Comparison of Lysimeter and Neutron Scatter Techniques for Measuring Evapotranspiration from Semiarid Rangelands[1]

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Highlight

Evapotranspiration (*ET*) calculated from changes in soil water content measured by the neutron scatter method was compared to *ET* measured by lysimetry. During 1968, a near-average precipitation year (33 cm), the neutron method was effective for determining *ET* over periods of 4 weeks or longer. Cumulative *ET* curves as determined by lysimetry and the neutron method were in excellent agreement. In 1969, a year with high precipitation in June and July, reliability of the neutron method was severely limited by deep percolation and possibly by surface runoff. Failure of the neutron method to measure accurately water content near the soil surface following periods of precipitation was the major source of error when percolation and runoff were not factors. Sensitivity of the neutron method during a 30-day drying cycle was equal to that of a hydraulic lysimeter. Upward soil water fluxes were evident and are potential sources of error.

Knowledge of evapotranspiration (*ET*) is important in the study of rangeland hydrology and ecology. Lysimeters, which measure *ET* directly, and indirect methods such as aerodynamic and energy budget, are expensive and not adapted to routine measurements of *ET*. Assuming no upward movement of water into the soil profile, *ET* can be calculated from the following relationship: *ET* = precipitation ± change in soil water – runoff – percolation. Thus, accurate measurements of changes in soil water content can provide a reliable means of determining *ET* when precipitation is measured and when runoff, deep percolation, and upward flux are known or negligible.

The neutron scatter method has been used successfully to determine *ET* from lysimeters under irrigation and subhumid conditions (McGuinness et al., 1961; Bowman and King, 1965; Harrold and Dreibelbis, 1967; and Van Bavel and Stirk, 1967). This paper discusses the utility of the neutron scatter method for *ET* determinations on semiarid rangeland and compares results with those obtained from small hydraulic lysimeters.

Methods

The study area was located near Sidney, Montana, on a sandy glaciated plains range site with 1 to 2% slope. Annual precipitation averages 33 cm with about 70% received during the growing season. Vegetation is a *Bouteloua-Carex-[Stipa]* (Blue grama (*B. gracilis*), threadleaf sedge (*C. filifolia*), needleandthread (*S. comata*)) faciation of the mixed prairie association (Weaver and Albertson, 1956). Basal cover by the point method was 13%.

Evapotranspiration from native range was measured with six hydraulic lysimeters similar to those described by Hanks and Shawcroft (1965). The lysimeters were 1 × 1 m in surface dimension and 1.2 m deep with no provision for drainage. One lysimeter was monitored daily, except on weekends, throughout the growing season of 1968 and 1969. Soil water was determined weekly both in and adjacent to this lysimeter. Soil water of the other five lysimeters and adjacent areas was measured periodically throughout the 1968 growing season.

One access tube was used to measure soil water in each lysimeter, and two or three access tubes were used in the adjacent rangeland. Measurements were made at 15-, 45-, 75-, and 90-cm depths in the lysimeters and 15-, 45-, 75-, and 105-cm depths in adjacent areas. Distance between center of measurement and end of probe[2] prohibited readings in the lysimeters beyond about 90 cm. The neutron source was 100 mc of Am^{241}-Be.

A separate study was conducted to evaluate the neutron method for determining *ET* on a daily basis. During periods in August and September 1969, daily changes in soil water content of a lysimeter were determined by lysimetry and neutron techniques following an application of 5.9 cm of water. Changes in soil water content were calculated from neutron readings taken at 7.5-cm intervals between the 15- and 90-cm profile depths. Total profile water was calculated by averaging the soil water fractions determined at each point of measurement and multiplying by 120 cm—the depth of the lysimeter. Changes in water content were also calculated from readings taken at 15-cm intervals and 30-cm intervals, and results were compared with those from the 7.5-cm interval measurements.

Results and Discussion

For 1968, a year with near-average precipitation, there was relatively close agreement between the lysimeter and neutron methods of measuring changes in soil water content inside the lysimeter and between soil water inside and outside the lysimeter. However, in 1969, a relatively wet year (approximately 36 cm of precipitation from April through mid-August as compared to 27 cm for the same period in 1968), the discrepancy between neutron and lysimeter measurements and between soil water inside and outside the lysimeter (Fig. 1) was greater than in 1968. Following heavy precipitation in late June and early July, the neutron method recorded peak soil water content a week

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[2] Troxler Depth Moisture Gauge 105A, Troxler Electronic Laboratories, Inc., Raleigh, N. C. (Company name is included for the benefit of the reader and does not imply any endorsement or preferential treatment by the U. S. Department of Agriculture of the product listed.)

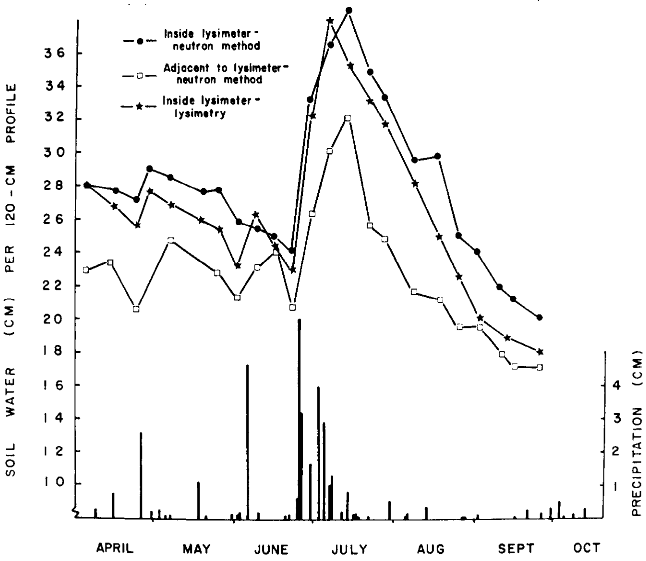

FIG. 1. Changes in soil water content inside and adjacent to a lysimeter and the precipitation pattern for 1969.

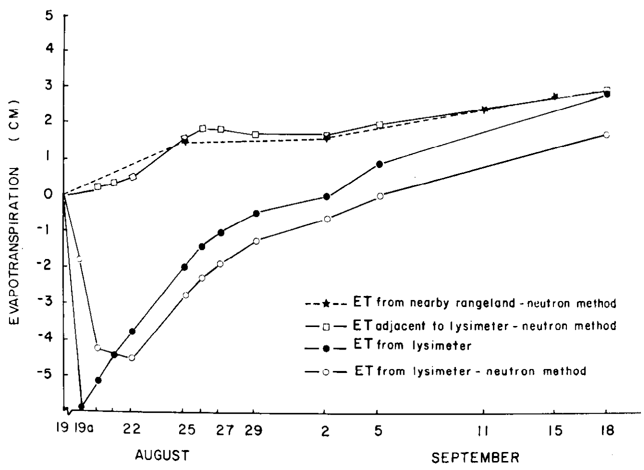

FIG. 2. Evapotranspiration from a wetted lysimeter and from adjacent rangeland. (Time 19a occurred 30 minutes following application of 5.9-cm water. Applied water is plotted as negative *ET*.)

later than the lysimeter. Figure 1 also indicates that the soil water outside the lysimeter was significantly less than inside the lysimeter for a major portion of the 1969 growing season. The increase in soil water inside the lysimeter was due to restriction of percolation and to a gain in soil water over the winter. The lysimeter was more effective in holding snowmelt than adjacent rangeland.

The delayed response of the neutron method to surface application of water is further illustrated in Figure 2. Following an application of 5.9 cm of water, the lysimeter immediately registered the full amount added; however, 30 minutes after application, the neutron method measured only 1.8 cm, and 24 hours after application, only 4.3 cm. The neutron method, as used in this experiment, failed to measure the full amount of water that was initially concentrated in the upper layer of soil. Maximum soil water was not indicated by the neutron method until 3 days later—about the same time maximum depth of percolation occurred. From the third day on there was excellent agreement between the lysimeter and neutron method of measuring changes in soil water content, even on a daily basis.

Errors in measuring water near the soil surface are inherent with the neutron method and have been discussed by Lawless et al. (1963). Errors also may arise due to placement of the neutron probe in relationship to a wet layer of soil; i.e., if a wet layer of soil is located above or below the center of measurement, total amount of water measured will be less than if the center of measurement is in the center of the wet layer. Immediately following precipitation, soil water is concentrated in a wet layer near the surface; and, with the upper profile measurements taken at 15-cm below the surface, water content of this layer is underestimated. After water has had a few days to move down into the soil profile, the neutron method accurately measures the total quantity present.

Supplementation with other techniques for measuring water in the soil surface would improve the neutron method. McGuinness et al. (1961) used resistance blocks to determine soil water in the top 18 cm of soil. With proper technique and special calibration curves, the neutron method can be improved for water measurements near the soil surface (Van Bavel and Stirk, 1967; Black and Mitchell, 1968; and Luebs et al., 1968). I found that neutron readings taken at 7.5- or 15-cm intervals were more sensitive to small changes in profile water content than readings taken at 30-cm intervals.

Differences between soil water content inside and outside the lysimeter in 1969 were due primarily to restricted percolation inside the lysimeter. Water content of the lower half of the lysimeter remained above field capacity from the first of July to the first week in August. Some runoff may have occurred outside the lysimeter but not enough to account for the difference in soil water content. Evapotranspiration determined by both lysimetry and the neutron method in 1969 was higher than actual *ET*; restriction of percolation resulted in more water available for *ET* inside the lysimeter than adjacent to it. Also, deep percolation outside the lysimeter was considered a component of *ET* using the neutron method. For years with precipitation patterns similar to 1969, a lysimeter with provisions for drainage would be needed for accurate *ET* measurements. Measurements to a greater depth in the soil profile would help account

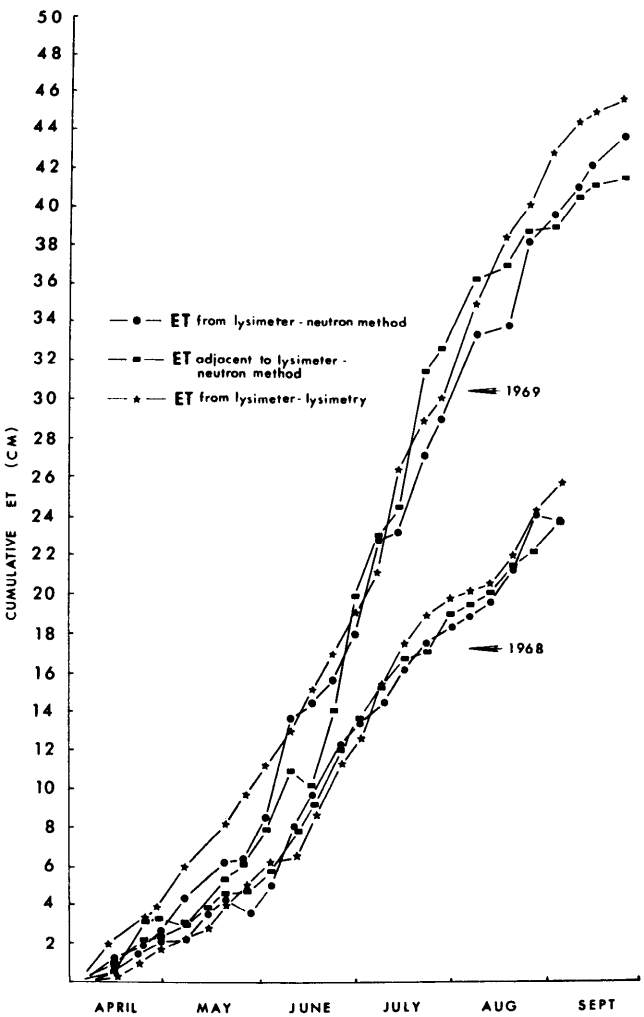

FIG. 3. Evapotranspiration from a lysimeter and from adjacent rangeland, 1968 and 1969.

for percolation and thereby improve accuracy of the neutron method.

Weekly cumulative *ET* curves for the lysimeter and neutron methods are generally in close agreement (Fig. 3). Cumulative *ET* inside and outside the lysimeter also closely agreed. In 1969, however, an unknown amount of deep percolation was measured as part of *ET*. Data from five other lysimeters (Table 1) further demonstrate reliability of the neutron method for 1968. There was no evidence of percolation through the profile in 1968.

Evapotranspiration values calculated from neutron soil water measurements for time intervals of less than 3 to 4 weeks were generally unreliable. Correlation coefficients (*r* values) comparing the two methods and *ET* inside the lysimeter with *ET* from adjacent rangeland are shown in Table 2.

Use of the neutron method for daily *ET* measurements during selected periods is questionable. Under favorable conditions—e.g., no runoff, no percolation, or no recent precipitation—the sensitivity of the neutron method appears to be adequate (Fig. 2). Standard error for the repeatability of measurement of total profile (120 cm) water for the period and profiles in Fig. 2 was about 0.5 mm, well within the realm of accuracy needed for daily *ET* determinations. However, upward movement of water into the soil profile limits the neutron method. Van Bavel et al. (1968) reported upward fluxes as high as 4 mm per day under irrigation. To what extent upward fluxes occur in semiarid rangeland is not known. The plot of *ET* from rangeland adjacent to the lysimeter (Fig. 2) indicates a gain in soil water between August 26 and September 5 (a period during which only 0.5 mm of precipitation occurred). A similar trend for that period was noted on nearby rangeland where soil water was determined weekly. Soil water between the 75- to 120-cm depths also increased slightly during this period, indicating upward movement of water from deeper depths. Evapotranspiration measured in the lysimeters (Table 1) was, with the exception of the 0% cover plot, slightly higher than the measured *ET* from adjacent rangeland.

Table 1. Comparison of seasonal *ET* values (cm) for lysimeters as determined by two methods of measurement and for rangeland adjacent to the lysimeters as determined by the neutron method. April 22 to August 22, 1968.

Treatment (% of native plant cover removed[1])	*ET* from the lysimeter: Lysimetry	*ET* from the lysimeter: Neutron method	*ET* from rangeland adjacent to lysimeters
0	24.8	25.5	22.7
25	20.6	21.2	20.4
50	23.6	23.8	20.6
75	20.8	21.6	18.7
100	13.5	16.8	17.5

[1] Plant cover was removed by rototilling appropriate portions of meter-wide strips of native range.

Table 2. Correlation between *ET* measured by a lysimeter and the neutron method and between a lysimeter and adjacent rangeland as measured over increments of time.

Time intervals for which *ET* was determined	1968 L vs I[1]	1968 L vs O	1968 I vs O	1969 L vs I	1969 L vs O	1969 I vs O
	r values					
1 week	.36	.57	.58	.16	.11	.56
2 week	.40	.77	.79	.41	.18	.14
3 week	.66	.75	.81	.51	.69	.86
4 week	.74	.92	.86	.66	.97	.59
Weekly cumulative	.99	.99	.99	.99	.99	.99

[1] L = *ET* determined by the lysimeter.
I = *ET* determined by the neutron method inside the lysimeter.
O = *ET* determined by the neutron method on rangeland adjacent to the lysimeter.

These differences may be due to small errors of measurement on the adjacent rangeland resulting from upward water fluxes.

Nonweighing lysimeters similar to the one proposed by Van Bavel and Stirk (1967) would eliminate both the problem of upward water movement and percolation through the profile. In conjunction with the neutron method, these lysimeters would be a useful tool for determining *ET* over short time intervals.

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