first elaborated by him. However, the world of science should understand that Paczoski was a Pole and that the natural environments of eastern Poland were those which most significantly influenced his thoughts and researches in phytosociology and ecology.

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SEASONAL SOIL MOISTURE PATTERNS IN ADJACENT GREASEWOOD AND SAGEBRUSH STANDS[1]

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Abstract. Soil moisture measurements were made over a 2-year period in adjacent greasewood (*Sarcobatus vermiculatus*) and sagebrush (*Artemisia tridentata*) stands in the desert steppe region of southeastern Washington. Soil moisture accumulated during fall and winter. The greater accumulation of moisture in the upper 4 dm of the greasewood stand appeared to be the result of decreased evaporation losses and the lack of transpiration from shrub species which are leafless during winter and early spring. The more luxuriant growth of cheatgrass in the greasewood stand was related to winter and spring retention of soil moisture.

[1] This paper is based on work performed under United States Atomic Energy Commission Contract AT (45-1)-1830.

Introduction

On the Hanford Reservation of southeastern Washington, greasewood, *Sarcobatus vermiculatus*, has a limited geographic distribution. Shrubs occasionally occur along the banks and bluffs of the Columbia River, but extensive stands occur only along the Dry Creek drainage in the immediate vicinity of Rattlesnake Springs. Here greasewood is intermingled with hopsage, *Grayia spinosa*, on the more or less level terrain, while stands of big sagebrush, *Artemisia tridentata*, occupy the adjacent benches and slopes.

The entire Rattlesnake Springs area has been intensively grazed especially in the years before 1943. The greasewood stand has probably received the greater total amount of grazing pressure because of its proximity to drinking water. Grazing has been intermittent between 1943 and 1960 and has been excluded since 1961.

Greasewood is often regarded as a plant indicator of saline-sodic soil. For this reason it could be expected that plants such as cheatgrass, *Bromus tectorum*, would not grow as well in greasewood soils as they would in sagebrush soils. However, the herbaceous understory, which was comprised mostly of cheatgrass, was more dense and luxurious in the greasewood stand.

Because moisture is a limiting factor for plant growth in this region, having an annual precipitation of slightly less than 7 inches, it was decided that comparative measurements of the seasonal soil moisture patterns in plant communities of similar physiognomy, but with different shrub species, might yield information to explain the observed differences in grass cover.

Methods

One study location was selected well within the boundaries of an extensive stand of greasewood and another within the boundaries of a contiguous sagebrush stand. Both sites occupied essentially level ground. The elevation of the greasewood site was about 720 ft above sea level. The sagebrush site was located on a bench estimated to be 15–20 ft higher than the greasewood site. The two sites were less than one-fourth of a mile apart with no pronounced changes in topography separating them.

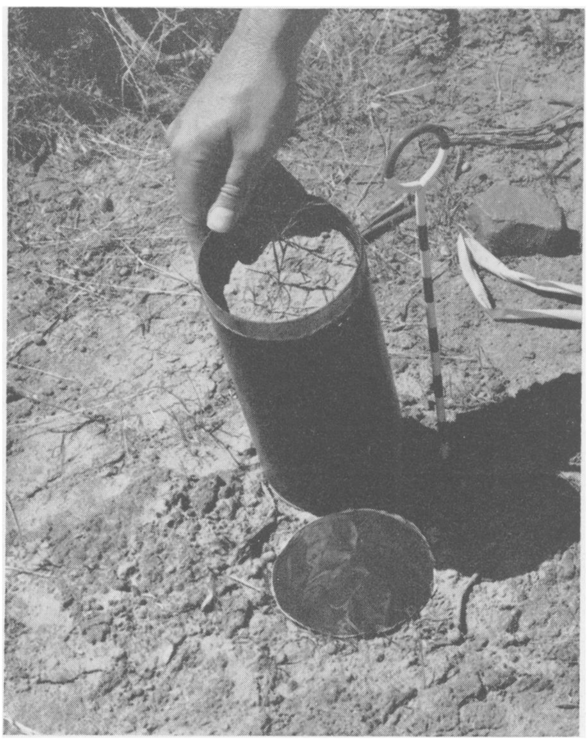

Fig. 1. Soil-filled can showing the aluminum foil sleeve which enabled the can to be lifted from its buried position for frequent weighings.

The soil profile at both sites was essentially free of stones so that a sand auger could be used to obtain samples to a total depth of 1 m. Two soil borings were made in each site at 2- to 3-week intervals during the autumn of 1961 and through the winter, spring, and summer of 1962. Moisture content of samples taken at decimeter-deep increments was determined upon drying at 105°C for 48 hr.

Measurements of soil moisture gains and losses were continued in 1962–63 by twice-weekly weighings of buried, soil-filled cans. Twenty cans (10 in each stand), each 25 cm high and 10.1 cm in diameter, were filled to within 1 cm of the rim with soil from the upper 2 dm of the soil profile (Fig. 1). Soil was placed inside each can in approximately the same profile sequence as it occurred in the field. Cans were arranged in the open spaces between shrub clumps in late September 1962 when the soil was at the lowest moisture value for the year, i.e. 2% moisture by weight. Prior to field installation each can was painted inside and out with black asphaltum paint to prevent rusting. A heavy duty aluminum foil cylinder was used to line the augered hole within which each can was individually fitted. The aluminum sheet casing allowed each can to be lifted out of the ground for weighing on a torsion balance. Cans were weighed on all occasions except when covered by snow. Accuracy of the 5-kg capacity balance used for weighing was ± 1 g. The weight of ovendry soil was 2,690 g/can in the greasewood community and 2,560 g/can in the sagebrush community.

Five cans in each stand were kept free of vegetation and are referred to as bare cans, while another five cans were planted with cheatgrass seeds.

The permanent wilting percent of soil was measured using the wilted sunflower method as described by Daubenmire (1959). The bulk density of the upper 2 dm of soil was determined by weighing soil cores and measuring the volume of removed soil by filling the holes with measured volumes of dry sand.

Some of the pertinent aspects of soil chemistry and physical properties of the soil profile were obtained on samples submitted to the soil testing laboratory at Washington State University.

Results and Discussion

In this region, soil moisture attains seasonal dryness in early autumn after the customary hot, dry summer. Soil moisture measurements made in September showed that soil moisture in the upper 4 dm of both greasewood and sagebrush profiles ranged between 2% in the upper decimeter to 4% at 4 dm (Fig. 2). However, at depths below 4 dm the moisture content of the greasewood soil varied between 5% and 11%. The sagebrush soil profile showed a relatively stable soil moisture content usually ranging between 4% and 5% at depths below 4 decimeters.

The upper layers of soil increased in moisture content from October to March. During the spring months, however, the moisture content of these layers steadily decreased (Fig. 2). The drying trend was reversed for a time following periods of precipitation in late April

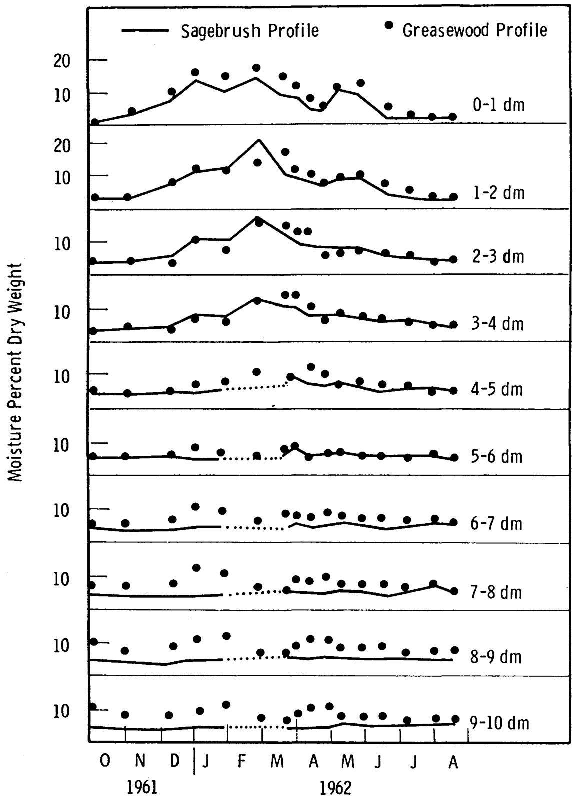

FIG. 2. Seasonal soil moisture content (dry weight) of decimeter-deep increments of the upper meter of soil in adjacent greasewood and sagebrush stands, October 1961 to August 1962. Dotted lines indicate missing values.

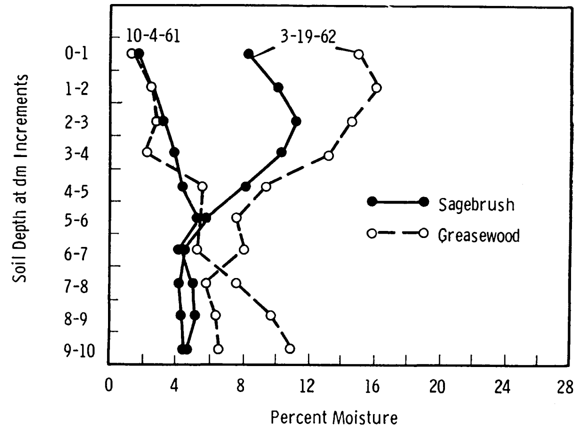

FIG. 3. The vertical distribution of soil moisture in greasewood and sagebrush soil at seasonal minimal and maximal moisture contents.

and early May. At the annual peak of moisture accumulation the upper 4 dm of soil in the greasewood stand contained more moisture than the sagebrush profile (Fig. 3). Also, seasonal moisture percolation in the sagebrush soil did not proceed much beyond 6 dm. The depth of soil moisture penetration in the greasewood soil was not so readily observed because of the highly variable nature of the residual moisture in the lower half meter of profile which also had a high salt content (Table 1). On March 19 the upper 4 dm of soil in the greasewood stand averaged 14.8% moisture as compared to 10% for sagebrush soil. The available moisture (i.e. that above permanent wilting—6.2% in the greasewood site and 5.5% in the sagebrush site) in the upper 4 dm per square meter of soil was 49 liters in the greasewood profile as compared to only 24 liters in the sagebrush profile. Since the bulk density of the soil was similar in each site, the bulk density value of 1.32 and the determined soil moisture percentage by weight were used to calculate moisture percentage by volume. The failure of the sagebrush soil to accumulate winter precipitation was attributed to evaporation and transpiration losses. Moisture losses by shrub transpiration seemed possible because sagebrush retained most of its leaves in winter. Transpiration losses from greasewood and hopsage were unlikely because both species are leafless in winter. Transpiration in spring months would be increased greatly when the seedlings of fall germinating cheatgrass begin to grow rapidly as air and soil temperatures gradually increase from winter low values and provide a better growth environment.

TABLE 1. Hydrogen-ion concentration (pH), conductivity of saturation extract (mmhos/cm), and exchangeable sodium per cent (ESP) in greasewood and sagebrush soil profiles

Soil depth (dm)	Sagebrush site			Greasewood site		
	pH	Conductivity	ESP	pH	Conductivity	ESP
0-1	7.5	0.55	0.34	7.7	0.61	5
1-2	8.1	0.45	1.6	7.9	0.70	12
2-3	8.3	0.38	2.1	7.9	1.5	26
3-4	8.4	0.36	2.7	8.6	1.9	39
4-5	8.5	0.30	2.8	9.2	4.9	61
5-6	8.6	0.30	2.9	9.3	5.7	70
6-7	8.5	0.34	3.7	9.7	8.0	80
7-8	8.7	0.34	6.1	9.8	13.0	84
8-9	8.8	0.30	12.0	10.0	15.0	93
9-10	9.0	0.58	20.0	10.1	18.0	83

[a]Saline or sodic soil below this line.

A tentative conclusion was made that the more efficient storage of winter moisture in the upper profile of the greasewood soil was responsible for the more dense stand of grass.

The density of cheatgrass plants was determined in both sites. The average density of cheatgrass plants on the greasewood site was 47 plants/dm^2 (n=24) as compared to 1.4 plants/dm^2 (n=36) in the sagebrush site.

Soil moisture gains and losses were measured directly by periodic weighing of soil-filled cans in 1962-63 (Fig. 4). By eliminating plants in some of the cans, evaporation losses from soil could be measured without interfering losses from transpiration. The results show that autumn rains penetrated less effectively in the greasewood soil than in the sagebrush soil. However, by early spring the greasewood soil had accumulated more moisture than the sagebrush soil as previously observed by gravimetric sampling. It was concluded that in the spring the greasewood soil did not lose moisture as readily as did the sagebrush soil; this suggested that different soil temperatures and wind conditions in the sagebrush habitat may have been the important factors in soil moisture losses. This stored moisture was subsequently used during spring growth of grass. Cheatgrass seeds placed in the cans germinated with the onset of autumn rains and grew to maturity without artificially applied moisture. The demand cheatgrass made upon the soil moisture as it grew rapidly during April is illustrated in Fig. 4. Transpiration reduced the soil moisture supply quickly so that by May 20, moisture in the cans with grass was reduced to a low point that was not attained by the bare cans until late July and early August.

In the sagebrush stand accumulations of salt or sodium ions in the upper meter of soil were not large enough to seriously interfere with water or mineral nutrient relations. In the greasewood stand, however, the soil below 5 dm was distinctly saline-sodic (Table 1). The surface soil beneath the canopy spread of greasewood shrubs also had high accumulations of sodium (Rickard 1965*a*, 1965*b*). It was abundantly clear that cheatgrass was able to grow in the space between shrub clumps and that the grass did not need to derive moisture from saline-sodic soil to account for the observed differences in cheatgrass cover. It was thought that cheatgrass might not grow as well in the sagebrush soil because of a lack of or excess of some mineral element. However, when cheatgrass was grown with adequate soil moisture under growth chamber conditions of light and temperature for 6 weeks, the plants grew best when planted in soil taken from the sagebrush stand (Table 2).

From these data it was concluded that the more dense

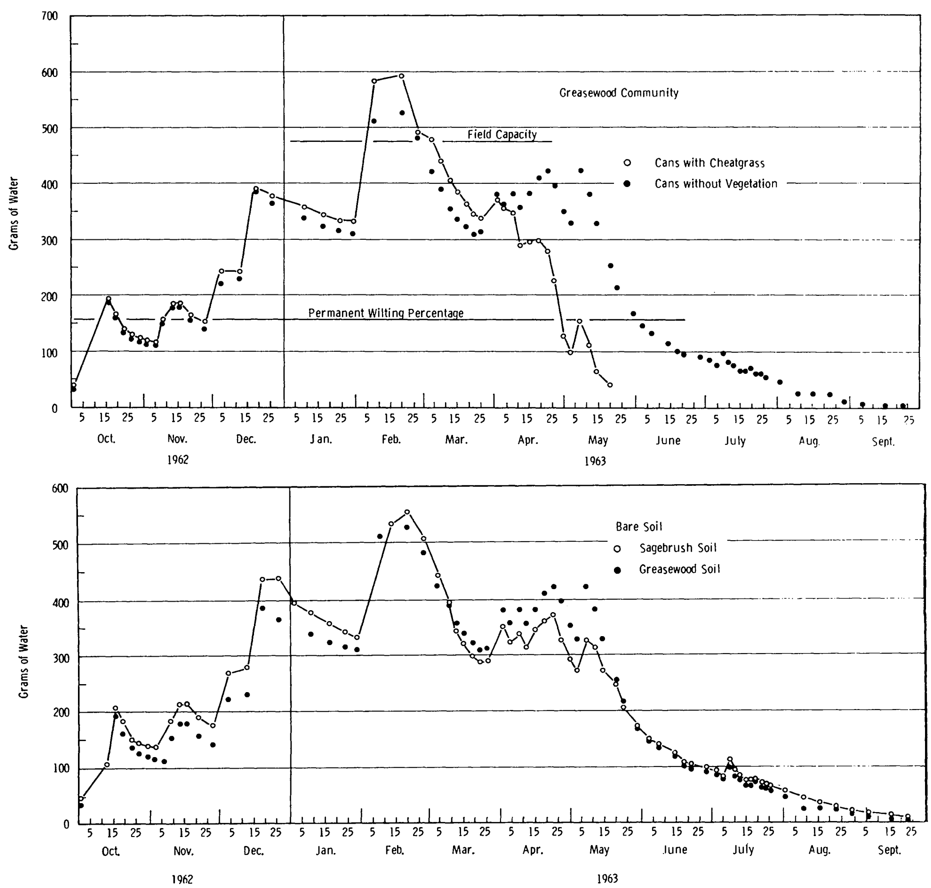

FIG. 4. Seasonal gains and losses in soil moisture as measured by periodic weighing of buried cans during the season of 1962–63. The upper figure compares average moisture gains and losses from five cans without cheatgrass with cans in which three cheatgrass seedlings were allowed to grow and attain maturity in the greasewood stand. The lower diagram compares the gains and evaporation losses of moisture from buried cans free of vegetation in adjacent greasewood and sagebrush stands.

and luxurious stand of cheatgrass associated with greasewood was a result of the accumulation and retention of winter moisture in the upper parts of the soil profile. Moisture accumulation is attributed to reduced evaporation during spring and to reduced competition for moisture by the surrounding deciduous shrubs.

TABLE 2. Dry weight (g) of 6-week-old cheatgrass plants grown in soil taken from adjacent greasewood and sagebrush communities

Source of soil	Shoot	Root	Total
Greasewood stand	0.606 ± .010[a]	1.768 ± .056	2.374
Sagebrush stand	1.760 ± .049	4.798 ± .416	6.558

[a] n = 6, ± standard error

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MEASUREMENT OF LEAF WATER POTENTIAL BY THE DYE METHOD

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Abstract. The dye method for measuring leaf water potential is simple, inexpensive, and suitable for both laboratory and field work. Leaves are immersed in a graded series of solutions, and the solution which neither gains nor loses water is assumed to have a water potential equal to that of the leaf. Although limited by certain inherent errors, the dye method can be used to measure relative values and changes in potential. Specific procedures are described for the successful use of the method.

There are few techniques for measuring leaf water potential (Kramer, Knipling, and Miller 1966) that are truly suitable for field work. The recently described pressure chamber method appears promising for some species (Scholander et al. 1965, Boyer 1967, Waring and Cleary 1967). The dye method, also known as the Shardakov (1948) or density method, is another useful technique because it is simple and requires no elaborate or expensive equipment. The dye method has been described elsewhere, but no comprehensive discussion is readily accessible to many workers. This report examines the method and describes specific procedures and precautions that need to be taken for its successful use.

In the dye method (Fig. 1) samples of leaf tissue are immersed in a graded series of solutions of known water potential contained in test tubes. The leaf water potential is assumed to lie between the solutions in which the leaf samples absorb water and those in which the samples lose water. The directions of this water exchange are determined from the resulting density changes in the test solutions. Each test solution is colored lightly with a small amount of a powdered dye such as methylene blue or methyl orange. Drops of the colored solutions are then introduced with medicine droppers into the centers of the corresponding members of a parallel series of uncolored control solutions. The drops fall if the test solutions have been concentrated and rise if the solutions have been diluted. In case the leaf sample has a water potential equal to that of one of the solutions used, there theoretically is no water exchange and no density change, and hence the colored drop diffuses outward in all directions.

The purpose of the dye is to make the test solution drops visible when they are placed in the control solutions. The small amount of dye used to color the solutions lightly does not significantly alter their densities.

The precision of measurement by the dye method depends on the size of the water potential increment between test solutions. It is possible to use increments as small as 0.5 bar, but in order to have a workable number of solutions (generally 6 to 10) bracketing an unknown leaf water potential, 1- to 5-bar increments often are the only reasonable choices.

Test solutions generally are made with sucrose or mannitol. When sucrose is used, it is suitable to use the commercial (trade) type. The solutions of known

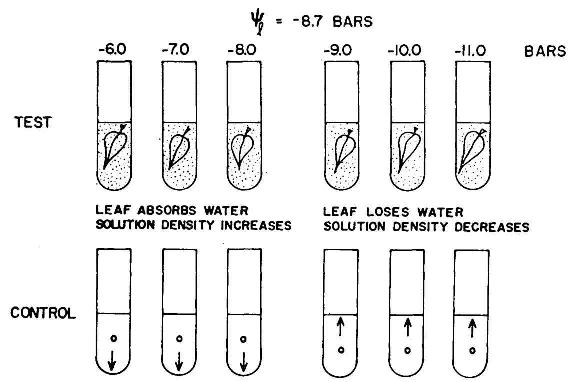

FIG. 1. Diagram representing dye method for measuring leaf water potential. The measured water potential is taken to be between the solutions in which the colored test solution drops rise and fall, i.e., —8.5 ± 0.5 bars.

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