Indifference of Mountain Big Sagebrush Growth to Supplemental Water and Nitrogen

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Abstract

The responses of mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana* (Rydb.) Beetle) to small annual additions of water and/or nitrogen were investigated in southwestern Wyoming. A factorial field experiment with 2 levels of water (0 or 4 liters per plant in May) and 2 levels of ammonium nitrate fertilizer (0 or 31 kg N ha^{-1}) was conducted with mountain big sagebrush tubelings from 1981 through 1984. End-of-season aboveground biomass and relative growth rate were not affected during 1982-84. Twig growth, ephemeral leaf survival, plant phenology, plant water potential and its components were likewise unaffected by the water and nitrogen treatments during the 1983 and 1984 growing seasons. Lack of a supplemental water main effect or a water × nitrogen fertilizer interaction probably were not evident because of above-average precipitation at the research site during the experimental period. The most likely explanation for the observed lack of nitrogen effect is that the nitrogen additions were small in relation to the total amount available to the plants.

Key Words: *Artemisia tridentata* ssp. *vaseyana*, water potential, phenology

Water is commonly believed to be the factor most limiting to plant growth in arid and semiarid areas (MacMahon and Schimpf 1981). When adequate water is provided, nitrogen may be regarded as the factor that limits plant growth in arid environments (Skujins 1981). Consequently, shrubs in these environments should respond to irrigation and nitrogen fertilization. However, reports in the literature are not unanimous in this regard (e.g., Hodgkinson et al. 1978; Skujins 1981).

A field experiment was initiated to test the hypothesis that mountain big sagebrush individuals receiving supplemental water and nitrogen have more favorable water relations and leaf survival, which should lead to greater twig growth and greater seasonal biomass production.

Methods

This study was conducted at the Pittsburg and Midway Coal Mining Company's coal strip mine located near Kemmerer in southwestern Wyoming. The site is located in the western Intermountain sagebrush steppe vegetation type (West 1983) at an elevation of 2,210 m. The mean annual precipitation from 1951–1980 at Kemmerer (about 15 km from the site and 100 m lower in elevation) was 230 mm, about half of which typically falls as snow (National Oceanic and Atmospheric Administration 1982). For additional information about the site, see Allen 1983, Parmenter and MacMahon 1983.

The site is a reclaimed mine pit where the spoils were backfilled and regraded in 1979 with original, stockpiled topsoil reapplied to a depth of 0.1 to 0.2 m in 1981. The topsoil removal and redeposition resulted in the homogenization of soil nutrients, eliminating islands of fertility (Garcia-Moya and McKell 1970), which may have existed prior to mining (Allen and MacMahon 1985).

On 15 May 1982, container-grown, 1-year-old mountain big sagebrush individuals were transplanted to the study site, and each plant received 1 liter of water. Throughout the period of the study, weeds were regularly removed in a circular area 2 m in diameter around each plant.

The experimental design was a completely randomized, 2-factor factorial design with 2 levels of each factor. There were 4 treatments: control, added water, added nitrogen fertilizer and both added water and nitrogen fertilizer. One hundred forty-seven mountain big sagebrush individuals were planted 2.5 m apart in a regular grid pattern with each plant being an experimental unit. Thus, each treatment was replicated 36 or 37 times.

This experiment was part of a larger project aimed at determining if snow and litter or soil fines which accumulate under big sagebrush plants affect plant performance. Because the water equivalent of the snow and the nitrogen equivalents of the accumulated materials were anticipated to be modest during the first 3 years of shrub growth, the amounts of added water and nitrogen used in this study were correspondingly small.

Plants in the water treatment received an additional 4 liters of water on 29 May 1982, 26 May 1983, and 18 May 1984. Each of the fertilizer treatment plants received about 1.15 g of ammonium nitrate fertilizer on the same dates as the added water. The water + fertilizer plants received both supplements simultaneously and the control plants received neither.

On 17 June 1982, the initial aboveground biomass of each of the experimental plants was estimated using the reference unit method (Andrew et al. 1979, 1981). This procedure was repeated on 3 Sep. 1982, 15 Aug. 1983, and 15 Aug. 1984 to estimate end-of-season aboveground biomass. Biomass in this study refers to aboveground plant parts only.

At the beginning of the 1983 and 1984 growing seasons, 25 plants were randomly selected in each treatment. Three twigs on each plant were randomly selected and tagged with different colored wires. The length of each marked twig, survival, and phenology of each marked twig were recorded at approximately weekly intervals each summer. On 7 June 1983, one ephemeral leaf on each of the marked twigs was tagged with 28 gauge wire, and the survival of each marked leaf was recorded on each sampling date.

Leaf water potentials of 6 plants in each treatment were measured about once a week from June–August 1983 using a pressure chamber. The samples were collected within 0.5 hours of 1400 MDT when leaf-air vapor pressure differences were likely to be greatest. Treatment differences were anticipated to be most apparent under these conditions. In 1984, leaf water potentials were measured from May–August with leaf psychrometers. Leaf samples from 7 to 9 shrubs in each treatment were collected predawn (0500 MDT) and near midday (1400 MDT) about once a week.

Experimental data were tested for normality using an algorithm in Minitab (Ryan et al. 1982). The 1982 and 1983 end-of-season biomass data were normalized using a $\log_e$ transformation. Treatment differences were evaluated using analysis of variance with untransformed or transformed data as appropriate. Statistical sig-

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Research was funded by the National Science Foundation grant DEB 81-01827 to the Utah State University Ecology Center. The Pittsburg & Midway Coal Mining Company provided the research site and important logistical support. The comments of Drs. Michael F. Allen, Douglas A. Johnson, and anonymous reviewers greatly improved the manuscript.

Manuscript accepted 13 April 1987.

nificance was assessed at P=0.05.

Results

End-of-season biomass means (1982–1984) were not significantly different among treatments. The pooled treatment means at the end of the 3 growing seasons were 5.5, 98, and 230 g, respectively. Although average relative growth rates varied among 3 years of the study, differences among treatments were not significant. The pooled treatment means for the 1982, 1983, and 1984 growing seasons were 1, 3, and 1 g g^{-1} $season^{-1}$, respectively.

Twig elongation rates did not differ significantly among treatments in 1983 or 1984 on any sampling date. Therefore, the data were pooled across treatments to show seasonal trends (Fig. 1).

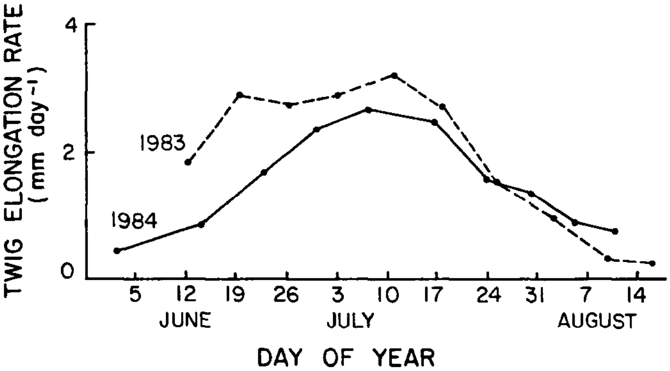

Fig. 1. *Twig elongation rates of watered and fertilized mountain big sagebrush plants during June–August 1983 and 1984. Because treatment differences were not significant, data have been pooled across treatments.*

During 1983, sagebrush plants had greater elongation rates from early June to mid July compared to 1984. From mid July to mid August, twig elongation rates were similar for both years.

Leaf water potential was not significantly affected by treatment in 1983 or 1984. During both years, leaf water potential means for data pooled across treatments did not fall below -2.3 MPa (Fig. 2). Predawn and midday leaf osmotic and turgor potential were not significantly different among treatments during 1984.

Survival of ephemeral leaves and twigs in 1983 and 1984 was very similar among treatments. The onset of mortality of tagged leaves appeared to be related to decreasing leaf water potential in 1983, but this relationship was less apparent in 1984 (Figs. 2, 3). In 1983 twigs began dying about the same time as ephemeral leaves began dying. The greater twig mortality in 1984 may have been caused by increased shading of twigs which were overshadowed by more rapidly growing branches.

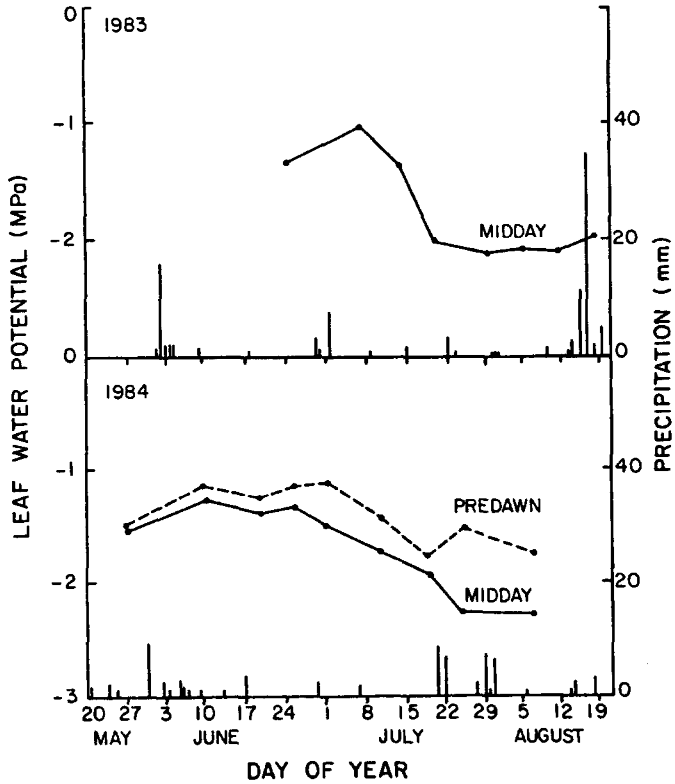

Fig. 2. *Predawn and midday leaf water potential of watered and fertilized mountain big sagebrush plants during 1983 and 1984. Predawn measurements were not made in 1984. Data have been pooled across treatments because treatment differences were not significant. Dashed lines connect predawn means, and solid lines connect midday means. Vertical lines denote precipitation at the site during the summer.*

There was little indication that treatment had any effect on the phenological state of the marked twigs. Chi-square tests of association for each sampling date for cells with an expected value greater than 5 were all nonsignificant. In 1984, most twigs began elongating at a later date than in 1983, as reflected in the lower percentage of twigs in phenological stage 3 until mid July 1984 (Table 1). The development of floral buds, phenological stage 4, began about 3 weeks later in 1984 than in 1983. Also, fewer twigs developed floral buds while more twigs never elongated in 1984.

Table 1. Percentage of twigs tagged 7 June 1983 and 16 May 1984 in each phenological stage on successive dates in 1983 and 1984, respectively. Phenological state 2 = buds dormant; 3 = twigs rapidly elongating; 4 = floral buds developing. Data were pooled across treatments.

	Sampling date in 1983										
Pheno. stage	9 June	14 June	23 June	29 June	6 July	14 July	20 July	28 July	5 Aug	12 Aug	17 Aug
Dead	0.0	0.0	0.0	0.2	0.5	0.5	2.2	3.8	8.2	10.0	13.5
2	19.0	10.5	6.2	4.2	3.5	3.5	3.0	2.2	1.0	1.0	0.2
3	81.0	89.5	93.8	95.5	78.8	63.0	53.0	50.2	46.0	44.8	42.2
4	0.0	0.0	0.0	0.0	16.5	32.5	41.5	43.5	44.8	44.2	43.5
	Sampling date in 1984										
Pheno. stage	26 May	9 May	18 June	26 June	2 July	12 July	19July	26 July	1 Aug	7 Aug	13 Aug
Dead	0.0	0.0	2.0	2.8	2.8	3.8	7.0	11.5	15.8	19.8	24.5
2	96.8	76.5	58.2	42.2	34.8	31.2	28.0	23.2	19.8	15.8	11.2
3	3.2	23.5	39.8	54.8	62.8	64.5	64.5	54.0	53.5	54.2	53.8
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.5	11.5	12.8	12.8

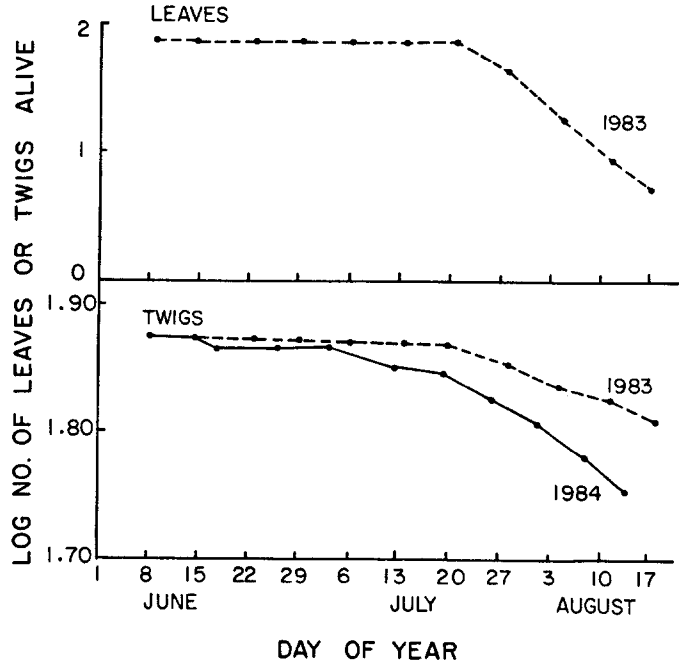

Fig. 3. *Survival of ephemeral leaves and twigs during June–August 1983 and 1984 for watered and fertilized mountain big sagebrush plants. Leaf survival data were not collected in 1984. Data have been been pooled across treatments.*

Discussion

Many authorities have stated that water limits plant growth in arid and semiarid environments (MacMahon and Schimpf 1981). Thus, one would expect the addition of water to stimulate growth in desert perennial plants. However, field irrigation trials using shrubs native to the Great Basin and Mojave Desert have sometimes failed to elicit a growth response (e.g., MacMahon et al. 1976, Hodgkinson et al. 1978, Romney et al. 1978, Johnson and Norton 1980).

In this study, there was no evidence that small additions of water or nitrogen fertilizer in the late spring had any effect on mountain big sagebrush. The lack of response to the 4 liters of added water during 3 successive years is not surprising in light of the abundant precipitation during this period, ranging from 524 to 429 mm annually, much more than the long-term mean (230 mm). The lowest mean leaf water potential for mountain big sagebrush recorded during this study was -2.4 MPa on 5 Aug. 1983, indicating that soil moisture was relatively abundant in the rooting zone of these plants. This minimum plant water potential was considerably higher than seasonal minima for big sagebrush reported by Branson et al. (1970, 1976) from Montana and Colorado (-5.5 MPa), by Dina and Klickoff (1973) from Utah (-7.0 MPa), and by Campbell and Harris (1977) from Washington (-7.0 MPa).

According to Skujins (1981), nitrogen fertilization has little effect on perennial plant growth in unirrigated, desert conditions. In a 2-year study in northern Utah, James and Jurinak (1978) found that shadscale and big sagebrush had variable responses to nitrogen fertilization. One year's application of fertilizer at a rate of 67 kg N ha^{-1} failed to produce any effect in either species. Another year's application of nitrogen fertilizer at the same rate produced greater tissue nitrogen concentration in sagebrush and greater shoot weight and tissue nitrogen concentration in shadscale. Goodman (1973) applied ammonium sulfate fertilizer on salt desert vegetation in northern Utah. He found no significant growth response of the shrub species he tested to the fertilization, although he did find that fertilizer encouraged the growth of exotic annuals.

Trumble and Woodroffe (1954) stated that once soil moisture is plentiful, nitrogen is the factor which limits plant growth in arid or semiarid situations. This is consistent with the resouce-ratio hypothesis of Tilman (1982, 1985). According to Tilman's hypothesis, when a limiting essential resource (such as water) is added to a habitat, the increased biomass which is produced leads to increased demand for other resources. The abundant soil moisture from 1982–1984 probably increased sagebrush biomass over what it would have been in dry years, causing an increased sagebrush demand for resources such as available nitrogen. Thus, the added nitrogen would be expected to promote additional sagebrush growth, but this was not observed. There was no significant effect of nitrogen on any of the response variables monitored. There may be several possible explanations for this lack of response.

Perhaps, the simplest explanation is that the amount of nitrogen fertilizer added was too small relative to the amount of nitrogen already available in the soil to be of much consequence. To assess this possibility, we estimated the amount of nitrogen present in the rooting zone of a hypothetical mountain big sagebrush plant and compared this to the estimated amount of nitrogen contained within the same hypothetical plant. We assumed a rooting zone 0.2 m in radius and 0.8 m deep (Rodriguez 1985) consisting of topsoil 0.2 m deep with a total nitrogen concentration of 0.1% by weight and subsoil (actually mine spoil) 0.6 m deep with a total nitrogen concentration of 0.01% and a soil bulk density of 2.7 g cm^{-3}. These nitrogen concentrations are typical of topsoil and subsoil at the site. The total nitrogen contained within this volume would be 88 g; this is equivalent to 7,010 kg N ha^{-1}, very similar to that found for a saltbush-dominated site in northern Utah (West and Skujins 1977).

Assuming an aboveground biomass increase of 125 g, typical of the experimental big sagebrush plants between 1983 and 1984, a root:shoot production ratio of 3:1 (Caldwell and Camp 1974), and an average tissue nitrogen concentration of 2%, the total amount of nitrogen required for the year's growth would be 10 g. Not all of the nitrogen present would be available to the plant. Even if only a modest fraction were available, the big sagebrush plants in 1984 could have met their nitrogen needs without using any of the added nitrogen. During 1982 and 1983 when the plants were much smaller, the ratio of nitrogen available in the soil to nitrogen needed by the plant would have been even greater.

It is possible that the lack of nitrogen effect reflects the lack of genetic capability of the plants used in this study to utilize more than modest amounts of nitrogen. Wildland plants from sites with low to moderate soil fertility are generally regarded as being relatively unresponsive to increased soil fertility, particularly when compared to crop plants (Chapin 1980). Long-lived plant species of harsh, nutrient-poor environments frequently exhibit little or no growth response when fertilized but may increase nutrient concentrations in their tissues. The plants may indulge in luxury consumption, taking up more nitrogen than they can immediately use, sequestering the excess for later use by the plant for growth or dropped as litter. In this study, total percentage nitrogen of ephemeral mountain big sagebrush leaves collected in June 1984 averaged 3.2, 3.1, 3.1, and 3.3% for the control, water, fertilizer, and water + fertilizer treatments, respectively. Treatment differences were not significant. These high values indicate that luxury consumption of nitrogen may have occurred, a conclusion consistent with the lack of a nitrogen effect on big sagebrush growth.

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