Soil Moisture Response to Spraying Big Sagebrush the Year of Treatment

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Highlight: *Spraying big sagebrush with 2,4-D in Wyoming reduced soil moisture loss 24% between June 24, the treatment date, and September 30. All of the reduction accrued by August 4, during the time of active vegetative growth. Moisture was measured to a 6-ft depth and 83% of the reduction was located in soil 2 to 6 ft deep.*

Livestock grazing is the dominant land usage on 145 million acres of sagebrush lands in the West. Numerous studies, substantiated by ranchers' practical experiences, amply demonstrate that production by grasses at least doubles after chemical control of sagebrush. This practice is now one of the chief management techniques for improving rangeland production. Kearl[1] estimates that 1.3 to 1.4 million acres of sagebrush range have been sprayed in Wyoming alone through 1970, and extensive areas have also been sprayed in other western states.

Ecologic changes, other than herbaceous production, which accompany spraying have not received attention commensurate with their importance. Modification of the soil moisture regime is one such important change. After control, the moisture normally withdrawn by sagebrush becomes available for other on-site uses, or may ultimately enter a groundwater system and augment streamflow. The ultimate test of how sagebrush control affects water yield must come from precise streamflow measurements before and after treatment. Streamflow, however, is an integrated product of all hydrologic processes operating within a watershed and indicates little about functioning of individual components. This paper focuses on one of the most important hydrologic processes of sagebrush rangeland—soil moisture withdrawal during the summer months—and how chemical control of big sagebrush (*Artemisia tridentata* Nutt.) affects withdrawal in the treatment year.

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[1]Unpublished material from W. G. Kearl, agricultural economist, University of Wyoming, Laramie.

Literature Review

Most studies concerned with the effects of big sagebrush control on the soil moisture regime have been conducted in Wyoming, but the results are inconclusive. Sonder (1959) measured soil moisture gravimetrically the year after treatment at a low-elevation site in the Red Desert of Wyoming and 6 years after spraying at a middle-elevation site in the Big Horn Mountains. Soil samples were collected once a month in July, August, and September at depths of 0-1, 6-7, 12-13, and 18-19 inches. Soil moisture content, when averaged over all sample depths and sampling dates at the Red Desert location, was 1.7% higher under the sprayed stand. Treatment differences were not detected in the Big Horn Mountains. Sheets (1968) followed soil moisture levels under sprayed and unsprayed sagebrush stands in southcentral Wyoming for 4 years after treatment. Soil moisture content was measured with the neutron probe to a depth of 4 ft. Spraying had no effect on moisture depletion the treatment year, but withdrawal was reduced in June the year after treatment. However, no differences were detected in the second, third, or fourth year after treatment.

In still another Wyoming study at a high-elevation big sagebrush stand, the neutron probe was used to evaluate soil moisture change to a depth of 6 ft the second growing season after treatment. In contrast to other studies, Tabler's (1968) data indicated that summer moisture withdrawal was substantially reduced by spraying. Soil moisture was measured every 2 to 3 weeks at 1-ft increments. An overall reduction of 14% in seasonal moisture depletion was found with 86% of the difference accruing between June 24 and August 22, and 75% of the total difference localized in soil deeper than 3 ft. Moisture extraction was actually greater at the 1-2 ft depth in the sprayed stand, which was attributed to increased moisture use by grasses responding to release from sagebrush competition.

In Utah, Cook and Lewis (1963) measured soil moisture gravimetrically at depths of 1, 2, and 3 ft during July and August for 3 years after sagebrush control. Soil moisture content at the 1-ft depth was similar for sprayed and unsprayed sagebrush stands each year. Moisture content was 1.2 and 1.9% greater at depths of 2 and 3 ft, respectively, under sprayed sagebrush the year following treatment, and 0.8 and 1.5% greater at these depths the second year. By the third year after spraying, no differences were found at any depth.

Tabler's (1968) data indicate that the zone of greatest treatment effect is missed when soil moisture measurements are confined to the surface 3 ft of soil. Sagebrush rooting characteristics help explain this finding. Both Tabler (1964) and Cook and Lewis (1963) conducted root studies in the same location as their soil moisture work. Sagebrush plants in Wyoming were between 21 and 56 years old, with a maximum root depth between 5 and 6 ft and a lateral spread of 5 ft. The Utah plants were only 7 or 8 years old, but still exceeded 5 ft in depth and had a maximum lateral spread of more than 25 inches. These rooting patterns verify results from big sagebrush root studies conducted throughout the West.

Fig. 1. *The 14 study plots are located on a north-facing slope in two strips separated by an access road.*

Experimental Area and Procedures

The experimental site lies within the Stratton Sagebrush Hydrology Study area in southcentral Wyoming, 18 miles west of Saratoga. The climate is characterized by long, cold winters with strong southwesterly winds averaging 15 mph, and a short but relatively warm growing season extending from mid-May into September. Average annual precipitation, October 1 through September 30, for the 1968-1971 period was 14.36 inches with two-thirds of this amount falling as snow. The study site is 7,300 ft in elevation and lies in a moderate snow accumulation zone. Consequently, water available from snow for soil moisture recharge exceeds winter precipitation. Summer precipitation is recorded onsite with a recording rain gauge.

The soil has developed in place from sandstone of the Brown's Park formation. The A and B horizons are both 12 inches thick with a sandy-loam and loam texture, respectively, and are slightly acid. The C horizon is composed of from 25-90% fine-grained sandstone fragments embedded in a sandy loam matrix. The rocks are not well cemented, readily transmit water, and offer no significant barrier to root growth.

Fourteen 1-acre plots were established along the contour in two strips on a 6% north-facing slope in October 1968 and fenced to exclude grazing (Fig. 1). Vegetation consists of a dense stand (19,000 plants per acre) of big sagebrush, with a productive understory of bunch grasses comprised chiefly of Idaho fescue (*Festuca idahoensis* Elmer) and bluegrasses (*Poa* spp.). Most sagebrush plants were 30-50 years old, and the sagebrush stand had an average live, leafy canopy cover intercept of 28%. Vegetation was grazed by sheep each year prior to study establishment.

The soil moisture measurement area on each acre plot was isolated by placing a buffer strip 33 ft wide around the perimeter of a plot. Soil moisture was measured to depths of 6 ft with a neutron moisture meter at four access tubes per plot; access tubes were randomly located inside the buffer strip. Data from the four tubes were averaged to indicate average plot moisture content. Moisture content was measured at six depths per access tube, beginning at 6 inches and continuing downward by 12-inch increments to 66 inches. One-minute slow-neutron field counts were converted to volume moisture content with the manufacturer-supplied calibration curve for all but the 6-inch depth. Here, field counts were corrected for the escape of neutrons through the soil surface using the polyethylene shield technique described by Pierpoint (1966). Soil moisture measurements began in May subsequent to snowmelt and continued at 2-3 week intervals through September, except at the time of spraying when additional measurements were made.

Data were tested by analysis of variance within a split-plot experimental design containing 14 whole-units (the 1-acre plot) arranged in seven blocks; the six measurement depths at an access tube comprised subunits. Treatments were assigned at random within a block. Besides testing for total treatment differences, the variance model permitted testing withdrawal at the six measurement depths for differences and testing for a treatment-depth interaction. A separate variance analysis based on the change in plot moisture content between sampling dates was made for each measurement interval and for total seasonal change.

Moisture withdrawal characteristics were measured in the 1969 growing season when all plots were untreated. Treatment plots were sprayed June 23 and 24, 1970, with 2.8 pounds of 2,4-D per acre applied from a truck-mounted spray rig. The purpose of measurements in 1969 was to establish whether or not plots assigned to the two treatments had similar withdrawal characteristics prior to spraying, to identify plot variability for all measurement parameters, and to test the adequacy of the experimental design to detect expected treatment differences.

Results

The Year Preceding Treatment

Soil water content on May 13, the initial measurement date in 1969, was almost identical for both treatments. Plots assigned to the unsprayed treatment had an average water content of 27.8 inches over the 6-foot measurement zone, while plots assigned to the spray treatment contained 27.6 inches water. Moisture measurements continued through the summer until September 29; 4.25 inches precipitation fell during the 139-day measurement interval. Cumulative seasonal moisture loss and daily precipitation are shown for both treatments in Figure 2.

Moisture depletion was similar for both treatments in 1969, attesting to the uniformity of soil and vegetative conditions across the experimental site (Fig. 2). Cumulative seasonal withdrawal equalled 11.2 inches on plots assigned to the spray treatment and 10.9 inches for plots in the unsprayed treatment. This difference was not statistically significant, nor was the difference in withdrawal between treatments significant for any sampling interval. The only term consistently significant ($P < 0.05$) in the variance analysis was "depth," as moisture withdrawal was greater in surface soil than at greater depths. Based on the 1969 data for cumulative seasonal moisture withdrawal, a 10% decrease in depletion was detectable at the 0.05 probability level for a type I error and a 0.20 probability level for a type II error.

Treatment Year

Moisture measurements began May 27, 1970, 2 weeks later than in 1969 because of delayed snowmelt, and terminated September 30. Soil water content to a 6-ft depth was the same for both treatments on May 27, and within 1 inch of that on the first measurement date in 1969. Summer precipitation was 5.29 inches.

Both treatments had similar depletion patterns until application of 2,4-D June 23 (Fig. 2). Then, depletion decreased sharply on sprayed plots in comparison to undisturbed vegetation (Table 1). Seasonal depletion in the surface 6 ft of soil was reduced 24% between June 22 and September 30, which was highly significant ($P < 0.01$). Depletion from sprayed and unsprayed sagebrush stands after treatment equalled 7.1 and 9.4 inches, respectively.

Sagebrush was growing rapidly when sprayed, and an excellent kill was achieved. Brush appearance had changed noticeably within 1 week after spraying, but most leaves remained on the sprayed plants until mid-August, even though they were brown and brittle. More than 95% of the sagebrush plants were estimated as dead in early October.

Spraying with 2,4-D greatly modified the quantity of vegetation produced. Herbaceous production, including current growth of sagebrush, was measured in July both years as grasses matured. Total production averaged 1,265 pounds per acre of oven-dry herbage the year before treatment. The contribution by sagebrush, grass, and forbs was 921, 295, and 49 pounds per acre respectively or 73, 23, and 4% of the total. Untreated sagebrush plots produced 1,167 pounds oven-dry herbage per acre in 1970, which was similar to production in 1969. Spraying decreased total production 63%, to 437 pounds per acre, because of the loss of sagebrush. Grass production increased 20% with respect to unsprayed plots, but combined grass-forb production was similar for both treatments since the decrease in forb production on sprayed plots was offset by increased grass production.

Table 1. Moisture loss (inches) at six measurement depths following sagebrush control, June 23–September 30, 1970.

Treatment	Depth (ft)	Depletion between sampling dates 6/22–7/1	7/1–7/8	7/8–7/22	7/22–8/4	8/4–8/19	8/19–9/2	9/2–9/16	9/16–9/30	Cumulative season change 6/22–9/30
Sprayed	0–1	0.9	0.4	+0.5	0.6	0.1	+0.1	+0.9	0.3	2.3
Unsprayed		1.0	0.4	+0.6	0.7	0.0	+0.1	+0.8	0.4	2.5
Sprayed	1–2	0.3	0.3	0.6	0.2	0.3	0.1	0.1	0.0	1.9
Unsprayed		0.5	0.6	0.7	0.2	0.1	0.0	0.0	0.0	2.1
Sprayed	2–3	0.1	0.1	0.2	0.1	0.3	0.1	0.2	0.0	1.1
Unsprayed		0.2	0.2	0.6	0.4	0.2	0.1	0.1	0.0	1.8
Sprayed	3–4	0.1	0.1	0.1	0.0	0.2	0.1	0.1	0.0	0.7
Unsprayed		0.1	0.1	0.3	0.2	0.3	0.1	0.1	0.0	1.2
Sprayed	4–5	0.0	0.1	0.1	0.0	0.2	0.1	0.1	0.1	0.7
Unsprayed		0.0	0.1	0.2	0.1	0.3	0.2	0.1	0.0	1.0
Sprayed	5–6	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.4
Unsprayed		0.0	0.1	0.2	0.0	0.3	0.1	0.1	0.0	0.8
Sprayed	0–6	1.4	1.0	1.1	0.9	1.2	0.5	0.6	0.4	7.1
Unsprayed		1.8	1.5	2.0	1.6	1.2	0.5	0.4	0.4	9.4

Soil moisture was measured 8 and 15 days after spraying to determine how quickly the depletion rate changed after treatment. The herbicide acted almost immediately; sprayed plots lost 22% less moisture the first 8 days after treatment and 33% less moisture over the next 7 days. Moisture withdrawal on treatment plots was significantly less ($P < 0.05$) after spraying for sampling intervals through August 4, but after this date depletion was similar for both treatments (Table 1).

The reduction in depletion was not uniform with depth (Fig. 3). The difference in withdrawal between unsprayed and sprayed vegetation equalled 0.2, 0.2, 0.7, 0.5, 0.3, and 0.4 inch per foot at the six measurement depths beginning at the 0-1 ft depth. Thus 83% of total reduction came at depths greater than 2 ft. The

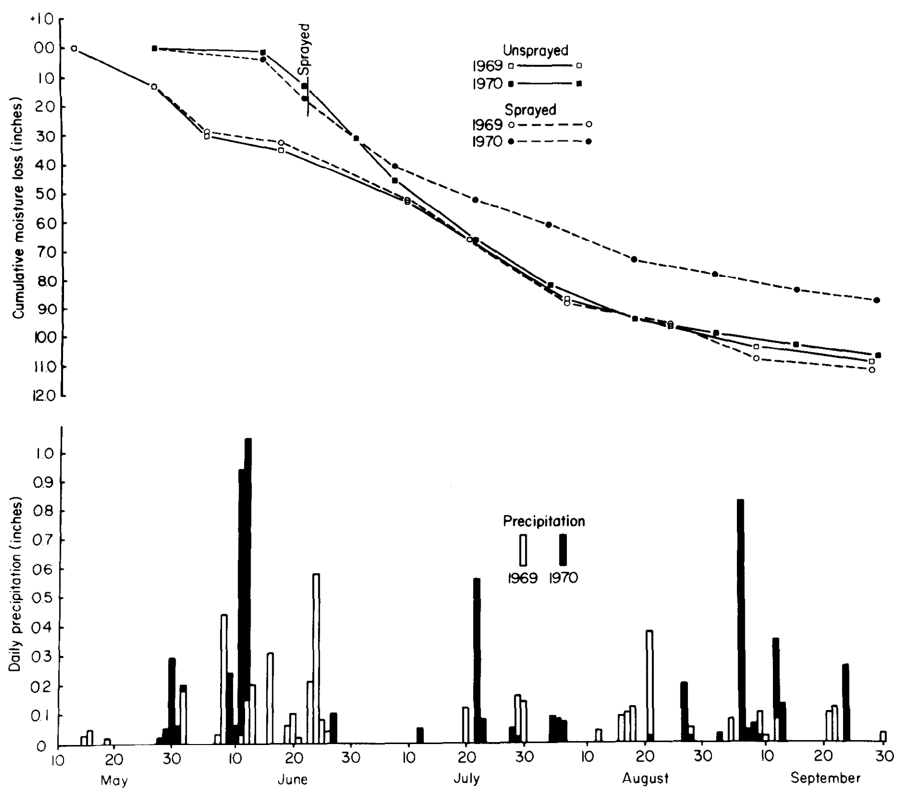

Fig. 2. *Cumulative change in moisture content and daily precipitation for the 1969 and 1970 growing seasons.*

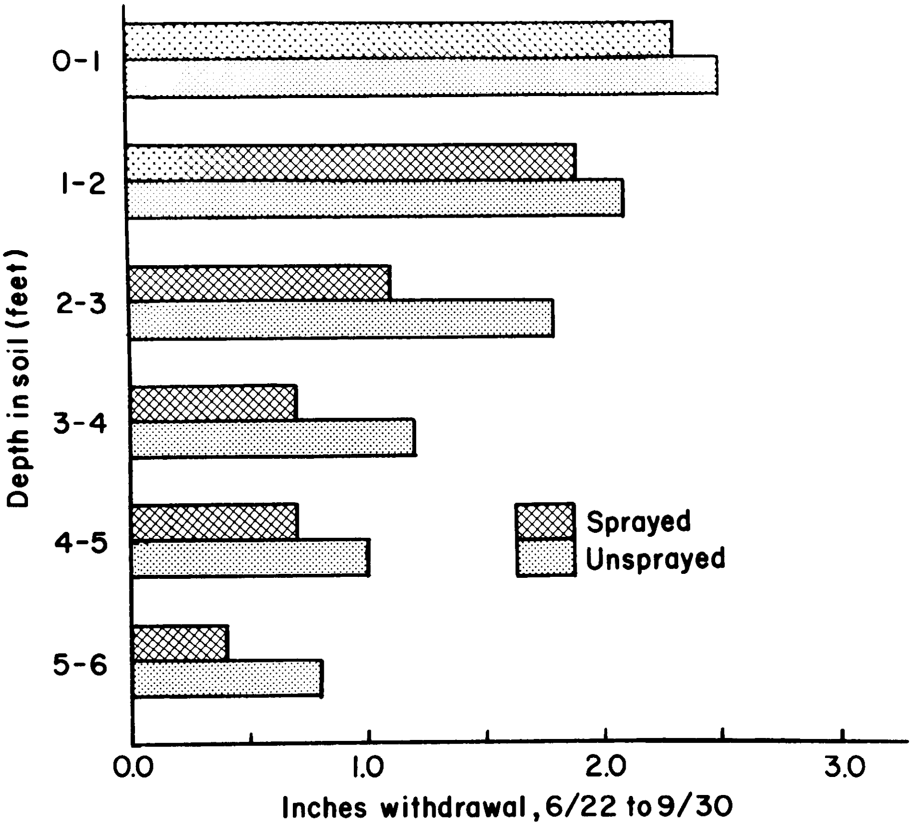

Fig. 3. *Seasonal moisture withdrawal at six measurement depths following sagebrush control June 22, 1970.*

reduction was also concentrated into a relatively short time period. The overall difference in withdrawal was 2.3 inches, and all of the difference accrued by August 4.

The change in withdrawal between treatments was concentrated in the upper 3 ft of soil immediately after spraying. Major withdrawal zones shifted to the 3-6 ft depth under sagebrush stands as the season advanced and remained there until mid-September. Moisture withdrawal for the August 4-19 period depicts the shift in depletion zones particularly well. Both treatments had an average profile loss of 1.2 inches, but losses were almost reversed at the 0-3 and 3-6 ft depths (Table 1). The loss under sprayed and unsprayed plots in the surface 3 ft of soil was 0.7 and 0.3 inch, respectively, but at depths of 3-6 ft, losses were 0.5 and 0.9 inch. Grasses were still using some water from the upper 3 ft of soil during this period, although most species had matured and set seed. The deep root system of sagebrush enabled it to draw water from below the major rooting zone of herbaceous species.

Discussion

The seemingly contradictory results of this and Tabler's (1968) study with conclusions of earlier authors probably stem from several sources. Most importantly, early studies failed to sample soil moisture throughout the full rooting zone of sagebrush. Current results as well as those of Tabler indicate that most of the reduction in moisture withdrawal after spraying is from soil deeper than 2 or 3 ft. Sonder (1959) sampled only to 18 inches, while Cook and Lewis's (1963) deepest sample depth was 3 ft.

The neutron probe is superior to gravimetric sampling for soil moisture studies, particularly when the parameter of interest is the *change* in moisture content. The covariance between repeated measurements at the same location greatly reduces sampling variance. The neutron probe has a sphere-of-influence large enough to smooth out many of the micro-variations in soil moisture content encountered with gravimetric sampling, which also decreases sampling variance.

By sampling soil moisture throughout the soil profile and at frequent intervals during the growing season, major zones of water use can be identified, as well as periods of active moisture extraction. Rainfall during the period of most active growth, mid-June-July was 1.82 and 0.86 inches in 1969 and 1970, respectively, and usually less than 0.25 inch was received per day. Consequently, depletion largely reflected evapotranspirational losses in the period. Depletion rates for natural sagebrush stands were similar in both years (Fig. 2) and reflect extraction rates necessary to sustain physiologic processes during active growth. Early in August, however, the rate of depletion decreased sharply, which coincided with the time grasses were maturing and sagebrush was completing its vegetative growth for the year.

The 24% reduction in depletion measured in this study indicates that spraying can have a pronounced influence on the soil moisture regime of sprayed sagebrush lands where conditions are similar to those at the study site. The sagebrush stand was extremely dense, soils were deep, and deposition of winter snow ensured sufficient water to fully recharge the soil mantle. The reduction in soil moisture withdrawal was not uniform through the soil mantle, but was concentrated below 2 ft in soil formerly occupied by live sagebrush roots but below the major rooting zone of residual vegetation. The reduction in depletion was also concentrated into a short time interval while vegetation was actively extracting water to support vegetative development, and did not accrue uniformly through the summer months.

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