1974

Effect of Soil Water Potential on Soil Moisture Absorption, Transpiration Rate, Plant Water Potential, and Growth of Artemisia Tridentata

Gaylon S. Campbell

Grant A. Harris

1973 PROGRESS REPORT

EFFECT OF SOIL WATER POTENTIAL ON SOIL MOISTURE ABSORPTION, TRANSPIRATION RATE, PLANT WATER POTENTIAL, AND GROWTH OF *ARTEMISIA TRIDENTATA*

Gaylon S. Campbell, Project Leader
and Grant A. Harris
Washington State University

US/IBP DESERT BIOME
RESEARCH MEMORANDUM 74-44

Reprint from Reports of 1973 Progress, Volume 3: Process Studies
Abiotic Section, pp. 7-14

1973 Proposal No. 2.3.5.3.

MAY, 1974

Citation format: Author(s). 1974. Title.
US/IBP Desert Biome Res. Memo. 74-44. 8 pp.

Ecology Center, Utah State University, Logan, Utah 84322

ABSTRACT

This study was undertaken to relate leaf water potential, stomatal diffusion resistance, and evapotranspiration of *Artemisia tridentata* to soil water potential. Relevant soil, plant and atmospheric measurements were made at two sites in eastern Washington to obtain data. Some measurements were also made at the Curlew Valley site in Utah to compare with the Washington data. Measurements were made from April through October. Climatic data obtained at one site included solar radiation, precipitation, wind run, vapor pressure, maximum and minimum temperature, and soil temperatures at five depths. Soil water content was measured with a neutron probe. The data so obtained were used to determine evapotranspiration rate throughout the season. Evapotranspiration reached 2 mm/day early in the season, then decreased to 0.5 mm/day or less by around the first of July. Leaf water potentials at midday were around -15 bars in April and early May with osmotic potentials around -20 bars. By about mid-June, leaf osmotic and water potentials began to decrease markedly, reaching -40 to -50 bars in August. Midday turgor pressures during this time were essentially zero. Stomatal diffusion resistance was measured using a new steady state technique. Diffusion resistances around 2 sec/cm were common during April. As water potential decreased, diffusion resistance increased, and midday resistances of 40 sec/cm and higher were reached by August.

INTRODUCTION

This study was undertaken to relate plant water potential, stomatal diffusion resistance and evapotranspiration to soil water potential for *Artemisia tridentata.* Production data have not been taken, as originally planned, because it is a time-consuming operation, and intensive production sampling is underway at other Desert Biome sites. Water relations modelling is being pursued somewhat more intensively than was outlined in the original proposal, partly because of availability of improved measurement and analysis techniques. The use of a steady-state diffusion porometer, developed during the early part of this year, has provided diffusion resistance measurements which are much better than originally thought possible. Simple methods for determining soil hydraulic conductivity, an extremely important parameter in any soil-plant water model, have also been developed. During the coming year we intend to try some modelling of the system in addition to extending measurements to other sites.

OBJECTIVES

The objectives of this study are to:

1. Determine transpiration, evaporation, and growth for *A. tridentata* and relate these to soil and plant water potential and stage of plant development.
2. Determine the soil water potential at which absorption of water by roots of *A. tridentata* and associated grasses is reduced or ceases and how it changes with root depth in the soil.

For 1973, our specific objectives were to establish sites and collect data on plant water potential, stomatal diffusion resistance, plant osmotic potential, evapotranspiration, and soil water potential and temperature. Relevant meteorological measurements were also documented. We also intended to collect data on soil hydraulic conductivity and moisture retention, but do not have it available for this report.

METHODS

Two study sites near Washtucna, Washington, were selected for the 1973 studies. Site 1 was located in the SE ¼, SE ¼, NE ¼, SE ¼ Sec. 15, T. 15N, R36E WM in Adams County. The soil series is listed as Esquatzel silt loam. A small stand of *Artemisia tridentata* which is relatively undisturbed by grazing and farming and which is in an area adjacent to the highway, a farm access road and a drainage, was selected for study. An area approximately 20 x 20 m was fenced and a weather station including an accumulating rain gauge, a maximum-minimum thermometer, an anemometer at 2 m height, and a solar radiaton integrator, was installed. Areas which are primarily grass, small sagebrush, large sagebrush, and bare soil exist within the fenced area. Neutron access tubes were installed in each of these areas and in an adjacent sagebrush area across the access road west of the fenced area. Small sagebrush is up to 50 cm high, while the large sage is about 200 cm.

Site 2 was located in Franklin County on a drier site with a sandier soil. The site location is NE ¼, SW ¼, SW ¼, SW ¼ Sec. 22 T14N, R35EWM. The soil series designation was not available for this site. The study area was not fenced, and the area had been heavily grazed in previous years, as it was during 1973. The site was plowed about 50 years ago. Neutron access tubes were installed along with one set of soil psychrometers. No meteorological measurements were made at this site.

Soil Data

Soil water content was measured using neutron scattering. A Nuclear Chicago Model P 19 depth moisture gauge and Model 2800 scaler were used. These were calibrated for the soil at the sites. Water content (cm^3/cm^3) is given by 0.42 CR - 0.05, where CR is the ratio of the soil count to the shield count. Nine aluminum tubes were installed in site 1 and four in site 2. Table 1 shows the depths and surrounding vegetation for each tube location. Water content was measured every two weeks from April through October. The counts (30 sec) were converted to water content, and the water contents recorded in DSCODE A3UCJ02.

Soil psychrometers were installed to monitor water potential, but readings obtained were quite erratic and were not used. Instead, we intend to infer water potentials from water content measurements and moisture retention data. This procedure should give reasonable accuracy on the wet end of the scale, while estimates on the dry end may be in error by several bars. We intend to supplement our soil psychrometer data with measurements made on soil samples during 1974 to obtain more reliable measurements.

Evapotranspiration was calculated using the difference in profile water content at two successive times and adding to this the precipitation occurring within that time period. Precipitation was assumed to be the same at site 2 as at site 1. Site 2 is judged to be somewhat drier than site 1, but this has not been documented.

Plant Data

Plant water potential, osmotic potential and stomatal diffusion resistance were measured from April through October. Leaf water potential was measured with a pressure chamber (P.M.S. Instrument Co., Corvallis, Oregon). Leaf osmotic potential was measured on cell sap which was expressed from leaves previously frozen with dry ice. The sap was absorbed on a filter paper disk and the measurement was made with a commercial sample chamber hygrometer (Wescor, Inc., Logan, Utah). Stomatal diffusion resistance was measured using a steady state technique similar to that described by Beardsell, Jarvis and Davidson (1972).

The measurements were made by excising a 10 to 15 cm long branch tip and placing it in the porometer chamber. The diffusion resistance measurement was accomplished within 15 to 20 seconds of excision. The branch was then placed in the pressure chamber and leaf water potential was measured. It was then stored in a closed Tygon tube on ice for transport to the laboratory. There, several leaves were removed and frozen with CO_2 ice, the sap was expressed, and osmotic potential was measured with the hygrometer. The remainder of the leaves were run through a commercial optical leaf area meter. The leaf area measurement was used to determine diffusion resistance. Generally, duplicate readings were made on a large (old) and a small (young) sagebrush every two weeks when the site was visited (A3UCJ01). During part of the summer, the leaves were so dry that sap in sufficient quantity for osmotic potential measurement could not be obtained. At this time it would probably be safe to assume that the osmotic potential and the leaf water potential were equal. Notes on phenology were made and related to the numeric phenological code of Caldwell et al. (1973), which is reproduced in Table 2 for convenient reference.

Meteorological Data

Weekly measurements of precipitation, wind run, solar radiation, maximum and minimum temperature, and soil temperature were made. Wet and dry bulb temperatures were measured at the time the site was visited each week in order to calculate vapor pressure. Precipitation was measured with an accumulating rain gauge. Wind run was followed using a reed switch anemometer of the type described by Fritschen and Hinshaw (1972), operating into a battery powered counter (circuit available from project leader on request). A silicon solar cell of the type described by Kerr, Thurtell and Tanner (1967) was used to measure solar radiation. The signal was integrated using a low-power, battery-operated circuit and electro-mechanical counter (circuit also available on request). Maximum and minimum temperatures were obtained from a standard max-min thermometer inside a ventilated shelter at a height of about 50 cm. Soil temperature was measured with thermocouples installed along with the soil psychrometers. Wet and dry bulb temperatures were measured with a standard sling psychrometer (A3UCJ03).

RESULTS

Meteorological Data

Meteorological data for site 1 are shown in Figures 1 and 2. The summer of 1973 was much drier than normal in eastern Washington -- being about 30% below average in precipitation.

Plant Water Data

Plant water potentials, osmotic potentials, and diffusion conductances are shown in Figures 3 and 4. Data obtained for the small brush are plotted separately from those for large brush. Stomatal conductance, rather than resistance, is plotted since conductance is directly proportional to water loss (assuming equal vapor pressure gradients) and thus gives a better feeling for relative importance of changes. Osmotic potential measurements cease in August because plant tissues became too dry for the methods used. It is probably safe to assume that the osmotic potential throughout this period is about the same as the water potential.

Positive turgor was generally maintained in April and part of May. Stomatal conductance was relatively high throughout this period of maximum growth. As daytime turgor pressures reached zero, conductance dropped and the spring leaves began to shed. As summer progressed, water potentials and osmotic potentials continued to decrease, finally reaching -40 to -50 bars. Stomatal conductance decreased somewhat during this period, but the reduction was not nearly so great as occurred early in the season. Recovery of conductance and water potential occurred to some extent, after the rain in September, but the values were much lower than for the spring vegetation.

The small sagebrush on site 1 reached lower water potentials by 10 bars or more than the larger sagebrush. Apparently the rooting system was not as well developed

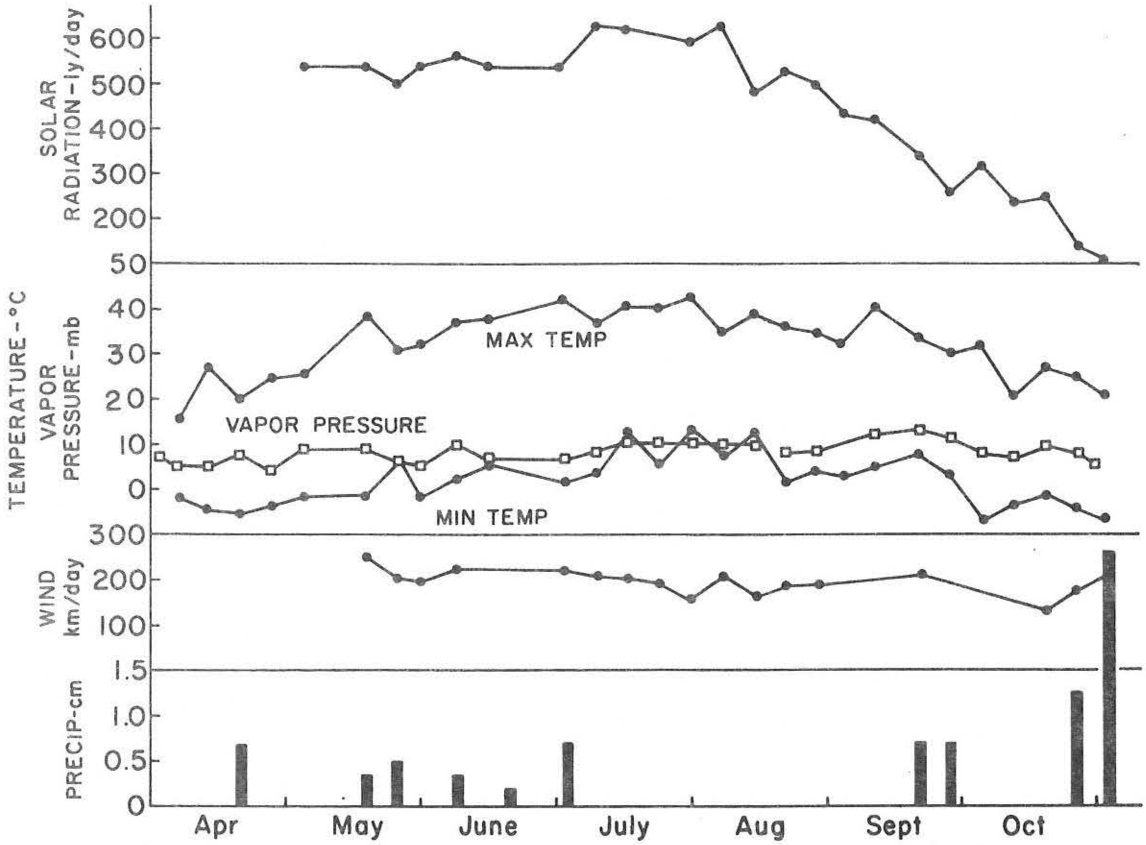

Figure 1. Solar radiation, maximum and minimum temperature, vapor pressure, average daily wind run, and weekly precipitation measured at site 1.

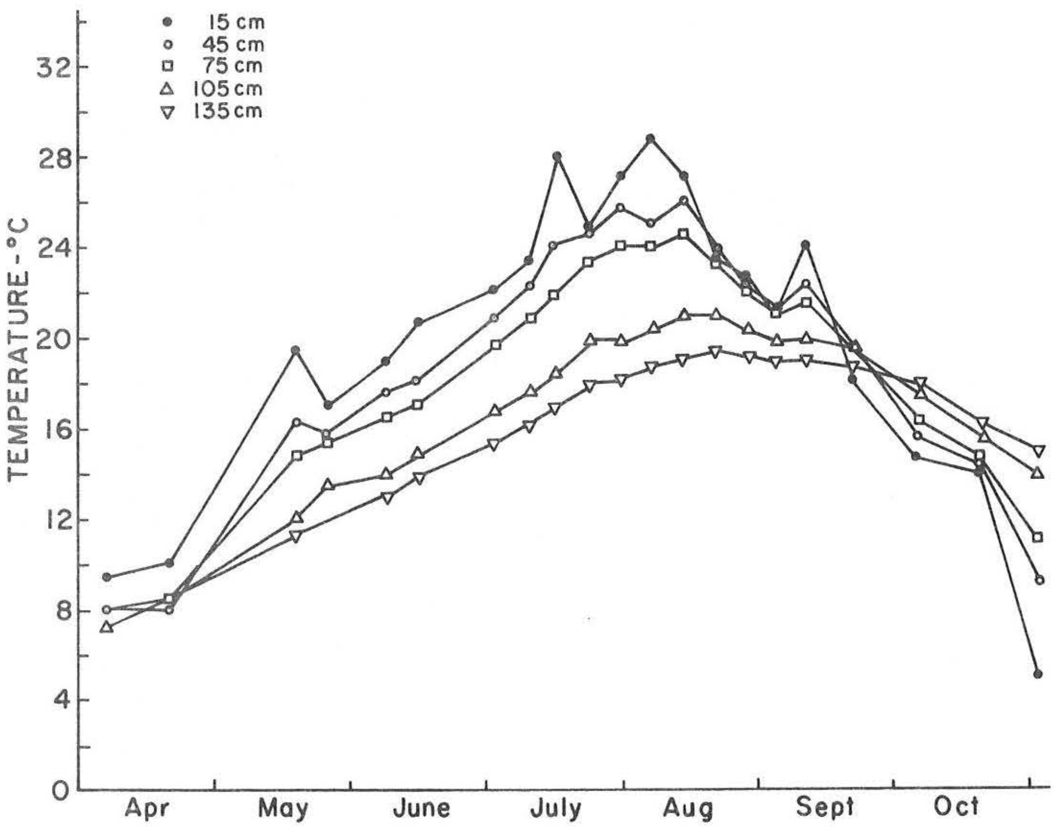

Figure 2. Soil temperatures measured at 15, 45, 75, 105, and 135 cm depths at site 1.

and water was not as readily available as for the older brush. This effect is not apparent at site 2, possibly because of smaller differences in brush age. Site 2 had been plowed about 50 years ago, thus limiting the age of the oldest brush. As previously noted, this site was heavily grazed, thus reducing competition for moisture by grasses.

Soil Moisture Data

Figure 5 gives the water use data for the two sites. Water losses for tubes 5, 6, 8, and 9 (Table 1) were averaged for the large brush graph; tubes 2, 3, 4, and 7 were averaged for the small brush and grass graph, and tubes 1, 2 and 3 were averaged for the site 2 data. Tube 1 at site 1 and tube 4 at site 2 are not shown. Instrument problems sometimes resulted in negative water loss values, even when no rain had occurred. These numbers were not averaged in with the other data. Some of the fluctuations in the Figure 5 data might also be the result of instrument malfunction, though the general picture is felt to be approximately correct. In general, transpiration rates tended to increase in the spring with evaporative demand until the plants began to limit water loss by stomatal closure. The plant data indicate that this may have occurred in mid-May. Evapotranspiration rate was then low (around 0.5 mm/day) until it rained in September. In September, it increased somewhat, but evaporative demand was reduced sufficiently by this time so that evapotranspiration still did not become high.

Table 1. Neutron tube locations and depths

Tube Number	Depth-cm	Vegetation
Site 1		
1	210	Bare soil
2	210	Grass
3	210	Grass
4	210	Grass and small brush
5	180	Large brush
6	270	Large brush
7	210	Grass
8	210	Large brush
9	270	Large brush
Site 2		
1	180	Large brush
2	210	Large brush
3	210	Large brush
4	90	Grass

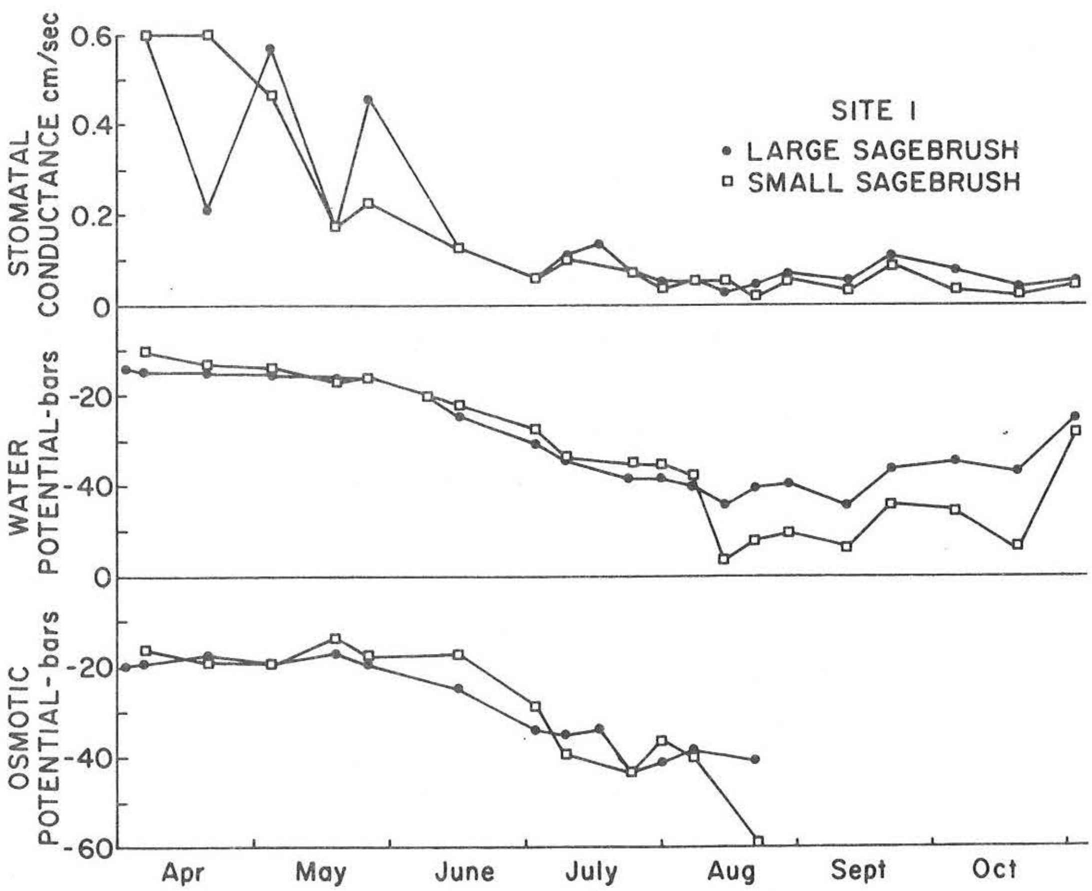

Figure 3. Stomatal conductance, leaf water potential and leaf osmotic potential as a function of time for the 1973 growing season at site 1. Measurements were made near mid-day. Each point is the average of two measurements.

Table 2. Numeric phenological code of Caldwell et al. for *Artemisia tridentata.* Taken from Desert Biome Research Memorandum RM 73-13

0 -- Winter dormancy
1 -- Post-dormant quiescence
2 -- Swelling leaf buds (mid-April to early May)
3 -- Emergent large new leaves on vegetative branches (mid-May)
4 -- Rapid new vegetative stem and leaf growth; reproductive shoots initiated (late May to mid-June)
5 -- Reduced vegetative growth; reproductive shoot and bud growth; ephemeral leaves growing on reproductive shoots; (early July to mid-July) "spring" leaves shed
6 -- Reproductive shoots full size; flower buds developing; little vegetative growth (mid-July to late August)
7 -- Flower buds fully develped -- some beginning to burst; ephemeral leaves on reproductive shoots dying and being shed (September)
8 -- Flowering (early October)
9 -- Fruit developing (late October to early November)
10 -- Shedding of fruit; predormancy quiescence (mid-November on)

Data from Curlew Valley

One set of measurements was made at Curlew Valley on May 19. Water potential, osmotic potential and diffusion resistance were measured at 700 and again at 1700 hr to obtain roughly maximum and minimum values. A heavy rain had occurred on May 14, so the surface soil was wet, and the plants apparently had not suffered for water previously that season. Soil samples were also taken and water potentials measured. A summary of the data are shown in Table 3. Water potentials were about the same as for Washington sites at this time of year, but positive turgor was still being maintained, and stomatal resistances were considerably lower. These differences might be at least partially explained by the higher salt concentration in the Curlew Valley soil. The soil water potential measurement was not separated into matric and osmotic components, but the lower samples almost certainly contained quite high salt concentrations since the water potential becomes low while the water content changes are relatively slight.

DISCUSSION

The general pattern which emerges from the measurements taken so far is about as one would expect.

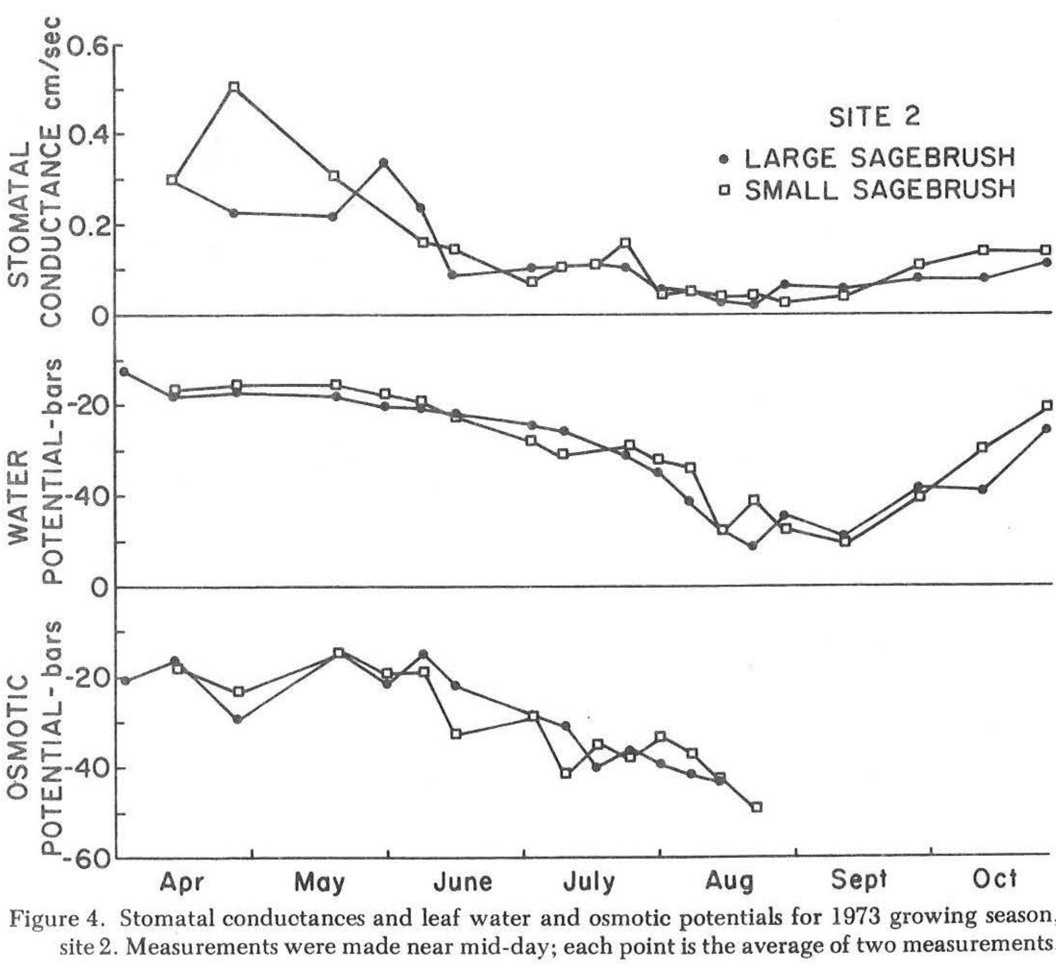

Figure 4. Stomatal conductances and leaf water and osmotic potentials for 1973 growing season, site 2. Measurements were made near mid-day; each point is the average of two measurements.

Maximum growth, turgor pressure, evapotranspiration, and minimum stomatal diffusion resistance correlate with favorable spring growing conditions. As soil moisture in the zone of dense root growth is depleted, resistance to water flow to the plant is increased, resulting in compensating stomatal closure. The soil water potential at which this occurs depends on rooting density and soil hydraulic conductivity. We hope to develop a quantitative explanation of this phenomenon in the near future.

An important plant adaption to summer moisture stress is the shedding of spring leaves and development of summer leaves. These are smaller and better suited to convective heat exchange. They have smaller leaf area and less evaporative loss due to reduced leaf temperatures.

The entire reproductive portion of the life cycle occurs

Table 3. Summary of data collected at Curlew Valley on *Artemisia tridentata*, May 19, 1973

Plant Data				Soil Data		
Time	Leaf water Potential-bars	Leaf Osmotic Potential-bars	Diffusion Resistance-sec/cm	Depth-cm	Water Content g/g	Water potential bars
700	-8.0	-25.2	1.6	15	0.21	-2.1
700	-7.0	-24.7	1.7	30	0.17	-7.3
700	-9.5	-20.5	1.5	45	0.19	-10.0
1700	-26	-31	4.5	60	0.22	-9.3
1700	-21	-28	4.9	90	0.19	-38.4
1700	-21	-28.5	4.2	120	0.14	-58.4
				150	0.15	-59.8

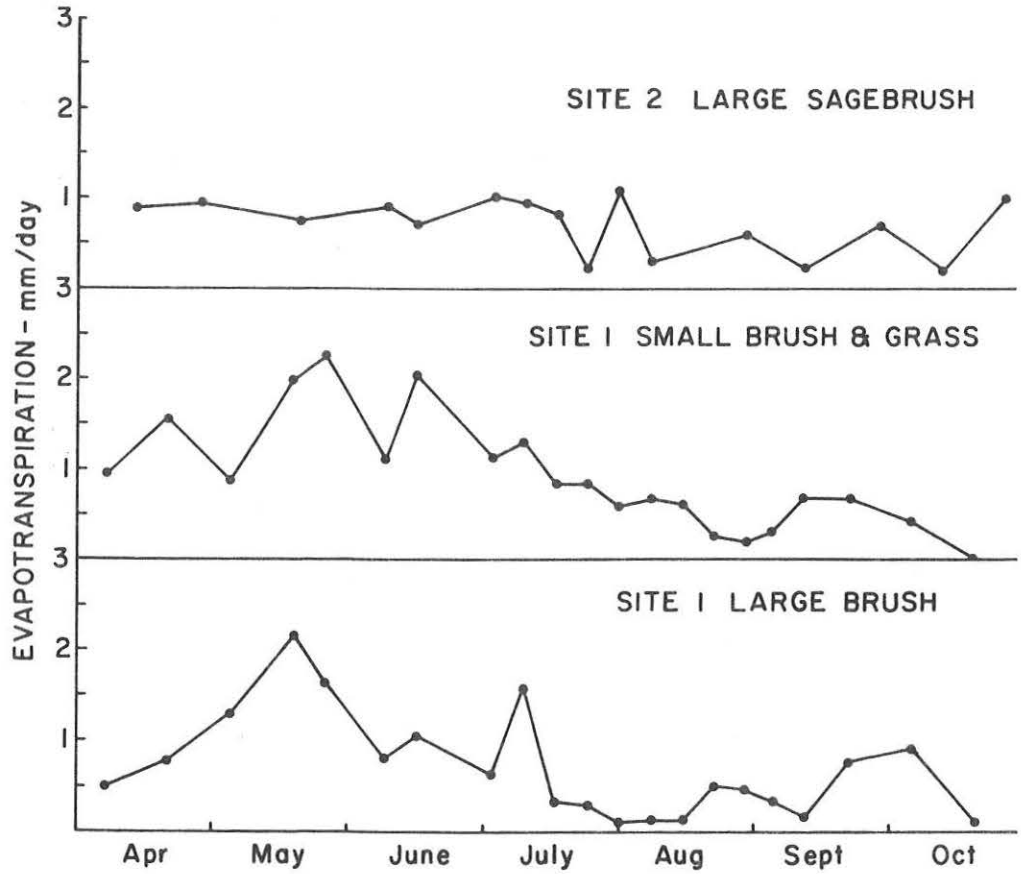

Figure 5. Average evapotranspiration for sites 1 and 2. Each point is the average of measurements in several locations at each site. The large fluctuations are thought to be the result of instrument malfunction, and the best indication of water loss is probably a relatively smooth curve drawn through the average of the points.

during the period of summer water stress with high temperatures, high diffusion resistances, and low water potentials. Water uptake and loss continue throughout the summer, but at only about one-fourth the rate it did during the spring months. Daytime water potentials during the rapid growth phase are around -15 bars with osmotic potentials around -20 bars. Driest leaf water and osmotic potentials are around -40 to -50 bars. These values are considerably lower than those commonly observed in non-desert vegetation, but are similar to some which have been measured on sagebrush (Hsieh et al., 1971). Stomatal resistances around 2 sec/cm are typical of the spring growth of sagebrush, and these are about the minimum resistances found for many plants. Maximum resistances of 40 to 50 sec/cm and higher are relatively uncommon in non-desert plants since leaves of most plants abscise when high diffusion resistances are maintained for longer than a few days. The fact that the sagebrush endures the drought rather than becoming dormant would require that the plant maintain very high diffusion resistances for long periods of time.

EXPECTATIONS

Our main interest in 1974 will be to put the information we are collecting into a useful form for predicting plant water potentials and diffusion resistances from environmental variables. We will continue to monitor site 1 and will make spot checks on other sites, some of which will be much drier than this year's sites. We intend to obtain the soil hydraulic conductivity and moisture retention information necessary to complete this year's picture on soil water potential, plant water potential and stomatal diffusion resistance. We will also attempt to increase the frequency of sampling in the spring when things are changing rapidly. This, in addition to the experience we now have with our measuring techniques on sagebrush should improve our springtime data.

ACKNOWLEDGEMENTS

In addition to financing by the Desert Biome, this project was supported by funds from the Washington Agricultural Experiment Station. This support is gratefully acknowledged by the investigators.

LITERATURE CITED

Beardsell, M. F., P. G. Jarvis, and B. Davidson. 1972. A null-balance diffusion porometer suitable for use with leaves of many shapes. J. Appl. Ecol. 9:677-690.

Caldwell, M. M., H. H. Wiebe, E. J. DePuit, O. Fernandez, L. B. Camp and M. Fareed. 1973. Gas exchange, translocation and root growth of cold desert plants. US/IBP Desert Biome Res. Memo. RM 73-13.

Fritschen, L. J., and R. Hinshaw. 1972. A reed switch anemometer. J. Appl. Meteor. 11:742-744.

Hsieh, J. J. C., G. S. Campbell and W. H. Gardner. 1971. Psychrometric determination of water potential of desert plants. Northwest Sci. 45:209-212.

Kerr, J. P., G. W. Thurtell and C. B. Tanner. 1967. An integrating pyranometer for climatological observer stations and mesoscale networks. J. Appl. Meteor. 6:688-694.