July	August
Mean Daily Temp. (°C)				
1962-75	11	16	20	19
1976	15***	13***	15***	12***
Mean Daily Max. Temp. (°C)				
1962-75	17	22	27	26
1976	21***	20**	27	27
Mean Daily Min. Temp. (°C)				
1962-75	4	9	12	11
1976	6***	7*	12	12
Radiation (sunlight hr)				
1962-75	248	255	338	290
1976	353***	261*	378***	270***
Precipitation (cm)				
1962-75	3.9	6.0	2.6	3.0
1976	.76**	11.6***	1.7	3.0

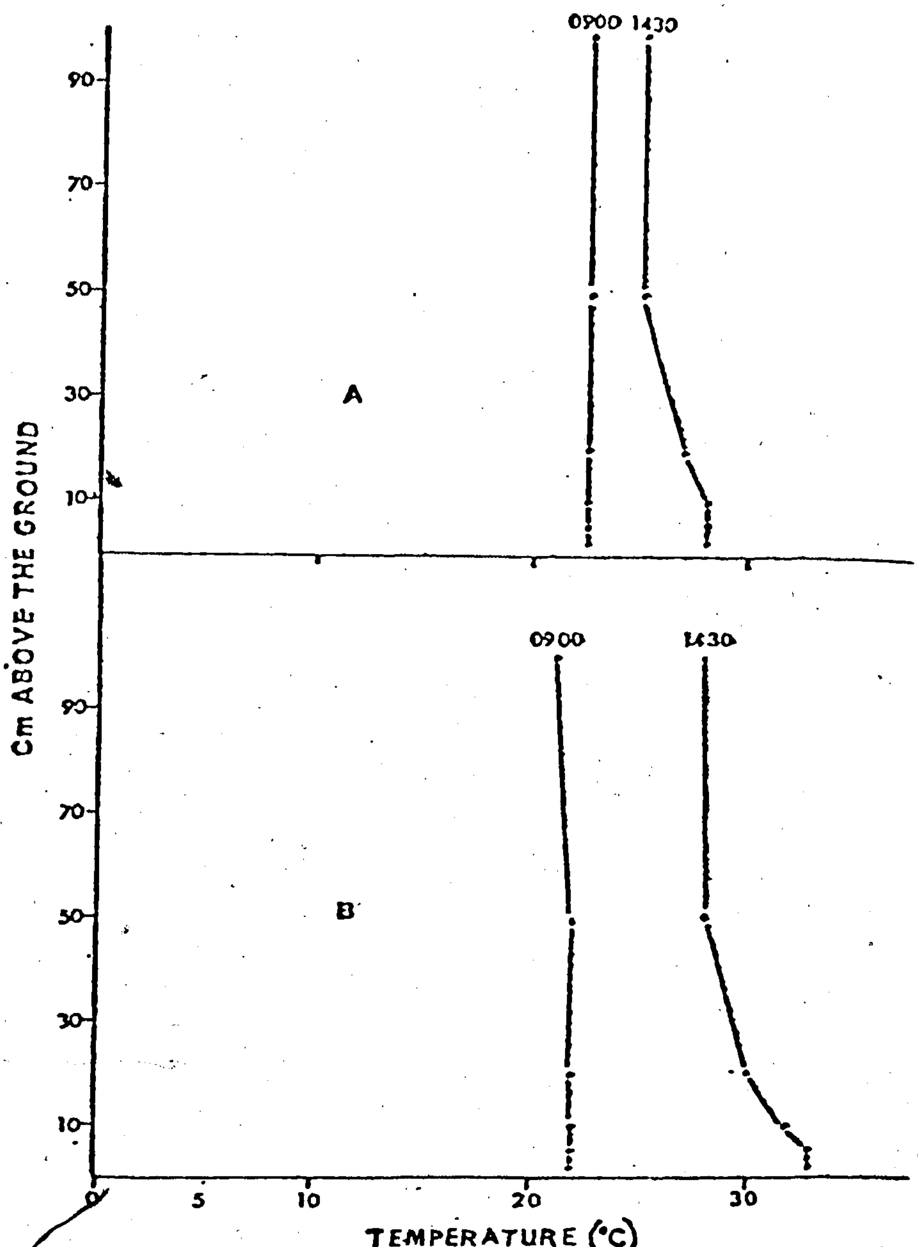


Figure 9. Air temperature profiles at the Lost River yucca site on July 6 (A) and July 15 (B) 1976, at 0900 and 1430 hrs.

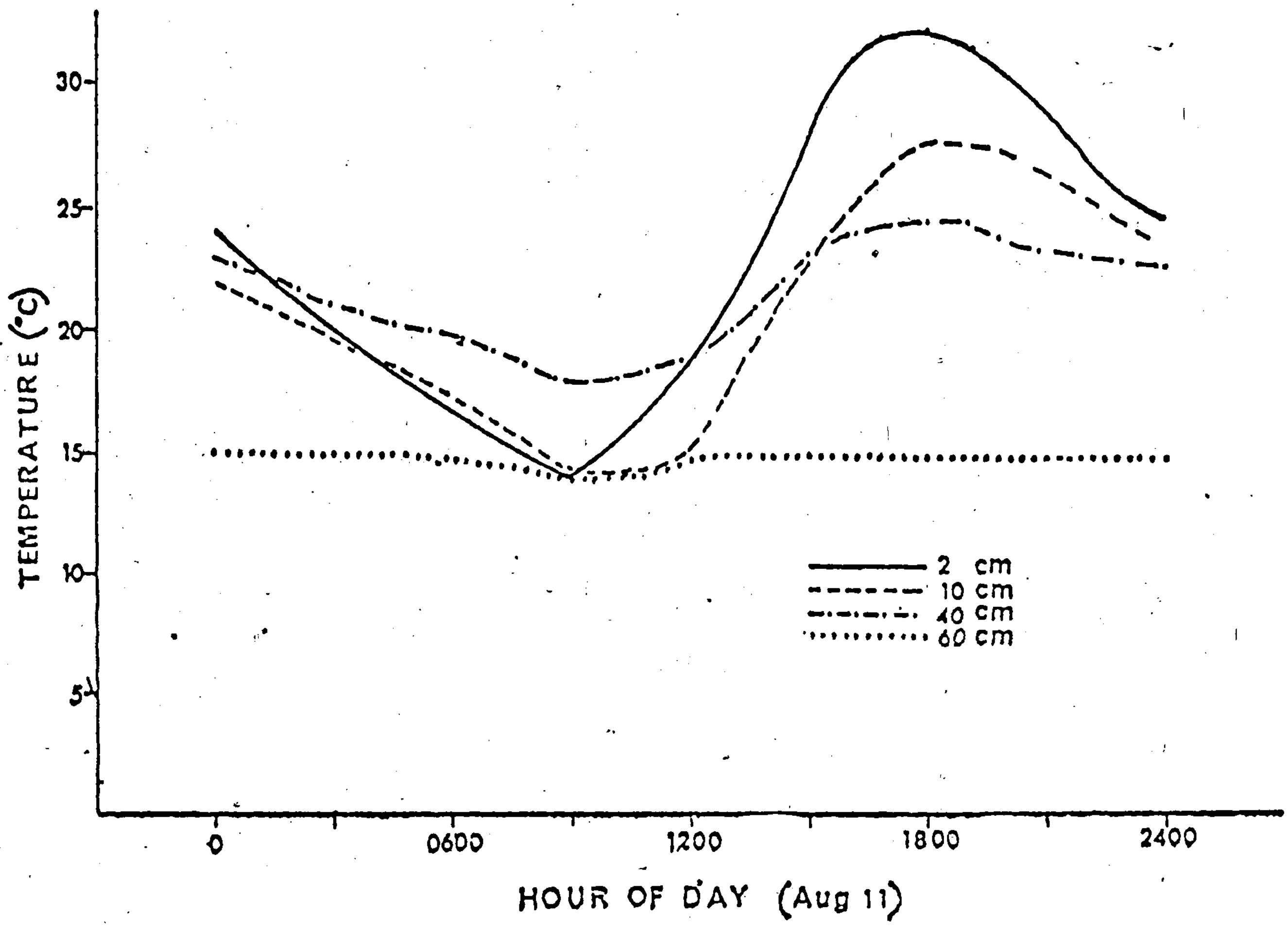


Figure 10. Diurnal soil temperature profile for the Lost River yucca site on August 11, 1976, at -2, -10, -40, and -60 cm.

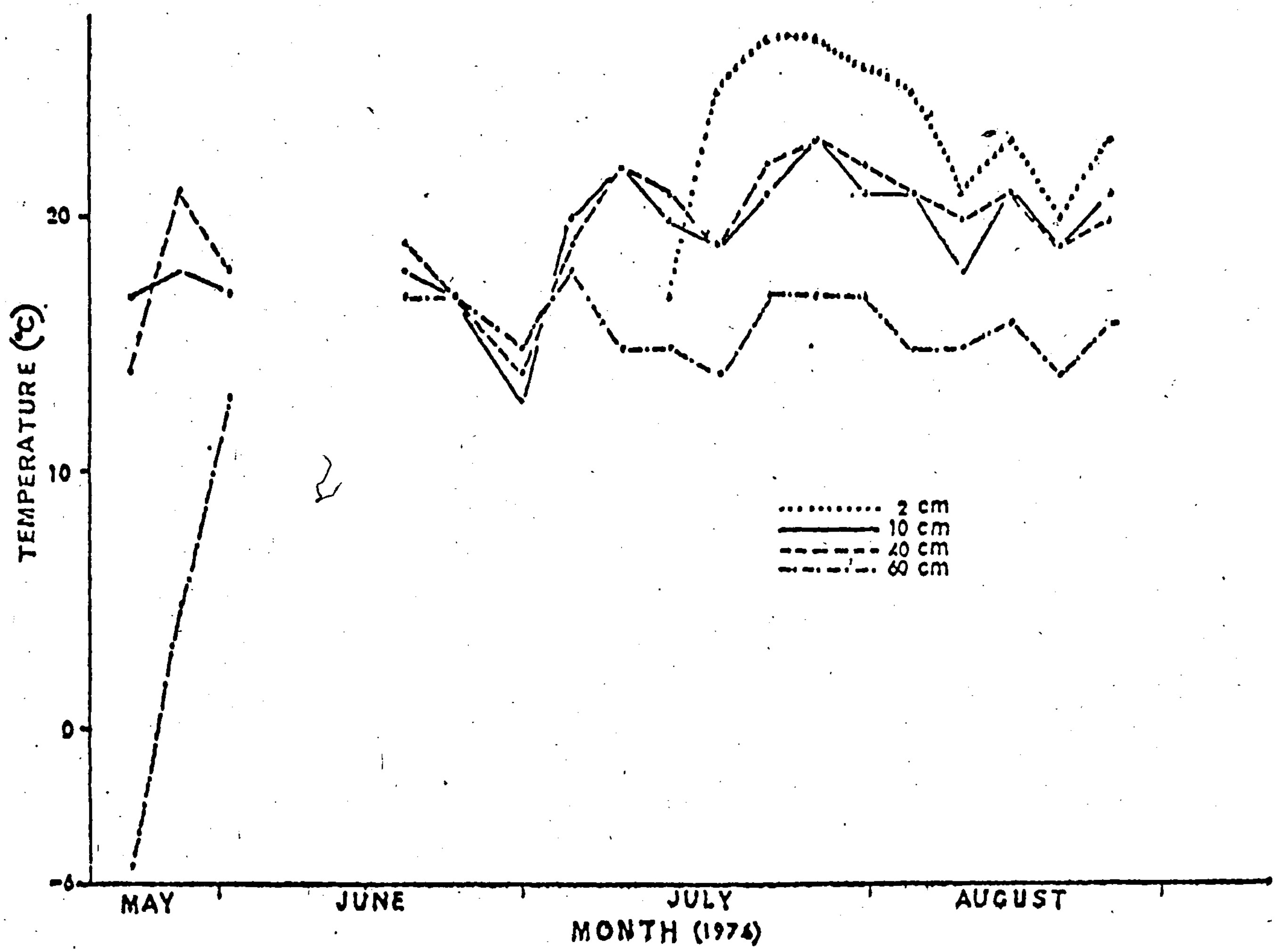


Figure 11. Soil temperature profile at -2, -10, -40, and -60 cm from May 15-August 26, 1976, for the Lost River yucca site. Values are 5-day means.

in May. The absolute minimum temperature of 11°C was recorded in May at 60 cm.

Wind

As previously indicated, southwest winds predominate in the area. There is a relationship between direction of exposure to the prevailing southwest winds and wind speed (Fig. 12). Slopes facing west are subject to stronger winds (Beaty 1975).

Wind profiles vary with wind direction for the yucca and non-yucca sites (Fig. 13 A, B, and C). Mean wind speeds were similar for both sites when winds were from the southeast (A). As winds changed to a more southern direction, they were generally higher for non-yucca sites (B). This difference was even more pronounced when winds were from the southwest (C). Based upon spot readings, mean wind speeds were 7.5 and 2.6 km hr^{-1} for non-yucca and yucca sites respectively at 2 cm above the surface. At 20 and 50 cm, mean wind speeds were 19 and 26 km hr^{-1}, respectively, for the non-yucca and 5 and 10 km hr^{-1} respectively, for the yucca site.

Soils

Glacial till is the parent material for soils of the plains adjacent to the Lost River yucca population. The exposed coulee slopes have a complex of erosional, depositional, and colluvial materials combined with some bedrock exposures. Soil profiles for both yucca and non-yucca sites are regosolic in nature. They have an A_h<10 cm thick and lack a B horizon (Canada Soil Survey Committee 1974). Two different soil profiles occur for the non-yucca sites. The most common has a shallow,

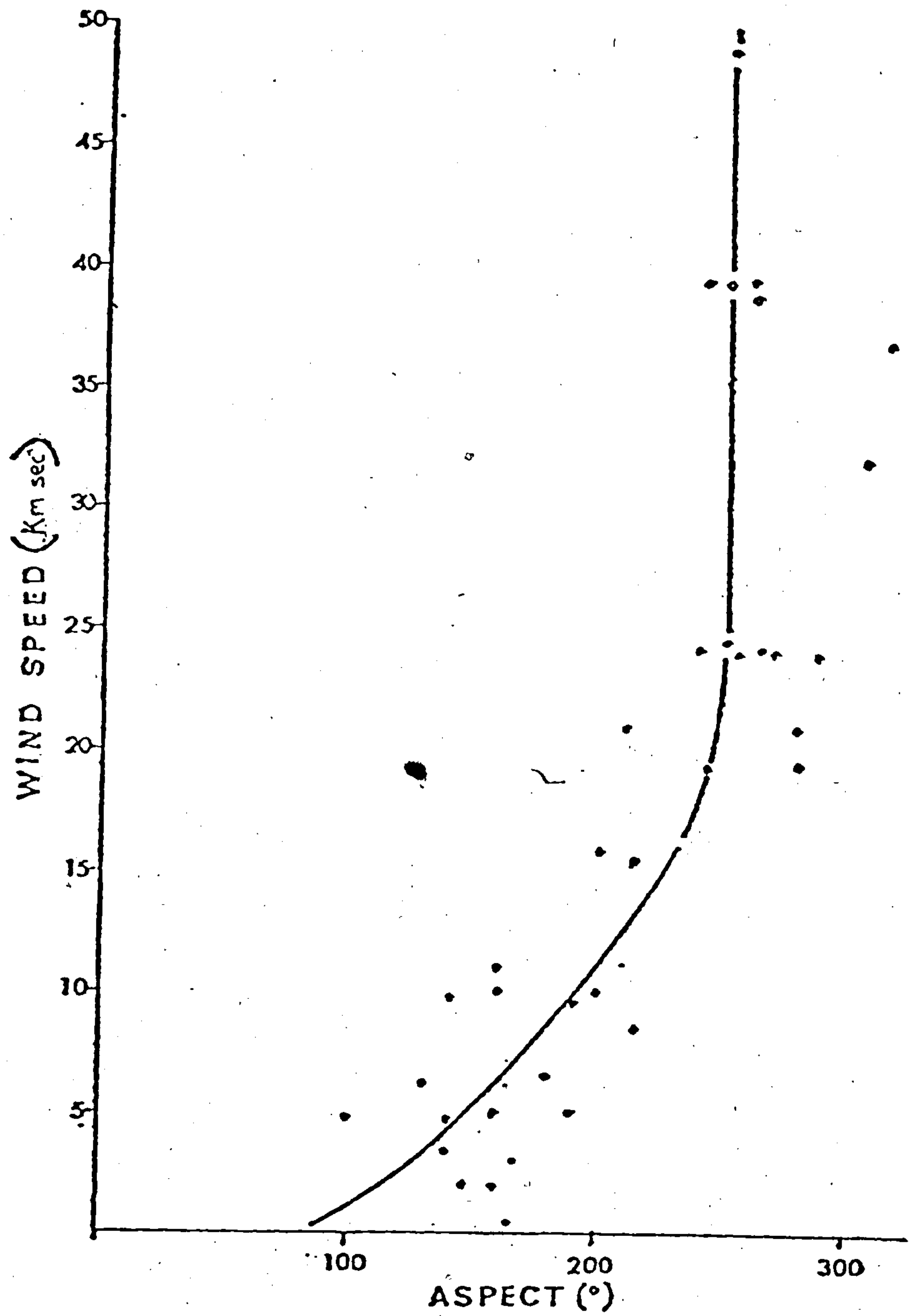


Figure 12. Mean wind speeds according to aspect for south-west winds (240-280°) at 20 cm (1976)(n=17).

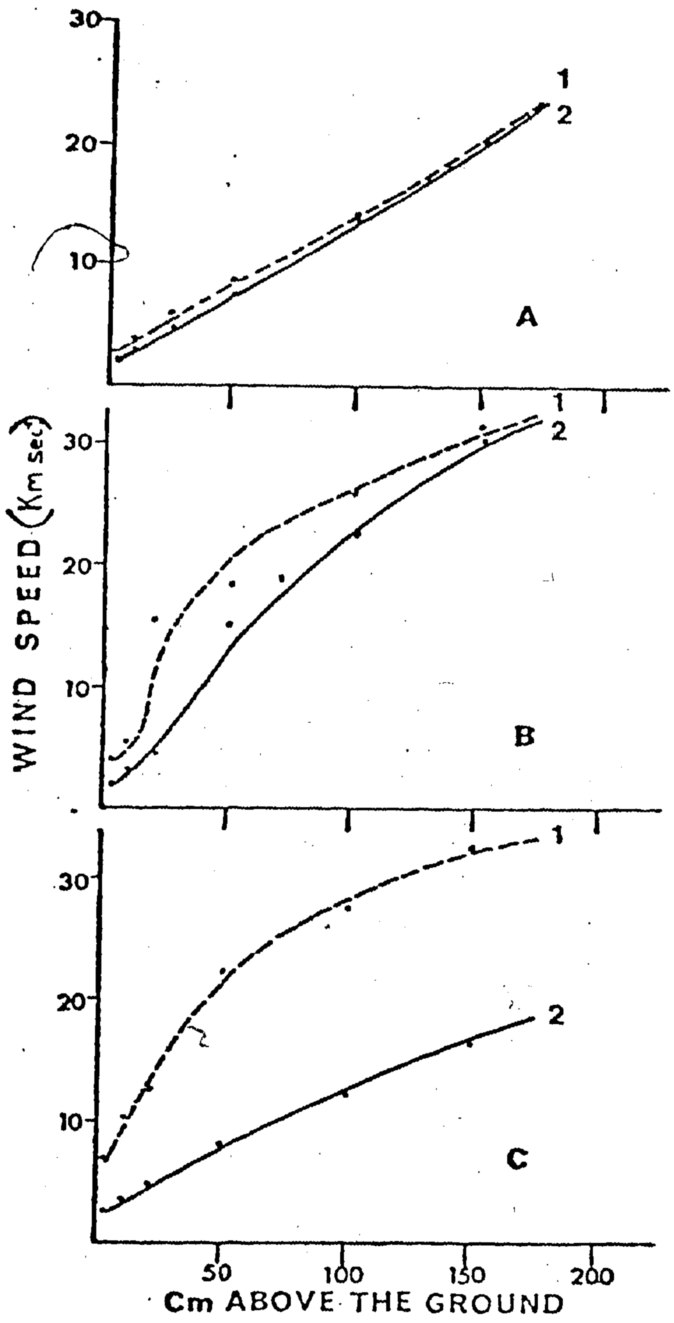


Figure 13. Summer 1976 mean wind profiles at Lost River yucca (2) and non-yucca (1) sites for southeast (A), south (B), and southwest (C) winds. (n=27).

soft to slightly hard, single grained horizon to a depth of 20-30 cm (C_k) followed by a hardpan with very course, strong, subangular blocky structure having a bulk density of 1.92 (C_{kx}) (as determined by the Alberta Soils Survey Laboratory) (Fig. 14). The colour of the C_k horizon is brown (10 YR 5/3 d) to dark brown (10 YR 3/3 d). A few very fine, fine and medium roots occur in the upper 20 cm but are not present in the hardpan layer. The second type of soil is similar to that of the yucca sites (Appendix A).

Depth to hardpan was significantly less on the margin of yucca and non-yucca sites (Table 12). It was often found at depths less than 40 cm but did occur at greater than 100 cm.

The profile of the yucca site consists of a single grained structure to a depth of 100 + cm (C_k) (Fig. 15). Abundant fine and medium roots penetrate into the C_k horizon to depths of 80 cm. The colour of this horizon is pale brown (10 YR 6/8 d) (Appendix A).

Profile description for the Milk River yucca site is the same as described for the site on the Lost River.

Soil pH, $CaCO_3$ equivalents and % organic matter for yucca and non-yucca sites are given in Table 9. Soils of both sites are moderately alkaline with an average pH of 8.0; $CaCO_3$ equivalents range from 4% to 9%, the difference between the sites being minor. Organic matter contents are lower for the non-yucca sites at both depths but the limited data did not permit statistical analyses. These data show that yucca and non-yucca sites are similar in pH and $CaCO_3$ equivalents but differ in organic matter accumulation which corresponds to the difference in plant cover.

Texture analysis (Table 10) shows a greater percentage of sand and silt to be associated with yucca and a greater percentage of clay with

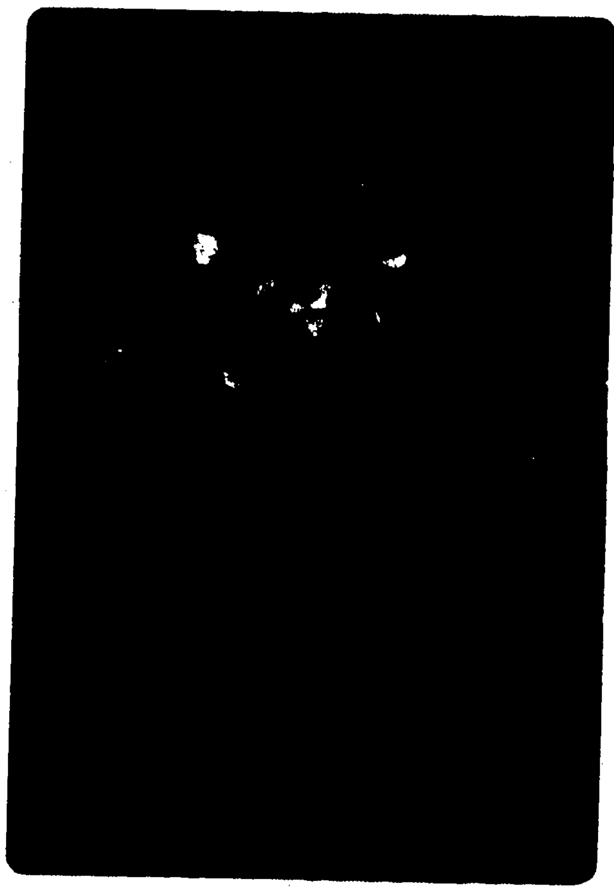


Figure 14. Soil profile from non-yucca site showing hardpan 20-30 cm below the surface.

Figure 15. Soil profile from yucca site showing sandy texture to a depth greater than 100 cm.

Table 9. Soil pH, $CaCO_3$ equivalent and organic matter for two yucca (Y) and non-yucca (NY) sites within the Lost River study area (n=12).

Soil Depth (cm)	pH Site 1 Y	pH Site 1 NY	pH Site 2 Y	pH Site 2 NY
2-5	8.1	8.1	8.2	7.9
10	8.1	8.0	8.2	8.1
20	8.1	8.0	8.0	7.9
40	8.1	8.0	8.0	8.0
60	8.1	8.0	8.1	8.0
100	8.0	-	8.0	8.0
	$CaCO_3$ Equivalents (%)			
2	7	7	8	7
5	7	9	7	4
20	8	8	6	8
40	8	7	7	8
60	8	6	5	6
	Organic Matter (%)			
0-5	3.5	1.7	1.8	1.2
20	1.5	1.1	1.8	1.1

Table 10. Texture analysis for Lost River yucca (Y) and non-yucca (NY) plots (I & II) including texture class (n=12).

Site	Soil Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture Class
Yucca I	5	75	15	10	SL
	10	70	18	12	SL
	20	62	24	14	SL
	40	60	22	18	SL
	60	64	20	16	SL
	100	64	28	8	SL
Non-yucca I	5	64	12	24	SCL
	10	66	10	24	SCL
	20	64	12	24	SCL
	40	64	14	22	SCL
	60	64	12	24	SCL
Yucca II	5	72	16	12	SL
	10	72	12	16	SL
	20	62	26	12	SL
	40	84	10	6	LS
	60	92	2	6	S
	100	82	12	6	LS
Non-yucca II	5	78	10	12	SL
	10	66	18	16	SL
	20	68	18	14	SL
	40	68	16	16	SL
	60	64	14	22	SCL
	100	92	0	8	S

non-yucca sites.

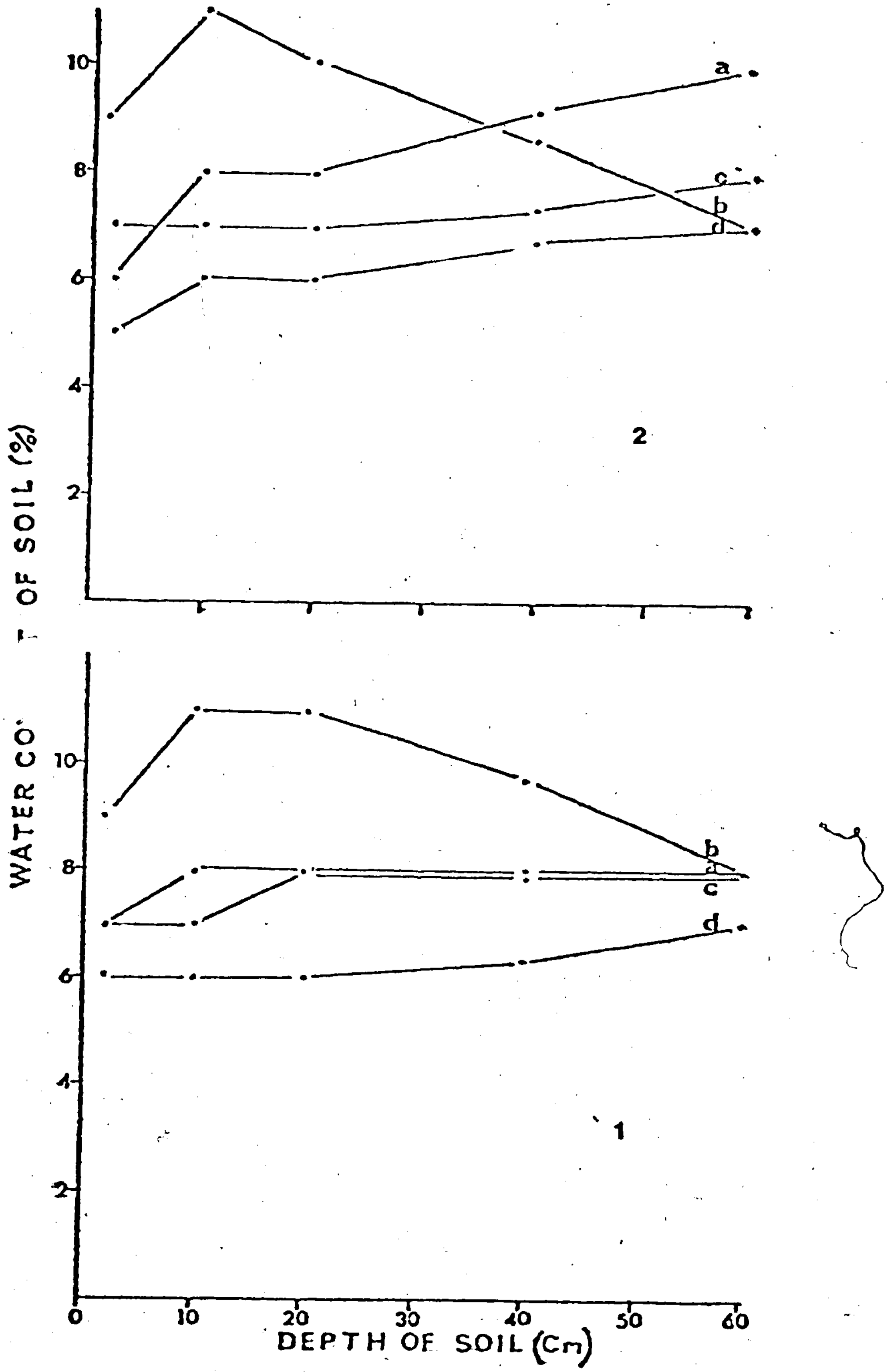
Mean monthly measurements of soil water contents are low (7-8%) with no significant difference between sites (Fig. 16 and 17). Soils were generally moister during the spring and early summer than in mid to late summer. June was the month of highest soil water content at both sites, again reflecting the high rates of precipitation.

Associated Vegetation

Diagrams of yucca and non-yucca plots show the distribution of Yucca glauca (Fig. 18 A and B, Fig. 19 C and D). The degree to which the slopes are oriented away from a direct southwest exposure tends to influence density of the two species. In yucca site I, Y. glauca is more abundant at the NE corner, tending to become more sparse toward the western part of the plot where the non-yucca site begins. Yucca site II differs in having greatest distribution of yucca along the top of the plot, becoming gradually less toward the bottom.

Both species numbers and cover are greater on yucca compared to non-yucca plots (Table 11). Eighteen species were found on the yucca sites compared with fourteen on the non-yucca. Muhlenbergia cuspidata is of greater importance on yucca plots, while Stipa comata is more important on non-yucca areas. Bouteloua gracilis has a greater cover and importance value on yucca sites. Phlox hoodii, Hymenoxys richardsonii, and H. acaulis which occupy more exposed areas on the prairie are more important on the non-yucca sites. Mean total cover is greater on yucca sites, being [illegible] compared to 48% for non-yucca plots.

Figure 16. Mean water content at -2 to -60 cm for May (a), June (b), July (d), and August (c), 1976, for the Lost River yucca (2) and non-yucca (1) sites. (n=24).


WATER CO
OF SOIL (%)
DEPTH OF SOIL (Cm)
10
8
6
4
2
0
10
20
30
40
50
60
a
b
c
d
2
1

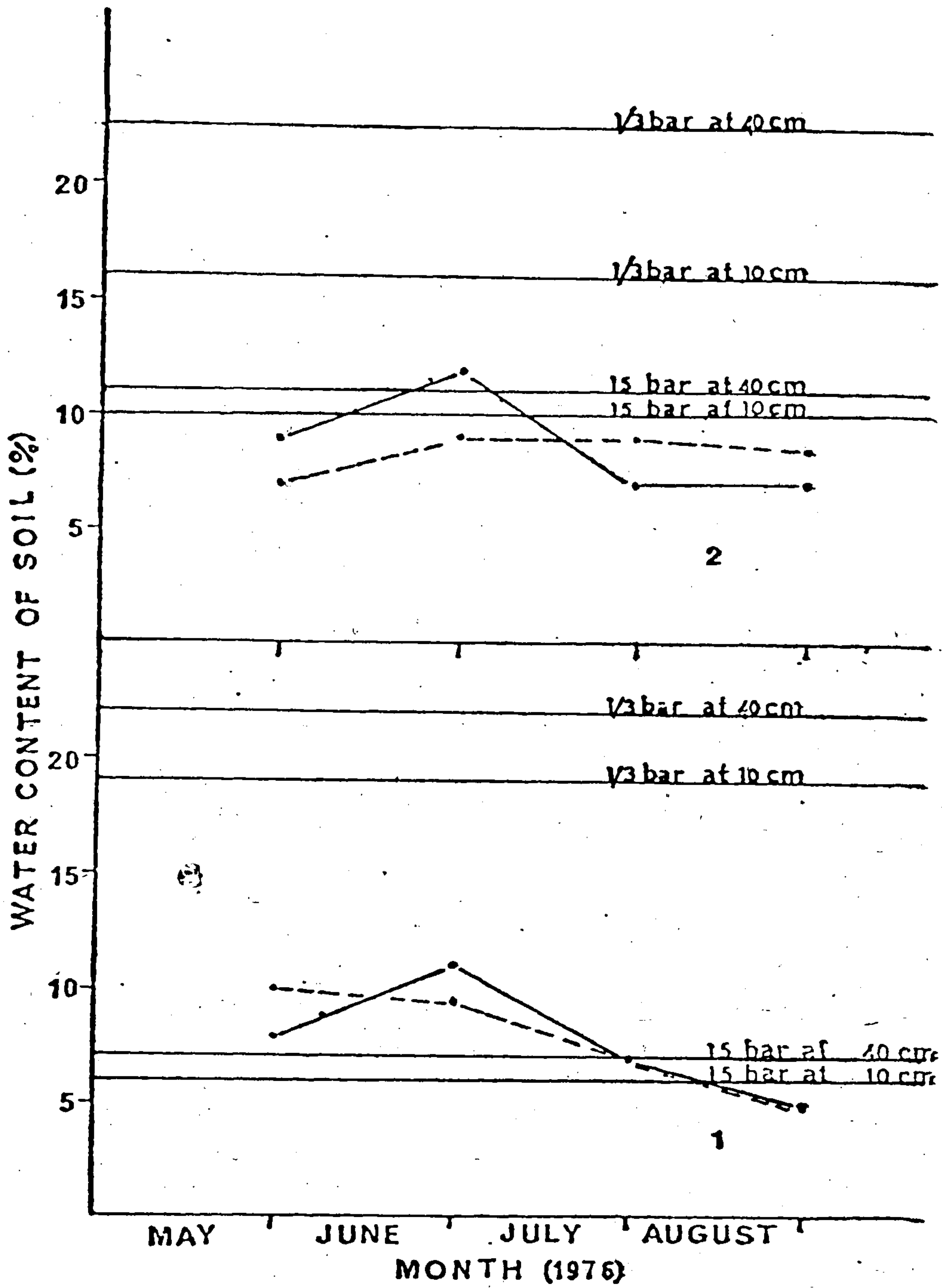


Figure 17. Mean monthly water content for Lost River yucca (1) and non-yucca (2) soils at -10 and -40 cm. Data are presented in relation to range of available soil water (1/3 and 15 bars)(n=24).

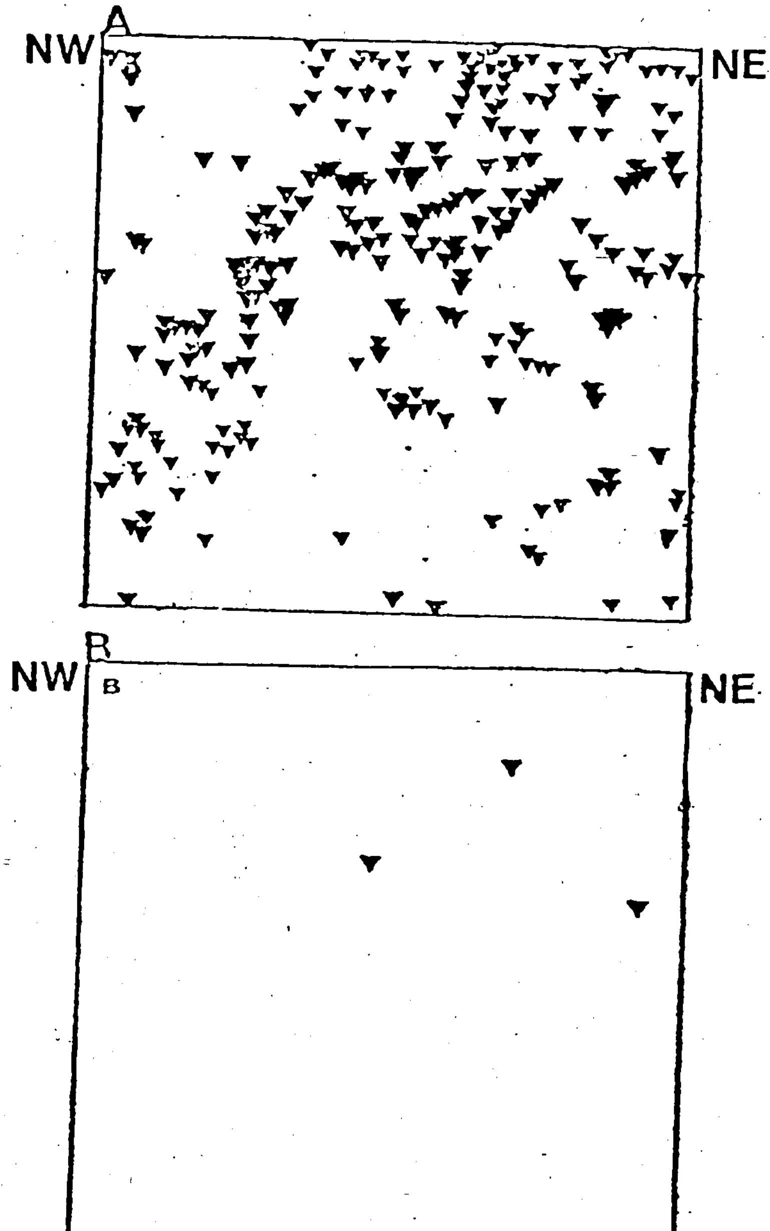


Figure 18. Distribution of Yucca glauca in two 25 X 25 m plots along the Lost River coulee face, where A is yucca site I and B is non-yucca site I.

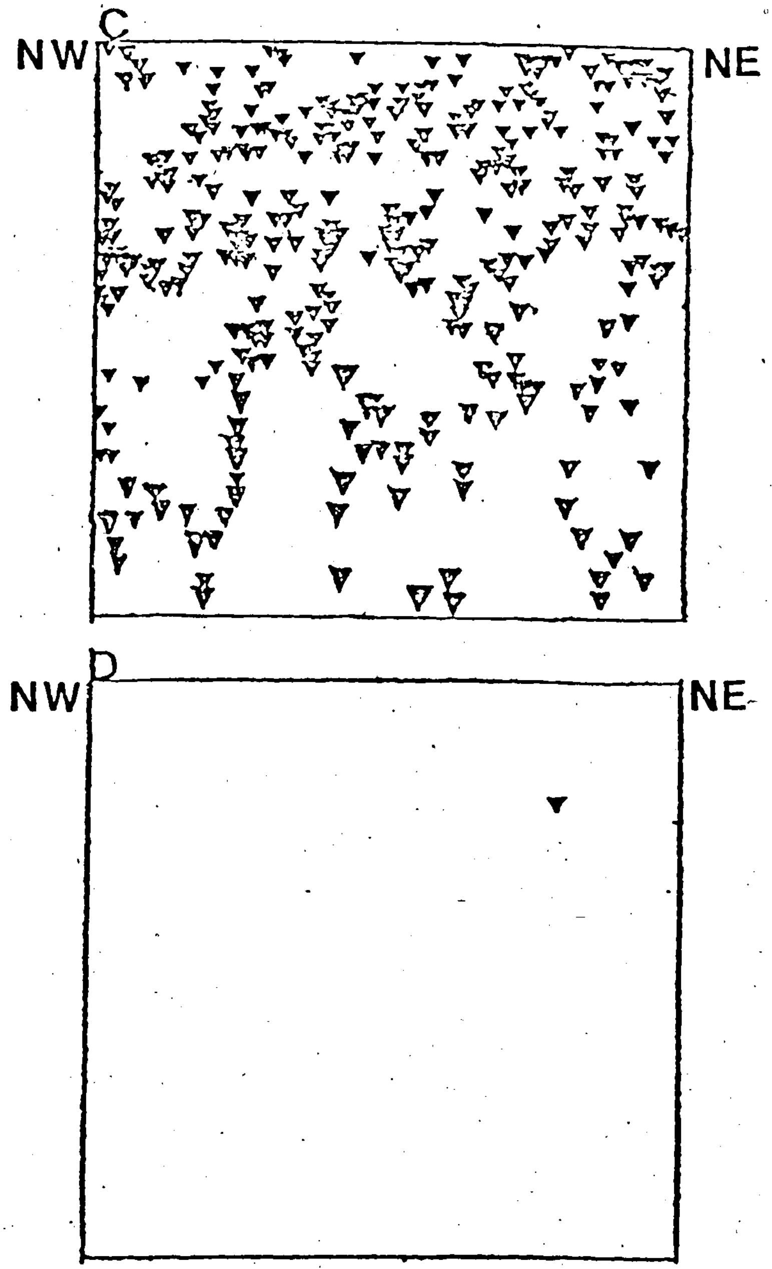


Figure 19. Distribution of *Yucca glauca* in two 25 X 25 m plots along the Lost River coulee face, where C is yucca site II and D is non-yucca site II.

Table 11. Relative frequency (RF), relative cover (RC), importance values (IV), and total cover for species occurring on Lost River yucca (Y) and non-yucca (NY) plots. (n=18).

Species	YS I RF (%)	YS I RC (%)	YS I IV (%)	YS II RF (%)	YS II RC (%)	YS II IV (%)	NYS III RF (%)	NYS III RC (%)	NYS III IV (%)	NYS II RF (%)	NYS II RC (%)	NYS II IV (%)
Bouteloua gracilis	17	8	25	7	11	18	10	5	16	7	9	16
Koeleria cristata	15	21	36	6	3	9	15	9	24	2	1	3
Muhlenbergia cuspidata	11	11	22	13	10	23	5	4	9	5	8	13
Calamovilfa longifolia	7	5	12	19	11	30	3	2	5	26	11	37
Stipa comata	6	6	12	21	17	38	24	16	30	37	44	81
Linium rigidum	1	+	+	1	+	+	3	1	4	5	1	6
Phlox hoodii	7	3	10	1	1	2	10	7	17	7	13	20
Artemesia cana	11	18	39	9	17	26	10	11	21	7	9	16
Opuntia polycantha	1	+	1	4	3	7	2	+	2	2	1	3
Yucca glauca	9	19	28	12	24	36						
Eriogonum flavum	1	+	2									
Penstemon gracilis	13	8	21	3	+	+	12	5	17			
Gutierrezia sarothrae				1	+	+	3	5	8	2	+	3
Artemesia frigida				1	+	1						
Astragalis pectinatus	1	+										
Sphaeralcea coccinea	1	+		1						2	+	
Oxytropis macounii	1	+										
Asclepius viridiflora	1	+		1	+							
Hymenoxys richardsonii							2	+		2	+	
H. acaulis							2	+		2	+	
ΣC		63			59			44			52	
Σspecies	16			15			13			13		

Morphological Studies

The Shoot and Flowers

In southern Alberta, Yucca glauca occurs both singly and in clumps. Clumps consist of shoots growing from the parent rhizome, dead plants, and old flower stalks. The average number of shoots per clump was 3 ± 1, but as many as 14 were recorded. Mean plant height (top of leaves) was 22 ± 6 cm. A maximum height of 35 cm was made for several plants. Mean leaf length was 30 ± 5 cm, but this measurement could vary from 8 to 45 cm. Leaf width varied from .3 cm to .7 cm.

The plants in Alberta are generally smaller in size than those found toward the southern extent of their range. Mean leaf length further south is 50-70 cm, and flower stalks are between 88-125 cm. Floral parts also tend to be smaller (Webber 1953) (Table 13).

Underground System

The underground system of Y. glauca consists of a large rhizome oriented vertically, then turning to a horizontal position about one-half way down its total length. This is a general morphological feature regardless of soil type. Numerous rootlets project in a horizontal direction from this rhizome, penetrating the soil for up to a meter in length. The rhizome, including rootlets, is a reddish colour, about 3 mm in diameter, with the rhizome ending in a whitish knob.

Depth of penetration of yucca rhizomes is significantly less at the margin of yucca sites where hardpan often occurs at less than 50 cm from the surface (Table 12). Rhizomes may grow to a depth of 50-65 cm in the centre of yucca sites compared to 20-35 cm on the margin. They penetrate only the top few centimeters of the hardpan layer before they

Table 12. Influence of hardpan on growth of Yucca glauca on margin compared to center of yucca site I. Numbers represent mean values where: P 0.05*, P 0.01**, and P 0.001*** (n=15) (±SE).

	Centre of Yucca Site I	Margin of Yucca Site I
Depth to hardpan (cm)	100+	47***±9
Yucca rhizome length (cm)	131±5	70**±12
Yucca rhizome depth (cm)	56.2±2	34***±5
Plant height (cm)	30±2	24±3
Leaf width (cm)	5±.2	5±.2
Number flower stalks	2±.73	1*±.3
Number plants in clump	3±.32	1**±.16

Table 13. Floristic comparison of Yucca glauca from southern Alberta (49 N. latitude) and distribution centre (ca. 40 N. latitude) (Webber 1952).

Plant Characteristics (Mean Values)	[illegible]n Extent [illegible] Range ([illegible]N. lat.)	Distribution Centre (ca. 40°N. lat.)
Number of flowers per plant ([illegible]15)	26	-
Height of flower stalk (cm) (n=15)	57	108
Sepal length (cm) (n=40)	5	5
Sepal width (cm) (n=40)	2.5	3
Petal length (cm) (n=40)	5	5
Petal width (cm) (n=40)	3	3.7
Stamen length (cm) (n=40)	1.5	2.1
Pistil length (cm) (n=40)	2.8	3.3

turn to a horizontal position and grow along the top. Although the hardpan impedes rhizome growth, it does not influence shoot growth. Mean plant height and leaf width were similar both in the yucca site and toward the margin. More plants had flowered and there was a greater number of clumps in the centre of the yucca site (Table 12).

Leaf Water Potential

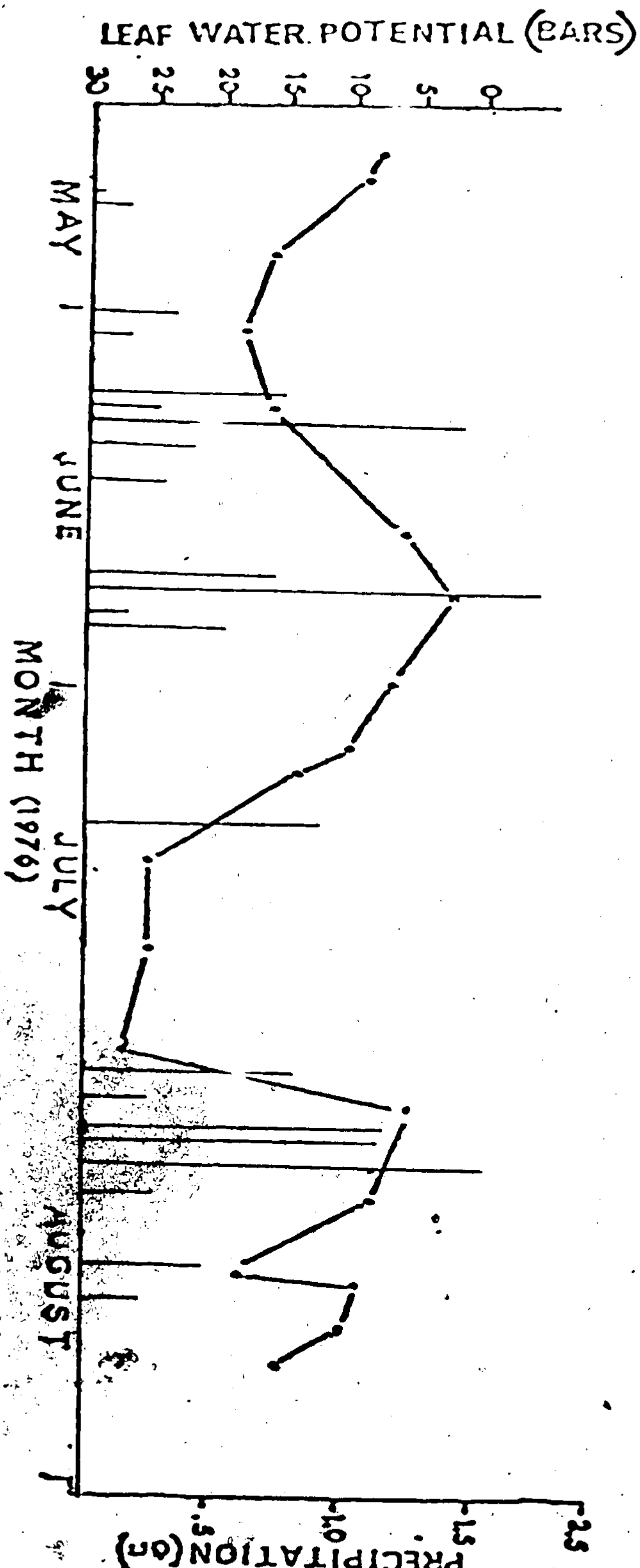
Both soil moisture levels and absorption capacity of the roots in addition to potential leaf transpiration interact continuously in determining the leaf water potential (Ψ leaf) (Slatyer 1967). Leaf water potentials serve as an indicator of the relative moisture status and the efficiency of the plant to obtain and store moisture.

The fluctuation of leaf water potential with precipitation is shown in Figure 20. June was the period of greatest rainfall, highest soil water contents and highest leaf potentials (-2 bars). As the soil dried out during July, leaf potentials decreased reaching a low of -25 to -27 bars in mid-July. Thundershowers were common during the latter part of July and early August having little influence on soil moisture which remained at low levels. The intense rain from these thunderstorms were sufficient to raise leaf water potentials to -5 bars during early August. As shower activity decreased through August, so did leaf water potentials.

Seed Germination

Germination of Yucca glauca seeds has been reported by McKelvey (1947), Webber (1953), Arnott (1962), and McCleary and Wagner (1973). The seeds are flat, black, asymetrical, with a hard tough seed coat, relatively small embryo and abundant endosperm. Those obtained from

Figure 20. Fluctuation of leaf water potential with precipitation, from May 15-August 31, 1976. Dots (·) represent 7-day means (n=4).


LEAF WATER POTENTIAL (BARS)
30 25 20 15 10 5 0
MAY
JUNE
JULY
AUGUST
MONTH (1976)
PRECIPITATION
.5 1.0 1.5

southeastern Alberta have a mean length of 12 ± 2 mm, width of 9 ± 1 mm and were 1 mm thick. They contain no starch, some lipid, a vascular bundle, and a bundle lacuna (Arnott 1962).

Throughout the range of Yucca glauca, germination and seedling success is low (Webber 1953). Many of the flowers in southern Alberta fail to produce seeds because of damage by wind, rain, or hail. Many seeds are consumed by the yucca moth, rodents, and birds, or are washed onto erosion channels to be buried. Rainfall is irregular in southern Alberta, as it is throughout the range of the plant, which also limits germination and establishment of seedlings. Yucca seedlings are extremely slow in growth. They retain their grasslike juvenile leaves for over a year, during which time they are susceptible to rodent and insect damage (Webber 1953).

Seeds obtained from the Lost River site germinated after 2 days with maximum number of seeds germinating after 10 days. Radicle length increases rapidly, approximately 4 mm each day. Maximum germination occurred at 20°C (92%) (Table 14). No significant difference in germination occurred from 16 to 24°C. There was a significant influence of temperature on germination (Table 15). A nonsignificant difference in seed germination occurred between replicates (Table 15).

Table 14. Percent germination of <u>Yucca glauca</u> seed at various temperatures (underlining refers to non-significant differences) (n=90).

Temp. (°C)	0	5	10	14	16	18	20	24	28	37	43
Germ. (%)	-	-	-	16	69	90	92	88	66	3	4

Table 15. One-way analysis of variance for seed germination.

A. Treatment

	Mean Square	F value	P=0.01
Treatment	165.32	17.35	4.30
Error	9.53		

B. Replicates

	Mean Square	F value	P=0.01
Replicates	67.01	1.40	6.11
Error	94.03		

DISCUSSION

Habitat of Yucca glauca in Alberta

Study Area

Aspect of prairie slopes has been reported to influence the patterning of plants through changes in soils and microclimate (Aikman 1941, Dix 1958, 1960, Cooper 1961, Ayyad and Dix 1964). It also determines the northern limits of distribution of a species when the environment is within its tolerance limits (Boyko 1947, 1949, McMillan 1959 B). As with numerous species, Yucca glauca reaches its northern limits on warm dry and south facing slopes. In Alberta, the species is located along portions of the Lost and Milk River coulee faces. Differences in orientation of the coulees leading to variation in slope exposure can be related to its distribution. For the Lost River yucca population, the species occurs where slope aspect is south to east. The species does not occur where the slope exposure is southwest to west (non-yucca sites). Of the microclimatic parameters measured, there appeared to be a relationship between the prevailing southwest wind speed and occurrence of Yucca. Wind speeds (mean values) were 65% higher at 2 cm, 73% at 20 cm and 62% greater at 50 cm on the non-yucca sites than on the yucca ones. A relationship exists between southwest wind speeds and sheet and gully erosion on the southwest exposed coulee slopes, drier conditions, and more sparse vegetation.

With the exception of wind speeds, the microclimate along the Lost River yucca site was quite uniform. Summer climate, based on May through August, 1976 observations, was characterized by high solar radiation (range 144-1181 cal cm^{-2} day^{-1}, summer mean 697 cal cm^{-2} day^{-1}), high temperatures (range 2 to 26^{o}C, summer mean 18^{o}C), low precipitation (range from 4.3 mm in May to 103 mm in June, summer mean 40 mm), moderate wind speeds (range 2-13 km hr^{-1}, summer mean 8 km hr^{-1}), moderate relative humidity (range 35-100%, summer mean 61%), and a high percent of sunny days (53% of summer season). Air and soil temperature profiles varied by not more than 1 C between 0 and 100 cm for the yucca and non-yucca sites. Mean daily and mean maximum temperatures on the prairie (as recorded further inland at Onefour) were generally lower (3 to 8^{o}C) than on the Lost River coulee face. Winds were usually higher further inland (3-10 km hr^{-1}). Precipitation was similar at the two stations.

Adaptive Features of <u>Yucca glauca</u>

The growth form of <u>Yucca glauca</u> is smaller at its northern limit than near the centre of its range (McKelvey 1947, Webber 1953). Leaves, flower stalk, floral parts, and other morphological features are all smaller. It was not determined whether these morphological differences were an ecotypic differentiation for adaption to a cold climate or merely a non-genetic response to the effects of limiting factors such as soil nutrition, soil moisture, temperature, and length of growing season on plant growth (Hains 1941, Braddshaw 1960).

Plants were often observed in clumps of several shoots growing out from a single rhizome. Persistance of dead shoots and flower stalks contributed to the size of clumps. These clumps could act as windbreaks for the accumulation of wind-blown snow. Snow pattern is influenced by the high winds of the mixed prairie. These sweep the powdery snow from uplands, blowing it to leeward slopes (Weaver and Albertson 1956, Longley 1967). It insulates the meristematic tissue from wind-blown abrasive agents and low winter temperatures which prevail in this region. Snow has an extremely low thermal conductivity giving rise to large vertical temperature gradients where cover is deep (.6-1.5 m). Snow surface temperatures may be -20°C to -35°C yet the temperature near ground surface is seldom below 0°C (Geiger 1965). In spring, the snow contributes moisture for seed germination and for growth of shoots (Beard 1964).

Mature plants are characterized by an oblique or horizontal rhizome penetrating the soil to a depth of 1-1.5 m (McKelvey 1947, Webber 1952, and Weaver and Albertson 1956). Numerous rootlets project in a horizontal direction from this rhizome. As the rhizome matures it becomes more swollen, covered with a smooth reddish-brown epidermis and has a protostele vascular structure.

Clumped shoots, the long horizontal rhizomes, and plant longevity together contribute to plant stability and modification of the habitat by this species. As with snow, wind blown soil may accumulate around the wind breaks created by Yucca and associated species such as Artemisia cana and the various grasses. The stable nature of these long lived perennials can continuously help to protect the soil from further erosion by wind and water and aid in preventing excessive water loss through evaporation. This leads to further community richness from other plants and animals that rely on this stability for their own development (Campbell 1932, Webber 1953).

Soils

Within the two Alberta populations, Yucca is restricted from certain sites (non-yucca sites) by differences in soil depth and water availability. Where the general aspect of the coulee face is southwest to west (Fig. 5), a hardpan layer is often present at 20-30 cm. The hardpan has a high bulk density and is impenetrable to yucca rhizomes.

On the leeward side of slopes or where the coulee has a south exposure, soils are a single-grained sandy texture. On these sites yucca rhizomes penetrate to over 100 cm in depth. At the margin of these yucca sites, toward the non-yucca areas, hardpan often occurs less than 50 cm below the surface. Depth of rhizome penetration in yucca sites is over 20 cm greater than for plants occurring along the margin of these sites. As the hardpan becomes closer to the surface toward the centre of the non-yucca sites, the shallow depth for rhizome penetration results in dessication or uprooting by wind of the plants. It is felt that the progressive change in depth to hardpan from yucca to non-yucca sites is a result of the prevailing southwest winds removing soil from southwest exposed slopes, and deposition occurring on the lee sides. High wind speeds were recorded, and soil removal was observed during the summer of 1976. Sheet and gully erosion on the more exposed slopes may also contribute to shallower profile above the hardpan.

The sandy soils of the yucca sites have a deeper profile and therefore more available water than the non-yucca site due to their greater infiltration, and thus slower evaporation (Terwilliger 1969, Redmann 1975). With the low soil moisture levels during the summer, it was found that sufficient moisture was available for plants on yucca sites during most of the season. This was not so with hardpan soils associated with non-yucca areas. These soils supported fewer species and had a lower total plant cover (Weaver and Darling 1949, Box 1961, Mueggler and Harris 1969).

Seed Germination

Seeds of *Yucca glauca* require relatively high temperatures to germinate. They will germinate throughout the summer season whenever moisture is not limiting. Optimum germination temperature for Alberta plants was near 20°C (92% germination). Sixteen percent germination at 14°C and no germination occurred below 10°C. For individuals growing in the centre of its range, the optimum germinating temperature is higher. Webber (1952) reported *Y. glauca* seeds germinated in 4 days at 28-32°C. He does not specify percentage of seeds germinated. McCleary (1973) reported that 100% germination occurred at 25°C with a median time of 5.5 days. At 20°C, 80% germinated, 12% at 15°C and 7% at 10°C. As seems likely for a species growing at the northern end of its range, *Y. glauca* is adapted to somewhat lower temperatures during its growing season. Temperature requirements for germination most certainly influence the species distribution in Alberta, but the degree to which this is a major limiting factor is uncertain.

Leaf Water Potentials

Yucca glauca appears to be able to tolerate a range of moisture conditions. Leaf water potentials fluctuated from a high of -2 bars in June to a low of -25 bars in mid-July as soil moisture decreased through the season. The low leaf water potentials reached in mid-July are not exceptional for a xerophyte living in arid to semi-arid conditions. Nobel (1973) stated that the range of values for most mesophytes was -3 to -30 bars with -5 bars being typical for leaves of garden vegetables such as lettuce. A few desert species can develop leaf water potentials as low as -50 bars.

It was found that leaf water potentials measured for different leaves of the same plant showed considerable variation. Potentials for leaves from one plant ranged from -7 to -10 bars. Much variation occurred among plants. Two plants of approximately the same size growing next to each other gave readings of -12 and -15 bars. Repeated measurements of leaf water potential are needed to understand the relative state of water in the plant in relation to seasonal soil moisture fluctuation.

The Yucca Moth

In addition to climatic factors, the northern distribution of *Y. glauca* may be restricted by the range of its insect pollinator, the yucca moth. Several species of moth are reported to have a mutualistic relationship with yucca species. In Alberta, the moth is *Prodoxus quinquipunctellus*. Webber (1952) and Powell and Mackie (1966) discussed how both moth and plant are dependent on each other for survival.

On the Lost River site, *Yucca glauca* flowers in early to mid-July. Only at this time can the moth be found, singly or in groups, inside the flower. The moth is quite shy in daylight, venturing outside the flower only from dusk until sunrise.

The moth collects pollen in the form of pollinia, frequently forcing it down the stigmatic tube of the yucca plant. They are believed to fly from plant to plant enabling cross pollination, but this is not certain (Powell and Mackie 1966). While engaged in pollination, the moth will often (but not always) thrust its ovipositor through the ovary wall and lay eggs (Webber 1952). Seeds of yuccas are produced in tiers and the moth larva survives by eating its way through a tier of seeds. In early fall the larvae burrow out of the pod and crawl to the ground where they overwinter (Powell and MacKee 1966).

It is uncertain whether cross-pollination can occur by wind, another insect, or any agency other than the yucca moth. Plants grown in gardens north of the two Alberta populations flower, but no seed pods form or were moths observed. Powell and Mackee (1966) reported that no pods were produced for Yucca whipplei plants flowering beyond the range of the moth. They discussed experiments where the flowers have been screened from pollination by the moth, but other agencies allow to enter. Here there was little success in pod formation.

Few studies have been undertaken concerning the moth-yucca relationship and little is known of the moth's ecology. For example, it is unknown how sensitive the overwintering moth larva is to low winter temperatures. How the moth actually influences the northern distribution of Y. glauca is still open to speculation.

Summary

Wind speed in relation to soil and snow movement are probably the two major factors influencing the distribution of Yucca glauca along the coulee slopes in southern Alberta. The high wind speeds on slopes exposed to the prevailing southwest winds can remove the sandy soil. This phenomenon was observed during the 1976 summer. This and water erosion helps account for the progressive depths to the hardpan from (20-30 cm) on the non-yucca slopes as opposed to those with Yucca where the hardpan is 100+ cm. This hardpan has a high water retention potential and high bulk density (1.92) being impenetrable to the rhizome of Yucca. The rhizome must grow along the surface of this horizon being subject to dessication and uprooting by the wind in areas of shallow soil. Lower water availability also retards seed germination and seedling growth on these sites.

On slopes in the lee of, or protected from direct southwest exposure, dense populations of Yucca occur. Here rhizome and moisture penetration is deeper in the course textured soils. This leads to better support and greater water availability during the growing season. In winter, snow accumulation on lee slopes offers protection from winter temperature extremes and contributes moisture for plants in the spring.

It is still uncertain what factor, or set of factors, are actually responsible for restricting the species from migrating further north. Agriculture, including cultivation, would limit spread. Ecology of the yucca moth is still unknown and the northern range of the plant may be restricted by the moth's inability to tolerate certain environmental factors further north. Hopefully future work will be directed toward this latter problem, thus solving one of the basic questions of the autecology of Yucca glauca.

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Appendix A: Soil profile description for Lost River yucca and non-yucca sites.

Yucca Site (I & II):

Horizon	Depth (cm)	Description
A_{hk}	0-3	Brown (10 YR 5/3d; sandy loam; semidecomposed organic matter; abundant fine and medium roots; moderately calcareous; abrupt; smooth boundary; moderately alkaline.
	3-100	Yellowish Brown (10 YR 6/8d); sandy loam, single grain; soft to slightly hard; few very fine, fine, and medium roots, moderately calcareous; moderately alkaline.

Non-Yucca Site (I & II)

Horizon	Depth (cm)	Description
A_{hk}	0-2	Pale Brown (10 YR 6/3d); semi-decomposed organic matter; very few to few, very fine to fine roots; moderately calcareous abrupt, smooth boundary; moderately alkaline.
C_k	2-20	Yellow Brown (10 YR 6/8d); sandy clay loam; single grain; soft to slightly hard; few, very fine, fine and medium roots; some stones; moderately calcareous; moderately alkaline.
C_{kx}	20-60	Brown (10 YR 5/3d) to Dark Brown (10 YR 3/3d); sandy clay loam; very course, strong, subangular blocky, extremely hard; some stones; moderately calcareous; moderately alkaline.