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Science Bulletin

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A COMPARISON OF METEOROLOGIC MEASUREMENTS FROM IRRIGATED AND NON-IRRIGATED PLOTS, PROVO, UTAH, 1970-1972

by

Ferron L. Andersen[1], Phil D. Wright[2], and J. Carl Fox[3]

ABSTRACT

A comparative study of micrometeorologic conditions on irrigated and non-irrigated pasture plots was conducted at Provo, Utah, from 1970 to 1972. Daily measurements were taken of the following: precipitation either as rain or snow, new snowfall and total snow depth during the winter; relative humidity in a standard weather shelter; number of hours at maximum relative humidity; cloud cover each morning; potential evaporation; total wind 1 m above ground level; temperature extremes in a standard weather shelter; and temperatures both on irrigated and non-irrigated plots with sensing devices located 5 cm beneath soil surface under grass cover, at soil surface under grass cover, and at soil surface on bare ground. During the pasture months of May through October, weekly soil moisture measurements from irrigated and non-irrigated plots were gravimetrically determined. All data were entered on columnized work sheets, key punched, and subsequently assimilated and tabulated by a FORTRAN IV program with the IBM 360/65 computer. Graphical representations of all daily measurements for the three years, as well as others depicting the effect of irrigation and snow cover for selected weeks, were completed.

The total precipitation for 1970, 1971, and 1972 was 491.0, 726.4, and 390.1 mm, respectively, and the average monthly mean temperatures in a standard weather shelter for the three years were 9.2, 8.8, and 9.4°C. Other representative yearly values for 1970, 1971, and 1972, respectively, were total snowfall: 1165.9, 1877.1, and 909.3 mm; average maximum and minimum relative humidity: 97 and 43, 97 and 46, and 97 and 46 percent; average hours at maximum relative humidity each day: 7, 8, and 8 hr; average cloud cover each morning: 3-, 3-, and 3-tenths of covered sky; total potential evaporation and daily average for May through October: 983.8 and 5.3, 1030.7 and 5.6, and 1274.2 and 6.9 mm; average monthly soil moisture content for both irrigated and non-irrigated plots for May through October: 16.1 and 8.4, 16.3 and 5.8, and 8.1 and 3.8 percent; wind totals and daily averages: 19,315 and 52, 22,691 and 61, and 22,255 and 60 km; average annual temperatures 5 cm beneath soil surface on irrigated and non-irrigated plots for 1971 and 1972: 8.4 and 9.0 and 8.2 and 10.4°C; average annual temperatures at soil surface under grass cover on irrigated and non-irrigated plots for 1971 and 1972: 9.7 and 10.6 and 10.9 and 12.8°C; and average annual temperatures at soil surface on bare ground on irrigated and non-irrigated plots for 1971 and 1972: 12.9 and 16.5 and 14.9 and 15.0°C. Temperature extremes on irrigated plots during the pasture season were moderated considerably from those recorded on the non-irrigated plots, and irrigation, when done routinely, provided adequate soil moisture throughout the entire pasture season. These findings are especially obvious when data other than yearly and monthly means are examined. Irrigation is undoubtedly the major factor in providing optimum moisture and temperature conditions for the development and survival of all types of pastureland biological organisms in creating optimum microenvironments in otherwise desolate, arid regions.

INTRODUCTION

Micrometeorology, the study of atmospheric conditions in microclimates, entails numerous difficulties, not the least of which is the lack of a uniform definition of the zone in question. Reference can be made to both horizontal and vertical measurements, which may vary from

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a few millimeters to many meters in both directions. Sutton (1964) stated that micrometeorology deals with atmospheric phenomena 'in the first few hundred feet above the earth's surface," whereas Holmes and Dingle (1965) stated that the microclimatic zone consists generally of the layer of air which is markedly altered by the surface of the earth or other surfaces thereon, and that the microclimate of a tree, therefore, is that area extending several meters out from the branches which acquires unique properties because of the tree. Whitman and Wolters (1965) defined microclimate as that zone beneath the level of a standard weather shelter (about 1.5 m). Andersen, Levine, and Boatman (1970) stated that the microclimate of the free-living stages of ruminant nematodes is the layer of space between the ground surface and the top of the pasture vegetation. Since the project described herein dealt with measurements on irrigated and non-irrigated pasture plots, the definition used is that given by the latter authors.

The practice of irrigation is the single most important process which permits maximum utilization of agricultural lands in arid regions of the earth. In the United States, of a total of 2,322,016,000 acres, 340,998,000 are cultivated, of which 33,022,000, or approximately 10 percent are irrigated (Israelsen and Hansen, 1967). In Utah, however, of 52,721,550 total acres, 2,155,186 are cultivated and 1,348,627, or about 63 percent, of that amount are irrigated. In Utah County, 76 percent of all cropland is irrigated (Utah Agricultural Statistics, 1972). Thus, we see that irrigation is far more important to agriculture in Utah and other western arid states than in areas where sufficient precipitation is accumulated through rain or snow only.

While irrigation is the most important factor toward creating cultivatable lands in arid regions, indiscriminate usage of available water often leads to soil erosion, alkalization, or high water tables, with resultant reduction in plant growth and productivity. In addition to these undesirable effects, irrigation may create suitable microhabitats for the development and survival of detrimental biological organisms, many of which could not exist or at least could not reach such high population levels on otherwise arid lands. The creation of desert bridges from one irrigation field to another may allow harmful insects to traverse broad expanses of arid regions (Rainy and Hess, 1967), and faulty irrigation may fill borrow pits or other depressions for long periods of time, thereby creating favorable breeding grounds for numerous arthropod or molluscan vectors of disease. Mosquitoes, for example, are by far the most important of all arthropods of public health significance, since several species are vectors of malaria and encephalitis. In spite of extensive eradication campaigns, malaria is still the most important infectious disease in the world; however, arboviral encephalitis is far more significant in the United States proper. In 1970, only sixteen persons acquired malarial infections in the United States (Center for Disease Control, Malaria Surveillance, 1971), whereas during the same year, 110 cases of arboviral encephalitis were reported (Center for Disease Control, Neurotropic Viral Diseases Surveillance, 1972). *Anopheles freeborni*, the primary vector for malaria in the western part of the United States, and *Culex tarsalis*, (the "irrigation mosquito"), the primary vector for western and St. Louis encephalitis, both breed in water impoundments and seepage areas, such as those associated with faulty or inefficient irrigation (Rainy and Hess, 1967). The breeding habitats of both species generally decrease each summer with the recession of surface waters, except where irrigation waters maintain their breeding sites. Surtees (1970) showed a 70-fold increase in malaria vectors in an irrigated area in Kenya, and Reeves and Hammon (1962) demonstrated that human infections with encephalitis were definitely associated with work on irrigated agricultural lands in California.

Snails, which serve as intermediate hosts for the blood flukes that cause schistosomiasis (bilharziasis) in humans in many tropical and subtropical regions, have reproduced extensively in newly created habitats associated with massive irrigation projects. The first report by the study group on schistosomiasis in Africa (World Health Organization, 1950) stated that: "The introduction or development of irrigation schemes, as well as the change from basin to perennial irrigation, has always resulted in a considerable increase in the incidence and intensity of bilharziasis wherever that infection existed or was introduced by outside laborers. The severity of the infection may be such as to cause the abandonment of an irrigation scheme created at considerable expense."

Irrigation also creates favorable microenvironments in pastures for the free-living stages of many parasitic nematodes which otherwise could not exist in overall arid zones. As early as 1944, Furman pointed out that irrigational practices in the dry interior Sacramento Valley regions of California resulted in increased populations of nematode larvae parasitic to sheep. Honess and Bergstrom (1966) showed comparable results for populations of nematode larvae parasitic to cattle in Wyoming. Surveys in central Utah have shown that 68 to 71 percent of all cattle and 90 to 96 percent of all sheep raised on irrigated pastures harbor parasitic helminths of at least one species (Fox, Andersen, and Hoopes, 1970; and Wright and Andersen, 1972). During the past decade numerous workers have shown that there is a positive correlation between optimum micrometeorologic conditions and the development and survival of many parasites (See Crofton, 1963; Levine, 1963; Kates, 1965; Williams and Mayhew, 1967; Andersen, Levine, and Boatman, 1970; Williams and Bilkovich, 1971; Gibson, 1973; and Levine and Andersen, 1973).

Because of the importance of irrigation to agriculture and animal husbandry in central Utah and the demonstrated high prevalence of parasites in domestic animals, a study was undertaken to measure microenvironmental conditions on irrigated and non-irrigated pasture plots in that area.

MATERIALS AND METHODS

A 9m x 9m experimental weather station designed to yield measurements from irrigated and non-irrigated plots was established at the Brigham Young University Animal Science Farm located at Provo, Utah (Fig. 1). Coordinates for the station are 111° 39' 1" W. longitude and 40° 16' 1" N. latitude. Elevation at the site is 4,653 feet (1163 m) above sea level. Meteorologic measurements from the area were either recorded or manually observed each day for 1970, 1971, and 1972. The plot was fenced with 5-foot (150 cm) chain link fence from the center of a 2-acre (.8-hectare) sheep pasture at the farm. The existing vegetation at the site consisted predominantly of meadow fescue (*Festuca elatoir*), alfalfa (*Medicago sativa*), clover (*Trifolium repens*), and dandelion (*Leontodon taraxacum*). The vegetative cover was mowed weekly to an approximate height of 3 to 4 in (7.5 to 10 cm) and the clippings discarded. The soil was characterized as the Keigley series (1 percent slope, dark brown, deep, well-drained, silty clay loam) (Soil Survey of Utah County, Utah, 1972). The average volumetric moisture content at field capacity (⅓rd bar) was 2.2 in (5.5 cm) of water per foot (30 cm) of soil, and at the permanent wilting point (15 bars) was 1.6 in (4.0 cm) per foot (30 cm) of soil (Soil Conservation Service, Utah, 1972).

Fig. 1. Weather station for measurement of meteorologic conditions on irrigated and non-irrigated pasture plots at BYU Animal Science Farm, Provo, Utah.

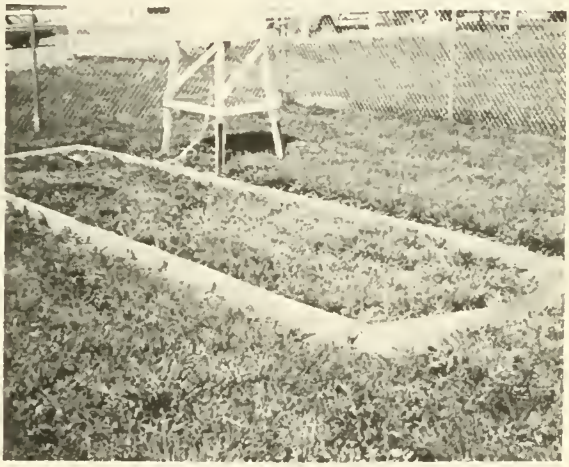


Fig. 2. Non-irrigated plot separated by a 5' x 20' metal frame.

A non-irrigated section near the center of the plot was established by placing a 5 ft by 20 ft (150 by 600 cm) rectangular galvanized metal frame into the ground to an approximate depth of 3 ft 8 in (110 cm), with about 4 in (10 cm) protruding above the ground (Fig. 2) in order to keep the water from that part of the plot during periods of irrigation. The pasture and the irrigated portion of the weather station were usually irrigated every 8 to 10 days during the warmer part of each pasture season; however, irrigation could only be performed by personnel not associated with the research project and the intervals between irrigations were not always consistent. During 1972, the timing was further disrupted until mid-June by road and ditch con-

Fig. 3. Standard non-recording rain gauge.

struction in areas directly adjacent to our experimental plot. In spite of these limitations, irrigation times are indicated on the precipitation and soil moisture graphs for each of the three years of the study (Fig. 12, 13, and 14) and hopefully give some indication of the effects produced.

Precipitation as rain was measured in a standard non-recording rain gauge (Fig. 3) in hundredths of an inch. During the winter, the total snow cover was determined with an ordinary ruler by measuring in inches the total depth of snow to the soil surface at several representative sites, and the daily snowfall was likewise determined by measuring the depth to the previous day's crust. Precipitation in the daily snowfall was calculated as one-tenth that of the measured new snow depth, since that is the average reported snow depth to water equivalent ratio (McIntosh and Thom, 1969).

During the six months from 1 May through 31 October, soil moisture content from both irrigated and non-irrigated plots was determined gravimetrically by taking 6-in (15-cm) core samples each Monday with a 1-in (2.5-cm) diameter soil auger. The samples were immediately taken to the laboratory, where they were weighed, dried at 105°C for four days, and then reweighed.

Relative humidity (RH) was measured in a standard U.S. Weather Bureau shelter (Steven-

Fig. 4. Hygrothermograph for daily measurement of temperature (top graph) and relative humidity (bottom graph) recorded in a standard weather shelter.

son screen) located approximately 5 feet (1.5 m) above ground level with a standard hygrothermograph which gave a dual record of both temperature and relative humidity on the same curvilinear chart (Fig. 4). The humidity element consisted of multiple strands of specially treated hygroscopic hairs which expanded over the 0-100 percent scale range with 3 percent accuracy between 20 to 80 percent RH and 5 percent beyond those points. The instrument was calibrated periodically by adjusting the recording arm to 100 percent RH during rainy periods, and it was checked occasionally with a sling psychrometer or Assman spring-driven psychrometer. The number of hours each day when the relative humidity was at maximum (98-100 percent) was also noted and recorded.

Potential evaporation over the irrigated plot was measured by an evaporimeter consisting of a metal pan with a 250-sq cm evaporating surface resting over a spring-loaded device and recording arm (Fig. 5). Since the clock revolved

Fig. 5. Evaporimeter for daily measurement of potential evaporation.

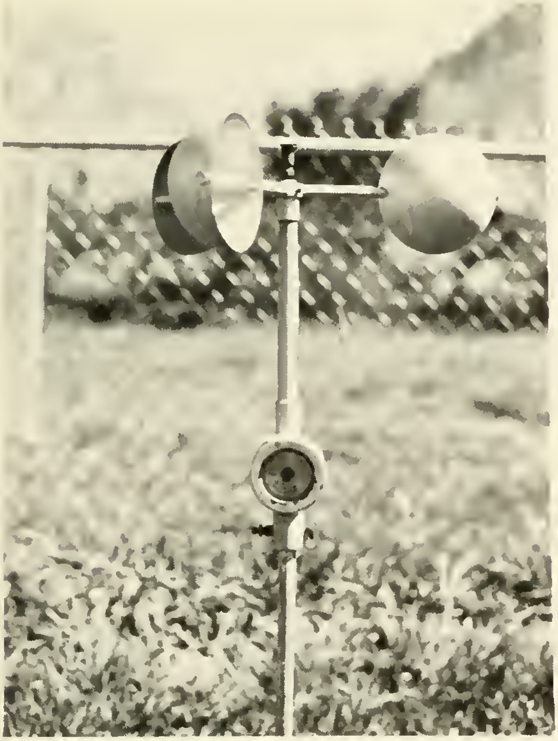


Fig. 6. Non-recording anemometer for measurement of daily wind total.

daily, the recorded spiral pattern was difficult to read once the chart had been removed; hence, the evaporation pan was filled daily and the potential evaporation read from the scale each morning.

Total wind movement at the site was read daily from a non-recording totalizing anemometer positioned 1 m above the vegetative surface (Fig. 6). Cloud cover for each day was estimated visually in tenths of sky covered so as to cast a shadow from the sun at the time the instruments were read.

Daily temperature measurements were taken with standard maximum and minimum thermometers in the weather shelter (Fig. 7) and also recorded by the hygrothermograph at that

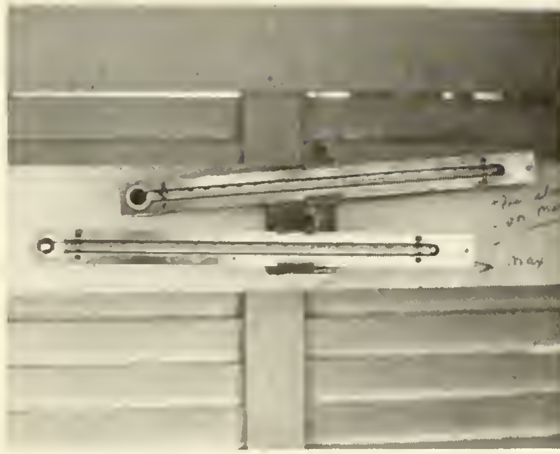


Fig. 7. Maximum and minimum thermometers located in a standard weather shelter.

location as described above. Temperatures were also recorded on the irrigated and non-irrigated plots by three-lead distance thermographs (Fig. 8) with mercury bulb sensors located 2 in (5 cm) beneath soil surface under 3 to 4 in (7.5 to 10 cm) of grass cover, at soil surface under grass cover, and at soil surface on bare ground (Fig. 9).

All meteorologic observations were taken daily at approximately 8:00 a.m. M.S.T., and charts for the recording instruments were changed each Monday morning. All data were entered on specially designed worksheets (Fig. 10 and 11) columnized for a FORTRAN IV program, keypunched on 80-column IBM cards, and then transferred to tape for storage and subsequent assimilation and tabulation of daily, monthly, and yearly summaries with the IBM 360/65 computer. All mensural data not already in the metric system were so transposed by appropriate subroutines. Daily measurements of most of the moisture and temperature totals or extremes recorded over the three-year period were graphed manually and photographed for reproduction herein.

RESULTS AND DISCUSSION

Meteorologic measurements of all data collected during the three-year study period as described above are tabulated as daily, monthly, and yearly summaries. However, since the daily summaries for any one month require three computer sheets per month, or 108 total pages, they are not included in this paper. Copies of these computer tabulations and the FORTRAN IV program are available upon request for the cost of reproduction. Monthly and yearly totals and means are included herein as Tables 1 to 3, 4 to 6, and 7 to 9 for 1970, 1971, and 1972, respectively. Tables 10 and 11 give the monthly precipitation and the average monthly mean temperatures, respectively, as recorded for these three years at the official weather station for Provo (KOVO radio station), located approximately 6 km south of our station.

Fig. 8. Three-lead distance thermograph located in a standard weather shelter.

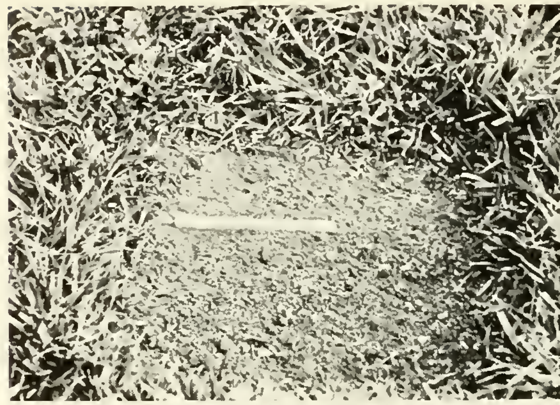
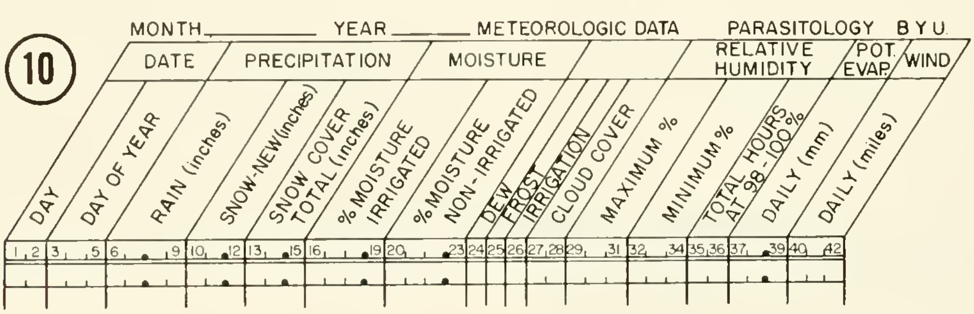


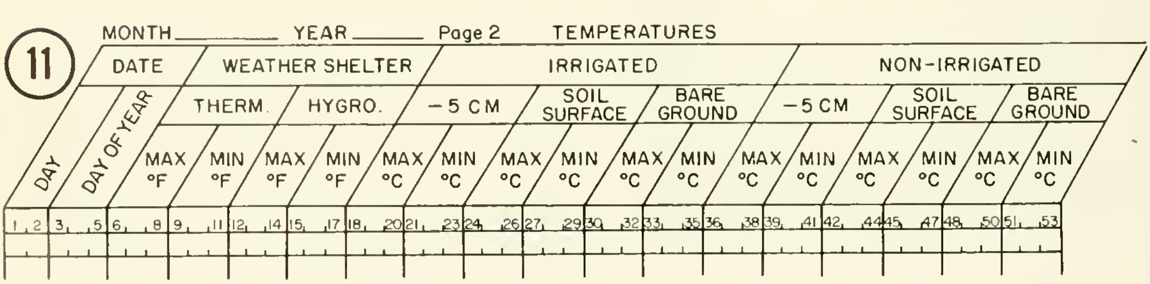
Fig. 9. Mercury-filled sensing device located at soil surface on bare ground.

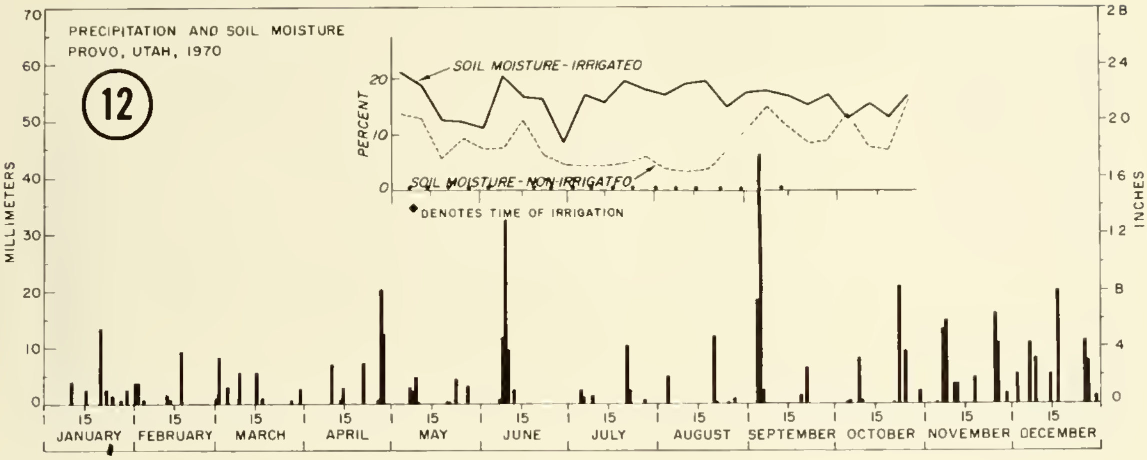
For additional comparisons herein, Tables 12 and 13 give average monthly values during 1970-72 for potential evaporation and total wind movement, respectively, when recorded for May through October at the Utah Lake weather station (approximately 25 km northwest of our station) near Lehi, Utah. Table 14 lists average monthly soil temperatures for 1970-72 recorded 4 in (10 cm) beneath barren, sandy-loam soil at Salt Lake City, Utah (Climatological Data, Utah. 1970, 1971, and 1972).

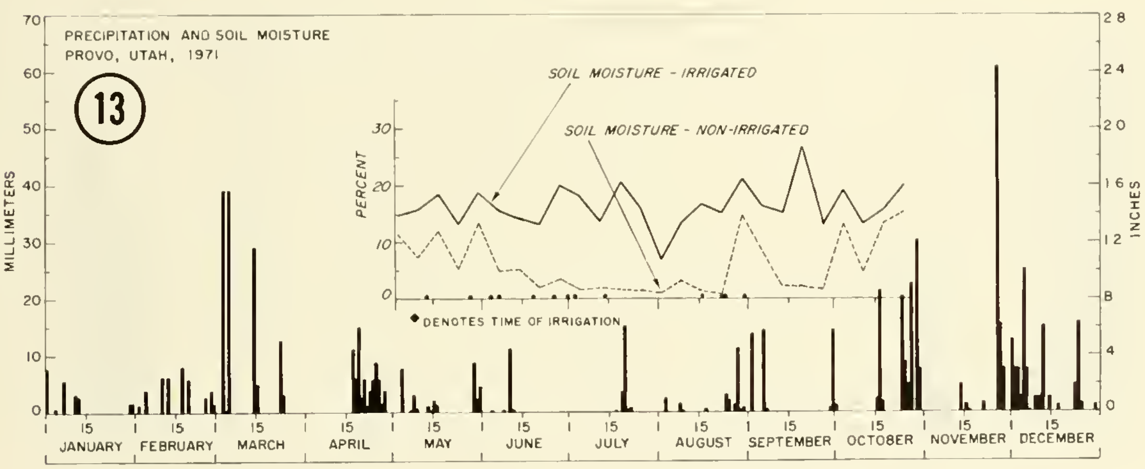
Graphical representations for all daily data measured in the study period (except daily cloud cover) are shown in Fig. 12 to 50. Fig. 51 depicts the marked impact of irrigation during one selected week as reflected in the temperatures recorded with the three-lead distance thermograph with sensors located at the three ground sites described above. Fig. 52 and 53 contrast the daily temperatures for two different weeks during winter periods with and without snow cover on the ground.

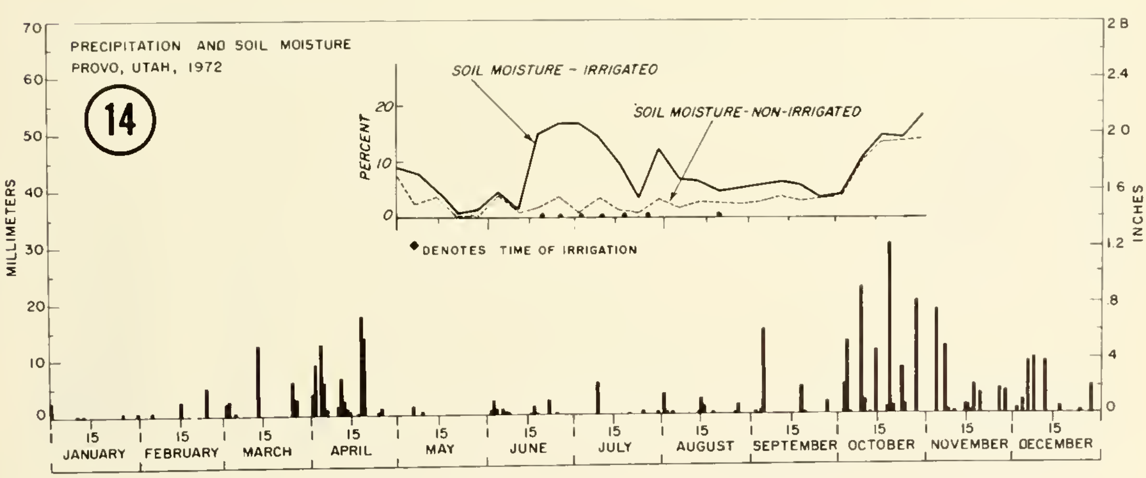
The yearly precipitation recorded in this study for 1970, 1971, and 1972 was 491.0, 726.4, and 390.1 mm, respectively (Tables 1, 4, and

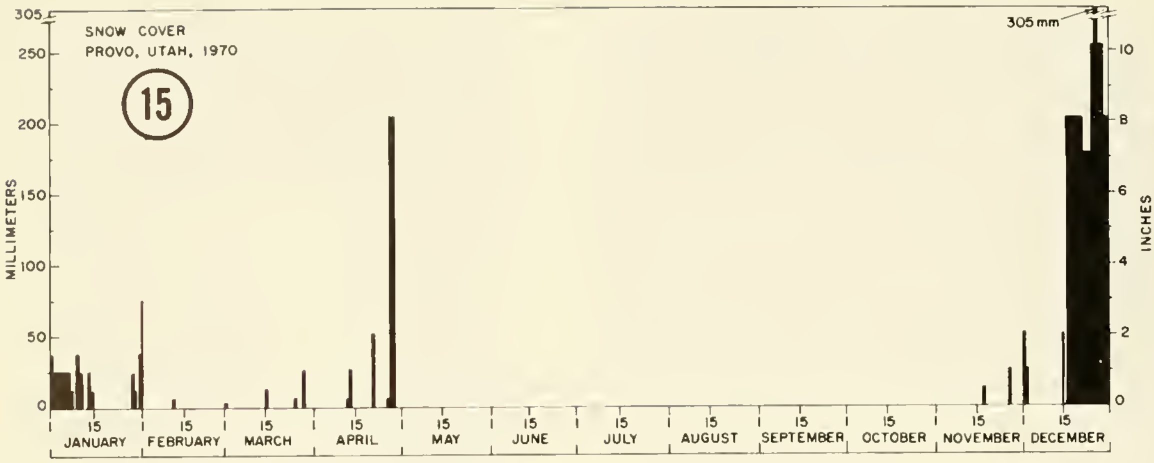


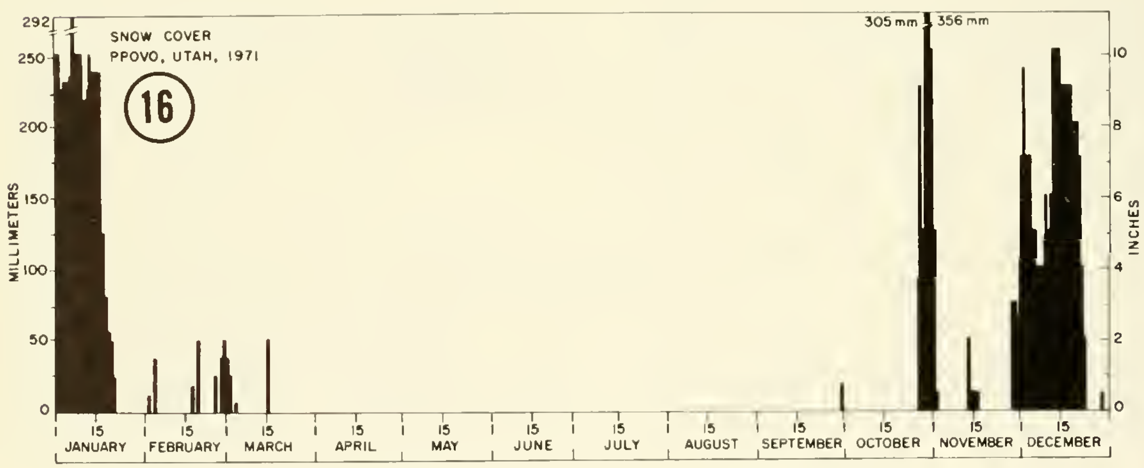


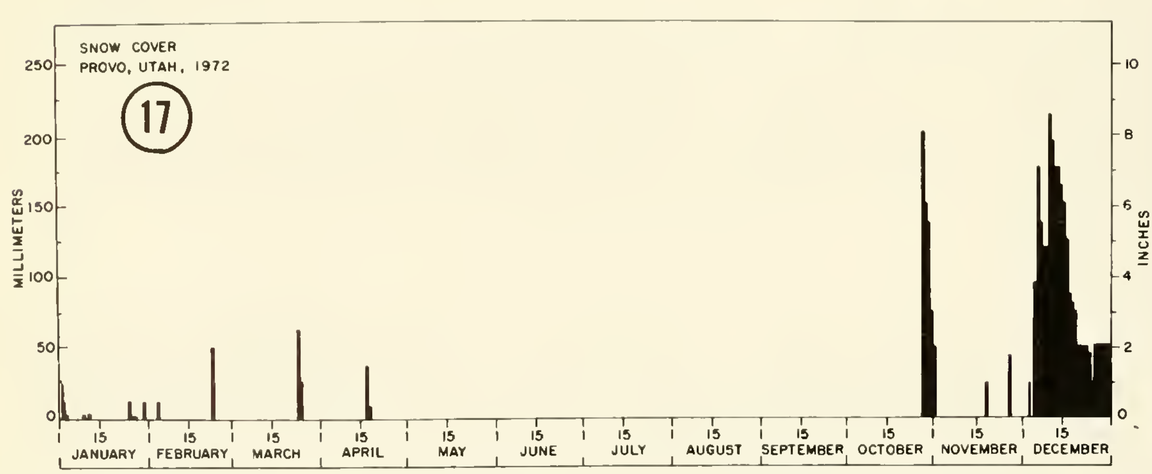

PRECIPITATION AND SOIL MOISTURE
PROVO, UTAH, 1970
12
SOIL MOISTURE - IRRIGATED
SOIL MOISTURE - NON-IRRIGATED
PERCENT
DENOTES TIME OF IRRIGATION
MILLIMETERS
INCHES
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

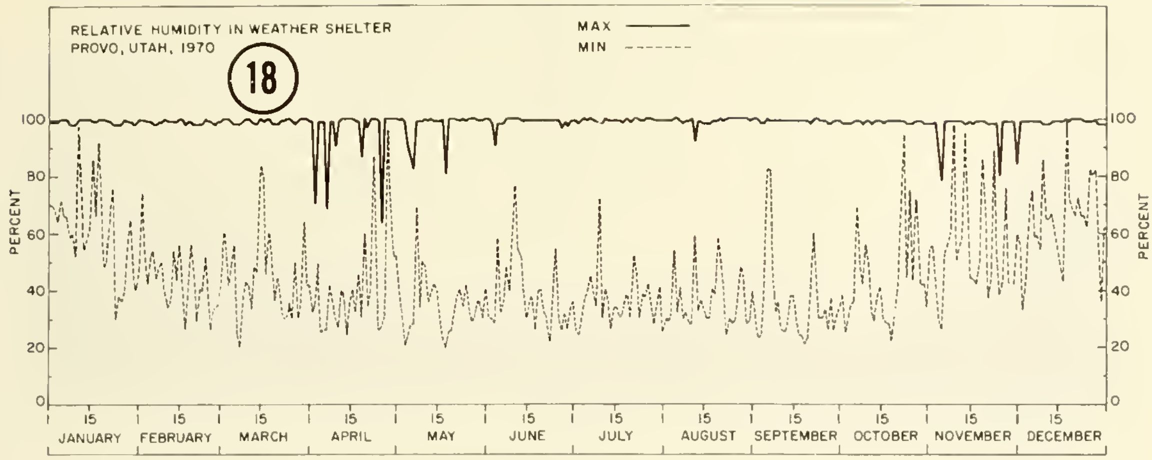

PRECIPITATION AND SOIL MOISTURE
PROVO, UTAH, 1971
13
SOIL MOISTURE - IRRIGATED
SOIL MOISTURE - NON-IRRIGATED
PERCENT
DENOTES TIME OF IRRIGATION
MILLIMETERS
INCHES
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

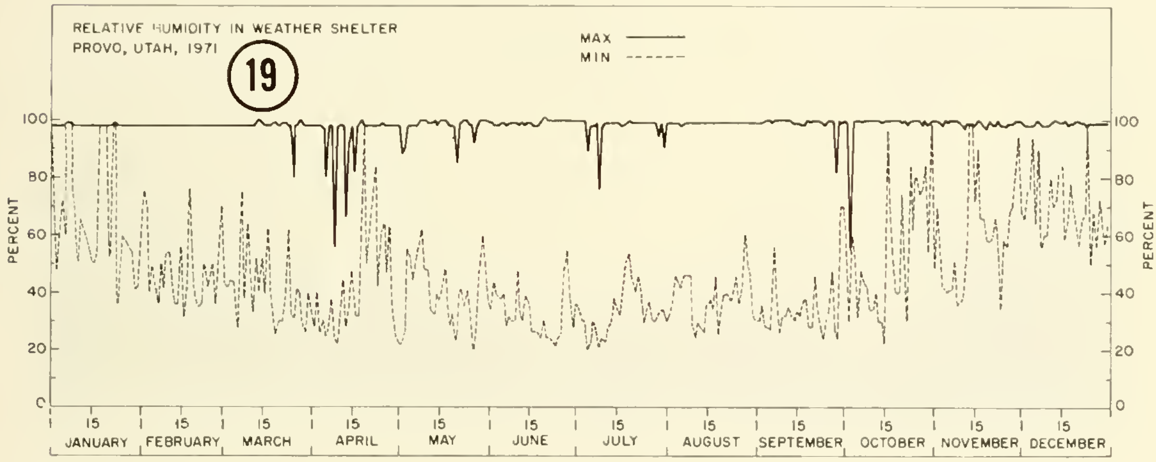

PRECIPITATION AND SOIL MOISTURE
PROVO, UTAH, 1972
14
SOIL MOISTURE - IRRIGATED
SOIL MOISTURE - NON-IRRIGATED
PERCENT
DENOTES TIME OF IRRIGATION
MILLIMETERS
INCHES
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

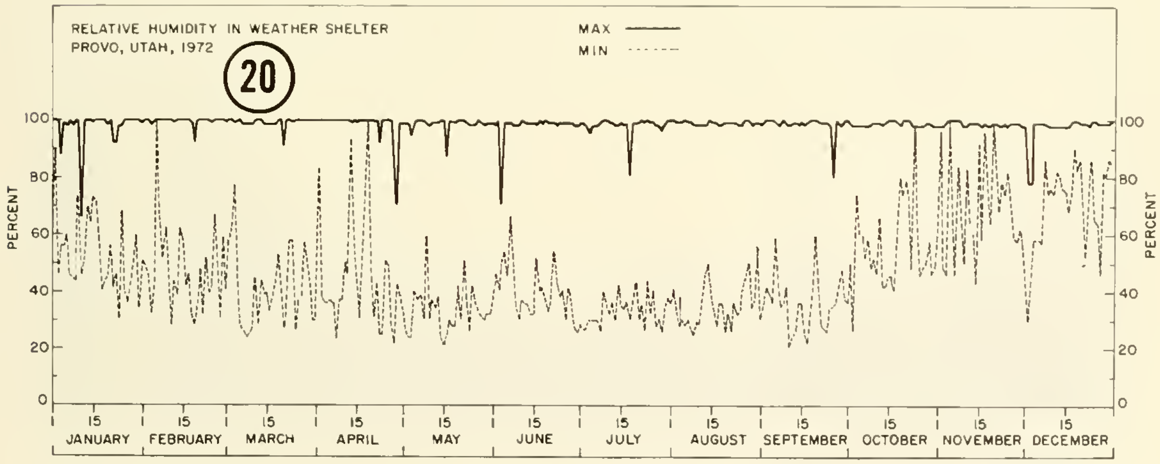

SNOW COVER
PROVO, UTAH, 1970
15
305 mm
MILLIMETERS
INCHES
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

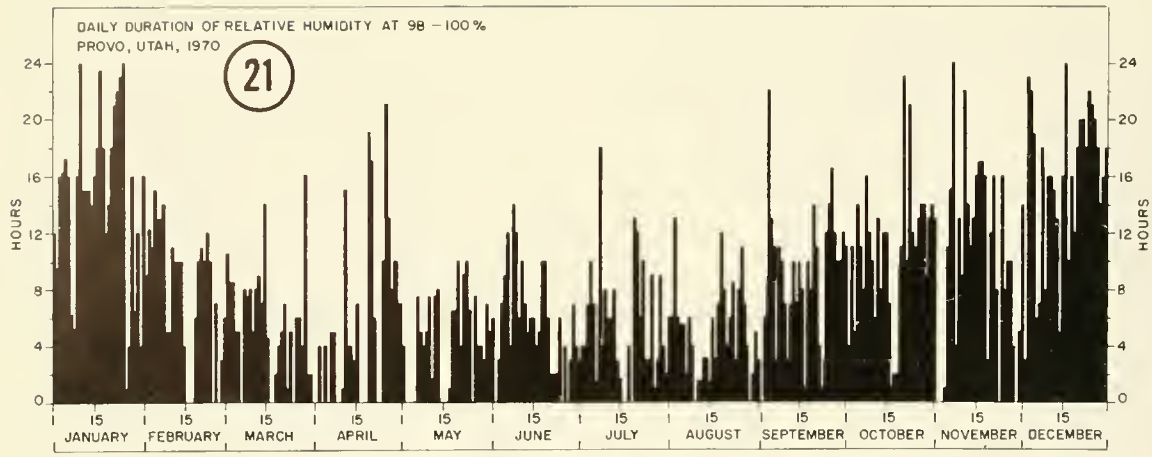

SNOW COVER
PPOVO, UTAH, 1971
16
305 mm
356 mm
MILLIMETERS
INCHES
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

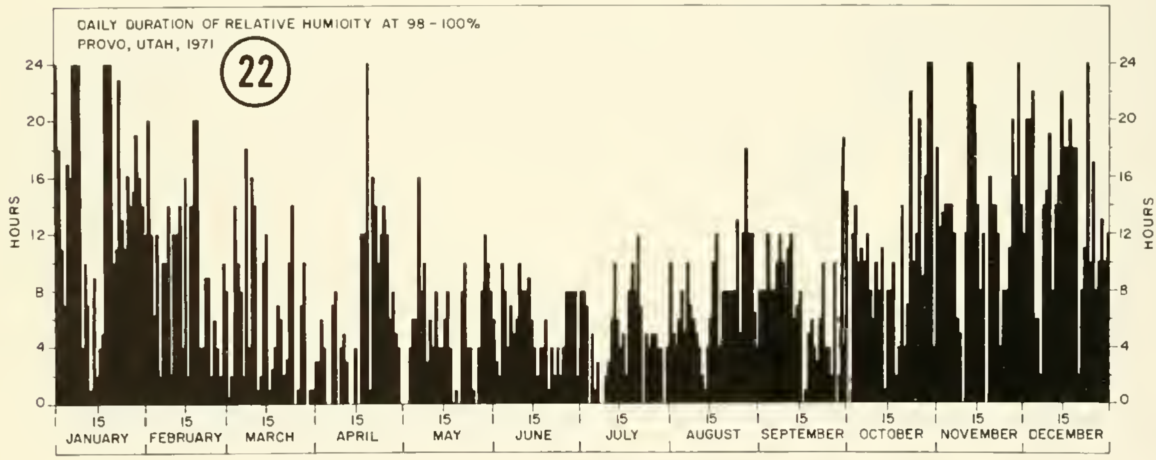

SNOW COVER
PROVO, UTAH, 1972
17
MILLIMETERS
INCHES
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

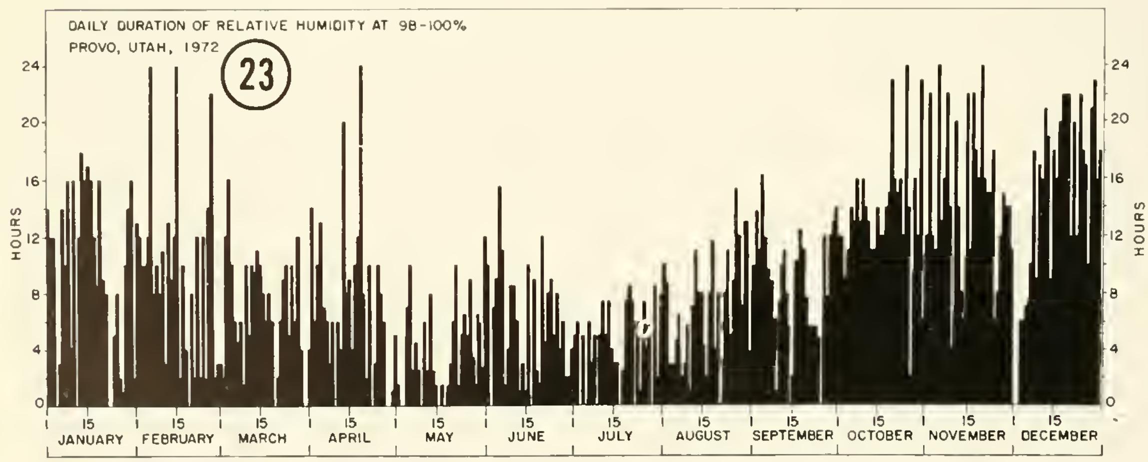

RELATIVE HUMIDITY IN WEATHER SHELTER
PROVO, UTAH, 1970
MAX
MIN
18
PERCENT
100
80
60
40
20
0
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

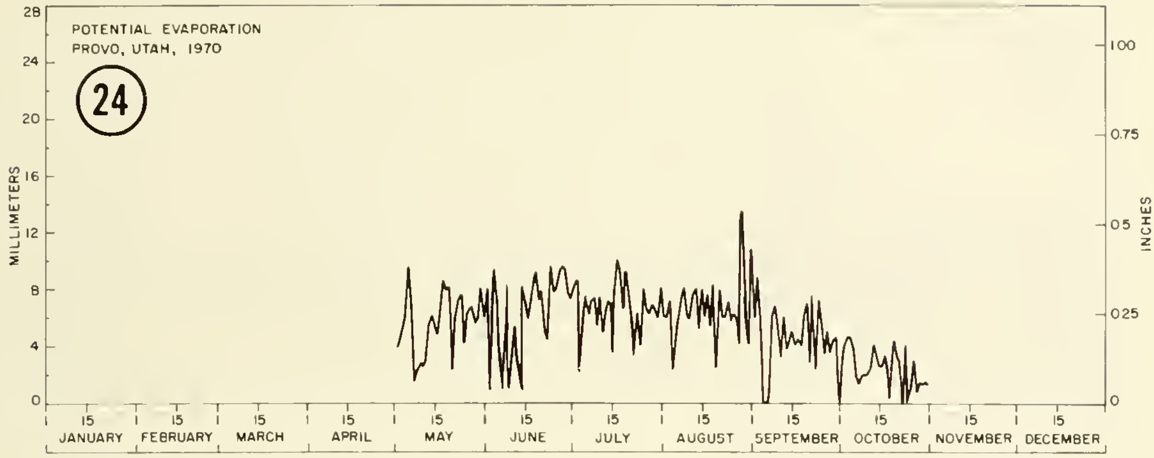

RELATIVE HUMIDITY IN WEATHER SHELTER
PROVO, UTAH, 1971
MAX
MIN
19
PERCENT
100
80
60
40
20
0
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

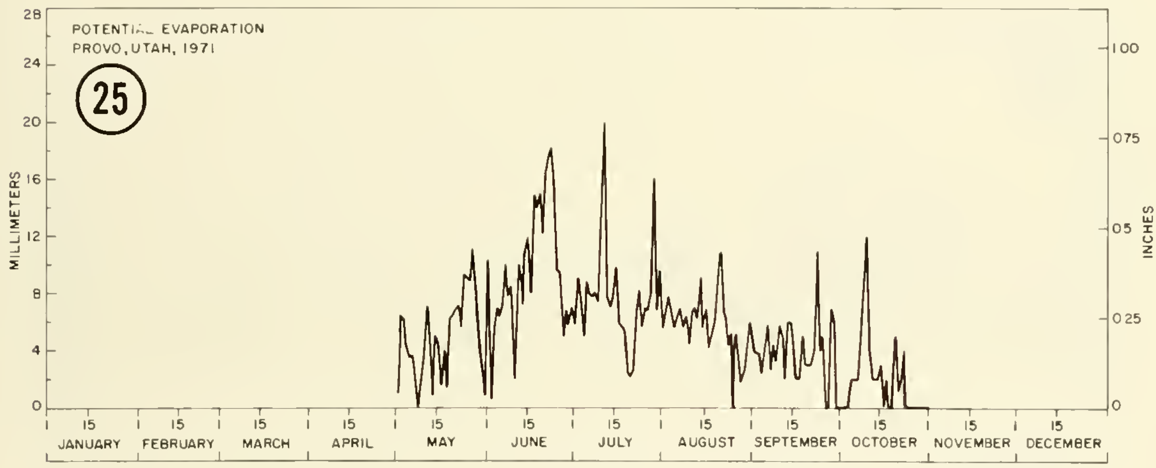

RELATIVE HUMIDITY IN WEATHER SHELTER
PROVO, UTAH, 1972
MAX
MIN
20
PERCENT
100
80
60
40
20
0
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

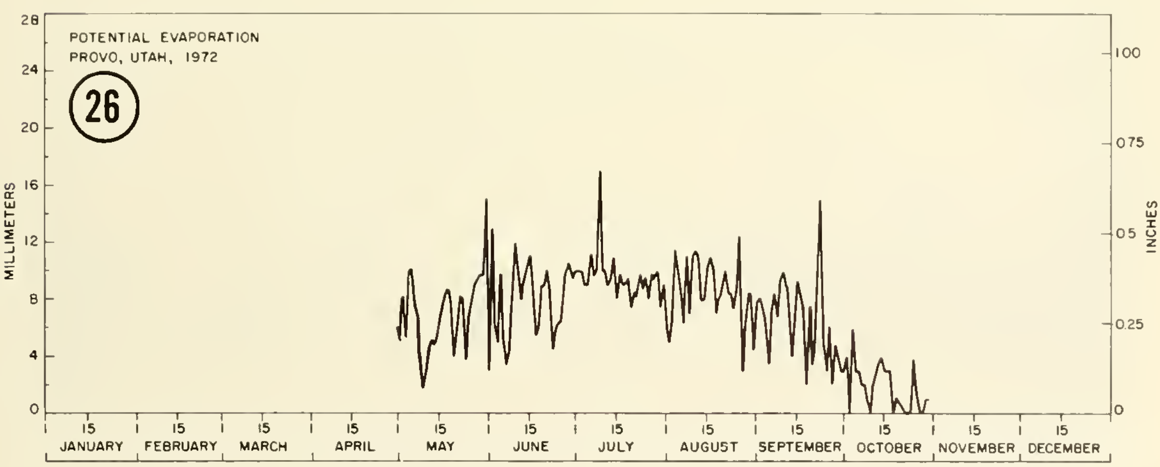

DAILY DURATION OF RELATIVE HUMIDITY AT 98 – 100%
PROVO, UTAH, 1970
21
HOURS
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER


DAILY DURATION OF RELATIVE HUMIDITY AT 98 - 100%
PROVO, UTAH, 1971
22
HOURS
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER


DAILY DURATION OF RELATIVE HUMIDITY AT 98-100%
PROVO, UTAH, 1972
23
HOURS
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER


POTENTIAL EVAPORATION
PROVO, UTAH, 1970
24
MILLIMETERS
INCHES
0
4
8
12
16
20
24
28
0
0.25
0.5
0.75
1.00
15
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER


POTENTIAL EVAPORATION
PROVO, UTAH, 1971
25
MILLIMETERS
INCHES
0
4
8
12
16
20
24
28
0
0.25
0.5
0.75
1.00
15
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER


POTENTIAL EVAPORATION
PROVO, UTAH, 1972
26
MILLIMETERS
INCHES
0
4
8
12
16
20
24
28
0
0.25
0.5
0.75
1.00
15
JANUARY
FEBRUARY
MARCH
APRIL
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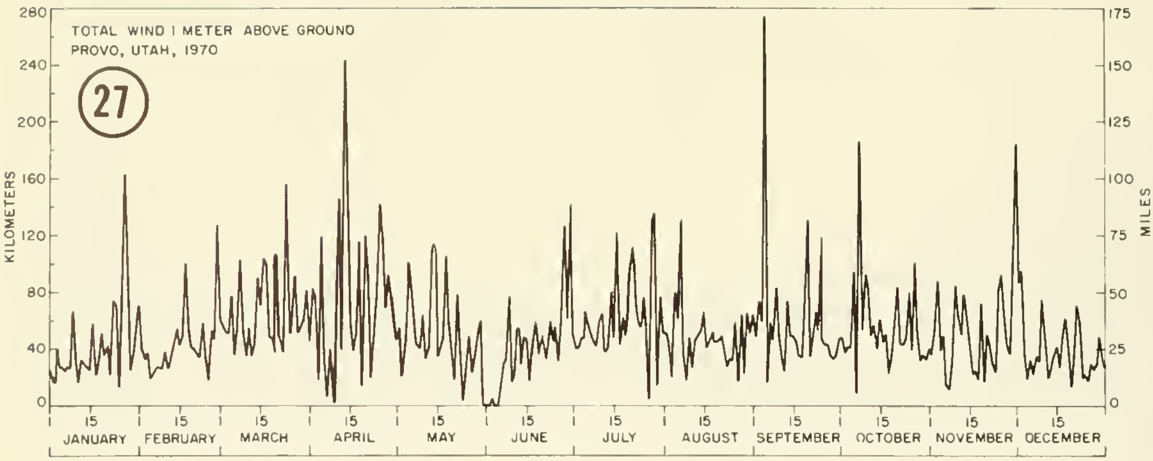
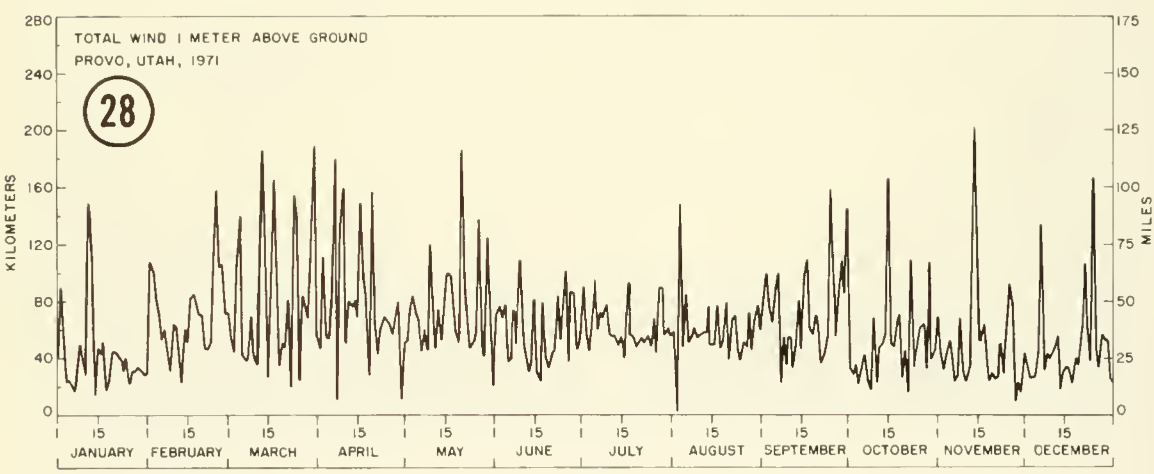
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER


TOTAL WIND 1 METER ABOVE GROUND
PROVO, UTAH, 1970
27
KILOMETERS
MILES
0
40
80
120
160
200
240
280
0
25
50
75
100
125
150
175
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER


TOTAL WIND 1 METER ABOVE GROUND
PROVO, UTAH, 1971
28
KILOMETERS
MILES
0
40
80
120
160
200
240
280
0
25
50
75
100
125
150
175
JANUARY
FEBRUARY
MARCH
APRIL
MAY
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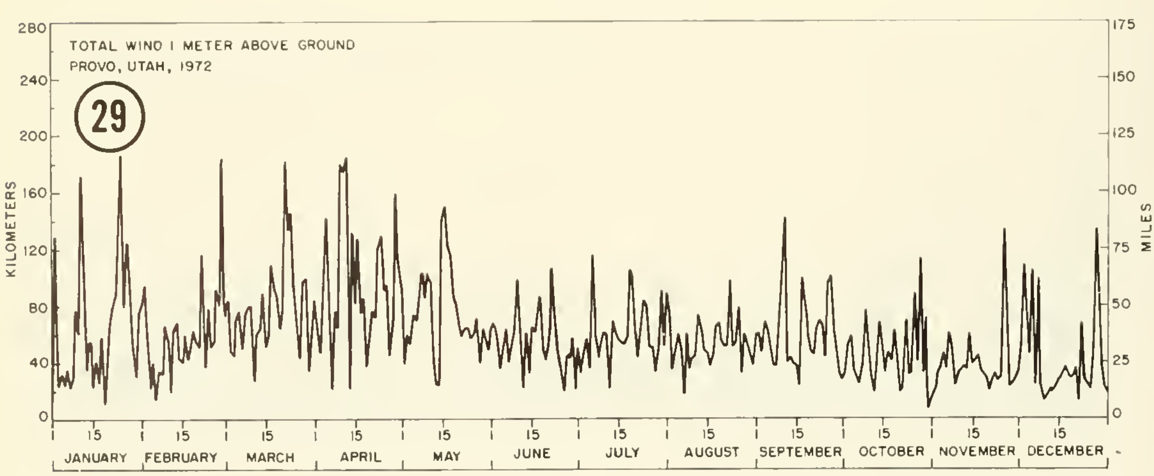
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER


TOTAL WIND 1 METER ABOVE GROUND
PROVO, UTAH, 1972
29
KILOMETERS
MILES
0
40
80
120
160
200
240
280
0
25
50
75
100
125
150
175
JANUARY
FEBRUARY
MARCH
APRIL
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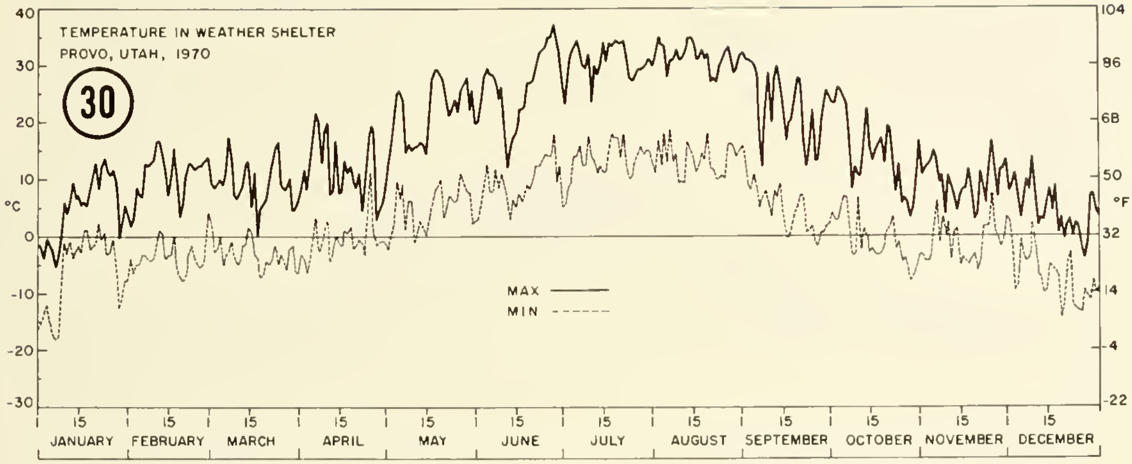
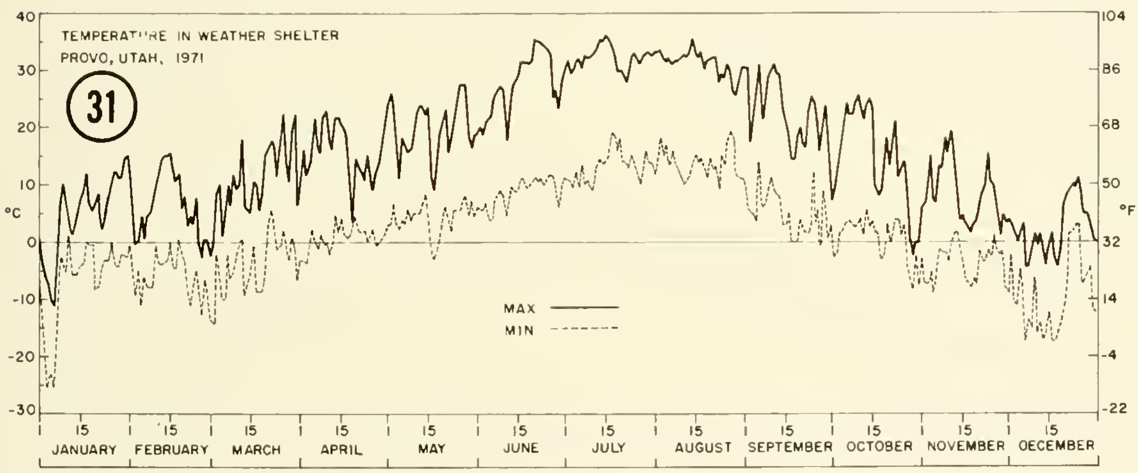
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER


TEMPERATURE IN WEATHER SHELTER
PROVO, UTAH, 1970
30
MAX
MIN
°C
°F
40
30
20
10
0
-10
-20
-30
104
86
68
50
32
14
-4
-22
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER


TEMPERATURE IN WEATHER SHELTER
PROVO, UTAH, 1971
31
MAX
MIN
°C
°F
40
30
20
10
0
-10
-20
-30
104
86
68
50
32
14
-4
-22
JANUARY
FEBRUARY
MARCH
APRIL
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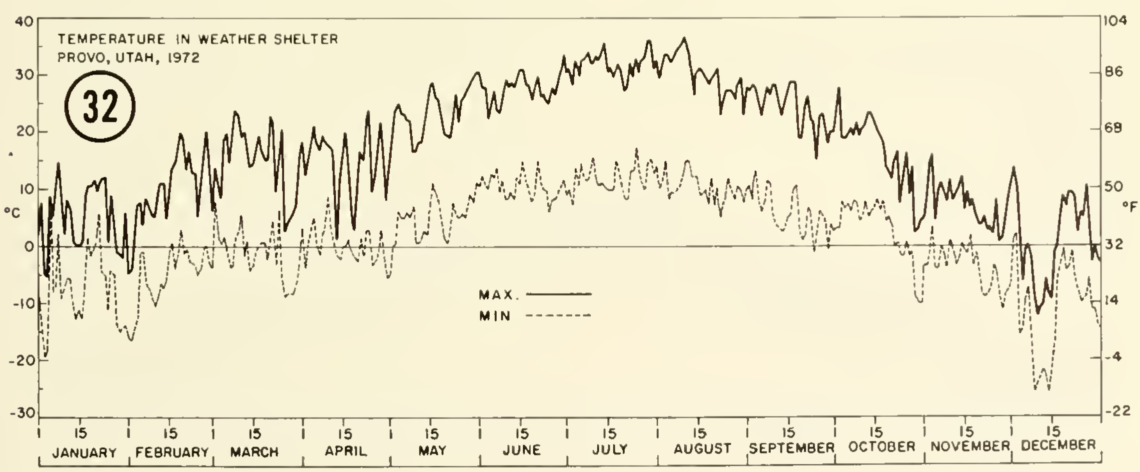
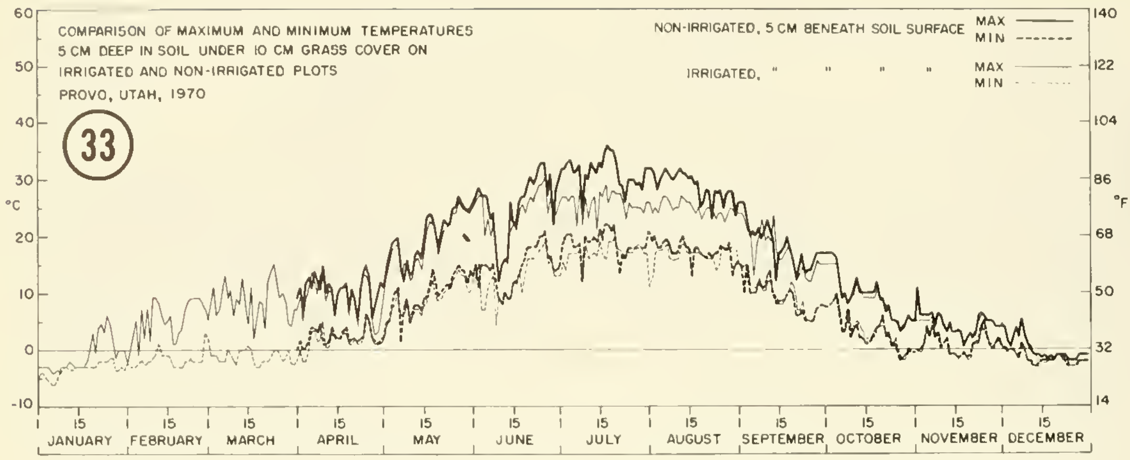
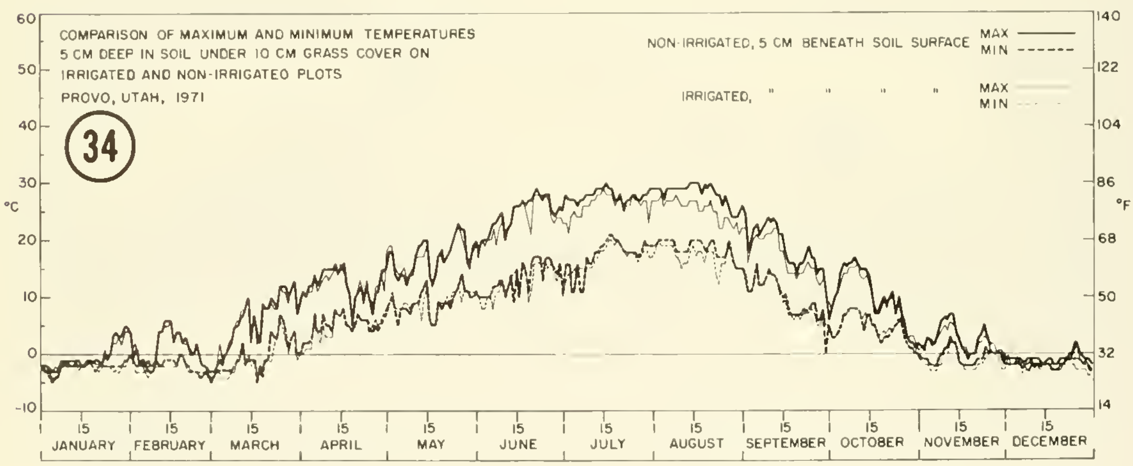
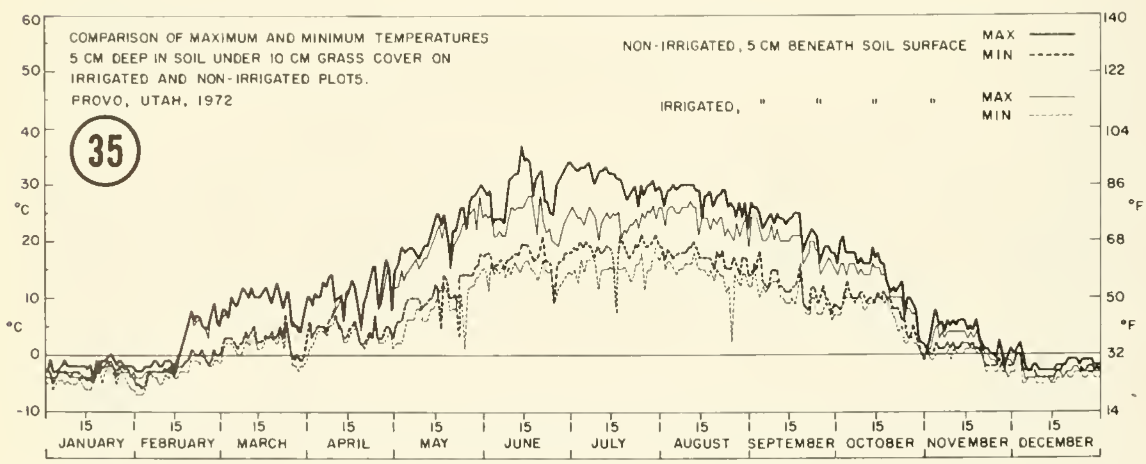
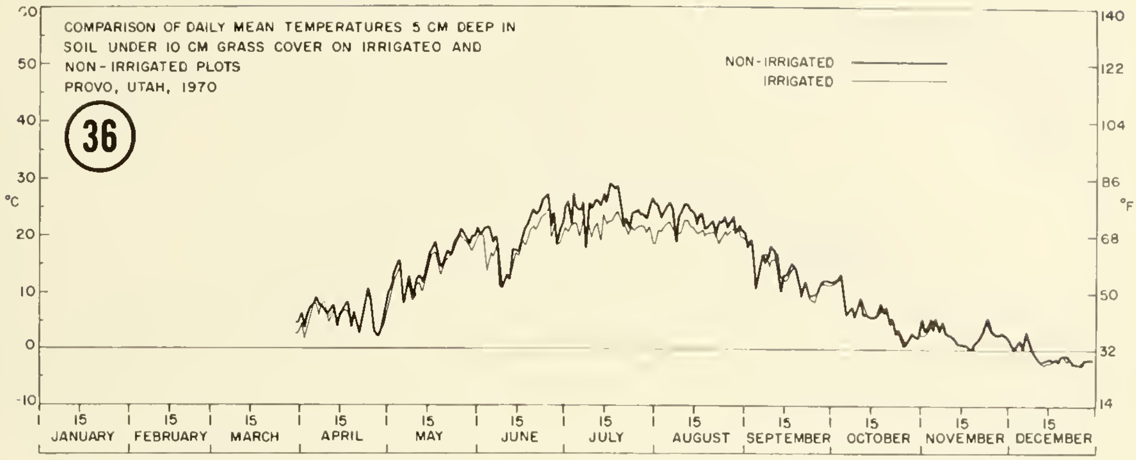
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

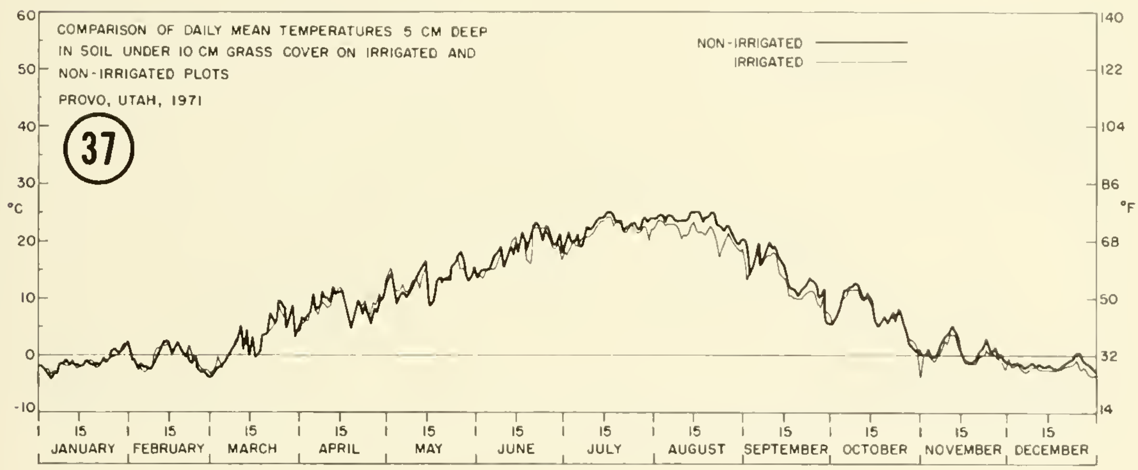

TEMPERATURE IN WEATHER SHELTER
PROVO, UTAH, 1972
32
MAX.
MIN
°C
°F
40
30
20
10
0
-10
-20
-30
104
86
68
50
32
14
-4
-22
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER

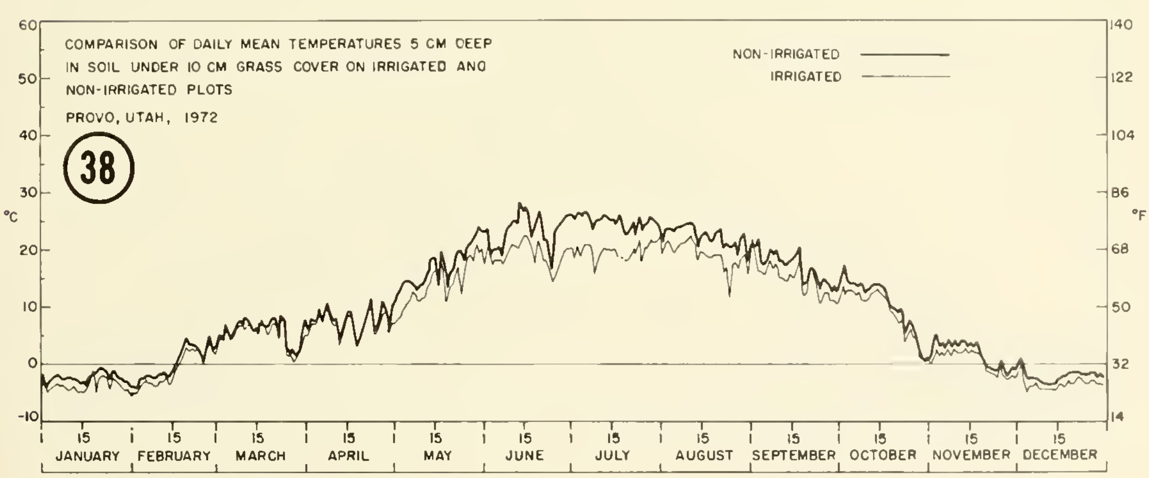

COMPARISON OF MAXIMUM AND MINIMUM TEMPERATURES
5 CM DEEP IN SOIL UNDER 10 CM GRASS COVER ON
IRRIGATED AND NON-IRRIGATED PLOTS
PROVO, UTAH, 1970
33
NON-IRRIGATED, 5 CM BENEATH SOIL SURFACE MAX MIN
IRRIGATED, " " " " MAX MIN
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

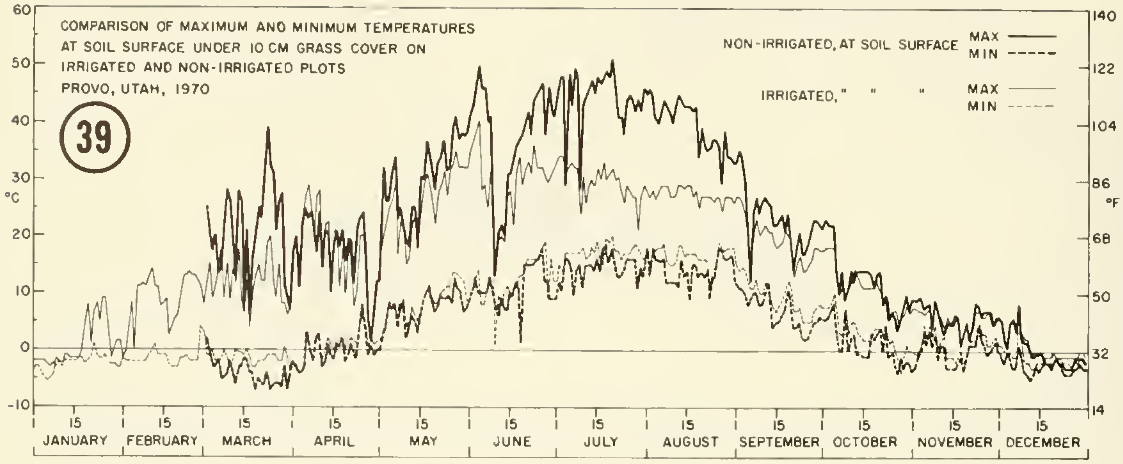

COMPARISON OF MAXIMUM AND MINIMUM TEMPERATURES
5 CM DEEP IN SOIL UNDER 10 CM GRASS COVER ON
IRRIGATED AND NON-IRRIGATED PLOTS
PROVO, UTAH, 1971
34
NON-IRRIGATED, 5 CM BENEATH SOIL SURFACE MAX MIN
IRRIGATED, " " " " MAX MIN
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

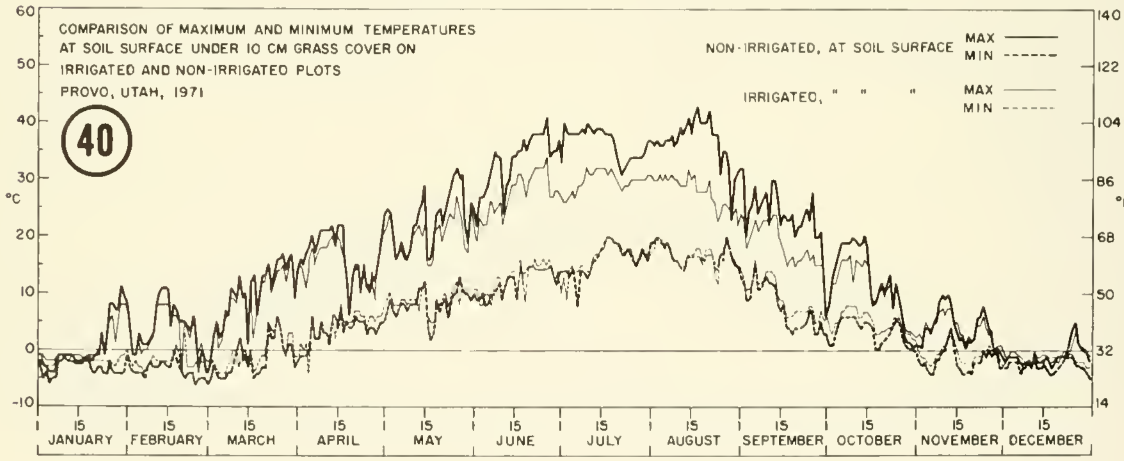

COMPARISON OF MAXIMUM AND MINIMUM TEMPERATURES
5 CM DEEP IN SOIL UNDER 10 CM GRASS COVER ON
IRRIGATED AND NON-IRRIGATED PLOTS.
PROVO, UTAH, 1972
35
NON-IRRIGATED, 5 CM BENEATH SOIL SURFACE MAX MIN
IRRIGATED, " " " " MAX MIN
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

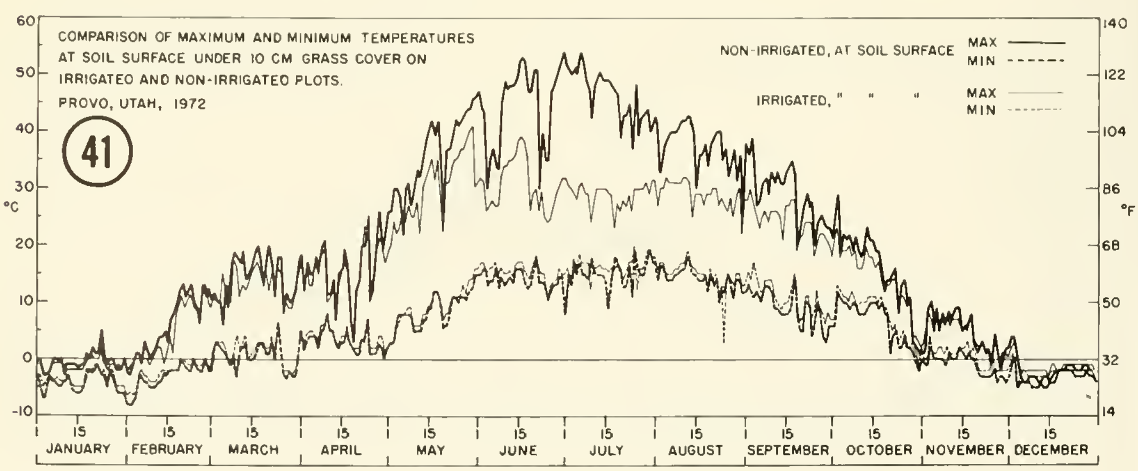

COMPARISON OF DAILY MEAN TEMPERATURES 5 CM DEEP IN
SOIL UNDER 10 CM GRASS COVER ON IRRIGATED AND
NON-IRRIGATED PLOTS
PROVO, UTAH, 1970
36
NON-IRRIGATED
IRRIGATED
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

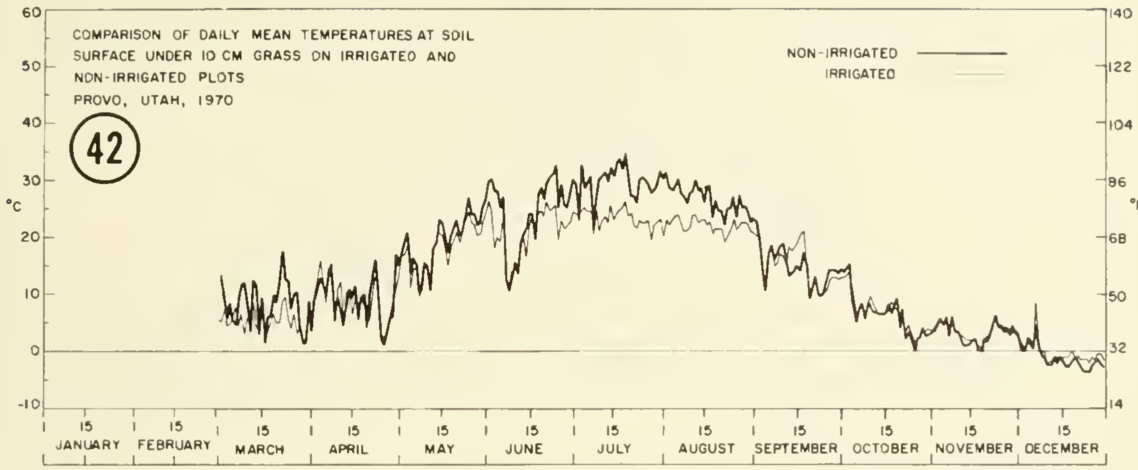

COMPARISON OF DAILY MEAN TEMPERATURES 5 CM DEEP
IN SOIL UNDER 10 CM GRASS COVER ON IRRIGATED AND
NON-IRRIGATED PLOTS
PROVO, UTAH, 1971
37
NON-IRRIGATED
IRRIGATED
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

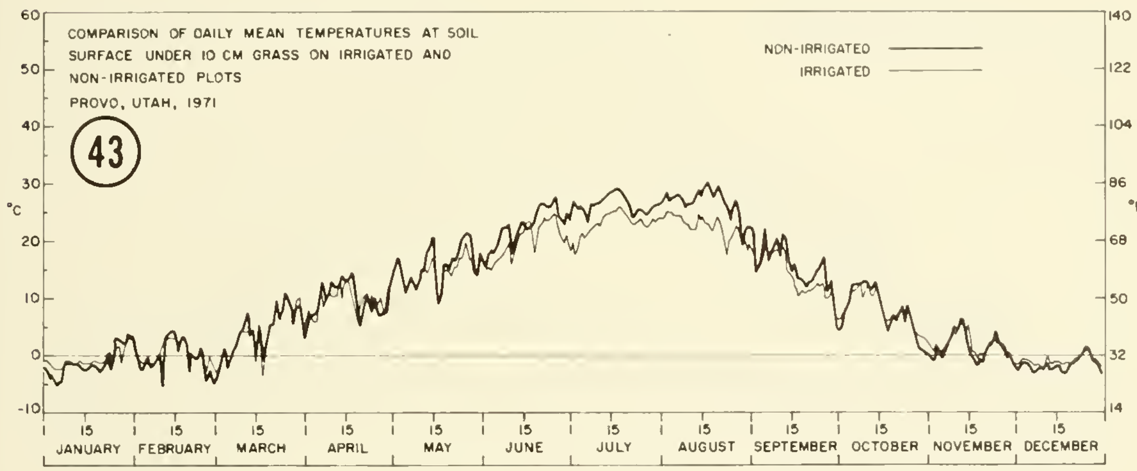

COMPARISON OF DAILY MEAN TEMPERATURES 5 CM DEEP
IN SOIL UNDER 10 CM GRASS COVER ON IRRIGATED AND
NON-IRRIGATED PLOTS
PROVO, UTAH, 1972
38
NON-IRRIGATED
IRRIGATED
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

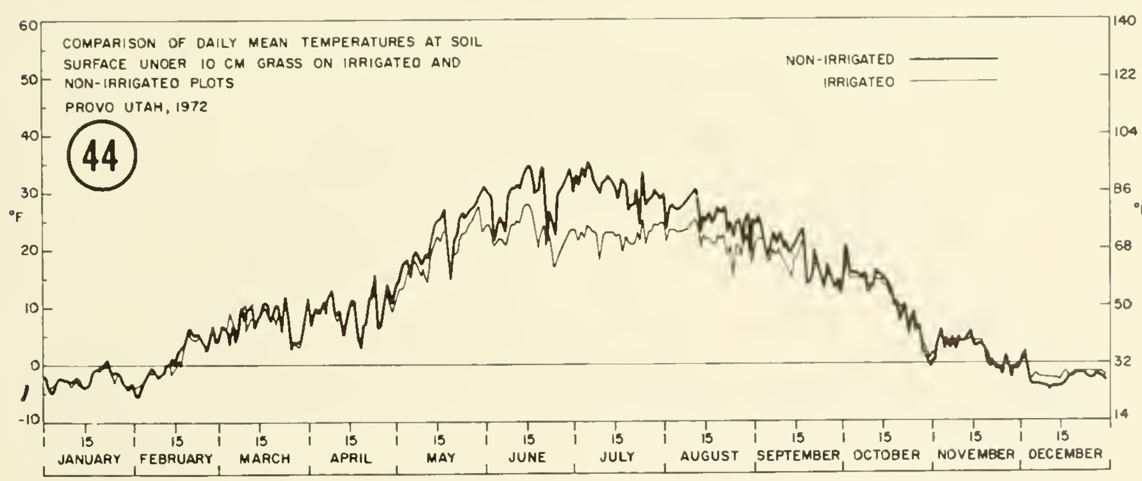

COMPARISON OF MAXIMUM AND MINIMUM TEMPERATURES
AT SOIL SURFACE UNDER 10 CM GRASS COVER ON
IRRIGATED AND NON-IRRIGATED PLOTS
PROVO, UTAH, 1970
39
NON-IRRIGATED, AT SOIL SURFACE MAX MIN
IRRIGATED, " " " MAX MIN
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

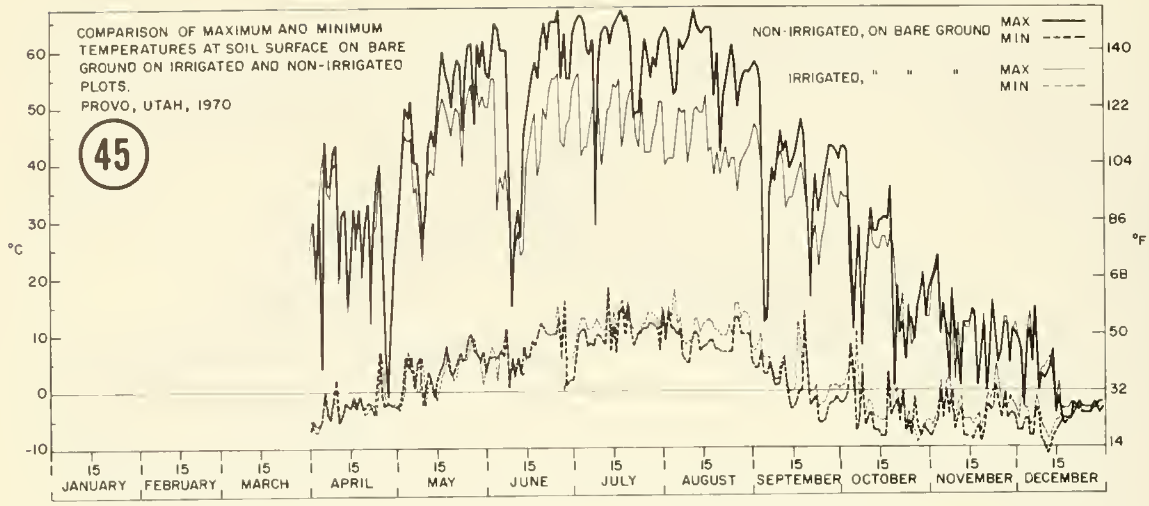

COMPARISON OF MAXIMUM AND MINIMUM TEMPERATURES
AT SOIL SURFACE UNDER 10 CM GRASS COVER ON
IRRIGATED AND NON-IRRIGATED PLOTS
PROVO, UTAH, 1971
40
NON-IRRIGATED, AT SOIL SURFACE MAX MIN
IRRIGATED, " " " MAX MIN
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

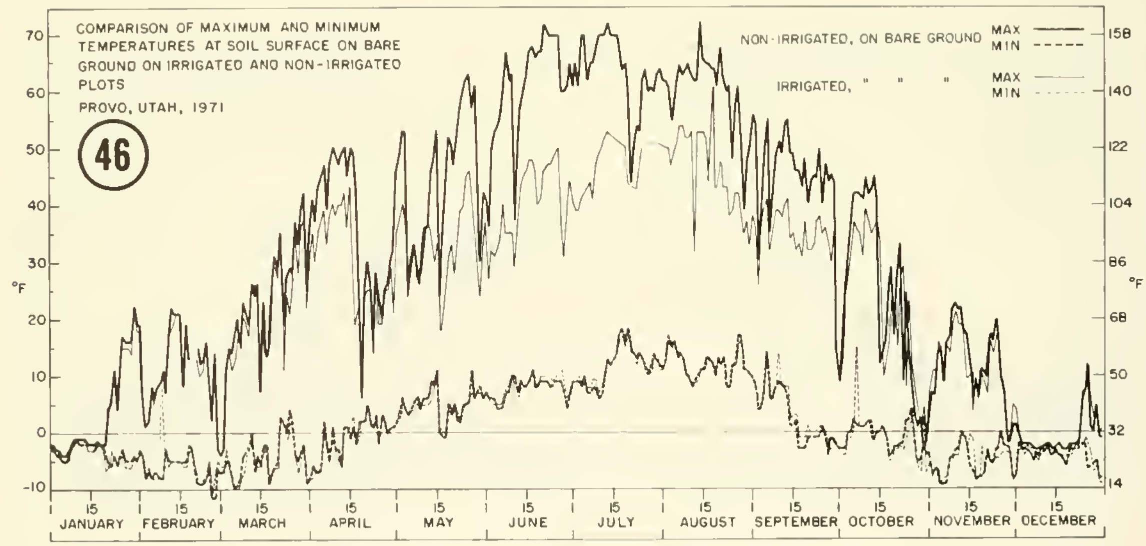

COMPARISON OF MAXIMUM AND MINIMUM TEMPERATURES
AT SOIL SURFACE UNDER 10 CM GRASS COVER ON
IRRIGATED AND NON-IRRIGATED PLOTS.
PROVO, UTAH, 1972
41
NON-IRRIGATED, AT SOIL SURFACE MAX MIN
IRRIGATED, " " " MAX MIN
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

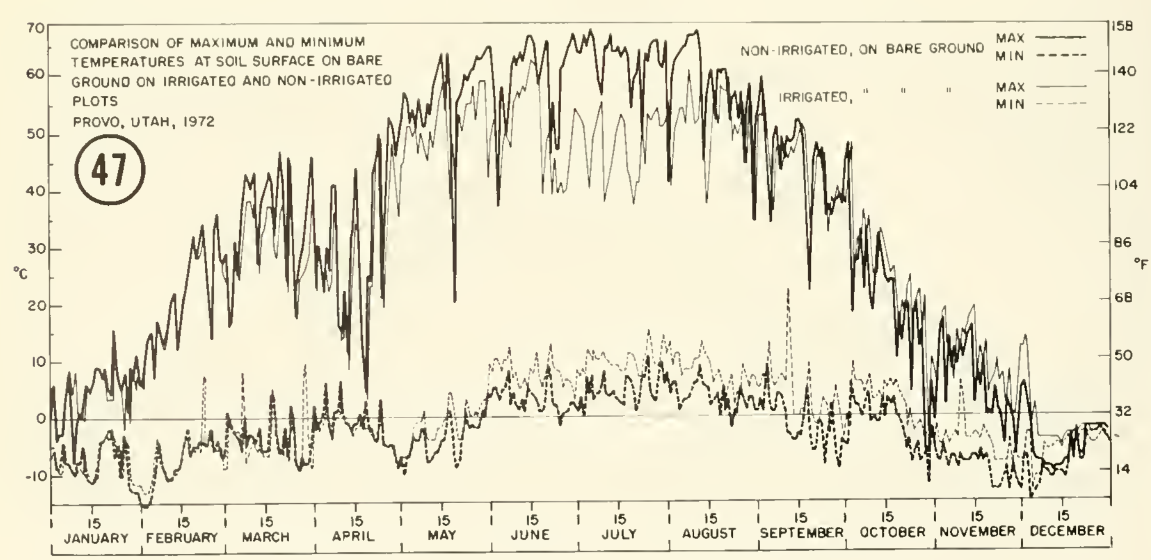

COMPARISON OF DAILY MEAN TEMPERATURES AT SOIL SURFACE UNDER 10 CM GRASS ON IRRIGATED AND NON-IRRIGATED PLOTS PROVO, UTAH, 1970
42
NON-IRRIGATED
IRRIGATED
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

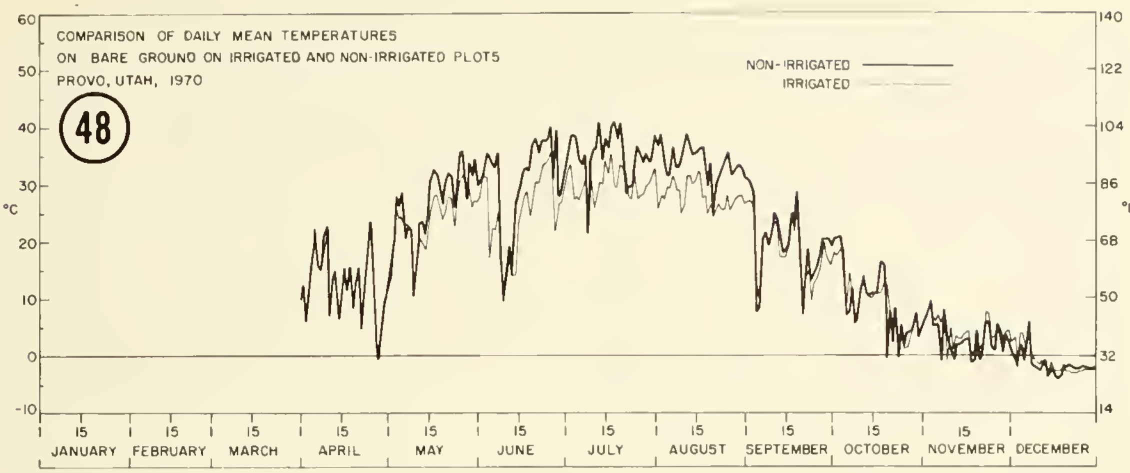

COMPARISON OF DAILY MEAN TEMPERATURES AT SOIL SURFACE UNDER 10 CM GRASS ON IRRIGATED AND NON-IRRIGATED PLOTS PROVO, UTAH, 1971
43
NON-IRRIGATED
IRRIGATED
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

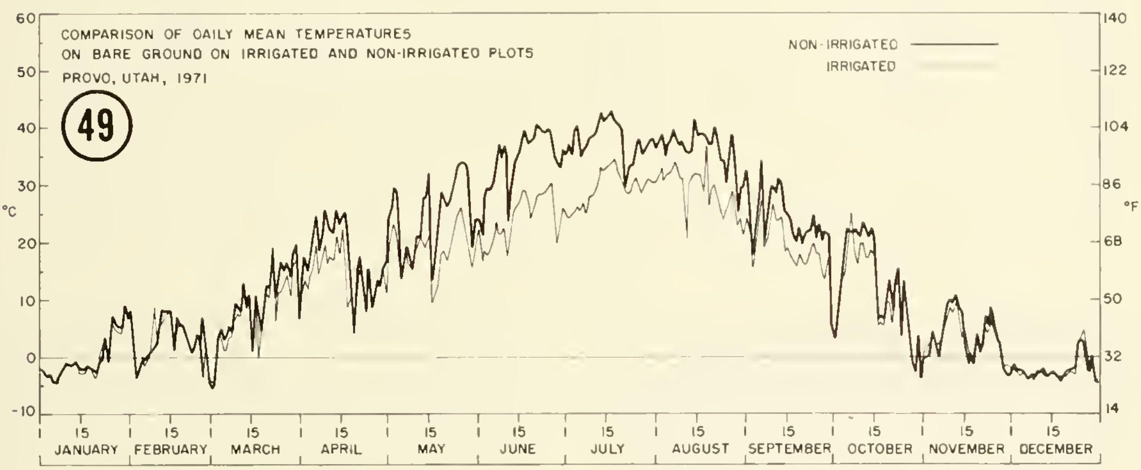

COMPARISON OF DAILY MEAN TEMPERATURES AT SOIL SURFACE UNDER 10 CM GRASS ON IRRIGATED AND NON-IRRIGATED PLOTS PROVO UTAH, 1972
44
NON-IRRIGATED
IRRIGATED
°F
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

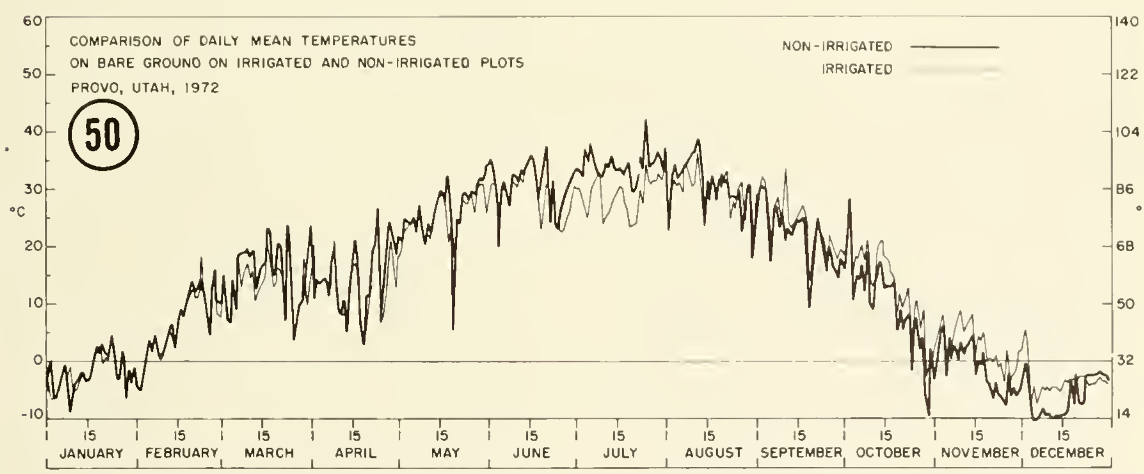

COMPARISON OF MAXIMUM AND MINIMUM TEMPERATURES AT SOIL SURFACE ON BARE GROUND ON IRRIGATED AND NON-IRRIGATED PLOTS.
PROVO, UTAH, 1970
45
NON-IRRIGATED, ON BARE GROUND MAX MIN
IRRIGATED, " " " MAX MIN
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

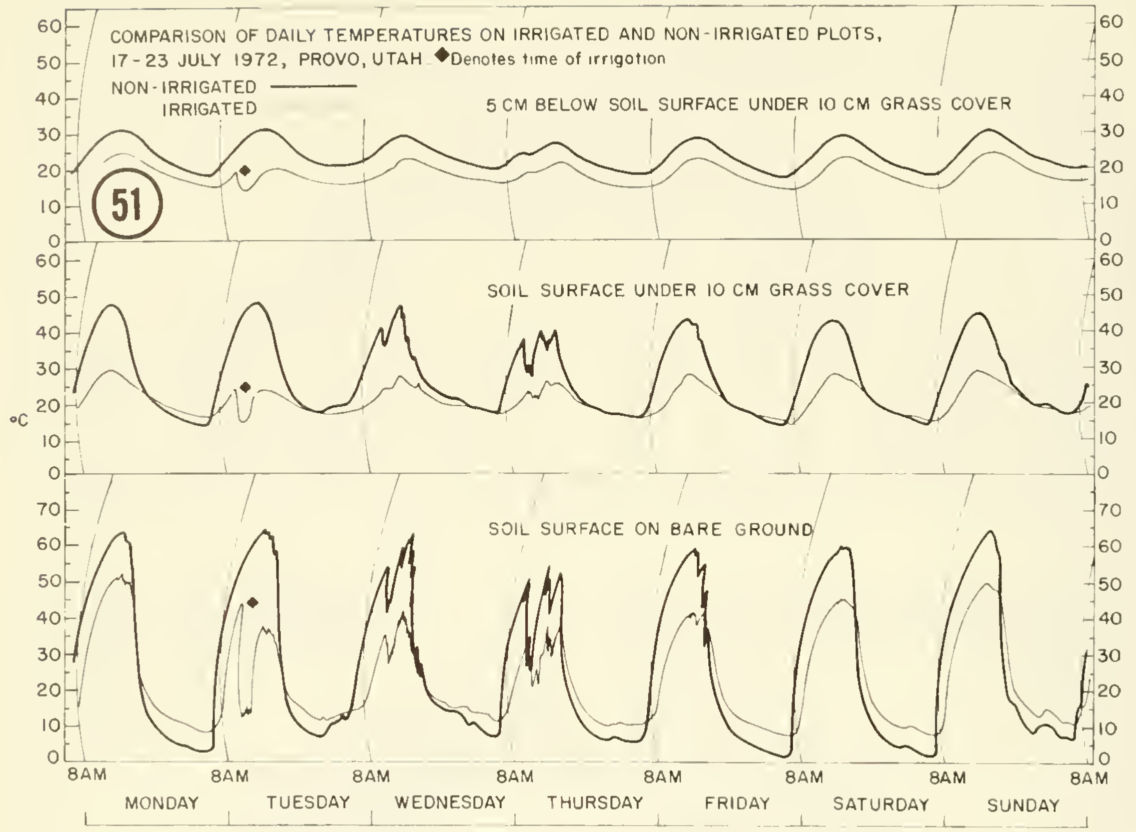

COMPARISON OF MAXIMUM AND MINIMUM TEMPERATURES AT SOIL SURFACE ON BARE GROUND ON IRRIGATED AND NON-IRRIGATED PLOTS
PROVO, UTAH, 1971
46
NON-IRRIGATED, ON BARE GROUND MAX MIN
IRRIGATED, " " " MAX MIN
°F
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER


COMPARISON OF MAXIMUM AND MINIMUM TEMPERATURES AT SOIL SURFACE ON BARE GROUND ON IRRIGATED AND NON-IRRIGATED PLOTS
PROVO, UTAH, 1972
47
NON-IRRIGATED, ON BARE GROUND MAX MIN
IRRIGATED, " " " MAX MIN
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER


COMPARISON OF DAILY MEAN TEMPERATURES
ON BARE GROUND ON IRRIGATED AND NON-IRRIGATED PLOTS
PROVO, UTAH, 1970
48
NON-IRRIGATED
IRRIGATED
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

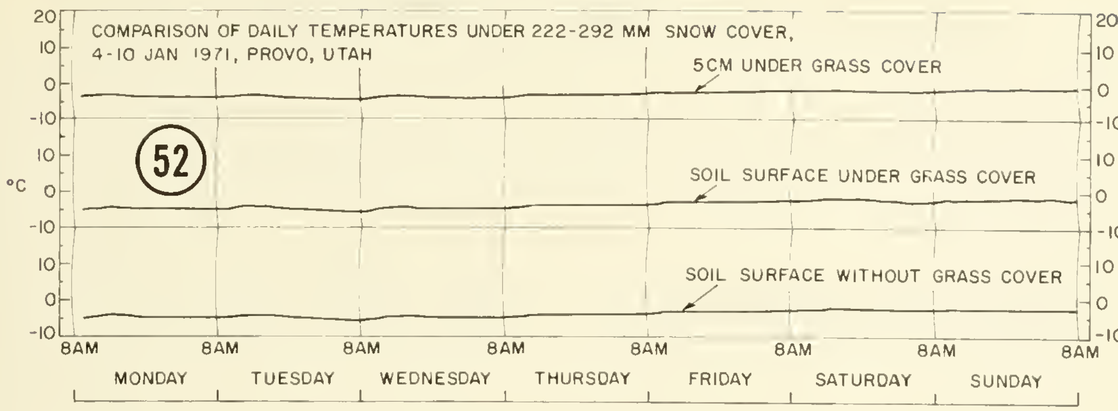

COMPARISON OF DAILY MEAN TEMPERATURES
ON BARE GROUND ON IRRIGATED AND NON-IRRIGATED PLOTS
PROVO, UTAH, 1971
49
NON-IRRIGATED
IRRIGATED
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER

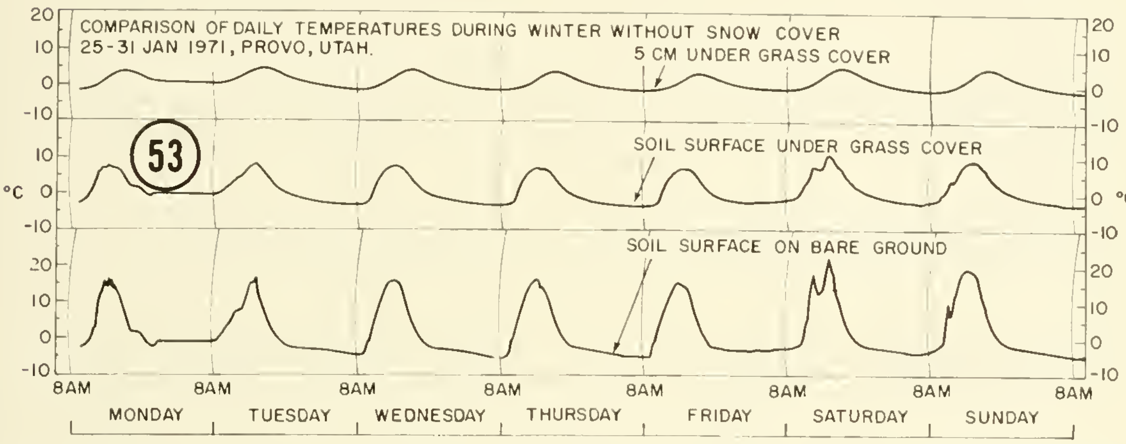

COMPARISON OF DAILY MEAN TEMPERATURES
ON BARE GROUND ON IRRIGATED AND NON-IRRIGATED PLOTS
PROVO, UTAH, 1972
50
NON-IRRIGATED
IRRIGATED
°C
°F
JANUARY FEBRUARY MARCH APRIL MAY JUNE JULY AUGUST SEPTEMBER OCTOBER NOVEMBER DECEMBER



7) with the highest monthly amount of 125.7 mm received during March 1971 and the lowest amount of 2.0 mm recorded during May 1972. The yearly precipitation totals at the official Provo weather station (KOVO) were 494.8, 323.5, and 274.8 mm, respectively, for the three years indicated (Table 10). Whereas the totals for 1970 and 1972 were quite similar for the two sites, the total amount recorded for 1971 at our station was more than twice that reported at KOVO. Even though the rainfall may be irregular in distribution for any one storm, such a discrepancy for an entire year's total is difficult to explain. The fact that KOVO radio station is located more toward the center of Utah Valley, whereas our station is to the north and considerably closer to the surrounding mountains, may have contributed significantly to this difference. Also, since the main differences recorded occurred during the months of March, October, November, and December of that year, some of the discrepancy may be attributed to the fact that different methods were employed at the two stations to determine the precipitation in snow. As mentioned above, we measured snowfall with an ordinary ruler and calculated precipitation therein as one-tenth that of the depth of each snowfall. Official weather stations either invert the rain gauge cone over the new snow cover to the last preceding crust or collect snowfall directly into the rain gauge at 1 m height. The collected snow is then melted and the water content therein measured directly with the rain gauge ruler. Collection of snow in the rain gauge cannister at 1 m height is more subject to errors associated with concurrent wind movements, whereas reliability of our method suffers from the fact that the amount of moisture in snow may vary between 1/6th to 1/30th of the total snow depth for any one storm. Since we had no way of conveniently melting the snow at our station, we felt it best to use the approximation as described.

In addition to this measured precipitation, as stated earlier, the amount of water applied to the station via flood irrigation was not measured; however, such water was usually applied for one to two hours during each irrigation period. Since our station was located at the end of an irrigation ditch that was used solely for that pasture, our plot was never excessively irrigated at any time during the study. When cultivated lands are located at the ends of main irrigation ditches where excess water cannot be transferred or shut down, or when located adjacent to laterals which run continuously dur-





ing the irrigation season, such lands can often receive far more water than is optimum. Holmes and Watson (1967) stated that farmers in certain areas of southern Australia customarily use too much water for irrigation and often apply water crest depths of about 20 cm in order to cover high spots on lands in that area. As a result, as much as 50 percent of the water applied through irrigation must be pumped back into the river. DeVries and Birch (1961) compared environmental measurements in Australia on three irrigation pastures to that of an adjacent dry lot east of Rochester, Victoria, where the frequency of irrigation was approximately once every 15 days, and found that the drainage from irrigation lands in that area varied from 3 to 26 percent of the irrigational inflow. They assumed an average of 10 percent of irrigational water supplied would eventually leave as drainage. To our knowledge, the only comparable data for irrigational lands in central Utah is that by Israelsen, et al., who showed that in 1944 the average efficiency of flood irrigation was 40 percent for 11 farms they tested in Utah County. Presumably the overall efficiency has improved since then, especially in areas in which sprinkler irrigation is used, but it is not uncommon to find pasture lands continually flooded with flows from drain streams during every day of the summer, and even into winter months in this area.

The impact of the precipitation pattern and the accompanying irrigation of pasture plots on the creation of suitable microenvironments for biological organisms is more apparent if one examines the precipitation data of this current study for June, July, August, and September, since irrigation in Utah is done routinely only during that approximate period of the year. During the three-year study period the total precipitation for those four months and the monthly averages over that period were 167.3 and 41.8 mm for 1970; 101.9 and 25.5 mm for 1971; and 53.9 and 13.5 mm for 1972. The long-term precipitation total and the monthly averages for those four months (based on all data collected from 1931 through 1960), as reported from the official Provo weather station, are 70.2 mm total and 19.5, 14.2, 21.0, and 15.5 mm for June, July, August, and September, respectively (Table 10). The normal values for all other months of the year average more than 25 mm of precipitation per month, whereas these four months all average below 25 mm per month. Parasitic nematodes, which are prevalent in cen-

Table 1. Monthly precipitation, relative humidity, cloud cover, potential evaporation, soil moisture, and total wind recorded at BYU Animal Science Farm, Provo, Utah, 1970.

Month		Precipitation (mm) Total Prec	Rain Prec	Snow Prec	Snow Fall	Snow Cover	Relative Humidity Max	Min	Hrs of 98-100 Rel Hum	Cloud Cover	Pot Evap (mm)	Soil Moisture Irrig	Non-Irrig	Wind (km)
January	Total	28.7	16.0	12.7	127.0	355.6	....	....	....	....	ND	....	....	1283
	Mean	0.9	0.5	0.4	4.1	11.5	99	60	14	5	ND	ND	ND	41
February	Total	16.8	12.4	4.3	43.2	81.3	....	....	....	....	ND	....	....	1226
	Mean	0.6	0.4	0.2	1.5	2.9	98	43	8	3	ND	ND	ND	43
March	Total	27.2	22.6	4.6	45.7	45.7	....	....	....	....	ND	....	....	2048
	Mean	0.9	0.7	0.1	1.5	1.5	99	43	5	4	ND	ND	ND	66
April	Total	48.8	7.1	41.7	416.6	492.8	....	....	....	....	ND	....	....	2187
	Mean	1.6	0.2	1.4	13.9	16.4	95	41	5	4	ND	ND	ND	72
May	Total	19.3	19.3	0.0	0.0	0.0	....	....	....	....	173.1	....	....	1484
	Mean	0.6	0.6	0.0	0.0	0.0	97	34	4	1	5.6	16.3	10.6	47
June	Total	57.1	57.1	0.0	0.0	0.0	....	....	....	....	187.3	....	....	1328
	Mean	1.9	1.9	0.0	0.0	0.0	98	38	5	3	6.2	14.6	7.9	44
July	Total	18.8	18.8	0.0	0.0	0.0	....	....	....	....	207.7	....	....	1881
	Mean	0.6	0.6	0.0	0.0	0.0	99	36	5	2	6.7	17.3	4.9	60
August	Total	18.8	18.8	0.0	0.0	0.0	....	....	....	....	200.7	....	....	1508
	Mean	0.6	0.6	0.0	0.0	0.0	99	36	4	2	6.5	17.3	4.6	48
September	Total	72.6	72.6	0.0	0.0	0.0	....	....	....	....	138.0	....	....	1792
	Mean	2.4	2.4	0.0	0.0	0.0	98	35	8	1	4.6	16.5	11.1	59
October	Total	42.2	42.2	0.0	0.0	0.0	....	....	....	....	77.0	....	....	1744
	Mean	1.4	1.4	0.0	0.0	0.0	98	44	10	3	2.5	14.5	11.4	56
November	Total	72.4	68.6	3.8	38.1	38.1	....	....	....	....	ND	....	....	1638
	Mean	2.4	2.3	0.1	1.3	1.3	96	54	10	5	ND	ND	ND	54
December	Total	68.3	18.8	49.5	495.3	3556.0	....	....	....	....	ND	....	....	1196
	Mean	2.2	0.6	1.6	16.0	114.7	99	63	15	4	ND	ND	ND	38
Yearly Total		491.0	374.4	116.6	1165.9	4569.5	....	....	....	....	983.8*	....	....	19315
Grand Mean		1.3	1.0	0.3	3.2	12.4	97	43	7	3	5.3*	16.1*	8.4*	52

ND = Not determined
*Calculated 1 May through 31 October only

Table 2. Average monthly temperatures (°C) in weather shelter and 5 cm beneath soil surface under grass cover recorded at BYU Animal Science Farm, Provo, Utah, 1970.

Month	Weather Shelter Temperatures						5 cm beneath Soil Surface					
	Thermometer			Hygrothermograph			Irrigated			Non-Irrigated		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
January	5.0	-6.1	-0.5	4.2	-5.9	-0.9	-0.9	-3.3	-2.1	ND	ND	ND
February	10.6	-3.6	3.5	9.7	-3.3	3.2	5.1	-1.7	1.7	ND	ND	ND
March	9.1	-3.3	2.9	8.3	-3.4	2.5	8.4	-1.1	3.6	ND	ND	ND
April	11.7	-0.7	5.5	10.9	-0.6	5.2	8.9	1.5	5.2	10.0	2.1	6.1
May	21.3	4.7	13.0	20.5	4.8	12.7	18.6	8.5	13.6	19.7	9.4	14.6
June	26.4	9.3	17.9	24.5	8.5	16.5	23.2	12.4	17.8	25.3	14.4	19.8
July	31.0	13.5	22.2	29.2	12.5	20.9	25.8	16.8	21.3	30.8	18.5	24.6
August	31.4	13.4	22.4	29.9	12.5	21.2	24.8	16.5	20.6	28.9	17.3	23.1
September	22.4	4.2	13.3	20.8	3.2	12.0	17.3	9.7	13.5	18.2	9.4	13.8
October	14.4	-1.0	6.7	12.8	-1.5	5.6	8.9	3.2	6.0	9.6	3.0	6.3
November	9.7	-0.7	4.5	8.3	-1.1	3.6	4.0	0.8	2.4	4.6	0.9	2.7
December	4.5	-7.4	-1.4	2.7	-7.7	-2.5	-0.2	-1.6	-0.9	0.0	-1.6	-0.8
Grand Mean	16.5	1.9	9.2	15.2	1.5	8.3	12.0	5.1	8.6	ND	ND	ND

Table 3. Average monthly temperatures (°C) at soil surface under grass cover at soil surface on bare ground recorded at BYU Animal Science Farm, Provo, Utah, 1970.

Month	Soil Surface under Grass Cover						Bare Soil Surface					
	Irrigated			Non-irrigated			Irrigated			Non-Irrigated		
	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
January	0.9	-2.4	-0.8	ND	ND	ND	ND	ND	ND	ND	ND	ND
February	8.6	-1.4	3.6	ND	ND	ND	ND	ND	ND	ND	ND	ND
March	11.6	-1.2	5.2	ND	ND	ND	21.1	4.4	8.4	ND	ND	ND
April	16.8	0.6	8.7	17.6	-0.2	8.7	26.4	-2.5	11.9	28.0	-2.4	12.8
May	25.6	8.0	16.8	29.5	6.9	18.2	42.6	3.1	22.9	48.3	3.6	26.0
June	29.2	12.2	20.7	37.7	10.9	24.3	41.8	7.2	24.5	53.5	7.2	30.4
July	29.7	16.8	23.3	44.4	14.2	29.3	47.2	11.9	29.6	60.1	9.9	35.0
August	27.4	16.6	22.0	39.7	14.2	27.0	43.5	12.1	27.8	58.7	9.0	33.8
September	19.2	9.4	14.3	23.1	7.0	15.0	33.8	3.5	18.6	39.3	0.8	20.1
October	10.9	3.2	7.1	12.2	1.3	6.8	21.5	-2.3	9.6	24.0	-3.9	10.1
November	5.6	1.1	3.3	6.0	-0.1	3.0	11.2	-2.6	4.3	10.6	-4.6	3.0
December	0.8	-1.0	-0.1	0.2	-2.5	-1.1	1.7	-4.1	-1.2	1.0	-5.5	-2.3
Grand Mean	15.5	5.2	10.3	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = Not determined

Table 4. Monthly precipitation, relative humidity, cloud cover, potential evaporation, soil moisture, and total wind recorded at BYU Animal Science Farm, Provo, Utah, 1971.

Month		Precipitation (mm) Total Prec	Rain Prec	Snow Prec	Snow Fall	Snow Cover	Relative Humidity Max	Min	Hrs of 98-100 Rel Hum	Cloud Cover	Pot Evap (mm)	Soil Moisture Irrig	Non-Irrig	Wind (km)
January	Total	22.6	3.0	19.6	195.6	4264.6	....	....	....	....	ND	....	....	1303
	Mean	0.7	0.1	0.6	6.3	137.6	98	65	14	5	ND	ND	ND	42
February	Total	38.6	19.0	19.6	195.6	233.7	....	....	....	....	ND	....	....	2002
	Mean	1.4	0.7	0.7	7.0	8.3	98	47	9	4	ND	ND	ND	71
March	Total	125.7	120.1	5.6	55.9	119.4	....	....	....	....	ND	....	....	2566
	Mean	4.1	3.9	0.2	1.8	3.9	97	42	6	4	ND	ND	ND	82
April	Total	70.9	70.9	0.0	0.0	0.0	....	....	....	....	ND	....	....	2325
	Mean	2.4	2.4	0.0	0.0	0.0	94	43	6	4	ND	ND	ND	77
May	Total	31.7	31.7	0.0	0.0	0.0	....	....	....	....	146.9	....	....	2317
	Mean	1.0	1.0	0.0	0.0	0.0	97	39	5	4	4.7	16.1	9.9	74
June	Total	12.4	12.4	0.0	0.0	0.0	....	....	....	....	284.2	....	....	1724
	Mean	0.4	0.4	0.0	0.0	0.0	98	32	5	2	9.5	15.6	3.7	57
July	Total	20.1	20.1	0.0	0.0	0.0	....	....	....	....	242.8	....	....	1924
	Mean	0.6	0.6	0.0	0.0	0.0	97	33	4	1	7.8	17.1	1.4	62
August	Total	23.4	23.4	0.0	0.0	0.0	....	....	....	....	178.8	....	....	1822
	Mean	0.8	0.8	0.0	0.0	0.0	98	38	7	2	5.8	14.7	4.2	58
September	Total	46.0	44.2	1.8	17.8	17.8	....	....	....	....	119.0	....	....	2151
	Mean	1.5	1.5	0.1	0.6	0.6	98	34	6	2	4.0	17.3	3.5	71
October	Total	122.4	61.5	61.0	609.6	1270.0	....	....	....	....	59.0	....	....	1666
	Mean	3.9	2.0	2.0	19.7	41.0	98	54	10	4	1.9	17.1	11.7	53
November	Total	98.3	84.3	14.0	139.7	431.8	....	....	....	....	ND	....	....	1414
	Mean	3.3	2.8	0.5	4.7	14.4	99	60	12	6	ND	ND	ND	47
December	Total	114.3	48.0	66.3	662.9	4089.4	....	....	....	....	ND	....	....	1477
	Mean	3.7	1.5	2.1	21.4	131.9	98	68	13	6	ND	ND	ND	47
Yearly Total		726.4	538.7	187.7	1877.1	10426.7	....	....	....	....	1030.7*	....	....	22691
Grand Mean		2.0	1.5	0.5	5.1	28.1	97	46	8	3	5.6*	16.3*	5.8*	61

ND = Not determined
*Calculated 1 May through 31 October only

Table 5. Average monthly temperatures (°C) in weather shelter and 5 cm beneath soil surface under grass cover recorded at BYU Animal Science Farm, Provo, Utah, 1971.

	Weather Shelter Temperatures						5 cm beneath Soil Surface					
	Thermometer			Hygrothermograph			Irrigated			Non-Irrigated		
Month	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
January	4.8	-7.2	-1.2	2.7	-6.2	-1.8	-0.7	-2.2	-1.5	-0.5	-2.2	-1.3
February	6.2	-5.7	0.2	4.3	-6.6	-1.2	1.0	-2.3	-0.7	0.9	-2.0	-0.6
March	10.5	-4.0	3.3	8.9	-4.1	2.4	5.4	-0.7	2.3	5.2	-0.2	2.5
April	15.5	0.4	8.0	14.1	-0.1	7.0	11.9	4.5	8.2	12.1	4.9	8.5
May	19.7	4.2	12.0	18.0	4.1	11.0	16.8	9.1	13.0	17.0	9.1	13.0
June	27.4	8.5	17.9	25.6	7.3	16.5	23.5	12.6	18.0	24.4	13.3	18.8
July	32.2	13.0	22.6	30.1	11.6	20.8	26.0	16.6	21.3	27.6	17.1	22.4
August	31.3	13.5	22.4	29.3	12.0	20.6	25.5	17.2	21.3	28.3	18.6	23.4
September	22.8	5.0	13.9	20.9	3.6	12.3	17.0	9.6	13.3	19.1	10.0	14.6
October	14.8	0.7	7.7	13.0	-0.2	6.4	9.6	4.9	7.2	10.1	4.6	7.3
November	8.5	-3.5	2.5	6.9	-3.9	1.5	1.7	-1.5	0.1	2.4	-0.5	0.9
December	2.2	-9.5	-3.7	0.4	-9.5	-4.6	-1.6	-2.6	-2.1	-0.9	-1.9	-1.4
Grand Mean	16.3	1.3	8.8	14.5	0.7	7.6	11.3	5.4	8.4	12.1	5.9	9.0

Table 6. Average monthly temperatures (°C) at soil surface under grass cover and at soil surface on bare ground recorded at BYU Animal Science Farm, Provo, Utah, 1971.

	Soil Surface under Grass Cover						Bare Soil Surface					
	Irrigated			Non-Irrigated			Irrigated			Non-Irrigated		
Month	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
January	0.4	-1.9	-0.7	0.4	-3.1	-1.3	2.7	-3.9	-0.6	3.0	-3.6	-0.3
February	3.0	-2.1	0.4	3.7	-3.4	0.2	10.3	-5.7	2.3	11.1	-6.3	2.4
March	8.5	-0.6	4.0	9.1	-1.6	3.8	19.7	-4.9	7.4	22.1	-4.4	8.9
April	15.1	3.9	9.5	16.3	3.3	9.8	29.5	-1.4	14.0	35.9	-0.9	17.5
May	20.2	9.0	14.6	23.0	8.1	15.6	32.5	4.7	18.6	44.3	4.8	24.6
June	27.2	12.8	20.0	33.2	12.0	22.6	40.0	8.0	24.0	60.5	7.6	34.0
July	29.7	16.1	22.9	36.5	16.0	26.2	46.9	11.6	29.3	63.6	11.6	37.6
August	28.2	17.0	22.6	36.7	16.6	26.7	46.4	11.8	29.1	60.3	12.0	36.2
September	18.8	9.6	14.2	24.3	7.8	16.0	34.5	3.5	19.0	45.3	2.6	24.0
October	10.8	5.1	8.0	12.0	3.2	7.6	21.8	-1.0	10.4	25.0	-0.8	12.1
November	3.7	-0.4	1.6	4.0	-1.5	1.3	11.3	-4.7	3.3	11.8	-4.8	3.5
December	-0.4	-1.6	-1.0	-0.8	-2.6	-1.7	-0.5	-4.1	-2.3	-0.5	-3.8	-2.2
Grand Mean	13.8	5.6	9.7	16.5	4.6	10.6	24.6	1.2	12.9	31.8	1.2	16.5

Table 7. Monthly precipitation, relative humidity, cloud cover, potential evaporation, soil moisture, and total wind recorded at BYU Animal Science Farm, Provo, Utah, 1972.

Month		Precipitation (mm) Total Prec	Rain Prec	Snow Prec	Snow Fall	Snow Cover	Relative Humidity Max	Min	Hrs of 98-100 Rel Hum	Cloud Cover	Pot Evap (mm)	Soil Moisture Irrig	Non-Irrig	Wind (km)
January	Total	5.6	0.0	5.6	55.9	73.7	....	....	....	....	ND	....	....	2044
	Mean	0.2	0.0	0.2	1.8	2.4	97	53	9	6	ND	ND	ND	65
February	Total	8.9	2.5	6.3	63.5	63.5	....	....	....	....	ND	....	....	1742
	Mean	0.3	0.1	0.2	2.2	2.2	99	47	9	4	ND	ND	ND	60
March	Total	27.2	18.3	8.9	88.9	88.9	....	....	....	....	ND	....	....	2443
	Mean	0.9	0.6	0.3	2.9	2.9	99	40	6	3	ND	ND	ND	78
April	Total	79.5	74.9	4.6	45.7	45.7	....	....	....	....	ND	....	....	2756
	Mean	2.7	2.5	0.2	1.5	1.5	97	45	7	4	ND	ND	ND	91
May	Total	2.0	2.0	0.0	0.0	0.0	....	....	....	....	218.6	....	....	2279
	Mean	0.1	0.1	0.0	0.0	0.0	98	33	3	2	7.1	4.7	2.4	73
June	Total	11.2	11.2	0.0	0.0	0.0	....	....	....	....	240.3	....	....	1631
	Mean	0.4	0.4	0.0	0.0	0.0	97	39	5	3	8.0	9.4	2.4	54
July	Total	7.4	7.4	0.0	0.0	0.0	....	....	....	....	297.8	....	....	1853
	Mean	0.2	0.2	0.0	0.0	0.0	98	33	4	1	9.6	11.3	1.8	59
August	Total	11.2	11.2	0.0	0.0	0.0	....	....	....	....	263.9	....	....	1661
	Mean	0.4	0.4	0.0	0.0	0.0	98	35	7	1	8.5	5.8	2.2	53
September	Total	24.1	24.1	0.0	0.0	0.0	....	....	....	....	197.2	....	....	1857
	Mean	0.8	0.8	0.0	0.0	0.0	98	36	8	2	6.6	5.3	3.2	61
October	Total	119.6	99.3	20.3	203.2	571.5	....	....	....	....	56.4	....	....	1435
	Mean	3.9	3.2	0.7	6.6	18.4	98	55	13	5	1.8	12.3	10.9	46
November	Total	54.1	47.2	6.9	68.6	119.4	....	....	....	....	ND	....	....	1183
	Mean	1.8	1.6	0.2	2.3	4.0	98	69	14	6	ND	ND	ND	39
December	Total	39.4	1.0	38.4	383.5	2702.6	....	....	....	....	ND	....	....	1371
	Mean	1.3	0.0	1.2	12.4	87.2	97	69	14	5	ND	ND	ND	44
Yearly Total		390.1	299.2	90.9	909.3	3665.2	....	....	....	....	1274.2°	....	....	22,255
Grand Mean		1.1	0.8	0.2	2.5	9.9	97	46	8	3	6.9°	8.1°	3.8°	60

ND = Not determined
°Calculated 1 May through 31 October only

Table 8. Average monthly temperatures (°C) in weather shelter and 5 cm beneath soil surface under grass cover recorded at BYU Animal Science Farm, Provo, Utah, 1972.

	Weather Shelter Temperatures						5 cm beneath Soil Surface					
	Thermometer			Hygrothermograph			Irrigated			Non-Irrigated		
Month	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
January	5.3	-7.5	-1.1	3.5	-7.9	-2.2	-3.1	-4.4	-3.8	-1.7	-3.1	-2.4
February	9.9	-5.2	2.3	8.1	-5.7	1.2	0.7	-3.2	-1.3	1.6	-2.0	-0.2
March	14.8	-1.3	6.7	13.3	-2.1	5.6	8.8	1.1	5.0	9.0	2.4	5.7
April	14.8	0.3	7.5	13.5	0.0	6.7	10.6	3.2	6.9	11.1	4.3	7.7
May	23.1	4.7	13.9	22.3	4.7	13.5	19.2	8.2	13.7	21.9	10.6	16.2
June	27.8	10.4	19.1	26.5	10.2	18.3	23.5	14.1	18.8	29.4	16.9	23.2
July	31.8	11.8	21.8	30.5	11.6	21.0	23.9	14.9	19.4	30.8	18.5	24.7
August	30.2	10.4	20.3	29.0	10.5	19.8	23.7	14.1	18.9	27.6	17.1	22.3
September	24.4	5.9	15.1	23.4	6.1	14.8	19.4	10.0	14.7	22.3	11.9	17.1
October	16.6	2.9	9.8	15.2	3.6	9.4	11.4	6.6	9.0	13.4	7.6	10.5
November	7.2	-3.6	1.8	5.9	-2.9	1.5	1.9	-0.9	0.5	3.3	0.1	1.7
December	1.1	-11.2	-5.0	-0.1	-10.3	-5.2	-3.0	-3.9	-3.5	-1.6	-2.7	-2.1
Grand Mean	17.3	1.5	9.4	15.9	1.5	8.7	11.4	5.0	8.2	13.9	6.8	10.4

Table 9. Average monthly temperatures (°C) at soil surface under grass cover and at soil surface on bare ground recorded at BYU Animal Science Farm, Provo, Utah, 1972.

	Soil Surface under Grass Cover						Bare Soil Surface					
	Irrigated			Non-Irrigated			Irrigated			Non-Irrigated		
Month	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
January	-1.2	-3.5	-2.3	-0.5	-4.2	-2.3	4.2	-8.1	-2.0	4.4	-7.7	-1.6
February	4.1	-2.4	0.8	5.6	-3.2	1.2	19.8	-7.5	6.2	20.2	-7.5	6.4
March	12.7	1.4	7.0	14.6	0.5	7.6	30.1	-3.9	13.1	34.2	-3.8	15.2
April	14.4	3.8	9.1	15.9	3.1	9.5	28.2	-2.1	13.1	31.6	-1.3	15.1
May	29.8	8.9	19.4	35.6	8.3	21.9	50.6	-0.9	24.9	55.9	-3.7	26.1
June	30.5	15.2	22.8	44.4	13.9	29.2	49.9	7.6	28.7	59.2	3.0	31.1
July	28.9	16.1	22.5	46.4	14.9	30.7	47.9	9.8	28.8	63.0	4.5	33.7
August	29.0	14.9	21.9	37.3	14.2	25.8	51.8	7.6	29.7	58.1	3.4	30.7
September	24.2	10.9	17.6	29.4	9.0	19.2	44.3	3.6	23.9	44.6	-1.2	21.7
October	14.6	7.8	11.2	16.4	6.5	11.4	24.4	1.8	13.1	21.1	-1.6	9.7
November	4.2	0.3	2.3	4.6	-1.0	1.8	9.8	-4.4	2.7	5.8	-8.8	-1.5
December	-1.2	-2.3	-1.7	-1.8	-3.3	-2.5	-1.7	-5.4	-3.5	-4.6	-7.7	-6.2
Grand Mean	15.8	5.9	10.9	20.7	4.9	12.8	30.0	-0.2	14.9	32.8	-2.7	15.0

Table 10. Total monthly precipitation for Provo, Utah (KOVO radio station).

	Normal*		1970 Amount		1970 Departure		1971 Amount		1971 Departure		1972 Amount		1972 Departure	
	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in	mm	in
January	36.00	1.44	47.00	1.88	11.00	.44	16.00	.64	-20.00	-.80	4.25	.17	-31.75	-1.27
February	32.25	1.29	18.25	.73	-14.00	-.56	53.75	2.15	21.50	.86	2.50	.10	-29.75	-1.19
March	31.25	1.25	27.50	1.10	-3.75	-.15	2.50	.10	-28.75	-1.15	14.50	.58	-16.75	-.67
April	29.75	1.19	59.50	2.38	29.75	1.19	56.50	2.26	26.75	1.07	31.50	1.26	1.75	.07
May	28.25	1.13	17.00	.68	-11.25	-.45	29.25	1.17	1.00	.04	.25	.01	-28.00	-1.12
June	19.50	.78	46.75	1.87	27.25	1.09	9.50	.38	-10.00	-.40	18.50	.74	-1.00	-.04
July	14.25	.57	21.50	.86	7.25	.29	11.75	.47	-2.50	-.10	5.25	.21	-9.00	-.36
August	21.00	.84	31.00	1.24	10.00	.40	18.25	.73	-2.75	-.11	19.50	.78	-1.50	-.06
September	15.50	.62	63.25	2.53	47.75	1.91	33.25	1.33	17.75	.71	16.25	.65	.75	.03
October	33.50	1.34	37.25	1.49	3.75	.15	53.25	2.13	19.75	.79	100.50	4.02	67.00	2.68
November	27.75	1.11	84.25	3.37	56.50	2.26	15.25	.61	-12.50	-.50	40.25	1.61	12.50	.50
December	32.75	1.31	41.50	1.66	8.75	.35	24.25	.97	-8.50	-.34	21.50	.86	-11.25	-.45
Total	321.75	12.87	494.75	19.79	173.00	6.92	323.50	12.94	1.75	.07	274.75	10.99	-47.00	-1.88

*Normals based on data from 1931-1960.

Table 11. Average monthly mean temperatures recorded from Provo, Utah (KOVO radio station).

	Normal*		1970		1971		1972	
	°C	°F	°C	°F	°C	°F	°C	°F
January	-3.5	25.7	-2.1	28.1 M	-2.0	28.3	-1.3	29.6**
February	.1	32.1	3.6	38.5	1.2	34.2 M	2.4	36.4 M
March	4.4	40.0	3.4	38.2	4.9	40.9 M	7.9	46.3 M
April	9.6	49.2	6.8	44.4 M	9.1	48.5	8.8	48.0 M
May	13.8	56.9	14.0	57.2	13.0	55.4	14.8	58.8 M
June	18.1	64.6	18.6	65.6	18.9	66.1	19.5	67.1 M
July	22.8	73.0	22.7	72.9 M	22.5	72.5 M	22.4	72.4 M
August	21.6	70.9	23.2	73.9 M	22.3	72.2 M	21.2	70.3 M
September	16.7	62.1	14.0	57.3 M	13.8	56.9 M	15.6	60.2 M
October	10.9	51.6	7.6	45.7	7.9	46.3 M	10.5	51.0 M
November	3.4	38.2	5.0	41.1	2.7	36.9 M	2.7	37.0 M
December	-1.3	29.7	-1.7	28.8	-4.4	24.0 M	-5.2	22.5 M
Annual	9.7	49.5	9.6	49.3	9.1	48.5	10.0	50.0

* = Normals based on data from 1931-1960
M = Some data missing during month
** = No dáta for Provo; data taken from Pleasant Grove, Utah

Table 12. Total monthly potential evaporation° at Utah Lake station, Lehi, Utah.

Month	1970		1971		1972	
	mm	in	mm	in	mm	in
May	187.00	7.48	164.25	6.57	221.75	8.87
June	206.00	8.24	229.00	9.16	225.25	9.01
July	232.25	9.29	272.00	10.88	293.00	11.72
August	220.50	8.82	226.50	9.06	218.25	8.73
September	115.00	6.20	171.00	6.84	151.00	6.04
October	86.75	3.47	ND	ND	ND	ND
Total	1,047.50	43.50	1,062.75°°	42.51°°	1,109.25°°	44.37°°

° Measured from standard 4-ft (120-cm) diameter evaporating pan
°° 5-month total only
ND = Not determined

Table 13. Total monthly wind movement° at Utah Lake station, Lehi, Utah.

Month	1970		1971		1972	
	km	miles	km	miles	km	miles
May	3,563	2,227	2,990	1,869	3,373	2,108
June	2,941	1,838	2,850	1,781	2,963	1,852
July	2,626	1,641	2,397	1,498	2,624	1,640
August	2,045	1,278	2,338	1,461	1,877	1,173
September	3,402	2,126	3,438	2,149	2,547	1,592
October	2,632	1,645	3,291	2,057	2,566	1,604
Total	17,209	10,755	17,304	10,815	15,950	9,969

° Measured with standard wind-totalizing anemometer located 6 inches (15 cm) above standard 4-ft (120-cm) diameter evaporating pan

Table 14. Average monthly soil temperatures° at Salt Lake City, Utah.

Month	1970		1971		1972	
	°C	°F	°C	°F	°C	°F
January	1.3	34.4	1.6	34.8	0.0	32.0
February	3.0	37.4	2.4	36.3	1.7	35.1
March	5.1	41.1	4.2	39.6	8.3	46.9
April	7.2	44.9	9.6	49.3	9.3	48.7
May	13.4	56.2	13.4	56.1	16.1	61.0
June	18.4	65.2	19.4	66.9	22.5	72.5
July	21.9	71.4	26.4	79.6	26.5	79.7
August	23.3	74.0	26.3	79.4	26.3	79.3
September	16.3	61.3	17.9	64.2	19.6	67.2
October	10.3	50.5	9.6	49.3	13.2	55.8
November	5.7	42.2	3.1	37.5	4.8	40.6
December	2.2	36.0	–0.5	31.1	1.1	33.9
Yearly Mean	10.7	51.2	11.2	52.1	12.4	54.4
Yearly Maximum	27.8	82.0	33.9	93.0	30.0	86.0
Yearly Minimum	–1.7	29.0	–2.8	27.0	–1.7	29.0

° Recorded 10 cm deep in barren, level, sandy-loam soil

tral Utah and which are picked up by animals grazing on pasture, reportedly require a minimum monthly average of 50 mm precipitation (Levine, 1963) in order for the free-living stages to develop and survive. Thus, it appears that irrigation is the factor which supplies the additional moisture needed to create optimum microenvironments for these parasites.

The total snowfall for each of the three years of this study was 1165.9, 1877.1 and 909.3 mm (Tables 1, 4, 7), and the percentage of total moisture received as snow during those years was 23.7, 25.8, and 23.3 percent for 1970, 1971, and 1972, respectively. The number of days with at least 25 mm of snow cover on the ground was 38, 62, and 39 days, respectively. Snowfall during winter months is important to this geographic area as the major source of water to be used in irrigation during the following summer season. The impact of snowfall on biological organisms in microenvironments comes about through the moderating effect it has on temperature extremes. This effect can be readily seen by examining Fig. 52 and 53, which depict temperature fluctuations at soil surface with and without snow cover. For those parasitic organisms with free-living stages outside their normal hosts, this moderation may be an important factor in their extended winter survival. Andersen, Levine, and Boatman (1970) showed that free-living infective larvae of certain nematodes parasitic in sheep could survive twice as long when placed on plots during winter months than during the warmer periods of the year, which fact may have been due in part to the moderating effect of snow cover. The impact of snow cover on temperature at ground level under snow cover compared to that in a standard weather shelter was also demonstrated by Andersen and Levine (1967) who recorded a range during one day in January 1965, at Urbana, Illinois, of 0 and –2.2°C under 10 cm snow cover compared to –6.1 and –17.8°C in a standard weather shelter. In the study herein reported, we found that the temperature on 4 January 1971 at soil surface under 22 cm of snow (Fig. 52) varied only from –3 to –4°C (mean of –3.5°C), whereas that in the weather shelter at the same location ranged from –7.8 to –25.6°C (mean of –16.7°C). Three weeks later on 25 January 1971, with no snow cover (Fig. 53), the temperature at soil surface on bare ground varied from 15 to –3°C (mean of 6°C), whereas that in the weather shelter ranged from 12.2 to 0.0°C (mean of 6.1°C).

The extremes in relative humidity measured in the weather shelter fluctuated markedly throughout the year in the present study, but the daily maximum recorded was generally high even during warm summer periods. The average maximum and minimum humidity percentages recorded for the three years were 97 and 43 percent, 97 and 46 percent, and 97 and 46 percent, respectively (Tables 1, 4, and 7). Percentages less than 98 to 100 percent were recorded only 18 days during each of the three years. In a comparable study of meteorologic measurements on pasture lands at Urbana, Illinois, Andersen, Levine, and Boatman (1970) recorded average daily maximum and minimum relative humidities of 96 and 56 percent for 1965 and 94 and 60 percent for 1966.

Whereas in our current study we measured relative humidity only over the irrigated plot, deVries and Birch (1961) compared relative humidity in a Stevenson screen (approximately 150 cm above soil surface) located over weather stations in three irrigated pastures in Australia with that measured over a dry lot area approximately 6 km away. By rotating hygrothermographs at 4 to 6 week intervals over a two-year study in order to eliminate systematic errors, they found that relative humidities were 5 to 10 percent higher in summer in the irrigated fields than in the non-irrigated region. The evaporation of moisture and increased transpiration from the higher vegetation in the irrigated stations undoubtedly contributed to this elevated reading and would naturally hold for any geographical region where such comparison could be made. Since our non-irrigated plot was confined within the irrigated section of the weather station, we were unable to make such a measurement. A comparison of relative humidities recorded within Stevenson screens on adjacent wet and dry plots would be meaningless as an adequate reflection of environmental influences emanating from the surface atmosphere, since as Halstead (1958) stated, meteorologic conditions may differ more from the instrument shelter to the ground below than might exist between weather stations located 100 miles apart.

Since the evaporimeter we used could not be read during freezing weather, data are given only for the pasture period of May through October. The totals and the daily averages of those periods for the three years were: 983.8 and 5.3 mm, 1030.7 and 5.6 mm, and 1274.2 and 6.9 mm, respectively (Tables 1, 4, and 7). Potential evaporation was generally highest during the months of July and August, except in 1971 when the greatest amount was recorded in June. Information on actual evaporation is preferred to that of potential evaporation, but as Holmes and Watson (1967) pointed out, the measurement of actual evaporation is one of the most difficult of all water budget components to obtain. Formulae are available for calculation of potential evapotranspiration—evaporation and transpiration—(Hamon, 1961) for indications of the overall water balance at specific locations, but they are not used herein, since our project dealt with basic actual measurements only. Levine (1963), however, pointed out that one should carefully differentiate between actual and potential evapotranspiration. The actual evapotranspiration amount would be low indeed over arid desert soils, but the potential there would be extremely high. This would be realized under conditions of irrigation such as occurred in our study. Burman and Louden (1968) showed that potential evapotranspiration was 20 percent greater for irrigated ryegrass-alfalfa pastures in Wyoming highlands than that for wheatgrass-alfalfa pastures but did not propose an explanation for this.

Potential evaporation recorded from our station compared to that at the Utah Lake Station near Lehi, Utah (Table 12), was 983.8 and 1047.5 mm, respectively, for May through October 1970; 971.7 and 1,062.75 mm for May through September 1971; and 1217.8 and 1,109.25 mm for May through September 1972. These comparisons suggest that the measured potential evaporation is similar throughout Utah Valley. However, since the wind totals for those periods at the Utah Lake Station (Table 13) were nearly twice that measured at our station, one would expect correspondingly higher potential evaporation measurements instead of such comparable levels as recorded. A partial explanation of this apparent discrepancy might relate to the fact that we used a recording instrument with an 18-cm-diameter evaporating pan, whereas the Utah Lake Station used a standard non-recording 120-cm-diameter evaporating pan. A reliable comparison between stations is further complicated in that the water level in our instrument was routinely within 1 cm of the surface of the pan, whereas it is not infrequent for water levels in large standard non-recording evaporimeters to be 10 to 15 cm below the surface. Such a difference would influence greatly the effect of wind movements upon the resultant evaporation recorded.

Daily cloud cover was only rated visually each morning and thus was the most subjective of all data taken during this study. Nevertheless, this showed a general pattern of approximately 40 to 60 percent average daily cover during the early and later parts of each year and 10 to 30 percent during the pasture season (Tables 1, 4, and 7). These data were accumulated in order to approximate the degree to which cloud cover might affect conditions at microenvironments, and in turn affect such factors as temperature and evaporation at that site. The amount of solar energy reaching the soil surface would naturally be the same on either irrigated or non-irrigated plots, providing the amount and type of vegetation were similar. Since vegetation is consistently less on non-irrigated pastures in such a region as central Utah, and since vegetation moderates the microclimate by providing a barrier between the soil and immediate atmosphere above (Caborn, 1973), one would generally expect warmer microenvironments on non-irrigated plots than on irrigated ones. The amount of solar energy available to warm the soil would depend further on such factors as the reflective properties of the soil (albedo), soil moisture, and the amount of water leaving the soil upward through evapotranspiration. Andersen, Levine, and Boatman (1970) measured solar radiation during June through November with a recording pyrheliometer over pasture lands at Urbana, Illinois, in 1965 and 1966 and noted this decreased gradually in the fall, naturally coincident with the decrease in daily sunlight hours. The average daily gram calories per cm^2 measured at their station for 1965 and 1966 were highest in July for both years (848 and 542) and lowest in November (385 and 188) for all months during the periods indicated. To our knowledge, comparable field data are not available for other sites near central Utah. The immediate effect of cloud cover upon temperatures can readily be seen by examining Fig. 51 herein. With the exception of the impact of .3 mm precipitation on Thursday of that week indicated, all other jagged lines in the temperature curves are attributed mainly to changes in cloud cover. While this effect is most marked in the temperatures recorded at soil surface on bare ground, the decrease in temperature during heavy cloud cover is detectable on the recordings at soil surface under grass cover as well.

Soil moisture measurements were taken weekly during May through October of each year. The yearly averages of soil moisture content on a dry-weight basis for those months for the irrigated and non-irrigated plots respectively were 16.1 and 8.4 percent for 1970, 16.3 and 5.8 percent for 1971, and 8.1 and 3.8 percent for 1972 (Tables 1, 4, and 7). In general, the percent soil moisture varied in accordance with times of irrigation or rainy periods (Fig. 12, 13, and 14), with the difference between irrigated and non-irrigated plots most apparent during 1970 and 1971. During 1972, road and ditch construction adjacent to the weather station prevented irrigation of the pasture until mid-June, at which time the moisture level on the irrigated plot climbed to 15.0 percent from the preceding week's measurement of 1.4 percent. Irrigation continued sporadically after that time, and differences in soil moisture content between the two plots were not marked during August and September. Both levels then climbed simultaneously in October, when a total of 119.6 mm of rain was recorded.

The results obtained from our soil moisture measurements appeared more erratic during the three years than anticipated. This may have been due in part to our small soil sample size and to the non-homogeneity of the soil. We routinely collected only 20 to 30 g of soil, whereas Israelson et al. (1944) used 200 g samples from the 11 farms they studied in Utah County. Obviously, samples of that size cannot be removed repeatedly from small plots such as we had available.

Of interest was the fact that the soil moisture showed an immediate decline within one to two days after each irrigation. This is undoubtedly due to evapotranspiration from the short grass cover on pasture lands as well as good soil permeability. Leonard et al. (1971) found that irrigation of soils once every 15 days under a red-pine forest in New York kept the soil moisture level near that measured shortly after snow melt in the spring. Crops grown on soils characteristic of Utah County, however, are commonly irrigated every 8 to 10 days maximum.

Andersen, Levine, and Boatman (1970) found that the actual soil moisture 2.5 cm below soil surface on pasture grasses at Illinois did not reach the permanent wilting point during 1965, when 1,069.9 mm of precipitation, somewhat evenly distributed throughout the year, were recorded; but that soil moisture did reach that level 27 consecutive days during 1966 when a total of 944.5 mm was recorded. During the second year, however, a five-week period in August and September received only a total of 12.2 mm rain at which time the moisture deficit occurred. Thus, we see that the distribution of precipitation during summer months is more influential in determining the microenvironmental conditions than is the total amount accumulated during any one month. In our study, the longest period of time without measureable precipitation during the summer months was 22 days during June and July in 1970, 35 days during June and July in 1971, and 23 days during May and June in 1972. Irrigation, if done routinely on well-managed pastures, compensates for these longer dry spells in arid regions such as central Utah and will effectively keep the soil moisture above levels detrimental to vegetative cover during the summer season.

Wind patterns measured at 1 m above the ground during the year were very erratic but usually totaled between 1,000 and 2,500 km per month over the three-year study period. The totals and the daily averages for each year were 19,315 and 52 km, 22,691 and 61 km, and 22,255 and 60 km, respectively (Tables 1, 4, and 7). The highest monthly total of 2,756 km was recorded during April 1972 and the lowest monthly total of 1,183 km during November 1972. Total wind movements during May through October for our station compared to that at Utah Lake Station near Lehi, Utah (Table 13), were 9,737 and 17,209 km for 1970, 11,604 and 17,304 km for 1971, and 10,716 and 15,950 km for 1972. Since the anemometer at the Utah Lake station was only one-half the approximate height above ground level as was ours, one would expect an even greater difference in wind totals had both measurements been recorded at the same level. The reduced wind at our station, situated on the east bench of Utah Valley near the mountains, is undoubtedly due to topological features and the location of numerous buildings nearby. As discussed above, since the Utah Lake station had considerably more wind than was measured at our plots, one would expect correspondingly more potential evaporation at that site. The fact that this did not occur, however, is probably explained in part by the two dissimilar gauges used.

Andersen, Levine, and Boatman (1970) found that total wind movement at soil surface on pasture lands was only 14 percent of that measured 1 m above ground at the same location. The impact of this phenomenon on pasture microenvironments would be that of reduced evaporation therefrom compared to that actually measured by standard evaporation pans located above the microclimatic zone of the pasture vegetation.

DeVries and Birch (1961) found that wind velocities at 2 m were generally greater at stations located in irrigated pastures in Australia than on a non-irrigated plot 6 km distant from irrigated lands, but they felt that the difference was due largely to different topography in the two areas and to the roughness of the irrigated pastures. They pointed out that the effect of irrigated lands on meteorologic conditions of adjacent drylands would become negligible at a distance equal to the length covered by the wind over the irrigated area.

Temperature extremes measured in the standard weather shelter showed that the annual averages for the monthly maximum, minimum, and mean temperatures were 16.5, 1.9, and 9.2°C; 16.3, 1.3, and 8.8°C; and 17.3, 1.5, and 9.4°C for the three years, respectively (Tables 2, 5, and 8). The average monthly means agreed very closely with the corresponding figures of 9.6, 9.1, and 10.0°C recorded for the same years at the official KOVO weather station (Table 11).

As discussed above, data from weather shelters are a poor indication of conditions at or near soil surface level; however, such data do offer the advantage of having been taken under similar physical conditions as prescribed by the U.S. Weather Bureau. Presumably geographical areas with similar macroclimates would have similar microclimates if measured under comparable vegetative cover, topography, soil texture, and soil moisture. Slight differences in temperatures measured with the maximum and minimum thermometers within the weather shelter in this project compared to those recorded with the hygrothermograph located at the same site can be explained in part by the difference in time lag before response of the different instruments. Mercury- or alcohol-filled thermometers have a time lag of approximately 3 minutes, whereas hygrothermographs require up to 30 minutes (Landsberg, 1941). Because of this, temperature trends recorded by the hygrothermograph would tend to level out sooner and would generally yield lower maximum and higher minimum temperatures.

Considerably more pertinent to the present study is the comparison of temperatures recorded at or near the soil surface on the irrigated part of the station with those on the non-irrigated plot. Since all leads for the 3-lead distance thermographs were not positioned until April 1970, comparative annual statistics for that year cannot be given. For 1971, the yearly averages for maximum, minimum, and mean temperatures recorded 5 cm beneath soil surface under grass cover were 11.3, 5.4, and 8.4°C in irrigated plots and 12.1, 5.9, and 9.0°C in non-irrigated plots (Table 5). Comparable figures for 1972 were 11.4, 5.0, and 8.2°C and 13.9, 6.8, and 10.4°C, respectively (Table 8). The yearly averages for maximum, minimum, and mean temperatures recorded at soil surface under grass cover were 13.8, 5.6, and 9.7°C in irrigated plots and 16.5, 4.6, and 10.6°C in non-irrigated plots for 1971 (Table 6). Comparable figures for 1972 were 15.8, 5.9, and 10.9°C and 20.7, 4.9, and 12.8°C, respectively (Table 9). The yearly averages for maximum, minimum, and mean temperatures recorded at soil surface on bare ground were 24.6, 1.2, and 12.9°C in irrigated plots and 31.8, 1.2, and 16.5°C in non-irrigated plots for 1971 (Table 6). Comparable figures for 1972 were 30.0, –0.2, and 14.9°C and 32.8, –2.7, and 15.0°C, respectively (Table 9). The annual maximum and annual minimum extremes for those years for each site where temperatures were measured were: weather shelter: 36.1 and –25.6°C for 1971 and 36.7 and –25.6°C for 1972; 5 cm beneath soil surface under grass cover: 29.0 and –4.0 (1971) and 28.0 and –7.0°C (1972) for the irrigated plot and 30.0 and –5.0 (1971) and 37.0 and –6.0°C (1972) for the non-irrigated plot; at soil surface under grass cover: 34.0 and –4.0 (1971) and 41.0 and –6.0°C (1972) for the irrigated plot and 43.0 and –6.0 (1971) and 54.0 and –8.0°C (1972) for the non-irrigated plot; and at soil surface on bare ground: 62.0 and –11.0 (1971) and 63.0 and –15.0°C (1972) for the irrigated plot and 72.0 and –12.0 (1971) and 68.0 and –16.0°C (1972) for the non-irrigated plot.

In the study at Illinois, where comparable measurements on pasture lands were taken during 1966 (Andersen, Levine, and Boatman, 1970), the annual maximum, annual minimum, and average monthly mean for temperatures recorded in the weather shelter were 35.6, –24.4, and 8.0°C, respectively; beneath soil surface under 10 cm grass cover: 36.0, –10.0, and 12.9°C; at soil surface under 10 cm grass cover: 46.0, –10.0, and 14.1°C; and at soil surface on bare ground: 64.0, –21.5, and 15.3°C. From this comparison, it is evident that the annual extremes and yearly means are similar at both geographical locations, especially if temperatures recorded from the non-irrigated plot are compared with those on the pasture plot at Illinois with no irrigation. The difference in the yearly means for each site monitored for the last year reported for each project (1966 for Illinois and 1972 for Utah) were: 1.4°C in the weather shelter, 2.5°C at 5 cm beneath soil surface under grass cover, 1.3°C at soil surface under grass cover, and 0.3°C at soil surface on bare ground.

The only temperatures routinely measured at or near soil surface in Utah of which we are aware are those recorded 10 cm beneath barren soil at Salt Lake City (Climatological Data, Utah, 1970, 1971, 1972). The annual maximum, annual minimum, and average mean at that site for 1970 were 27.8, –1.7, and 10.7°C, respectively; 33.9, –2.8, and 11.2°C for 1971; and 30.0, –1.7, and 12.4°C for 1972 (Table 14). Average annual means at that station compared to the average annual mean of the temperature 5 cm beneath soil surface under grass cover at our non-irrigated plot for the two years, where comparisons could be made, thus differed by 2.2°C for 1971 and 2.0°C for 1972. If compared, however, to means tabulated from measurements made at soil surface under grass cover, the difference was only 0.6°C for 1971 and 0.4°C for 1972.

DeVries and Birch (1961) noted that temperatures 5 cm beneath the surface in irrigated stations in Australia were approximately 10°C cooler in summer than at their non-irrigated plot. They attributed this partly to the cooling effect of evaporation and partly to the shading from the more dense vegetation on the irrigated stations. Watts (1973) noted that temperatures 5 cm beneath soil surface on bare ground in England reached a maximum earlier in the day and then decreased more quickly at night than did those temperatures measured at comparable depths under black polythene or glass cover. Also, the bare ground had to be irrigated six times as often as the covered plots. Of particular interest was the fact that he was able to closely correlate growth measurements in plant cover with mean daily temperatures at 5 cm depth. This suggests that this level would be a good one to monitor for all meteorologic projects directly or indirectly related to research on plant or animal productivity.

Leonard et al. (1971) noted that the impact of irrigation on soil temperatures was influenced considerably by the temperature of the irrigating water. In their study in New York with pine forest cover, temperatures of irrigation water ranging from 0 to 5.5°C above that of the soil surface brought about a subsequent corresponding increase in the soil temperatures. In our study, the temperature of the irrigation water was invariably lower than that of the soil surface. The reflection of this finding upon the soil temperature profile can readily be seen in Fig. 51, which shows a gradual drop of about 5°C in the temperature recorded 5 cm beneath soil surface under grass cover, an immediate drop of about 10°C in the temperature at soil surface under grass cover, and a corresponding decrease of about 30°C at soil surface on bare ground.

When the temperature data for this project are examined on a daily basis (Fig. 33-51), the effect of irrigation on these temperatures can readily be seen. Almost without exception, the maximum daily temperatures on the irrigated plots during the pasture season were cooler than on the non-irrigated plots. This difference was least demonstrable with the measurements taken 5 cm beneath soil surface under grass cover (Fig. 33, 34, and 35), next most noticeable on the soil surface measurements under grass cover (Figs. 39, 40, and 41) and most noticeable with the recording of the maximum levels on the bare soil surface plot (Fig. 45, 46, and 47). The difference in minimum daily temperatures was not nearly so obvious, however, as noted from the same figures referred to above. Because of these similarities in minimum temperatures, the compared means of the daily temperatures on the irrigated and non-irrigated plots for each of the three sites and for each of the three years (Fig. 36, 42, and 48 for 1970; Fig. 37, 43, and 49 for 1971; and Fig. 38, 44, and 50 for 1972) are nearly the same. Although mean comparisons may be helpful for general conclusions, the fact that they automatically eliminate extremes and ranges makes them difficult to interpret or use meaningfully. They are included herein only to show how similar these means were on the irrigated compared to the non-irrigated plot. Compared means of the three different sites or compared means for the three different years were not graphed, although the monthly averages of these data can be found in the annual summaries.

Even though daily observations were made on the presence or absence of dew or frost each morning in the present study, such measurements were somewhat subjective, especially during summer rainy periods or when snow covered the ground in the winter. Because of these facts, and since observations were made only for the irrigated section of the station, the data are neither graphed nor recorded herein. However, the mornings with detectable dew or frost are noted on the daily computer printouts which are available if desired. Under most circumstances dew was present on the pasture grass whenever the temperature at soil surface under grass cover was above freezing and when the relative humidity measured in the weather shelter reached 98 to 100 percent during the night. Frost naturally occurred with temperatures in the microclimate below freezing and when relative humidity was at maximum.

Andersen, Levine, and Boatman (1970) found that moisture from dew remained on pasture grass in Illinois for a daily average of 5.1 to 11.8 hours for months between May and October, when such measurements were recorded in their study. Daily totals were high even during warm summer days with relatively infrequent precipitation.

Even though the presence of dew on the pasture grasses would be an additional source of moisture for all biological organisms in that microenvironment, such moisture alone cannot prevent the ultimate drying of the vegetation later on during the day. Thus, as Andersen, Levine, and Boatman (1970) pointed out, the alternate hydration and dehydration of such organisms as nematode larvae may be more detrimental to their survival in microhabitats than that of continual desiccation. Additional studies are needed on the impact of moisture deficits upon biological organisms in microenvironments.

CONCLUSIONS

Meteorologic measurements obtained during the three-year study showed a marked impact of irrigation on the moisture and temperature profiles of experimental pasture plots. Irrigation not only lowers the soil temperature (due to evaporation and to the fact that the irrigating water used was invariably cooler than the soil on the plots) but also cools the air immediately above the soil surface. It also brings about a more dense vegetative cover with a resultant increase of shade, thereby contributing to increased evaporation and transpiration (evapotranspiration) from the additional surface area of the cover.

The overall moisture balance in the microclimate is thus dependent upon the accumulated precipitation and irrigation, contrasted with that lost to the macroclimate through evapotranspiration. This loss is influenced by the combined effects of the type and amount of vegetative cover, wind movements within or immediately above the grass, moisture content of the air, and the temperature at or near the soil surface zone. The temperature of the microclimate is dependent upon the solar energy reaching the surface, the albedo or reflective power of the soil and vegetative cover, the soil texture, and amount of soil moisture. It is therefore evident that irrigation influences directly or indirectly nearly all factors in the pasture microclimate. These interact in a complex manner to bring about favorable environments for increased plant productivity and optimum conditions for development and survival of biological organisms which inhabit that zone.

Irrigation was extremely sporadic in our study, but, as mentioned above, the timing of this was not under our control. A much better method would have been to use sprinkling irrigation, so that not only the timing but also the amount of water added could have been controlled. At the time the project was started, however, only flood irrigation was available and was therefore used throughout the study. Nevertheless, flood irrigation is considerably more common than sprinkling in this area, and irrigation intervals under natural conditions are also frequently sporadic.

Additional conclusions of this study relate to each of the meteorologic measurements taken. The precipitation patterns differed markedly during each year, which is typical of any semiarid region, but nevertheless showed the general dryness associated with the pasture season in Utah. The fact that the long-term averages of precipitation for Provo (Table 10) are less than 25 mm of rainfall during June, July, August, and September illustrates the necessity for irrigation of all cultivated croplands in this area. Other forms of precipitation, such as snow or dew, also have an impact upon the pasture microenvironment; but with respect to plant productivity or creation of optimum environments for living organisms, they are not nearly as important as rain or irrigation of cultivated croplands or pastures in Utah. Snow cover moderates temperatures considerably at ground level in the winter, and dew adds additional moisture during the pasture season which could provide the film of water necessary for vertical migratory movements on the vegetation by such organisms as nematode larvae. Even though dew may represent a helpful addition of moisture during the pasture season for increased plant productivity, its impact on living organisms in the microclimatic zone is not clear, since alternating hydration and dehydration of organisms in that environment have been shown to be more detrimental to development of organisms in that microhabitat than that of sustained desiccation. Additional research is needed on the effect of moisture deficits on organisms inhabiting pasture microenvironments.

Relative humidity measurements were generally near maximum at least once during each 24-hour period even in warm weather and periods of infrequent rains. Since the small non-irrigated plot was established in the center of the irrigated part of the station, no measurements of relative humidity over non-irrigated areas were obtained. Such comparison would only be possible if measurements could be taken from large fields, and then one would have difficulty locating two separate areas with similar topography, yet far enough removed where wind movements would not influence the readings. Also, no measurements were obtained on relative humidity from the pasture microclimate per se, since, to our knowledge, the only devices capable of measuring relative humidity from such an environment cannot withstand saturation and thus cannot be used in extended field trials such as this one.

Potential evaporation was recorded only from the irrigated part of our station, since, as discussed above, the non-irrigated plot was within the irrigated area and was too small to permit a valid measurement from that section only. The level naturally inclined during the early part of the pasture season, reached its peak during the warmest months, and declined gradually thereafter. Temperature and wind were the most influential factors on this measurement. Burying the recording part of the evaporimeter into the ground so that the top of the evaporating pan would be level with the top of the grass cover would yield a measurement of potential evaporation more indicative of that occurring in the microenvironment. Such an arrangement could be used with sprinkling, but with the irrigation system we had available, the instrument would likely have been flooded each time irrigation occurred.

The percent of cloud cover each morning was undoubtedly the most subjective of all data collected but nevertheless indicated trends during the year. The main drawback of this procedure was that it did not reflect subsequent changes during the day. Even though a rough indication of daily cloud cover was noticeable on the temperature curve recorded for one week on bare ground (Fig. 51), all other daily tracings of that measurement are not available to the reader. A recording pyrheliometer would be advisable for such studies in the future.

Soil moisture samples gave extremely erratic results, probably relating in part to the small sample size taken. However, the compared moisture percentages on the irrigated and non-irrigated plots gave a good indication of the importance of irrigation to this geographical region. Gravimetric measurements for determination of soil moisture are inferior to those available with more costly equipment but nevertheless give a simplified indication of the moisture present. Larger or duplicate samples would have helped considerably, as would have conversion to volumetric water content values to help smooth out soil non-homogeneity.

Wind measurements were recorded only at 1 m height and gave only a general indication of air movements in grass. We were unable to follow the method used by Andersen, Levine, and Boatman (1970) with an anemometer placed at soil surface level as well, since with flood irrigation the totalizing mechanism of the anemometer would have been flooded each time irrigation occurred. Such a measurement could be included, however, with a comparable project done with sprinkling irrigation.

Temperatures recorded in the present project were the most complete of all measurements included herein. Weather shelter temperatures were included only for comparison of the macroclimate with the pasture microclimate and for standardization of this project with such temperatures recorded in other geographical areas. Since temperatures in weather shelters are taken in a consistent manner as described by the U.S. Weather Bureau, measurements taken of macro- and microclimates at one site should provide a fairly accurate indication of the microclimate at a second comparable macroclimatic site, providing similar conditions of soil and vegetative cover existed. The average monthly maximum temperatures recorded in the weather shelter were generally higher and the average monthly minimum temperatures generally lower than those recorded on the irrigated plot 5 cm beneath soil surface or at soil surface under grass cover. However, the grand means of the monthly means for those measurements were quite comparable. Measurements on bare irrigated ground showed greater temperature extremes than those under grass cover or those recorded from the weather shelter. Also, those temperatures recorded on non-irrigated plots on bare ground showed extremes greater than those on irrigated plots. This was due in part to the fact that dry bare soil on non-irrigated surfaces loses more heat by outgoing radiation at night than those where the soil is darker due to the additional moisture from irrigation. Moist soils also have a higher heat capacity. Temperatures recorded 5 cm under grass cover were dampened in all effects and were influenced least by those factors which contribute to the overall heat and moisture balance of the pasture microenvironment.

The computer programs designed for this project proved to be very helpful in assembling and tabulating all data collected. Work is now in progress to develop additional programs for computerized construction and plotting of graphs of all daily observations after they are once columnized and keypunched on IBM cards. The successful completion of such programs will greatly facilitate the complete assimilation of all meteorologic data measured in future years.

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LITERATURE CITED

Andersen, F. L., and N. D. Levine. 1967. Methods and problems in microenvironmental measurements. Illinois Vet., 10:10-17.

Andersen, F.L., N. D. Levine, and P. A. Boatman. 1970. Survival of third-stage *Trichostrongylus colubriformis* larvae on pasture. J. Parasit., 56:209-232.

Burman, R. D., and T. L. Loudon. 1968. Evapotranspiration and microclimate of irrigated pastures and alfalfa under high altitude conditions. Transactions of the ASAE. pp. 123-128.

Caborn, J. M. 1973. Microclimates. Endeavor, 32:30-33.

Center for Disease Control, Malaria Surveillance. 1970 Annual Report, 1971. U.S. Department of Health, Education, and Welfare, Atlanta, Georgia. 25p.

Center for Disease Control, Neurotropic Viral Diseases Surveillance. 1970 Annual Report, 1972. U.S. Department of Health, Education, and Welfare, Atlanta, Georgia. 26p.

Climatological Data, Utah Annual Summaries. vol. 72 (no. 13), 1970; vol. 73 (no. 13), 1971; and vol. 74 (no. 13), 1972.

Crofton, H. D. 1963. Nematode parasite population in sheep and in pasture. Technical Communication no. 35. Commonwealth Agricultural Bureau, Farnham Royal, Bucks, England. 104p.

DeVries, D. A., and J. W. Birch. 1961. The modification of climate near the ground by irrigation for pastures on the Riverine Plain. Aus. J. of Agr. Res. 12:260-272.

Fox, J. C., F. L. Andersen, and K. H. Hoopes. 1970. A survey of the helminth parasites of cattle and sheep in Utah Valley. The Great Basin Nat., 30: 131-145.

Furman, D. P. 1944. Effects of environment upon the free-living stages of *Ostertagia circumcincta* (Stadelmann) Trichostrongylidae: II. Field Experiments. Am. J. Vet. Res., 5:147-153.

Gibson, T. E. 1973. Recent advances in the epidemiology and control of parasitic gastroenteritis in sheep. Vet. Rec., 92:469-473.

Halstead, M. A. 1958. Panel discussion, whither weather, climate and agriculture. Proc. 6th Ann. Counc. Publ. 576, (1958):60-75.

Hamon, W. R. 1961. Estimating potential evapotranspiration. Proc. Am. Soc. Civil Engrs., J. Hydraulics Div., 87, HY3:Pt. 1, pp. 107-120.

Holmes, J. W., and C. L. Watson. 1967. The water budget of irrigated pasture land near Murray Bridge, South Australia. Agr. Meteor., 4:177-188.

Holmes, R. M., and A. N. Dingle. 1965. The relationship between the macro- and microclimate. Agr. Meteor., 2:127-133.

Honess, R. F., and R. C. Bergstrom. 1966. Trichostrongylosis of cattle in Wyoming. Science Monograph 2. Agr. Ex. Sta., Univ. of Wyoming, Laramie, Wyoming.

Israelsen, O. W., and V. E. Hansen. 1967. Irrigation principles and practices. John Wiley and Sons., Inc., New York. 447 p.

Israelsen, O. W., W. D. Criddle, D. K. Fuhriman, and V. E. Hansen. 1944. Water-application efficiencies in irrigation. Agr. Exp. Sta., Utah State Agr. Coll., Logan, Utah. Bulletin 311, 55 p.

Kates, K. C. 1965. Ecological aspects of helminth transmission in domesticated animals. Am. Zool., 5:95-130.

Landsberg, H. 1941. Physical climatology. Gray Printing Company, Inc. Dubois, Pa. 283 p.

Leonard, R. E., A. L. Leaf, J. V. Berglund, and P. J. Craul. 1971. Annual soil moisture-temperature patterns as influenced by irrigation. Soil Science, 3:220-227.

Levine, N. D. 1963. Weather, climate, and the bionomics of ruminant nematode larvae. Adv. in Vet. Sci., 8:215-561.

Levine, N. D., and F. L. Andersen. 1973. Development and survival of *Trichostrongylus colubriformis* on pasture. J. Parasit. 59:147-165.

McIntosh, D. H., and A. S. Thom. 1969. Essentials of meteorology. Wykeham Publications (London) LTD. London and Winchester. 239 p.

Rainey, M. B., and A. D. Hess. 1967. Public health problems related to irrigation, pp. 1070-1081. In R. M. Hagan, H. R. Haise, and T. W. Edminster (eds.) Irrigation of agricultural lands. American Society of Agronomy, Madison, Wisconsin.

Reeves, W. C., and W. McD. Hammon. 1962. Epidemiology of the arthropod-borne encephalides in Kern County, California, 1943-1952. Univ. Calif. Publ. Hlth. vol. 4.

Soil Conservation Service, Utah. Central Utah County Soil Survey, 1972. 161 p.

Soil Survey of Utah County, Utah. 1972. United States Department of Agriculture, U.S. Government Printing Office, Washington, D.C. 161p.

Surtees, G. 1970. Large-scale irrigation and arbovirus epidemiology, Kano Plain, Kenya. I. Description of the area and preliminary studies on the mosquitoes. J. Med. Ent. 7:509-517.

Sutton, G. 1964. Micrometeorology. Sci. Amer., 208: 62-76, 142.

Utah Agricultural Statistics. 1972. Utah State Department of Agriculture, Salt Lake City, Utah. 129 p.

Watts, W. R. 1973. Soil temperature and leaf expansion in *Zea mays*. Expl. Agric., 9:1-8.

Whitman, W. C., and G. Wolters. 1965. Microclimatic gradients in mixed grass prairie, pp. 165-185. In R. H. Shaw (ed.), Ground level climatology. AAAS, Washington, D.C.

Williams, J. C., and F. R. Bilkovich. 1971. Development and survival of infective larvae of the cattle nematode, *Ostertagia ostertagi*. J. Parasit., 57:327-338.

Williams, J. C., and R. L. Mayhew. 1967. Survival of infective larvae of the cattle nematodes, *Cooperia punctata, Trichostrongylus axei*, and *Oesophagostomum radiatum*. Am. J. Vet. Res., 28:629-640.

World Health Organization. 1950. Joint study group on bilharziasis in Africa. Rep. 1st. Sess. Tech. Rep. 17:16.

Wright, P. D., and F. L. Andersen. 1972. Parasitic helminths of sheep and cattle in Central Utah. J. Parasit., 58:959.