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Chemical Management of Silver Sagebrush

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Introduction

Silver sagebrush is a shrub that grows on highly productive prairie soils with the potential to produce considerable grass herbage. The shrub, which is taller than the grasses and forbs in the plant community, shades the understory from sunlight, severely reducing herbaceous plant density and herbage biomass production; diminished carrying capacity of the grasslands results. Traditional grazing practices that include early or late season grazing or heavy utilization of the grass component increase the abundance of silver sagebrush. Numerous grazinglands in the Northern Plains have problem levels of silver sagebrush infestations and require brush management.

The goal of silver sagebrush management should be reduction rather than elimination, because the shrub is assumed to have value for some wildlife and a few subspecies or ecotypes are palatable as livestock browse. This report summarizes available biological information about silver sagebrush and evaluates chemical management treatments using tebuthiuron to reduce silver sagebrush plants.

Management of silver sagebrush is not simple. Biologically effective grazing management practices improve the health and competitive abilities of the native grass plants and enhance the biogeochemical processes within the ecosystem but do not reduce the size and density of preexisting silver sagebrush plants. Silver sagebrush topgrowth is relatively easy to kill with a heavy duty brush mower, prescribed burning, or 2,4-D applied at 2.0 lb ae/ac when rapidly growing new twigs are 3 to 4 inches long (Vallentine 1974). However, management practices that kill only the aboveground plant parts produce merely short-term setbacks.

Silver sagebrush has two well developed recovery mechanisms, and after the tops of the shrubs have been killed by management treatments, the plants usually grow back at densities greater than pretreatment levels. Silver sagebrush reproduces by both seedlings and vegetative sprouts. Seed viability is usually quite high, and germination is generally around 60% to 85% (Hou and Romo 1998a). Vegetative spouts grow from belowground vertical stems and horizontal rhizomes, with about 3 to 14 sprouts for each plant with topgrowth killed (White and Currie 1983).

Names

The scientific name of silver sagebrush is *Artemisia cana* Pursh, and the plant belongs to the Anthemideae tribe in the aster family, Asteraceae, which is also known as the sunflower family, Compositae (Great Plains Flora Association 1986, Johnson and Larson 1999). The "silver" portion of the shrub's common name comes from the impression given by sunlight reflecting off the pubescent leaves. The plant's other common names are dwarf sagebrush and hoary (white) sagebrush.

Distribution

Silver sagebrush is widely distributed throughout most of west central North America. The primary range includes western North Dakota, western South Dakota, northwestern Nebraska, northern Colorado, Wyoming, Montana, southern Alberta, southern Saskatchewan, and southwestern Manitoba. The shrub has scattered distribution in eastern North Dakota, central South Dakota, southern British Columbia, Washington, Oregon, Idaho, Nevada, Utah, Arizona, and California (Great Plains Flora Association 1986, Johnson and Larson 1999). The land area occupied by silver sagebrush is second in size only to the area occupied by big sagebrush (*Artemisia tridentata* Nutt.) (White and Currie 1983).

Habitat

Silver sagebrush grows in dry prairie on fertile, relatively deep clayey, loamy, and sandy soils. It is tolerant of alkali conditions (Johnson and Larson 1999) and occasionally supersaturated soils (Barbour and Billings 2000). Silver sagebrush is not known to grow in North Dakota on soils that developed from glacial till (Cosby 1964). Silver sagebrush grows in soils developed from alluvial deposits on floodplain terraces along streams, in soils developed in the unglaciated regions from sedimentary deposits, and in soils developed in the glaciated regions from sedimentary deposits that were exposed after the overlaying glacial till had been eroded away (Stevens 1950, Cosby 1964).

Associated herbaceous plants found growing with silver sagebrush in the Northern Plains are yarrow, white sage, white prairie aster, long-headed coneflower, western wheatgrass, slender wheatgrass, green needlegrass, and Kentucky bluegrass.

Plant Description

Silver sagebrush is a long-lived native deciduous warm-season shrub that can form extensive colonies. The aromatic shrub produces a characteristic strong odor that sometimes reaches irritating levels during the growing season. Mature shrubs are usually between 2 and 3 feet (0.61-0.91 m) tall; under some conditions, plants can reach a height of about 5 feet (1.52 m). Multiple large woody basal stems grow horizontal for a short distance belowground (the rhizome portion of the stem) before turning vertical (the upright portion of the stem). The horizontal rhizome portions do not appear to be progressive unless the upright portion of the stem is killed or removed. Rhizomes of young single stemmed plants are about 2 to 4 inches (5.08-10.16 cm) long, and rhizomes of mature plants have a length of about 2 to 4 feet (60.96-121.92 cm). The numerous twisted branches of aboveground stems form an elliptical aerial crown that is about as wide as the plant is tall. Plants with a history of damage from unfavorable environmental conditions or from management treatments are usually wider than they are tall. Older branches have grayish-brown shredding bark that is shed in irregular thin, long, narrow strips. Younger branches have tan bark. Current year's stems are silvery and covered with long, soft hairs. The long, narrow leaves are simple, alternate, linear, and pointed at both ends. Typical leaves are 0.75 to 3.25 inches (1.91-8.26 cm) long and up to 0.25 inch (0.64 cm) wide. Both top and bottom leaf surfaces are pubescent; the short, soft hairs covering the surface give the leaves a grayish or silvery hue. Leaf edges are usually entire (not toothed), but occasionally 1 or 2 lobes may develop (Great Plains Flora Association 1986, Johnson and Larson 1999).

Sexual Reproduction

Numerous small yellowish flowers develop from the upper leaf axils in August and September. Flowers are borne on tight branching stems that form small leafy panicles. Florets on each cluster mature from the bottom upwards. Each floret contains both male and female organs and produces one small fruit, an achene. Fruits containing a single seed within a brownish, dry, hard, oblong covering that has 4 or 5 ribs ripen during September, October, and November (Great Plains Flora Association 1986, Johnson and Larson 1999). Seed (achene) dispersal occurs by wind. The seeds can be transported greater distances during late fall and winter when they are carried along with drifting snow (Barbour and Billings 2000).

Hou and Romo (1998a) investigated the relationships among seed size, time of germination, and seedling growth in silver sagebrush. Generally, large vigorous seedlings that develop from large seeds show a greater advantage for successful establishment and survival than small seedlings from small seeds (Booth and Haferkamp 1995).

The silver sagebrush seeds (achenes) collected in late September by Hou and Romo (1998a) in Saskatchewan were separated into 7 weight classes, with weights ranging from 0.53 to 0.83 mg per seed. Germination rate was determined for 4 replicates of 50 seeds in each of the 7 weight classes. Length of seedling root (radicle) was measured 5 days after germination (Hou and Romo 1998a).

The larger silver sagebrush seeds produced seedlings with greater root length. Seedling length increased 3 mm per 0.1 mg increase in seed weight. However, the heavier seeds had lower germination than the smaller seeds. Seeds with greater weight than about 0.57 mg had reduced percent total germination (Hou and Romo 1998a).

Seedling root length was greater for seeds that germinated early (within the first 3 days of incubation) than for late germinating seeds. Seedlings that germinated on days 6 to 12 were about 15% shorter than seedlings that germinated on the first day of incubation (Hou and Romo 1998a). The germination rate of silver sagebrush seeds was similar among weight classes (Hou and Romo 1998a), and seed size did not influence how early or late seedlings germinated. Silver sagebrush seedling success seems to be affected more by early seed germination than by size of the seed.

Hou and Romo (1998b) conducted a study that evaluated freezing tolerance in silver sagebrush seedlings to determine if freezing temperatures limit establishment in the Northern Plains. Hou and Romo (1998b) evaluated mortality of 1, 2, 4, and 6 week old silver sagebrush seedlings grown in a growth chamber and exposed to freezing temperatures of 28.4°, 24.8°, 21.2°, 17.6°, 14.0°, 10.4°, and 6.8° F (-2, -4, -6, -8, -10, -12, and -14° C, respectively). Mortality was evaluated for 8, 10, 12, and 14 week old seedlings grown in a greenhouse, acclimated to decreasing temperatures in a growth chamber for 2 weeks, and exposed to freezing temperatures of 21.2°, 17.6°, 14.0°, 10.4°, 6.8°, 3.2°, -0.4°, -4.0°, and -7.6° F (-6, -8, -10, -12, -14, -16, -18, -20, and -22° C, respectively). Silver sagebrush seedlings grown in a field for one growing season were evaluated for mortality in November, March, and April, at 7, 11, and 12 months of age, respectively, and exposed to freezing temperatures of 15.8°, 5.0°, -5.8°, -27.4°, -38.2°, and -49.0° F (-9, -15, -21, -33, -39, and -45° C, respectively) (Hou and Romo 1998b).

Freezing tolerance in silver sagebrush increased with age of the seedlings. Silver sagebrush seedlings 1 to 6 weeks old had 50% mortality at 18.1° F (-7.7° C) and 95% mortality at 12.0° F (-11.1° C). Cold acclimated seedlings 8 weeks old had 54.7% mortality at 6.8° F (-14° C); 10 and 12 week old seedlings had only 1.3% and 0.7% mortality, respectively, and 14 week old seedlings had no mortality at 6.8° F (-14° C). Silver sagebrush seedlings grown in a field for a full growing season had no mortality at -27.4° F (-33° C) in November and March. At -38.2° F (-39° C), only 6.9% of the seedlings died in November, and after exposure to -38.2° F (-39° C) and -49.0° F (-45° C), an average of only 5.6% of the seedlings died in March. The cold-hardiness of silver sagebrush seedlings decreased between March and April, during early spring, as temperatures rose and day length increased. There was no mortality of seedlings at 15.8° F (-9° C) in April, but 100% mortality at -5.8° F (-21° C) (Hou and Romo 1998b). Freeze tolerance in silver sagebrush is adequate for most seedlings to survive their first winter in the Northern Plains.

Vegetative Reproduction

Silver sagebrush can reproduce vegetatively by sucker sprout development from the belowground vertical stem base or from horizontal rhizomes when topgrowth is destroyed by unfavorable environmental conditions or by management treatments.

Phenology

Phenology is the relationship between plant growth stages and calendar date. Because the calendar is based on the solar year, phenological information shows relationships of plant growth to seasonal changes and to changes in length of daylight. Perennial plants growing in temperate zones use daylight length, or photoperiod, to program their growth stages and biological activities appropriately with the seasonal conditions.

White and Currie (1984) tested a numeric phenological scoring system to predict phenological development in silver sagebrush. Three study areas located west of Miles City, MT, had three degrees of silver sagebrush infestation: light, with 5 to 10 meters between plants; moderate, with 2 to 5 meters between plants; and heavy, with less than 2 meters between plants. From early April to late October 1981, fifteen plants on each study area were evaluated biweekly for described morphological characteristics and assigned a corresponding numeric phenological score of 0.0 to 13.0.

White and Currie (1984) found that during the growing season, changes in the selected morphological attributes in silver sagebrush were readily described by linear regression when phenological development was examined as a function of calendar date. Phenological development of silver sagebrush on the three sites with different degrees of infestation showed only small differences of less than half of a scoring unit on each evaluation period. Generally, the plants on the heavily infested site were slightly more advanced than the plants on the moderately and lightly infested sites (White and Currie 1984).

White and Currie (1984) observed the progression of phenological growth stages in silver sagebrush: buds swell in early April, leaf expansion occurs during late April and May, rapid twig growth occurs from mid May to late June, floral development occurs during mid to late July and August, flowering (anthesis) occurs during August and September, and seed development occurs during mid to late September and October. Seed dispersal is by wind during late fall and winter.

Burning Management Research

White and Currie (1983) compared the effects of spring and fall prescribed burning of silver sagebrush on two mixed grass prairie sites near Miles City, MT. The spring burn was conducted in mid April 1977, when the soil moisture was near field capacity. The fall burn was conducted in early October 1979, after a summer drought had substantially reduced soil moisture and placed plants under considerable water stress. The spring burn was a headfire, and the fall burn was a backfire. Fuel amounts were comparable for both burns, and climatic conditions were similar, with temperature near 69.8° F (21° C) and wind speed less than 5.0 mi/hr (8 km/hr). Fire intensity was rated by progressive degree of plant parts consumed: foliage consumed, twigs consumed, and stems consumed. Measurements for survival/mortality, number of sprouts, height of sprouts, and a canopy cover index were taken along 10 line transects with 210 individual plants per site during July following each burn (White and Currie 1983).

Topgrowth of silver sagebrush was completely killed by both spring and fall burns at all three fire intensity ratings. Survival/mortality of belowground plant parts depended upon fire intensity and time of year. Plant survival was greater on the spring burn. On the spring burn, plants with foliage consumed and twigs consumed sustained less than 10% mortality, and plants with stems consumed to the stump sustained about 33% mortality. On the fall burn, plants with foliage consumed and twigs consumed sustained about 40% mortality and plants with stems consumed sustained about 75% mortality (White and Currie 1983).

Plants with only foliage consumed tended to resprout sooner than plants burned at greater fire intensity. The point of origin of sprouts was not different among fire intensity classes. However, fire intensity changed the rate of sprouting; as burning intensity increased, regrowth decreased. Spring burning under favorable soil moisture conditions resulted in low mortality and high survival of silver sagebrush plants. On the spring burn, surviving plants with foliage consumed and twigs consumed had 4.2 sprouts per plant, sprout height of 12.3 inches (31.4 cm), and a canopy index of 16.1 inches (40.9 cm). Surviving plants with stems consumed had 3.3 sprouts per plant, sprout height of 8.5 inches (21.6 cm), and a canopy index of 14.1 inches (35.8 cm). On the fall burn, surviving plants with foliage consumed and twigs consumed had 11.8 sprouts per plant, sprout height of 7.4 inches (18.8 cm), and a canopy index of 12.2 inches (31.0 cm). Surviving plants with stems consumed had 4.2 sprouts per plant, sprout height of 2.2 inches (5.6 cm), and a canopy index of 3.8 inches (9.6 cm) (White and Currie 1983). The spring burn treatment resulted in fewer sprouts per surviving plant than the fall burn treatment. However, with greater plant survival and more robust sprouts, the spring burn had greater restored brush cover than the fall burn. Fall burning under dry soil moisture conditions resulted in low survival and high mortality of silver sagebrush plants, and fall burning was more effective in reducing shrub canopy cover for a longer period.

Chemical Management Research

Whitson and Alley (1984) evaluated effects of tebuthiuron on silver sagebrush near Wheatland, WY. Tebuthiuron was applied as both a 10% and a 20% pelleted formulation at the rates of 0.27, 0.54, 0.71, and 0.98 lb ai/ac (0.3, 0.6, 0.8, and 1.1 kg ai/ha, respectively) on 12 June 1980 on plots arranged in a randomized complete block design with three replications. The study control treatment had no herbicide applied. Percent live canopy cover data were collected 15 July 1980, 28 July 1981, and 7 July 1982 (Whitson and Alley 1984).

The decreases in percent live canopy cover of silver sagebrush were not significant after one year of treatment. Two years after treatment, significant decreases in percent live canopy cover of silver sagebrush occurred with all tebuthiuron application rates and both product formulations. The second year reductions in percent live canopy cover for the tebuthiuron application rates of 0.27, 0.54, 0.71, and 0.98 lb ai/ac (0.3, 0.6, 0.8, and 1.1 kg ai/ha, respectively) were 70.6%, 76.0%, 90.6%, and 77.8% for the 10% product formulation, respectively, and 77.4%, 83.3%, 96.6%, and 94.7% for the 20% product formulation, respectively. None of the rates and product formulations of tebuthiuron eradicated silver sagebrush after two years of treatment. Percent live canopy cover of western wheatgrass decreased in areas treated with 0.98 lb ai/ac (1.1 kg ai/ha) tebuthiuron (Whitson and Alley 1984).

Tebuthiuron Herbicide

Tebuthiuron is an amide-urea derivative herbicide that is soil activated and absorbed by plants through the roots. Tebuthiuron interferes with or inhibits the photosynthetic process, causing premature aging and shedding of the leaves. Several leaf defoliation cycles deplete stored nonstructural carbohydrates and result in death of the plant (Bjerregaard et al. 1978). Tebuthiuron is moderately toxic, with an LD_{50} of >2000 mg/kg, for a single oral dose and slightly toxic, with an LD_{50} of >2000 mg/kg, for a single dermal dose (product material safety data sheet). Tebuthiuron may persist in soils for long periods. It is adsorbed to the organic matter and clay particles in the soil. Tebuthiuron resists photodecomposition and volatilization, and its breakdown by microbial activity is slow (Hamilton et al. 2004).

Spike 20P is the trade name for tebuthiuron. It is a surface applied soil-active pelleted product manufactured by Dow AgroSciences for control of woody plants in rangeland, pastureland, and noncropland. This product is also available as a wettable powder. This herbicide is toxic to fish and cannot be applied directly to water or to areas with a shallow water table (5 feet or less). The label rates for control of woody brush on grazingland are a maximum of 1.0 lb ai tebuthiuron (5 lb product) per acre in regions that receive less than 20 inches annual precipitation and a maximum of 2.0 lb ai tebuthiuron (10 lb product) per acre in regions that receive greater than 20 inches annual precipitation. Rates greater than 0.8 lb ai tebuthiuron (4.0 lb product) per acre may cause injury to perennial grasses. The product cannot be applied to an area more than once per year. Tebuthiuron has no grazing restrictions for beef animals at the labeled rates for pastures. The restriction period required between slaughter of animals and their removal from tebuthiuron treated pastures is zero days. Hay for livestock feed cannot be cut for one year after treatment. Intact treated woody plants should not be disturbed by mowing or burning for two years after treatment because the plants go through several defoliation cycles before stored nonstructural carbohydrates are depleted and death occurs (product label 2003). At low rates of 0.25 lb ai tebuthiuron per acre, additional time for control may be required.

Study of Tebuthiuron Management of Silver Sagebrush

A study was conducted to evaluate the effects of tebuthiuron on silver sagebrush, assess the effectiveness of application rates lower than the suggested 0.75 lb ai/ac rate, and evaluate longevity of treatment effectiveness by resampling treatment plots during the twenty-second growing season after herbicide applications.

Procedure

The trial of chemical management of silver sagebrush was conducted on a 0.50 acre (0.20 hectare) study area located in western North Dakota on the SW¼, SW¼, NW¼, sec. 12, T. 143 N., R. 96 W., at the Pyramid Park Experimental Area of the Dickinson Research Extension Center, from 1983 to 1986 and resampled in 2004. The study area was on a loamy overflow range site, and the soils were Glendive fine sandy loam and Haverlon silty loam, with both soils developed from deep alluvial deposits on a stream floodplain terrace. The plant community was Sagebrush type in the classification system of Hanson and Whitman (1938). Western wheatgrass, green needlegrass, and Kentucky bluegrass were the dominant grasses. Yarrow, white sage, white prairie aster, long-headed coneflower, and American vetch were the dominant forbs. Silver sagebrush infestation on the study site was heavy, with about one plant per square meter.

At the time this report was written, tebuthiuron was available as a 20% product formulation. At the time of study initiation, the chemical came in two product formulations, at concentrations of 20% and 40% active ingredient (ai) incorporated into dense clay pellets. Each product formulation was broadcast applied 24 May 1983 with a whirlybird hand spreader at three rates, 0.25, 0.50, and 0.75 lb ai/ac (0.28, 0.56, and 0.84 kg ai/ha, respectively). A control treatment with no herbicide applied was used as the reference. The 22 X 30 foot (6.71 X 9.14 m) plots were arranged in a randomized block design with two replications for the high and low rate treatments and four replications for the middle rate treatment and the control treatment.

Each silver sagebrush plant of each plot was permanently identified with a uniquely numbered tag affixed to a main branch. Measurements were collected 24-25 August 1983, 9-11 July 1984, 8-10 July 1985, 16-18 July 1986, and 8-9 and 12-14 July 2004. Each plant was measured for height from ground level and for crown diameter in two directions, north-south (N-S) and east-west (E-W). Diameter measurements were taken in two directions because the aerial crown of the shrub is more elliptical than round. Two sets of height and crown diameter measurements were collected for each plant. One set of data included only live branches, and the other set included live and dead branches. Measurements for the dead branches were determined from the difference between the live plus dead measurements and the live only measurements. The elliptical crown area per square meter was determined from the N-S and E-W diameter measurements, and the crown volume per cubic meter was determined from the crown area and height measurements for both the live and dead branches. Canopy cover was determined from the percentage of mean crown area covering a square meter of ground. The data collected in 2004 were from silver sagebrush plants with three distinctly different growth types: regrowth that developed from surviving aerial branches of old shrubs, mid aged shrubs produced by vegetative sucker sprouts that developed from surviving belowground stem bases and horizontal rhizomes, and young plants that developed from seedlings. Data for each growth type were treated separately. Total plant measurement values were the sum of the respective mean plant measurements for the mean number of old, mid aged, and young plants growing per square meter. Shrub density--number of plants per square meter--was determined from the total plant population on each plot. Differences between means were analyzed by a standard paired plot t-test (Mosteller and Rourke 1973). Cattle grazed the area each year from mid July to early November.

Results

The short-term and long-term effects that tebuthiuron applied at three rates and two product formulations had on the topgrowth of silver sagebrush and on plant survival/mortality were evaluated from plant measurements of crown diameter, crown height, shrub density, crown area, crown volume, and canopy cover. The collected information was used to describe the annual changes in live and dead branch measurements during the first four growing seasons after tebuthiuron application and to describe the changes in live and dead branch measurements between the fourth and twenty-second growing seasons for each treatment. The differences in live and dead branch measurements for old, mid aged, and young shrubs after twenty-two growing seasons were compared among the tebuthiuron and control treatments. The long-term differences in live branch measurements collected during the twenty-second growing season on the tebuthiuron and control treatments were compared to the respective plant measurements collected during the first growing season on the control treatment.

From 1983 to 1986, the amount of live branch material decreased and the amount of dead branch material increased on silver sagebrush plants treated with tebuthiuron at the rates of 0.25, 0.50, and 0.75 lb ai/ac at both 20% and 40% product formulations. The plant measurements of crown volume per m^3 for silver sagebrush on the tebuthiuron treatments changed precipitously between 1983 and 1985, from greater than 90% live branches at the time the herbicide treatments were applied to greater than 90% dead branches after three growing seasons. In 1986 (the fourth growing season), the percent dead branch crown volume per m^3 for the treatment rates of 0.25, 0.50, and 0.75 lb ai/ac was 91.9%, 98.2%, and 99.8% for the 20% concentration, respectively, and 92.4%, 98.3%, and 99.4% for the 40% concentration, respectively (table 1, figures 1, 2, 3, 4, 5, and 6). The percent crown volume per m^3 for silver sagebrush on the control treatment changed from 91.7% live branches in 1983 to 68.7% dead branches in 1986 (table 1, figure 7).

The plant measurements of N-S and E-W diameters, height, crown area per m^2, and crown volume per m^3 for silver sagebrush on the treatment plots with 0.25, 0.50, and 0.75 lb ai/ac rates at both the 20% and 40% product formulations of tebuthiuron decreased significantly for the live branches from 1983 to 1986 and increased significantly for the dead branches from 1983 to 1985 (tables 2, 3, 4, 5, 6, and 7). Some of the dead branches were sloughed or broken off the shrubs; this loss caused a decrease in dead branch measurements between 1985 and 1986.

The plant measurements of N-S and E-W diameters, height, crown area per m^2, and crown volume per m^3 for silver sagebrush on the control treatment plots decreased annually, but not significantly, for the live branches from 1983 to 1986 and increased annually, but not significantly, for the dead branches from 1983 to 1985 (table 8). Some of the dead branches were sloughed or broken off the shrubs; this loss caused a decrease in dead branch measurements between 1985 and 1986.

The field notes made in 1986 indicated that the shrubs on the control treatment appeared to be healthy and similar to untreated plants in adjacent areas. However, the data from the control treatments (table 8) appear to show decreases in live branch measurements and increases in dead branch measurements greater than natural branch senescence. The annual decrease in the amount of live branch material and the annual increase in the amount of dead branch material were not significant for silver sagebrush plants on the control treatments from 1983 to 1986 (table 8). The cumulative changes during the first four growing seasons were significant except the changes in shrub density. The percent decrease in live branch plant measurements of N-S and E-W diameters, height, crown area per m^2, and crown volume per m^3 from 1983 to 1986 was 44.5%, 42.6%, 33.0%, 68.5%, and 31.1%, respectively. The percent increase in dead branch plant measurements of N-S and E-W diameters, height, crown area per m^2, and crown volume per m^3 from 1983 to 1986 was 635.6%, 715.3%, 2694.2%, and 446.9%, and 431.8%, respectively. There is a possibility that leaves containing small amounts of tebuthiuron were shed from treated plants and landed on the control treatment plots, where absorption of the herbicide by control plants resulted in death of portions of some branches.

The shrub density tended to decrease slightly on the tebuthiuron treatment plots and control treatment plots between 1983 and 1986, but no significant changes occurred (tables 2, 3, 4, 5, 6, 7, and 8). The shrub density on the tebuthiuron treatment plots did not decrease during the first four years of the study because one or more of the large stem branches remained attached to the stem base of the dying plants.

The field notes made in 1986 indicated that the topgrowth of most of the shrubs on all tebuthiuron treatment plots appeared to be dead. A few plants on the periphery of the plots had miniature leaves growing from the surface of some large stems. The slower tebuthiuron effect on the periphery plants most likely resulted as a remnant of the herbicide application method that attempted to spread tebuthiuron pellets to the edge of the plots but not past the edge into an adjacent plot, causing lower-than-treatment rates along the periphery of the plots. In 1986, the percentage of silver sagebrush plants with topgrowth not totally dead on the tebuthiuron treatment plots with rates of 0.25, 0.50, and 0.75 lb ai/ac was 56.4%, 40.3%, and 19.8% for the 20% concentration, respectively, and 59.1%, 29.9%, and 27.7% for the 40% concentration, respectively (table 9).

All of the herbicide treatment rates of 0.25, 0.50, and 0.75 lb ai/ac tebuthiuron for both 20% and 40% product formulations caused greater than 92% of the topgrowth branches to die by the fourth growing season after one application. There was a trend of slightly increasing percent dead branches with increase in herbicide rate. None of the treatment rates caused total topgrowth kill. Some aerial branches and some belowground stem bases and rhizomes were still alive during the fourth growing season.

A considerable number of the silver sagebrush plants measured in 1986 continued to deteriorate from the effects of tebuthiuron, and both the aboveground and belowground plant parts died sometime after 1986. The percent of the silver sagebrush plants that were measured in 1986 and later totally died on the treatment plots with 0.25, 0.50, and 0.75 lb ai/ac rates was 49.4%, 79.0%, and 51.6% for the 20% concentration, respectively, and 38.4%, 68.8%, and 63.6% for the 40% concentration, respectively. On the control treatment, 42.2% of the plants measured in 1986 died at a later date.

Tebuthiuron affects the photosynthetic processes in the leaves, reducing the production of carbohydrates and causing a drawdown of the nonstructural carbohydrate reserves; when these stores are depleted, the plant dies. Numerous silver sagebrush plants required more than four growing seasons with disrupted photosynthesis to deplete their nonstructural carbohydrate reserves completely. Some plants had sufficient carbohydrate stores to outlast the effects from a single application of tebuthiuron.

Evaluation of long-term effects from tebuthiuron treatments was conducted by resampling the study plots in 2004--22 growing seasons after herbicide application. Percent old silver sagebrush plants with regrowth development from surviving aerial branches on the tebuthiuron treatment plots with rates of 0.25, 0.50, and 0.75 lb ai/ac was 26.4%, 11.1%, and 20.8% for the 20% concentration, respectively, and 28.3%, 20.4%, and 24.1% for the 40% concentration, respectively, in 2004. Percent surviving old silver sagebrush plants on the control treatment was 33.6%. Most of the main branches with permanently affixed identification tags had died and broken away from the stem base. Only 2.4% of 1235 tags remained attached to a living main branch in 2004. The largest portion, 40.0%, of these functional tags was still affixed to live branches of plants on the control treatment plots.

From 1986 to 2004, the amount of live branch material increased and the amount of dead branch material decreased on surviving old silver sagebrush plants on plots treated with tebuthiuron at the rates of 0.25, 0.50, and 0.75 lb ai/ac at both 20% and 40% product formulations. The plant measurements of crown volume per m^3 for old silver sagebrush on the tebuthiuron treatments changed from greater than 91% dead branches in 1986 to greater than 74% live branches in 2004. The percent live branch crown volume per m^3 of old shrubs treated with tebuthiuron at the rates of 0.25, 0.50, and 0.75 lb ai/ac was 96.5%, 75.8%, and 91.7% for the 20% concentration, respectively, and 79.0%, 81.2%, and 74.1% for the 40% concentration, respectively, in 2004 (table 1, figures 1, 2, 3, 4, 5, and 6). The percent crown volume per m^3 for silver sagebrush plants on the control treatment changed from 31.3% live branches in 1986 to 83.8% live branches in 2004 (table 1, figure 7).

The plant measurements of N-S and E-W diameters, height, crown area per m^2, and crown volume per m^3 for old silver sagebrush on the treatment plots with 0.25, 0.50, and 0.75 lb ai/ac rates at both 20% and 40% product formulations of tebuthiuron increased significantly for the live branches and decreased significantly for the dead branches from 1986 to 2004 (tables 2, 3, 4, 5, 6, and 7).

The live branch plant measurements for old silver sagebrush on the control treatment plots increased significantly for the N-S and E-W diameters, height, and crown area per m^2 measurements and increased, but not significantly, for the crown volume per m^3 measurements from 1986 to 2004. The dead branch plant measurements for old silver sagebrush on the control treatment plots decreased significantly for the N-S diameter measurements and decreased, but not significantly, for the E-W diameter, height, crown area per m^2, and crown volume per m^3 measurements (table 8).

Shrub density decreased significantly for old silver sagebrush on the tebuthiuron treatment plots and control treatment plots between 1986 and 2004 (tables 2, 3, 4, 5, 6, 7, and 8).

Live silver sagebrush plants on the study plots in 2004 had three distinctly different growth types: (1) old shrubs that had been present on the plots in 1983 and had regrowth that developed from surviving aerial branches, (2) mid aged shrubs that had no surviving old (1983) topgrowth and had been produced by vegetative sucker sprouts that developed from surviving belowground stem bases and horizontal rhizomes, and (3) young shrubs that developed from seedlings.

The percent of the silver sagebrush population comprised of shrubs developed from the regrowth of surviving aerial branches on the tebuthiuron treatment plots with 0.25, 0.50, and 0.75 lb ai/ac rates was 43.4%, 30.6%, and 19.8% for the 20% concentration, respectively, and 30.4%, 21.6%, and 39.6% for the 40% concentration, respectively. The percent of the silver sagebrush population comprised of shrubs developed from the vegetative sucker sprouts of surviving belowground stem bases or horizontal rhizomes on the tebuthiuron treatment plots with 0.25, 0.50, and 0.75 lb ai/ac rates was 30.2%, 25.0%, and 21.6% for the 20% concentration, respectively, and 31.3%, 11.4%, and 13.2% for the 40% concentration, respectively. The percent of the silver sagebrush population comprised of shrubs developed from successful seedlings on the tebuthiuron treatment plots with 0.25, 0.50, and 0.75 lb ai/ac rates was 28.3%, 44.4%, and 58.6% for the 20% concentration, respectively, and 38.4%, 68.2%, and 47.2% for the 40% concentration, respectively. On the control treatment, the percent of the silver sagebrush population comprised of shrubs developed from old surviving plants, from the vegetative sucker sprouts of surviving belowground stem bases or horizontal rhizomes, and from the growth of successful seedlings was 47.5%, 31.3%, and 21.2%, respectively.

The plant measurements of N-S and E-W diameters, height, crown area per m^2, and crown volume per m^3 collected in 2004 from the old shrubs of silver sagebrush on the tebuthiuron treatments were not significantly different from the respective plant measurements for the old shrubs on the control treatment plots. The shrub densities of the old silver sagebrush on the tebuthiuron treatments were lower than the shrub densities of the old shrubs on the control treatment, but not significantly, in 2004 (tables 10, 11, 12, 13, 14, and 15).

The plant measurements of N-S and E-W diameters, height, shrub density, crown area per m^2, and crown volume per m^3 collected in 2004 from the mid aged shrubs of silver sagebrush on the tebuthiuron treatments were not significantly different from the respective plant measurements for the mid aged shrubs on the control treatment plots, except the N-S diameter measurements on the 0.75 lb ai/ac 20% concentration treatment were significantly less and the shrub densities on the 0.50 lb ai/ac 20% concentration and 0.75 lb ai/ac 40% concentration treatments were significantly less than those collected on the control treatments in 2004 (tables 10, 11, 12, 13, 14, and 15).

The plant measurements of N-S and E-W diameters, height, and crown volume per m^3 collected in 2004 from the young shrubs of silver sagebrush on the tebuthiuron treatments were less than the respective plant measurements for the young shrubs on the control treatment plots, but not significantly. The measurements of crown area per m^2 for the young shrubs on the tebuthiuron treatments were not significantly different from those for the young shrubs on the control treatment. The densities of the young shrubs on the tebuthiuron treatments were not significantly different, except the shrub density on the 0.75 lb ai/ac 20% concentration treatment was significantly greater than that on the control treatment (tables 10, 11, 12, 13, 14, and 15).

The total plant measurements of N-S and E-W diameters, height, shrub density, crown area per m^2, and crown volume per m^3 resulting from the sum of the respective mean measurements of old, mid aged, and young shrubs per square meter on the tebuthiuron treatments were not significantly different from those on the control treatment for both the live and dead branches in 2004, except the E-W diameter measurements of dead branches on the 0.25 lb ai/ac 20% concentration and 0.75 lb ai/ac 20%

concentration treatments were significantly less than those on the control treatment (tables 10, 11, 12, 13, 14, and 15).

Long-term effects from tebuthiuron treatments after 22 growing seasons were evaluated by comparisons of live branch plant measurements of N-S and E-W diameters, height, shrub density, crown area per m^2, and crown volume per m^3 collected on tebuthiuron treatment plots in 2004 with the respective measurements collected on the control treatment in 1983.

The total N-S diameter measurements resulting from the sum of the mean measurements of old, mid aged, and young shrubs per square meter on the tebuthiuron treatments in 2004 were lower than the N-S diameter measurements collected on the control treatment in 1983; measurements collected in 2004 on the 0.25 lb ai/ac 20% concentration, 0.50 lb ai/ac 20% concentration, 0.50 lb ai/ac 40% concentration, and 0.75 lb ai/ac 40% concentration treatments were significantly less than N-S diameter measurements collected in 1983 on the control treatment (table 16).

The total E-W diameter measurements resulting from the sum of the mean measurements of old, mid aged, and young shrubs per square meter on the tebuthiuron treatments in 2004 were lower than the E-W diameter measurements collected on the control treatment in 1983; measurements collected in 2004 on the 0.25 lb ai/ac 20% concentration, 0.50 lb ai/ac 20% concentration, 0.50 lb ai/ac 40% concentration, 0.75 lb ai/ac 20% concentration, and 0.75 lb ai/ac 40% concentration treatments were significantly less than E-W diameter measurements collected in 1983 on the control treatment (table 16).

The total height measurements resulting from the sum of the mean measurements of old, mid aged, and young shrubs per square meter on the tebuthiuron treatments in 2004 were lower than the height measurements collected on the control treatment in 1983; measurements collected in 2004 on the 0.25 lb ai/ac 20% concentration, 0.50 lb ai/ac 20% concentration, 0.50 lb ai/ac 40% concentration, and 0.75 lb ai/ac 40% concentration treatments were significantly less than height measurements collected in 1983 on the control treatment (table 16).

The total shrub density measurements resulting from the sum of the mean measurements of old, mid aged, and young shrubs per square meter on the tebuthiuron treatments in 2004 were lower than the density measurements collected on the control treatment in 1983; measurements collected in 2004 on the 0.50 lb ai/ac 20% concentration and 0.75 lb ai/ac 40% concentration treatments were significantly less than density measurements collected in 1983 on the control treatment (table 17).

The total crown area per m^2 measurements resulting from the sum of the mean measurements of old, mid aged, and young shrubs per square meter on the tebuthiuron treatments in 2004 were lower than the crown area per m^2 measurements collected on the control treatment in 1983; measurements collected in 2004 on the 0.50 lb ai/ac 20% concentration and 0.50 lb ai/ac 40% concentration treatments were significantly less than crown area per m^2 measurements collected in 1983 on the control treatment (table 18).

On all tebuthiuron treatments but one, the total crown volume per m^3 measurements resulting from the sum of the mean measurements of old, mid aged, and young shrubs per square meter in 2004 were lower than the crown volume per m^3 measurements collected on the control treatment in 1983; the measurements were greater on the 0.25 lb ai/ac 20% concentration treatment. Measurements collected in 2004 on the 0.25 lb ai/ac 40% concentration, 0.50 lb ai/ac 20% concentration, 0.50 lb ai/ac 40% concentration, and 0.75 lb ai/ac 20% concentration treatments were significantly less than crown volume per m^3 measurements collected in 1983 on the control treatment (table 18).

The plant measurements of N-S and E-W diameters, height, density, crown area per m^2, and crown volume per m^3 collected on the control treatment in 2004 were not significantly different from the respective measurements collected on the control treatment in 1983 (tables 16, 17, and 18).

On the 0.25 lb ai/ac 20% concentration treatment, the plant measurements of N-S and E-W diameters and height collected in 2004 were significantly below the respective measurements collected on the control treatment in 1983 (table 16). On the 0.25 lb ai/ac 40% concentration treatment, the plant measurements of crown volume per m^3 collected in 2004 were significantly below the respective measurements collected on the control treatment in 1983 (table 18).

On the 0.50 lb ai/ac 20% concentration treatment, the plant measurements of N-S and E-W diameters, height, shrub density, crown area per m^2, and crown volume per m^3 collected in 2004 were significantly below the respective measurements collected on the control treatment in 1983 (tables 16, 17, and 18). On the 0.50 lb ai/ac 40% concentration treatment, the plant measurements of N-S and E-W diameters, height, crown area per m^2, and crown volume per m^3 collected in 2004 were significantly below the respective measurements collected on the control treatment in 1983 (tables 16 and 18).

On the 0.75 lb ai/ac 20% concentration treatment, the plant measurements of E-W diameter and crown volume per m^3 collected in 2004 were significantly below the respective measurements collected on the control treatment in 1983 (tables 16 and 18). On the 0.75 lb ai/ac 40% concentration treatment, the plant measurements of N-S and E-W diameters, height, and shrub density collected in 2004 were significantly below the respective measurements collected on the control treatment in 1983 (tables 16 and 17).

Canopy cover decreased annually on all tebuthiuron and control treatments between 1983 and 1986. The percent decrease in canopy cover in the fourth growing season after application of tebuthiuron at the rates of 0.25, 0.50, and 0.75 lb ai/ac was 89.6%, 95.5%, and 99.5% for the 20% concentration, respectively, and 88.7%, 95.9%, and 97.5% for the 40% concentration, respectively (table 19). The percent decrease in canopy cover on the fourth growing season on the control treatment was 68.5% (table 19).

A portion of the canopy cover had been recovered by the surviving shrubs sometime after 1986 and before 2004. The canopy cover of surviving silver sagebrush on most of the tebuthiuron treatments during the twenty-second growing season remained substantially below the silver sagebrush canopy cover on the control treatment during the first growing season. In 2004, the percent reduction of the canopy cover of the surviving shrubs on the tebuthiuron treatments with rates of 0.25, 0.50, and 0.75 lb ai/ac was 32.4%, 50.7%, and 55.1% for the 20% concentration, respectively, and 9.8%, 54.9%, and 37.7% for the 40% concentration, respectively, below the canopy cover on the control treatment in 1983 (table 19). The percent reduction of the canopy cover of the surviving shrubs on the control treatment in 2004 was 15.9% below the canopy cover on the control treatment in 1983 (table 19).

Between 1986 and 2004, some silver sagebrush plants developed from successful seedlings on all of the tebuthiuron and control treatments. The canopy cover of the shrubs developed from seedlings was low. On the twenty-second growing season, the canopy cover provided by shrubs developed from seedlings was substantially below the canopy cover of silver sagebrush in the first growing season. In 2004, the percent decrease in canopy cover of the shrubs developed from seedlings on the tebuthiuron treatments at the 0.25, 0.50, and 0.75 lb ai/ac rates was 98.9%, 97.1%, and 96.4% for the 20% concentration, respectively, and 95.1%, 98.0%, and 96.6% for the 40% concentration, respectively, below the canopy cover on the control treatment in 1983 (table 19). In 2004, the percent decrease in canopy cover provided by shrubs developed from seedlings on the control treatment was 95.9% below the canopy cover on the control treatment in 1983 (table 19).

The plant measurements collected in 2004 on the tebuthiuron treatments with 0.25, 0.50, 0.75 lb ai/ac rates at both 20% and 40% product formulation were lower than the respective plant measurements collected in 1983 on the control treatment. After 22 growing seasons following herbicide application, the silver sagebrush plants on the tebuthiuron treatments with 0.25, 0.50, and 0.75 lb ai/ac rates had not recovered fully in plant size and distribution to equal the measurements of untreated plants on the control treatment during the first growing season.

The changes in live and dead branch plant measurements for silver sagebrush plants on the control treatment followed a pattern similar to that of the changes for silver sagebrush plants on the tebuthiuron treatment plots; this similarity may indicate that the plants on the control plots were affected somewhat by herbicide transported to the control plots by leaves shed from treated plants. The recovery of silver sagebrush plants from the effects of inadvertent herbicide movement to control treatments was more rapid than the recovery of plants from the effects of tebuthiuron application on the treatment plots.

Tebuthiuron killed both the topgrowth and belowground plant parts of numerous plants at each of the herbicide treatment rates and product formulations by the time the effects of the chemical played out. Of the plants present in 1983 on the tebuthiuron treatment plots with 0.25, 0.50, and 0.75 lb ai/ac rates, the percent that had both the aboveground and belowground plant parts killed was 55.2%, 79.8%, and 56.6% for the 20% concentration, respectively, and 42.5%, 68.8%, and 67.8% for the 40% concentration, respectively (table 20). On the control treatment, 44.3% of the plants were totally killed (table 20). Of the plants present in 1983 on the tebuthiuron treatment plots with 0.25, 0.50, and 0.75 lb ai/ac rates, the percent that had entire topgrowth killed was 73.6%, 88.9%, and 79.3% for the 20% concentration, respectively, and 71.7%, 79.6%, and 75.9% for the 40% concentration, respectively (table 20). On the control treatment, 66.4% of the plants had the topgrowth killed (table 20). On some of the plants present in 1983, aerial branches or belowground stem bases and horizontal rhizomes survived the herbicide treatments. Recovery of the plants with surviving parts occurred as regrowth from the surviving aerial branches and as vegetative sucker sprouts from the surviving belowground parts. Of the plants present in 1983 on the tebuthiuron treatment plots with 0.25, 0.50, and 0.75 lb ai/ac rates, the percent that had aboveground or belowground plant parts survive was 44.8%, 20.2%, and 43.4% for the 20% concentration, respectively, and 57.5%, 31.2%, and 32.2% for the 40% concentration, respectively (table 20). On the control treatment, 55.8% of the plants survived (table 20).

Long-term reduction of silver sagebrush requires killing both the aboveground and belowground plant parts. Chemical management with tebuthiuron is a promising practice for long-term reduction of silver sagebrush. Chemical management of silver sagebrush with one application of tebuthiuron at 0.25, 0.50, and 0.75 lb ai/ac killed 92% to 99% of the aerial branches in four growing seasons, totally killed 43% to 80% of the individual plants in an unknown time period greater than four growing seasons, and prevented full recovery of plant size and distribution for at least 22 growing seasons. The 0.50 and 0.75 lb ai/ac rates were slightly more effective at total plant kill than the 0.25 lb ai/ac rate. Nevertheless, the low rate totally killed about 49% of the individual plants. None of the application rates killed all of the plants. An average of about 38% of the silver sagebrush plants had sufficient stores of nonstructural carbohydrates or regulated carbohydrate drawdown rates and were able to survive longer than the effects from one application of tebuthiuron. High mortality of existing plants is required for long-term management of silver sagebrush because regrowth from surviving plants can reoccupy treated areas faster than shrubs developed from seedlings. The relatively large number of surviving plants suggests that chemical management of silver sagebrush requires multiple applications of tebuthiuron in order to extend the period of effectiveness. Either an application of 0.50 lb ai/ac followed by an application of 0.25 lb ai/ac or a series of three applications of tebuthiuron at 0.25 lb ai/ac would be biologically effective for a longer period than a single application of 0.75 lb ai/ac tebuthiuron. Unfortunately, the interval between herbicide applications was not determined by this study. Extrapolation indicates that the interval between herbicide applications would be greater than four years but less than 22 years and probably less than 10 years. Most likely an application interval of 6 to 8 years would work satisfactorily.

Discussion

Tebuthiuron affects the photosynthetic processes in shrub leaves, resulting in premature leaf shedding. Production and shedding of successive sets of leaves cost the plant more nonstructural carbohydrates than the leaves produce during the brief period they are active. When the carbohydrate stores are depleted, the plant dies. The effects of tebuthiuron on silver sagebrush topgrowth are quantifiably noticeable in three months, and death of aerial branches occurs rapidly during the first three growing seasons following herbicide application. The rate of plant deterioration slows during the fourth growing season, and presumably the herbicide effects continue at progressively slower rates for an unknown number of growing seasons until the effects from tebuthiuron completely cease.

Numerous silver sagebrush plants had small portions of their stored carbohydrates remaining when the tebuthiuron was depleted. The surviving plants produced regrowth from aerial branches or vegetative sucker sprouts from belowground stem bases or horizontal rhizomes. The rate of recovery is assumed to start slowly and accelerate gradually. From the time of tebuthiuron application, recovery of a silver sagebrush colony requires more than twenty-two growing seasons to reach pretreatment infestation levels. A second application of a small amount of tebuthiuron just prior to depletion of the first application of the chemical would extend the period of effectiveness and result in carbohydrate depletion of most, if not all, of the silver sagebrush plants in the colony. After the chemical from the second application is depleted, the area would be prone to reinfestation by silver sagebrush seedlings. Implementation of biologically effective grazing management practices like the twice-over rotation method would improve the health and competitive abilities of the native grass plants and impede silver sagebrush seedling reinfestation.

Summary

Silver sagebrush is a problem plant that has infested considerable acreage of western grazinglands. This biologically successful shrub infests highly productive prairie soils and shades understory grasses and forbs from sunlight, reducing herbage biomass production and causing diminished carrying capacity and greatly reduced net income captured from grasslands. Infested areas require some type of shrub reduction management. Silver sagebrush topgrowth is not too difficult to kill with a heavy duty brush mower, prescribed burning during fall, or 2,4-D applied at 2.0 lb ae/ac when twigs are growing rapidly. Killing the topgrowth, however, does not solve the problem. Silver sagebrush has well developed mechanisms that provide rapid recovery from severe damage to the aerial crown. Recovery of silver sagebrush occurs with the regrowth from surviving aerial branches, with the vegetative sucker sprouts from surviving belowground stem bases or horizontal rhizomes, and with the growth from successful seedlings.

The herbicide tebuthiuron interferes with the photosynthetic processes in shrub leaves; its application results in the plant's ability to produce only small amounts of carbohydrates annually and causes the plant to draw down the stored nonstructural carbohydrates. The plant dies when the carbohydrate reserves are depleted. Tebuthiuron is a pelleted herbicide applied to the soil at relatively low cost; application of 0.50 lb ai/ac would cost about $6.00 per acre for the chemical. Chemical management of silver sagebrush could be accomplished by two or three applications of low rates of tebuthiuron at intervals of about 6 to 8 years. Management practices that reduce silver sagebrush long term would improve the health and condition of grassland ecosystems, increase grass herbage production, and increase carrying capacity of infested grazinglands.

Acknowledgment

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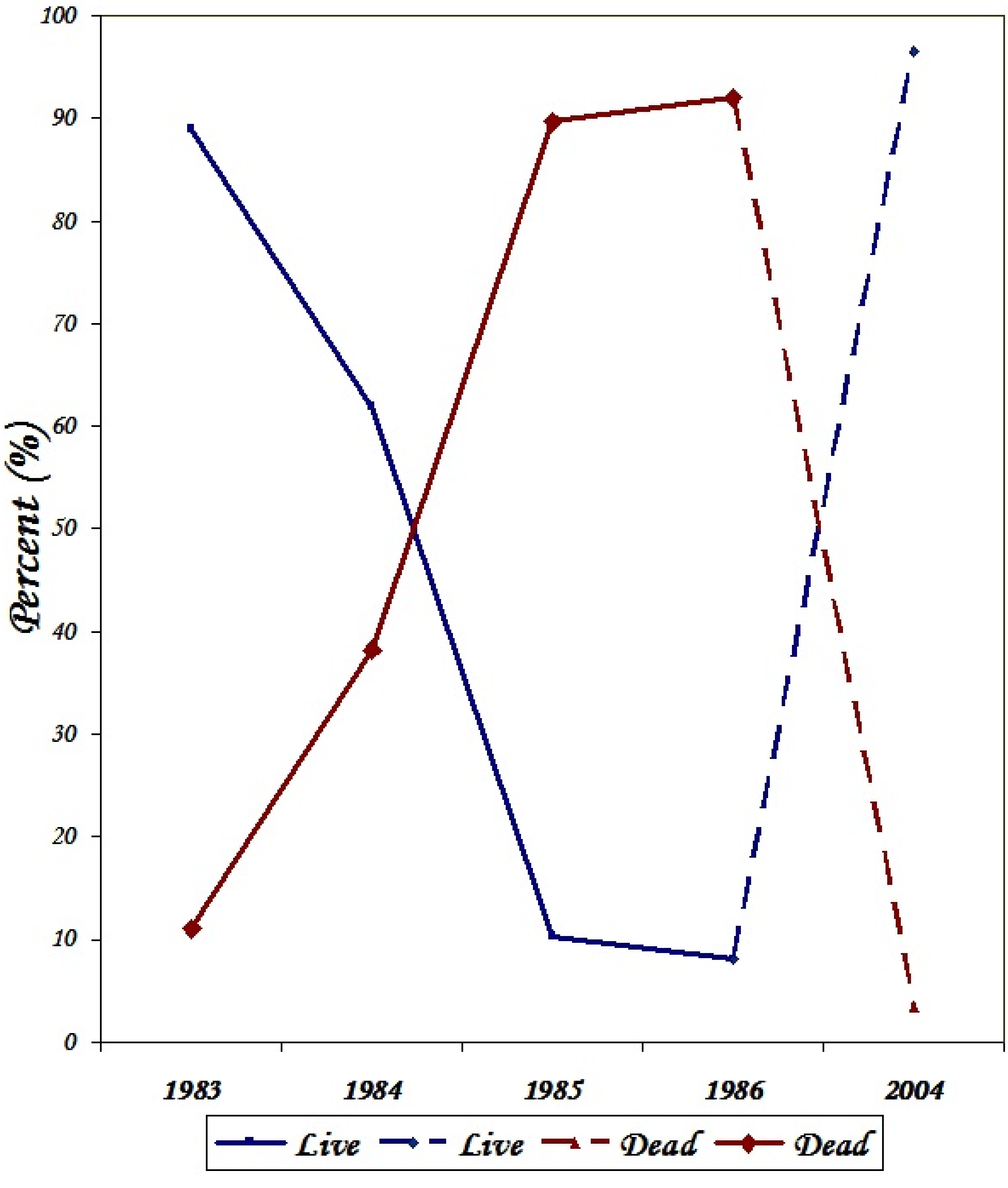

Fig. 1. Percent live and dead crown volume of silver sagebrush on the tebuthiuron with 20% concentration at the rate of .25 lb ai/acre treatments.

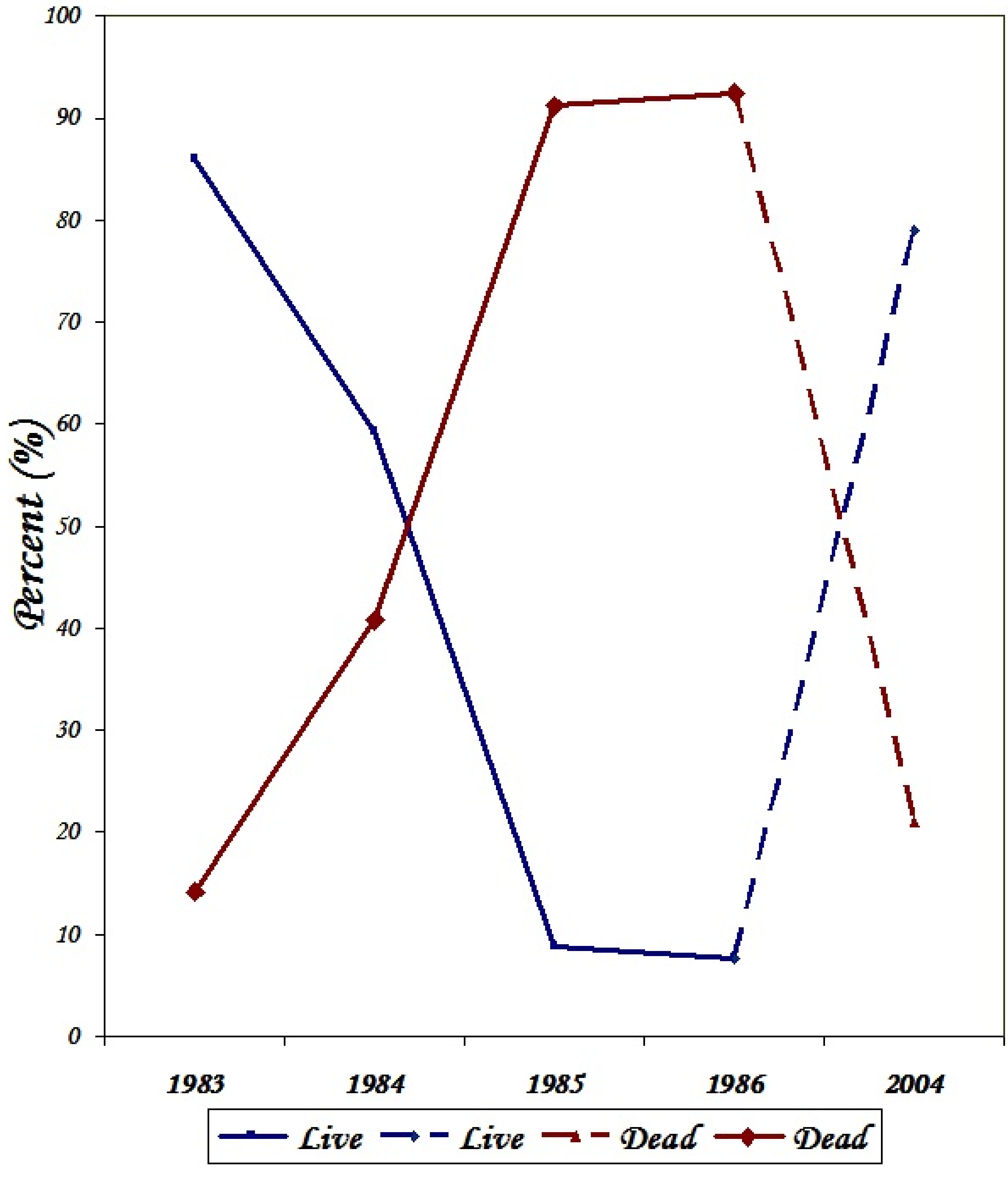

Fig. 2. Percent live and dead crown volume of silver sagebrush on the tebuthiuron with 40% concentration at the rate of .25 lb ai/acre treatments.

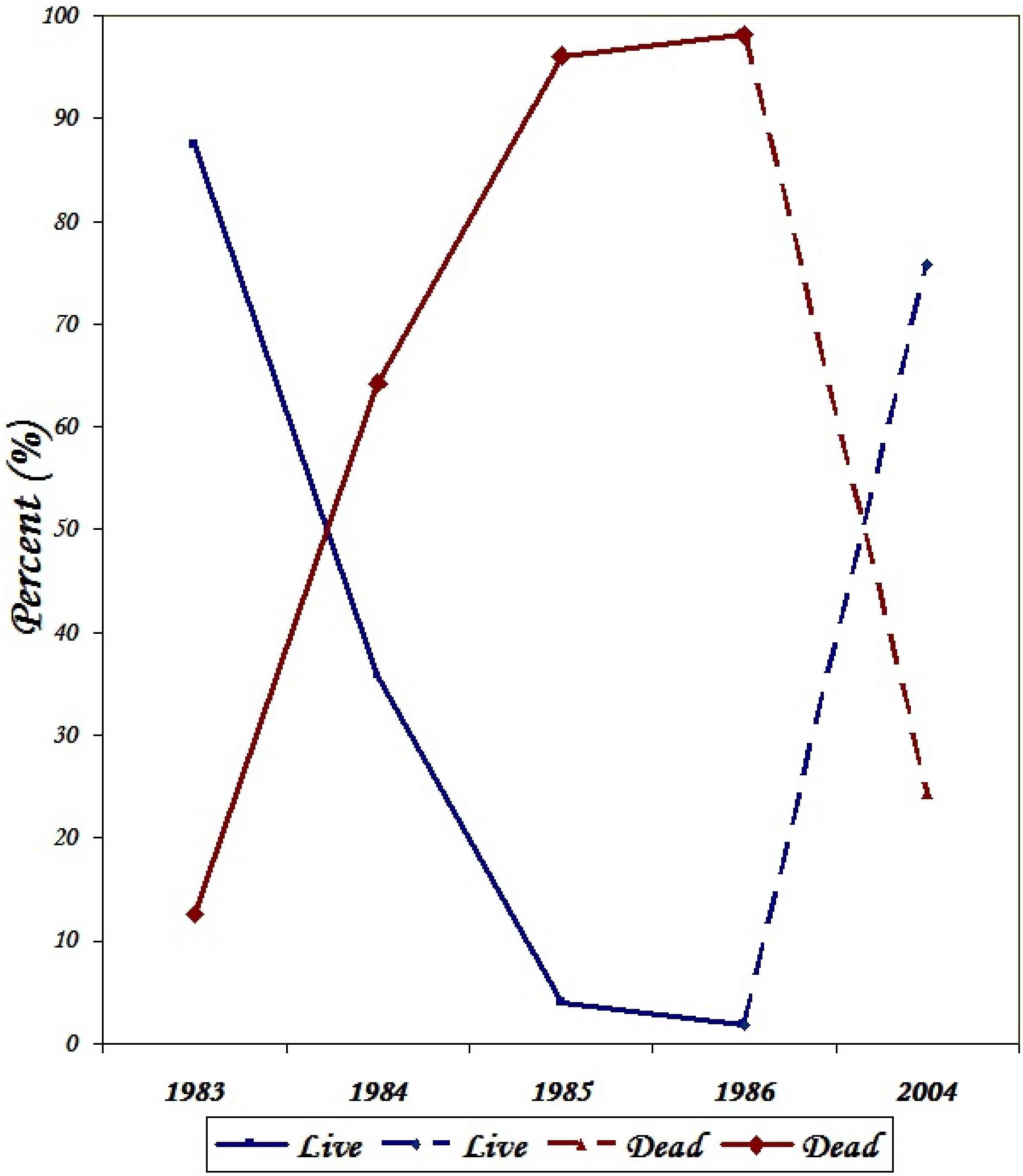

Fig. 3. Percent live and dead crown volume of silver sagebrush on the tebuthiuron with 20% concentration at the rate of .50 lb ai/acre treatments.

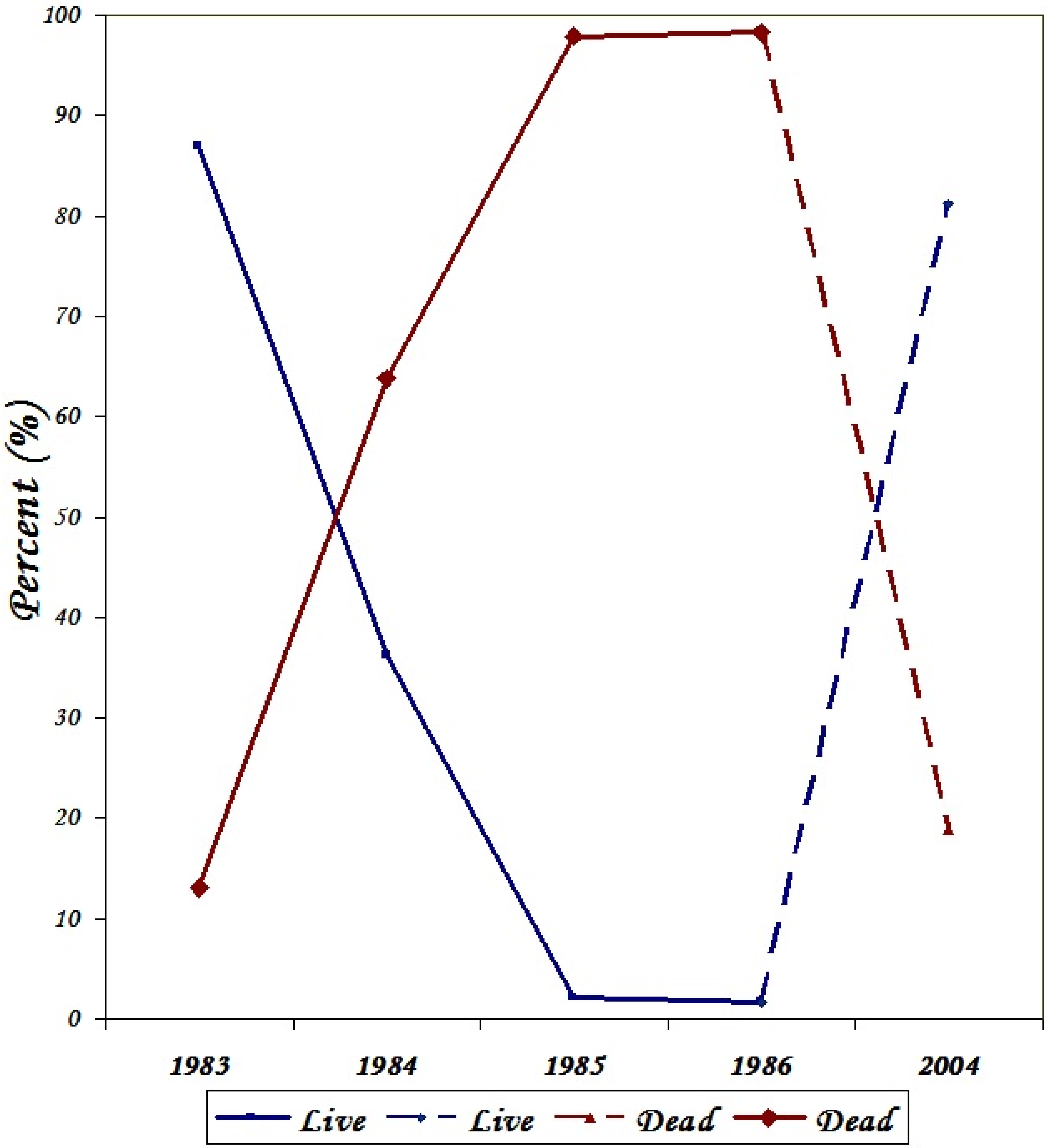

Fig. 4. Percent live and dead crown volume of silver sagebrush on the tebuthiuron with 40% concentration at the rate of .50 lb ai/acre treatments.

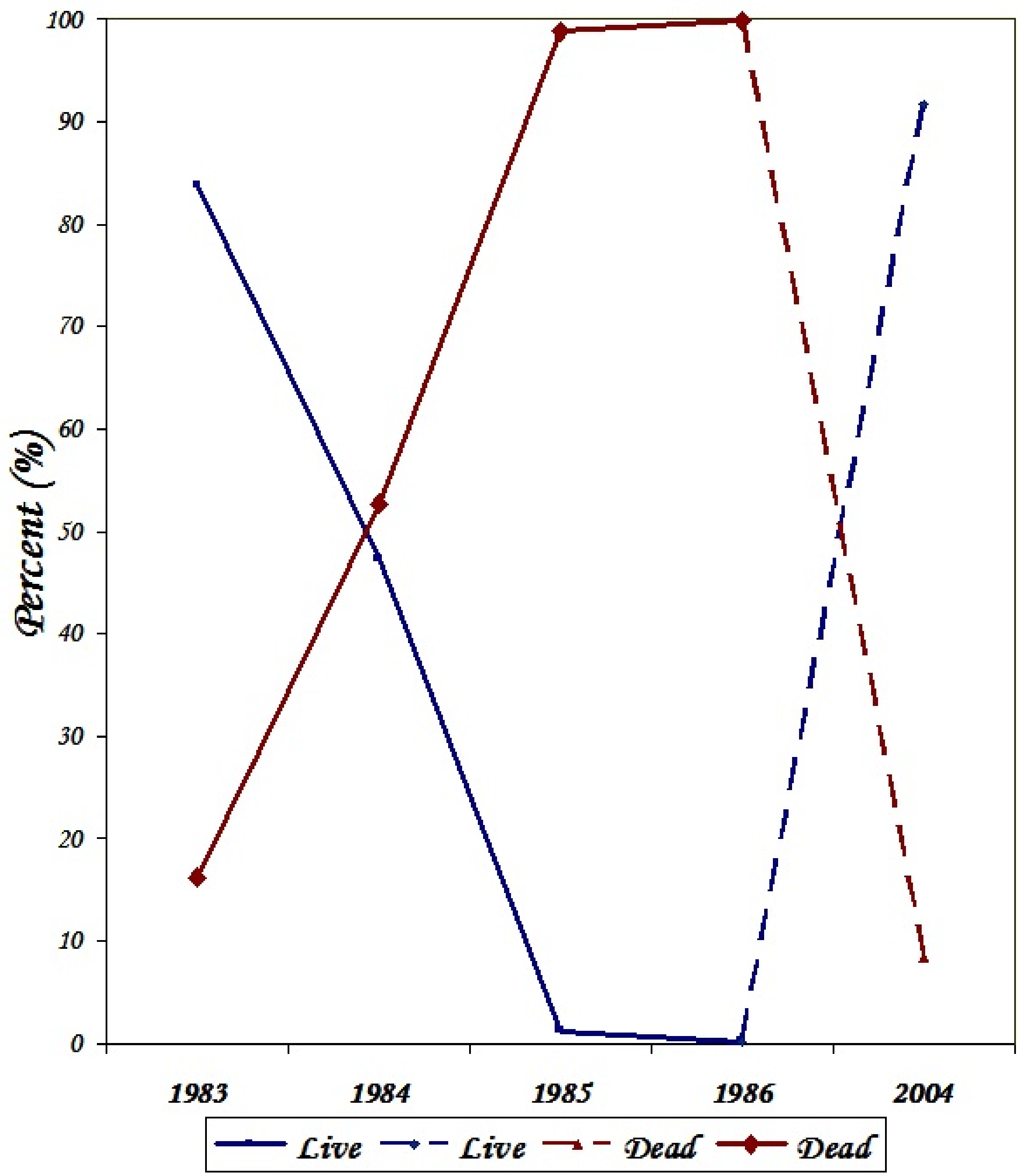

Fig. 5. Percent live and dead crown volume of silver sagebrush on the tebuthiuron with 20% concentration at the rate of .75 lb ai/acre treatments.

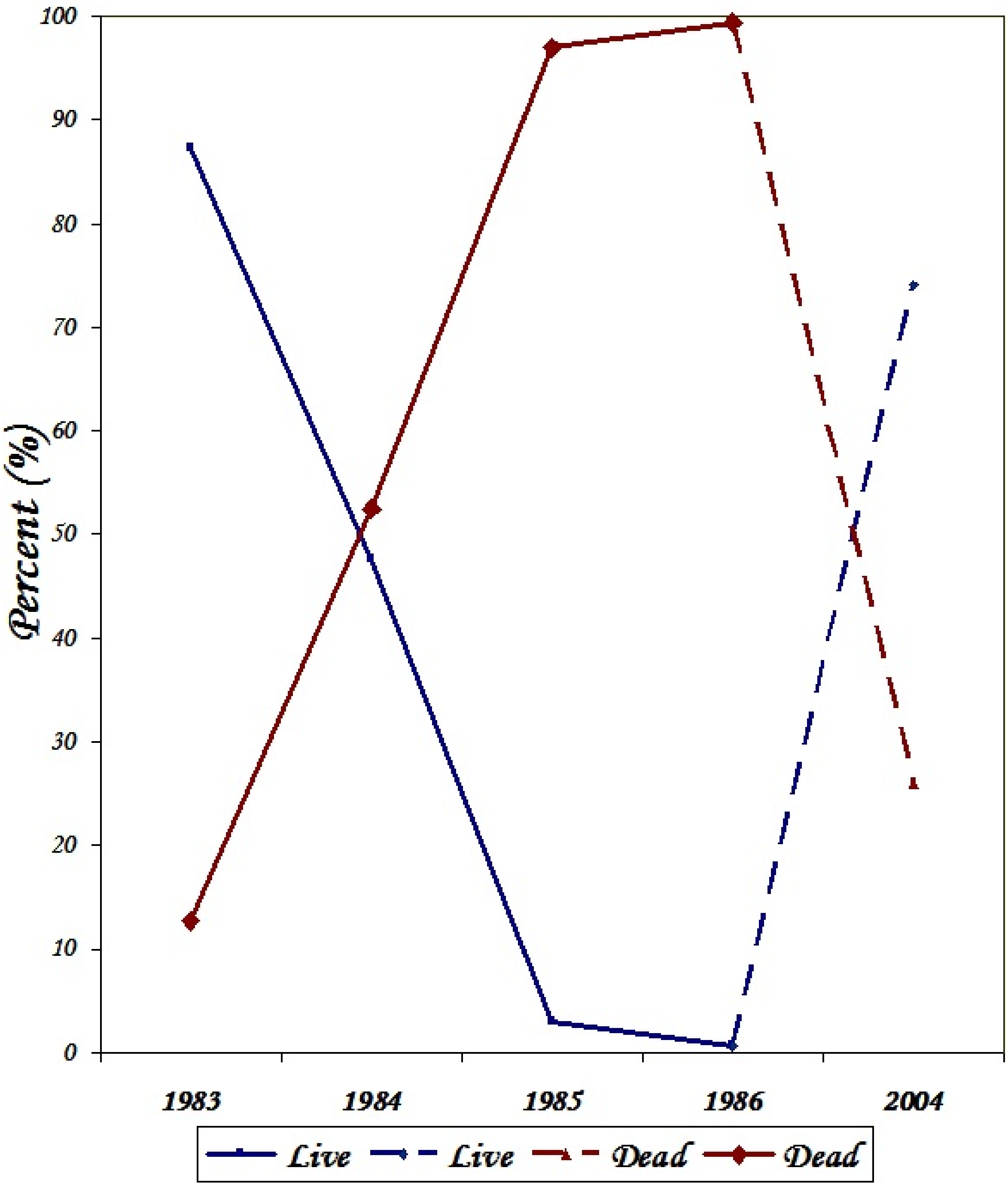

Fig. 6. Percent live and dead crown volume of silver sagebrush on the tebuthiuron with 40% concentration at the rate of .75 lb ai/acre treatments.

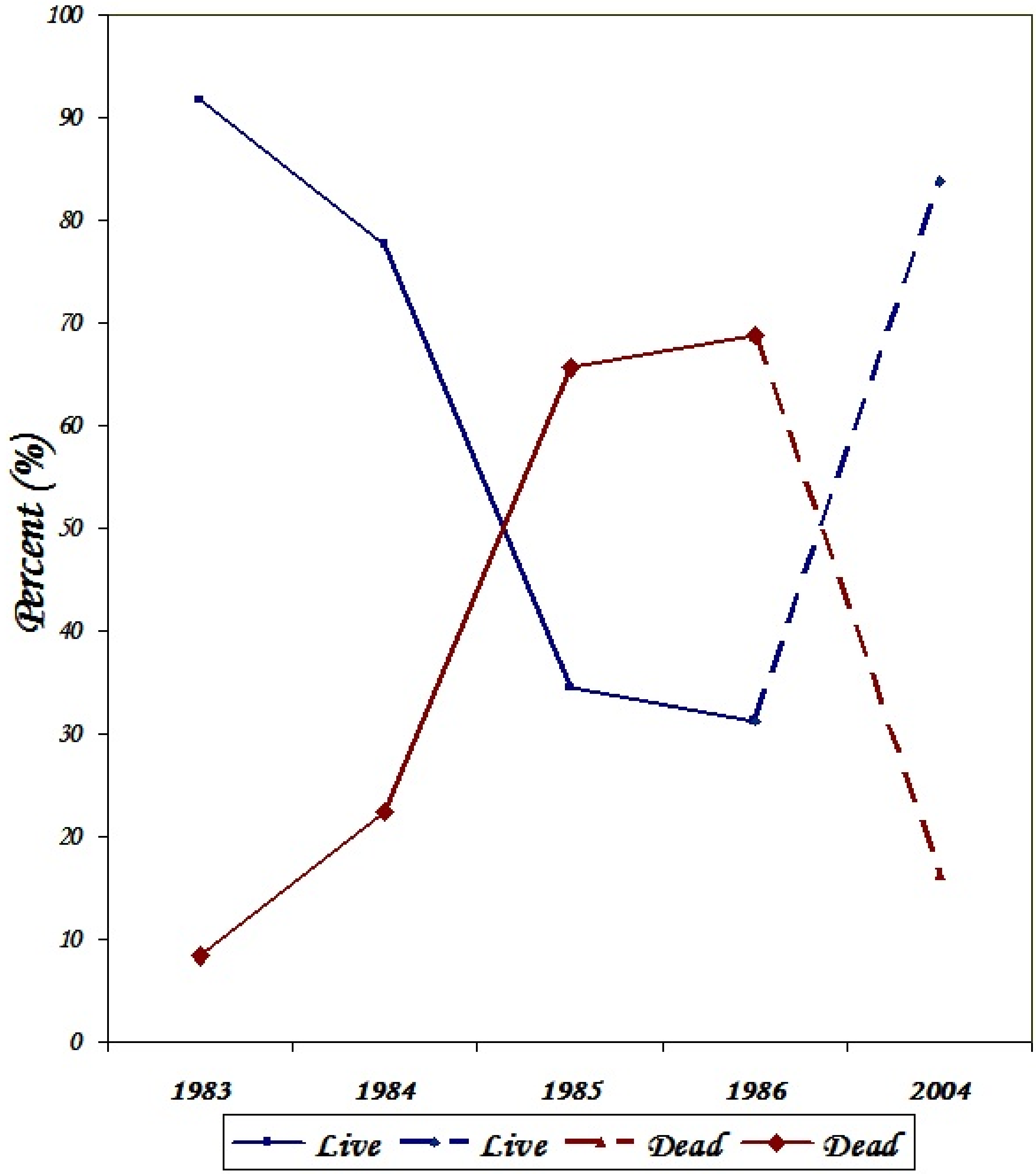

Fig. 7. Percent live and dead crown volume of silver sagebrush on the control treatment.

Table 1. Percent live and dead crown volume of silver sagebrush on tebuthiuron treatments.

Treatments		1983	1984	1985	1986	2004
LIVE BRANCHES						
Control		91.69	77.53	34.39	31.26	83.80
.25 lb ai/ac	20%	88.95	61.77	10.23	8.08	96.54
.25 lb ai/ac	40%	85.85	59.17	8.76	7.62	78.99
.50 lb ai/ac	20%	87.48	35.73	3.98	1.78	75.83
.50 lb ai/ac	40%	87.03	36.21	2.05	1.74	81.17
.75 lb ai/ac	20%	83.82	47.22	1.25	0.16	91.71
.75 lb ai/ac	40%	87.24	47.54	3.06	0.65	74.06
DEAD BRANCHES						
Control		8.31	22.47	65.61	68.74	16.20
.25 lb ai/ac	20%	11.05	38.23	89.77	91.92	3.46
.25 lb ai/ac	40%	14.15	40.83	91.24	92.38	21.01
.50 lb ai/ac	20%	12.52	64.27	96.02	98.22	24.17
.50 lb ai/ac	40%	12.97	63.79	97.95	98.26	18.83
.75 lb ai/ac	20%	16.18	52.78	98.75	99.84	8.29
.75 lb ai/ac	40%	12.76	52.46	96.94	99.35	25.94

Table 2. Mean plant measurements of silver sagebrush on the tebuthiuron with 20% concentration at the rate of .25 lb ai/acre treatments.

	1983 means of total shrubs	1984 means of total shrubs	1985 means of total shrubs	1986 means of total shrubs	2004 means of old shrubs developed from surviving aerial branches
LIVE BRANCHES					
N-S Diameter cm	87.17a	66.42bd	44.05c	29.47c	124.64d
E-W Diameter cm	81.28ad	62.09bd	37.73c	26.96c	115.15d
Height cm	82.56a	75.40b	48.17c	38.35c	107.49d
Shrub Density/m^2	0.87a	0.70a	0.75a	0.77a	0.23b
Crown Area cm^2/m^2	4528.13a	2230.07be	968.51c	471.84d	2367.54e
Crown Volume cm^3/m^3	373870.70ae	169001.32be	47337.54c	18499.36d	264408.57e
DEAD BRANCHES					
N-S Diameter cm	4.68ad	13.18b	55.51c	38.04c	0.43d
E-W Diameter cm	2.72ad	13.06b	53.53c	39.38c	2.21d
Height cm	2.43ae	8.93be	36.37c	46.67d	3.38e
Shrub Density/m^2	0.87a	0.70a	0.75a	0.77a	0.23b
Crown Area cm^2/m^2	419.13a	1008.97b	4481.64c	2251.22c	50.89d
Crown Volume cm^3/m^3	46458.59ad	104603.09b	415221.48c	210537.23c	9469.55d

Means in the same row and followed by the same letter are not significantly different ($P<0.05$).

Table 3. Mean plant measurements of silver sagebrush on the tebuthiuron with 40% concentration at the rate of .25 lb ai/acre treatments.

	1983 means of total shrubs	1984 means of total shrubs	1985 means of total shrubs	1986 means of total shrubs	2004 means of old shrubs developed from surviving aerial branches
LIVE BRANCHES					
N-S Diameter cm	59.38a	46.42b	23.29c	21.59c	85.97d
E-W Diameter cm	59.54a	43.16b	22.60c	19.82c	73.05d
Height cm	71.84a	58.04b	30.83c	29.93c	79.72d
Shrub Density/m^2	1.20a	1.17a	1.16a	1.12a	0.34b
Crown Area cm^2/m^2	3312.73a	1828.13bd	557.58cd	374.84c	1625.44d
Crown Volume cm^3/m^3	237705.16a	106088.04bd	23264.52c	12032.20c	128352.24d
DEAD BRANCHES					
N-S Diameter cm	4.13ad	9.65bd	42.63c	32.85c	5.75d
E-W Diameter cm	4.52ae	10.37b	44.10c	31.44d	4.95e
Height cm	0.93a	7.43bd	36.28c	34.98c	6.27d
Shrub Density/m^2	1.20a	1.17a	1.16a	1.12a	0.34b
Crown Area cm^2/m^2	497.73ae	913.05b	3392.17c	2059.21d	277.53e
Crown Volume cm^3/m^3	39165.30ae	73211.58b	242248.76c	145790.62d	34134.61e

Means in the same row and followed by the same letter are not significantly different ($P<0.05$).

Table 4. Mean plant measurements of silver sagebrush on the tebuthiuron with 20% concentration at the rate of .50 lb ai/acre treatments.

	1983 means of total shrubs	1984 means of total shrubs	1985 means of total shrubs	1986 means of total shrubs	2004 means of old shrubs developed from surviving aerial branches
LIVE BRANCHES					
N-S Diameter cm	64.05a	43.98a	20.80b	13.16b	106.80c
E-W Diameter cm	57.41a	42.21a	18.31b	20.66b	100.42c
Height cm	78.08a	60.62a	28.01b	23.48b	95.05c
Shrub Density/m^2	0.99a	0.94a	0.92a	0.95a	0.11b
Crown Area cm^2/m^2	3002.73ac	1409.59ac	305.42bc	135.50bc	913.10c
Crown Volume cm^3/m^3	242676.28ac	89923.54ac	11163.13bc	3808.25b	87251.97c
DEAD BRANCHES					
N-S Diameter cm	3.76ad	22.10bd	51.71c	49.57c	10.77d
E-W Diameter cm	4.82ad	21.40b	50.66c	46.90c	5.35d
Height cm	0.74a	16.82b	46.54c	49.45c	9.13d
Shrub Density/m^2	0.99a	0.94a	0.92a	0.95a	0.11b
Crown Area cm^2/m^2	412.19ac	1754.29b	3410.31b	2720.65b	183.81c
Crown Volume cm^3/m^3	34730.66ac	161721.81b	269601.08b	209744.38b	27805.23c

Means in the same row and followed by the same letter are not significantly different ($P<0.05$).

Table 5. Mean plant measurements of silver sagebrush on the tebuthiuron with 40% concentration at the rate of .50 lb ai/acre treatments.

	1983 means of total shrubs	1984 means of total shrubs	1985 means of total shrubs	1986 means of total shrubs	2004 means of old shrubs developed from surviving aerial branches
LIVE BRANCHES					
N-S Diameter cm	71.59abe	43.09bc	15.00cd	12.89d	100.78e
E-W Diameter cm	66.92abe	40.04bc	14.35cd	12.55d	87.71e
Height cm	78.22ae	51.72bc	20.09cd	18.14d	87.26e
Shrub Density/m^2	0.93a	1.02a	0.93a	0.93a	0.19b
Crown Area cm^2/m^2	3554.09a	1526.65abd	220.42bcd	145.85c	1104.47d
Crown Volume cm^3/m^3	284088.01a	94607.30abd	6426.21bc	3651.05c	92032.21d
DEAD BRANCHES					
N-S Diameter cm	4.02ad	23.39b	62.34c	49.84c	4.70d
E-W Diameter cm	4.64ad	21.63b	59.36c	47.01c	3.19d
Height cm	1.22a	24.17b	54.74c	54.79c	6.56d
Shrub Density/m^2	0.93a	1.02a	0.93a	0.93a	0.19b
Crown Area cm^2/m^2	466.29ad	1822.42b	3943.87c	2655.44c	176.62d
Crown Volume cm^3/m^3	42356.12ad	166655.10b	306484.16c	206060.59c	21351.05d

Means in the same row and followed by the same letter are not significantly different ($P<0.05$).

Table 6. Mean plant measurements of silver sagebrush on the tebuthiuron with 20% concentration at the rate of .75 lb ai/acre treatments.

	1983 means of total shrubs	1984 means of total shrubs	1985 means of total shrubs	1986 means of total shrubs	2004 means of old shrubs developed from surviving aerial branches
LIVE BRANCHES					
N-S Diameter cm	73.82a	58.74ac	11.98b	4.78b	101.46c
E-W Diameter cm	72.68a	51.80b	11.88c	4.74c	95.22a
Height cm	88.00a	64.14a	17.42b	9.06b	89.31a
Shrub Density/m^2	1.06a	0.92ab	0.94b	0.95b	0.22c
Crown Area cm^2/m^2	4434.00a	2292.41bd	185.71c	21.56c	1469.42d
Crown Volume cm^3/m^3	390634.22a	162571.98bd	6020.27c	286.12c	127256.99d
DEAD BRANCHES					
N-S Diameter cm	5.16a	16.18ad	77.21b	53.23c	0.0d
E-W Diameter cm	8.18a	22.04b	73.75c	46.71d	2.41e
Height cm	0.0a	21.52b	67.59c	68.98c	6.44d
Shrub Density/m^2	1.06a	0.92ab	0.94b	0.95b	0.22c
Crown Area cm^2/m^2	850.21a	1686.11ac	5438.65b	2263.53c	18.92d
Crown Volume cm^3/m^3	75421.28ad	181711.65bd	475797.29c	183221.93d	11505.80e

Means in the same row and followed by the same letter are not significantly different ($P<0.05$).

Table 7. Mean plant measurements of silver sagebrush on the tebuthiuron with 40% concentration at the rate of .75 lb ai/acre treatments.

	1983 means of total shrubs	1984 means of total shrubs	1985 means of total shrubs	1986 means of total shrubs	2004 means of old shrubs developed from surviving aerial branches
LIVE BRANCHES					
N-S Diameter cm	75.33a	59.39b	18.37c	12.07c	113.36d
E-W Diameter cm	73.63a	52.62b	18.90c	12.83c	107.34d
Height cm	81.40a	59.97b	22.93c	16.54c	98.28d
Shrub Density/m^2	0.87a	0.68b	0.74b	0.77ab	0.21c
Crown Area cm^2/m^2	3774.13a	1671.83bd	268.47c	93.17c	2017.11d
Crown Volume cm^3/m^3	307898.55ad	100237.75bd	8877.23c	1539.42c	197162.97d
DEAD BRANCHES					
N-S Diameter cm	4.72a	16.59b	64.09c	63.11c	16.14b
E-W Diameter cm	4.15a	15.35b	60.51c	55.76c	12.42b
Height cm	1.81a	16.27b	53.24c	59.79c	6.34d
Shrub Density/m^2	0.87a	0.68b	0.74b	0.77ab	0.21c
Crown Area cm^2/m^2	462.50ae	1080.84b	3537.98c	3013.24d	546.40e
Crown Volume cm^3/m^3	45043.38ae	110598.05be	281025.46c	235544.63d	69068.55e

Means in the same row and followed by the same letter are not significantly different ($P<0.05$).

Table 8. Mean plant measurements of silver sagebrush on the control treatment.

	1983 means of total shrubs	1984 means of total shrubs	1985 means of total shrubs	1986 means of total shrubs	2004 means of old shrubs developed from surviving aerial branches
LIVE BRANCHES					
N-S Diameter cm	64.31ac	53.52a	42.04ab	35.68b	92.75c
E-W Diameter cm	62.57ac	50.24ab	39.49ab	35.91b	88.67c
Height cm	76.46a	64.69b	45.74b	51.20b	85.19a
Shrub Density/m^2	1.13a	1.12a	1.11a	1.09a	0.38b
Crown Area cm^2/m^2	3524.88ad	2358.25bd	1712.83bcd	1112.23c	2106.77d
Crown Volume cm^3/m^3	271062.76ad	153774.13bd	98379.16bcd	59370.22cd	186725.42d
DEAD BRANCHES					
N-S Diameter cm	2.84ac	5.39ac	28.92bc	20.89b	6.34c
E-W Diameter cm	2.16abd	5.32bcd	26.37cd	17.61cd	11.62d
Height cm	0.69ae	4.50bce	25.05cde	19.28de	7.18e
Shrub Density/m^2	1.13a	1.12a	1.11a	1.09a	0.38b
Crown Area cm^2/m^2	287.36ad	502.93acd	2328.03bc	1571.69cd	330.09d
Crown Volume cm^3/m^3	24554.35ac	44567.59ac	187725.72b	130578.90bc	36088.51c

Means in the same row and followed by the same letter are not significantly different ($P<0.05$).

Table 9. Percent silver sagebrush topgrowth totally dead, partially dead, and not dead on tebuthiuron treatments and control treatment.

Treatments		1983	1984	1985	1986
Control					
plants totally dead	%	0.0	3.34	29.85	12.43
plants partially dead	%	29.50	35.61	48.09	77.10
plants not dead	%	70.50	61.05	22.06	10.48
.25 lb ai/ac 20%					
plants totally dead	%	0.0	4.65	34.78	43.62
plants partially dead	%	32.08	54.65	65.22	56.38
plants not dead	%	67.92	40.70	0.0	0.0
.25 lb ai/ac 40%					
plants totally dead	%	0.0	5.59	43.66	40.88
plants partially dead	%	34.93	45.45	51.41	56.20
plants not dead	%	65.07	48.95	4.93	2.92
.50 lb ai/ac 20%					
plants totally dead	%	0.0	17.98	54.17	59.69
plants partially dead	%	31.07	57.07	44.05	37.74
plants not dead	%	68.93	24.96	1.78	2.57
.50 lb ai/ac 40%					
plants totally dead	%	0.0	27.68	69.82	70.07
plants partially dead	%	37.72	43.52	27.19	29.93
plants not dead	%	62.28	28.80	2.98	0.0
.75 lb ai/ac 20%					
plants totally dead	%	0.0	16.81	73.91	80.17
plants partially dead	%	35.66	74.34	26.09	19.83
plants not dead	%	64.34	8.85	0.0	0.0
.75 lb ai/ac 40%					
plants totally dead	%	0.0	14.46	64.84	72.34
plants partially dead	%	23.58	32.53	35.17	27.66
plants not dead	%	76.42	53.01	0.0	0.0

Table 10. Mean N-S Diameter (cm) measurements of old, mid aged, and young silver sagebrush on tebuthiuron treatments, 2004.

Treatments		Old Shrubs developed from surviving aerial branches	Mid Aged Shrubs developed from vegetative sucker sprouts	Young Shrubs developed from seedlings	N-S Diameter cm/m²
LIVE BRANCHES					
Control		92.75ab	68.42a	41.49a	54.64ab
.25 lb ai/ac	20%	124.64ab	81.67a	9.50a	41.44ab
.25 lb ai/ac	40%	85.97b	81.89ab	20.20a	63.13a
.50 lb ai/ac	20%	106.80ab	89.92a	19.96a	23.74b
.50 lb ai/ac	40%	100.78ab	61.38ab	20.47a	30.88ab
.75 lb ai/ac	20%	101.46ab	57.30b	17.72a	45.61ab
.75 lb ai/ac	40%	113.36a	91.84ab	29.16a	35.35ab
DEAD BRANCHES					
Control		6.34xyz	19.93xy	0.0x	3.86xy
.25 lb ai/ac	20%	0.43yz	0.0y	0.0x	0.31y
.25 lb ai/ac	40%	5.75yz	45.44x	0.0x	6.82xy
.50 lb ai/ac	20%	10.77xz	1.50y	0.0x	1.34y
.50 lb ai/ac	40%	4.70yz	15.94xy	0.0x	1.59xy
.75 lb ai/ac	20%	-0.37yz	11.50xy	0.0x	0.01y
.75 lb ai/ac	40%	16.14x	19.00xy	0.0x	4.04x

Means in the same column and followed by the same letter are not significantly different (P<0.05).

Table 11. Mean E-W Diameter (cm) measurements of old, mid aged, and young silver sagebrush on tebuthiuron treatments, 2004.

Treatments		Old Shrubs developed from surviving aerial branches	Mid Aged Shrubs developed from vegetative sucker sprouts	Young Shrubs developed from seedlings	E-W Diameter cm/m^2
LIVE BRANCHES					
Control		88.67ab	63.46a	39.85a	50.62a
.25 lb ai/ac	20%	115.15ab	61.06a	11.53a	28.39a
.25 lb ai/ac	40%	73.05b	67.97a	18.77a	55.75a
.50 lb ai/ac	20%	100.42a	86.12a	22.27a	22.65a
.50 lb ai/ac	40%	87.71ab	53.91a	18.62a	27.72a
.75 lb ai/ac	20%	95.22ab	52.35a	16.07a	41.04a
.75 lb ai/ac	40%	107.34a	73.97a	36.67a	32.74a
DEAD BRANCHES					
Control		11.62xy	12.35xy	0.0x	4.48xz
.25 lb ai/ac	20%	2.12y	0.0y	0.0x	0.48y
.25 lb ai/ac	40%	4.95y	35.25x	0.0x	5.25xy
.50 lb ai/ac	20%	5.35xy	5.13y	0.0x	1.03yz
.50 lb ai/ac	40%	3.19xy	13.38xy	0.0x	2.04xy
.75 lb ai/ac	20%	2.41y	4.00y	0.0x	0.44y
.75 lb ai/ac	40%	12.42x	15.25xy	0.0x	2.92x

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 12. Mean height (cm) measurements of old, mid aged, and young silver sagebrush on tebuthiuron treatments, 2004.

Treatments		Old Shrubs developed from surviving aerial branches	Mid Aged Shrubs developed from vegetative sucker sprouts	Young Shrubs developed from seedlings	Height cm/m^2
LIVE BRANCHES					
Control		85.19ab	70.24a	45.85a	54.94a
.25 lb ai/ac	20%	107.49a	70.39a	17.92a	41.45a
.25 lb ai/ac	40%	79.72b	68.12a	31.86a	63.76a
.50 lb ai/ac	20%	95.05a	80.00a	34.19a	23.82a
.50 lb ai/ac	40%	87.26ab	50.18a	31.60a	33.79a
.75 lb ai/ac	20%	89.31ab	60.90a	27.69a	50.40a
.75 lb ai/ac	40%	98.28a	76.64a	43.36a	33.99a
DEAD BRANCHES					
Control		7.18x	26.00xy	0.0x	3.60x
.25 lb ai/ac	20%	3.38x	0.0y	0.0x	1.11x
.25 lb ai/ac	40%	6.27x	60.57x	0.0x	6.36x
.50 lb ai/ac	20%	9.13x	10.75y	0.0x	1.42x
.50 lb ai/ac	40%	6.56x	23.38y	0.0x	2.09x
.75 lb ai/ac	20%	6.44x	13.50y	0.0x	1.61x
.75 lb ai/ac	40%	6.34x	32.25xy	0.0x	2.31x

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 13. Mean shrub density (#/m^2) measurements of old, mid aged, and young silver sagebrush on tebuthiuron treatments, 2004.

Treatments		Old Shrubs developed from surviving aerial branches	Mid Aged Shrubs developed from vegetative sucker sprouts	Young Shrubs developed from seedlings	Density #/m^2
LIVE BRANCHES					
Control		0.38a	0.25a	0.17a	0.80ab
.25 lb ai/ac	20%	0.23a	0.16ab	0.15a	0.53ab
.25 lb ai/ac	40%	0.34a	0.35a	0.43ab	1.12ab
.50 lb ai/ac	20%	0.11a	0.09b	0.16a	0.36b
.50 lb ai/ac	40%	0.19a	0.10ab	0.60ab	0.88ab
.75 lb ai/ac	20%	0.22a	0.24ab	0.65b	1.11a
.75 lb ai/ac	40%	0.21a	0.07b	0.25a	0.53b
DEAD BRANCHES					
Control		0.38x	0.03x	0.0x	0.40x
.25 lb ai/ac	20%	0.23x	0.0x	0.0x	0.23x
.25 lb ai/ac	40%	0.34x	0.07x	0.0x	0.42x
.50 lb ai/ac	20%	0.11x	0.01x	0.0x	0.12x
.50 lb ai/ac	40%	0.19x	0.02x	0.0x	0.22x
.75 lb ai/ac	20%	0.22x	0.01x	0.0x	0.23x
.75 lb ai/ac	40%	0.21x	0.02x	0.0x	0.22x

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 14. Mean crown area (cm^2/m^2) measurements of old, mid aged, and young silver sagebrush on tebuthiuron treatments, 2004.

Treatments		Old Shrubs developed from surviving aerial branches	Mid Aged Shrubs developed from vegetative sucker sprouts	Young Shrubs developed from seedlings	Crown Area cm^2/m^2
LIVE BRANCHES					
Control		2106.77a	859.27ab	145.53a	3111.57ab
.25 lb ai/ac	20%	2367.54a	695.21ab	50.99a	3113.74a
.25 lb ai/ac	40%	1625.44a	1361.88a	160.54a	3147.86a
.50 lb ai/ac	20%	913.10a	567.30ab	87.85a	1568.26b
.50 lb ai/ac	40%	1104.47a	497.54ab	72.66a	1674.66b
.75 lb ai/ac	20%	1469.42a	524.22b	160.82a	2154.46ab
.75 lb ai/ac	40%	2017.11a	332.56b	127.89a	2477.56ab
DEAD BRANCHES					
Control		330.09xy	27.46x	0.0x	357.55xy
.25 lb ai/ac	20%	50.89x	0.0x	0.0x	50.89x
.25 lb ai/ac	40%	277.54xy	160.24x	0.0x	437.78xy
.50 lb ai/ac	20%	183.81xy	1.13x	0.0x	184.94xy
.50 lb ai/ac	40%	176.62xy	10.54x	0.0x	187.16xy
.75 lb ai/ac	20%	18.92x	1.54x	0.0x	20.46x
.75 lb ai/ac	40%	546.40y	15.03x	0.0x	561.43y

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 15. Mean crown volume (cm^3/m^3) measurements of old, mid aged, and young silver sagebrush on tebuthiuron treatments, 2004.

Treatments		Old Shrubs developed from surviving aerial branches	Mid Aged Shrubs developed from vegetative sucker sprouts	Young Shrubs developed from seedlings	Crown Volume cm^3/m^3
LIVE BRANCHES					
Control		186725.43a	48439.00ab	7929.53a	243093.95ab
.25 lb ai/ac	20%	264408.57a	53760.04ab	1826.95a	319995.55a
.25 lb ai/ac	40%	128352.24a	96039.22a	5274.99a	229666.44a
.50 lb ai/ac	20%	87251.98a	51352.24ab	3959.22a	142563.44b
.50 lb ai/ac	40%	92032.21a	37918.34ab	2341.37a	132291.91b
.75 lb ai/ac	20%	127256.99a	31612.22b	4955.42a	163824.63b
.75 lb ai/ac	40%	197162.97a	26857.59ab	5058.13a	229078.68ab
DEAD BRANCHES					
Control		36088.51xy	1446.38x	0.0x	37534.89xy
.25 lb ai/ac	20%	9469.55x	0.0x	0.0x	9469.55x
.25 lb ai/ac	40%	34134.61xy	8727.51x	0.0x	42862.12xy
.50 lb ai/ac	20%	27805.23xy	48.35x	0.0x	27853.58xy
.50 lb ai/ac	40%	21351.05xy	488.12x	0.0x	21839.17xy
.75 lb ai/ac	20%	11505.80x	41.55x	0.0x	11547.35x
.75 lb ai/ac	40%	69068.56y	969.26x	0.0x	70037.82y

Means in the same column and followed by the same letter are not significantly different ($P<0.05$).

Table 16. Percent change from 1983 control treatment of N-S and E-W diameter, and height (cm/m^2) measurements of silver sagebrush on tebuthiuron treatments, 2004.

		N-S Diameter		E-W Diameter		Height	
Treatments		cm/m^2	% change from 1983	cm/m^2	% change from 1983	cm/m^2	% change from 1983
LIVE BRANCHES							
Control 1983		71.88a		69.78a		86.59a	
2004							
Control		54.64a	-23.98	50.62a	-27.46	54.94a	-36.55
.25 lb ai/ac	20%	41.44b	-42.35	28.39b	-59.31	41.45b	-52.13
.25 lb ai/ac	40%	63.13a	-12.17	55.75a	-20.11	63.76a	-26.37
.50 lb ai/ac	20%	23.74b	-66.97	22.65b	-67.54	23.82b	-72.49
.50 lb ai/ac	40%	30.88b	-57.04	27.72b	-60.28	33.79b	-60.98
.75 lb ai/ac	20%	45.61a	-36.55	41.04b	-41.19	50.40a	-41.79
.75 lb ai/ac	40%	35.35b	-50.82	32.74b	-53.08	33.99b	-60.75
DEAD BRANCHES							
Control 1983		3.30x		2.54x		0.75x	
2004							
Control		3.86x	+16.97	4.48x	+76.38	3.60y	+380.00
.25 lb ai/ac	20%	0.31y	-90.61	0.48y	-81.10	1.11x	+48.00
.25 lb ai/ac	40%	6.82x	+106.67	5.25x	+106.69	6.36x	+748.00
.50 lb ai/ac	20%	1.34x	-59.39	1.03x	-59.45	1.42x	+89.33
.50 lb ai/ac	40%	1.59x	-51.82	2.04x	-19.69	2.09x	+178.67
.75 lb ai/ac	20%	0.01y	-99.70	0.44y	-82.68	1.61y	+114.67
.75 lb ai/ac	40%	4.04x	+22.42	2.92x	+14.96	2.31y	+208.00

Means in the same column and followed by the same letter are not significantly different ($P<0.05$) from the 1983 control value.

Table 17. Percent change from 1983 control treatment of shrub density (#/m^2) measurements of silver sagebrush on tebuthiuron treatments, 2004.

		Old Shrubs developed from surviving aerial branches		Mid Aged Shurbs developed from vegetative sucker sprouts	Young Shrubs developed from seedlings	Total Density	
Treatments		#/m^2	% change from 1983	#/m^2	#/m^2	#/m^2	% change from 1983
LIVE BRANCHES							
Control 1983		1.13a				1.13a	
2004							
Control		0.38b	-66.37	0.25	0.17	0.80a	-29.20
.25 lb ai/ac	20%	0.23b	-79.65	0.16	0.15	0.53a	-53.10
.25 lb ai/ac	40%	0.34b	-69.91	0.35	0.43	1.12a	-0.88
.50 lb ai/ac	20%	0.11b	-90.27	0.09	0.16	0.36b	-68.14
.50 lb ai/ac	40%	0.19b	-83.19	0.10	0.60	0.88a	-22.12
.75 lb ai/ac	20%	0.22b	-80.53	0.24	0.65	1.11a	-1.77
.75 lb ai/ac	40%	0.21b	-81.42	0.07	0.25	0.53b	-53.10
DEAD BRANCHES							
Control 1983		1.13x				1.13x	
2004							
Control		0.38y	-66.37	0.03	0.0	0.40y	-64.60
.25 lb ai/ac	20%	0.23y	-79.65	0.0	0.0	0.23y	-79.65
.25 lb ai/ac	40%	0.34y	-69.91	0.07	0.0	0.42y	-62.83
.50 lb ai/ac	20%	0.11y	-90.27	0.01	0.0	0.12y	-89.38
.50 lb ai/ac	40%	0.19y	-83.19	0.02	0.0	0.22y	-80.53
.75 lb ai/ac	20%	0.22y	-80.53	0.01	0.0	0.23y	-79.65
.75 lb ai/ac	40%	0.21y	-81.42	0.02	0.0	0.22y	-80.53

Means in the same column and followed by the same letter are not significantly different ($P<0.05$) from the 1983 control value.

Table 18. Percent change from 1983 control treatment of crown area and crown volume measurements of silver sagebrush on tebuthiuron treatments, 2004.

Treatments		Crown Area		Crown Volume	
		cm^2/m^2	% change from 1983	cm^3/m^3	% change from 1983
LIVE BRANCHES					
Control 1983		3524.88a		271062.76a	
2004					
Control		3111.57a	-11.73	243093.95a	-10.32
.25 lb ai/ac	20%	3113.74a	-11.66	319995.55a	+18.05
.25 lb ai/ac	40%	3147.86a	-10.70	229666.44b	-15.27
.50 lb ai/ac	20%	1568.26b	-55.51	142563.44b	-47.41
.50 lb ai/ac	40%	1674.66b	-52.49	132291.91b	-51.20
.75 lb ai/ac	20%	2154.46a	-38.88	163824.63b	-39.56
.75 lb ai/ac	40%	2477.56a	-29.71	229078.68a	-15.49
DEAD BRANCHES					
Control 1983		287.36x		24554.35x	
2004					
Control		357.55x	+24.43	37534.89x	+52.86
.25 lb ai/ac	20%	50.89y	-82.29	9469.55x	-61.43
.25 lb ai/ac	40%	437.78x	+52.35	42862.12x	+74.56
.50 lb ai/ac	20%	184.94x	-35.64	27853.58x	+13.44
.50 lb ai/ac	40%	187.16x	-34.87	21839.17x	-11.06
.75 lb ai/ac	20%	20.46y	-92.88	11547.35y	-52.97
.75 lb ai/ac	40%	561.43x	+95.38	70037.82y	+185.24

Means in the same column and followed by the same letter are not significantly different ($P<0.05$) from the 1983 control value.

Table 19. Percent canopy cover and percent change from 1983 canopy cover.

Treatments	1983 total shrubs	1984 total shrubs	1985 total shrubs	1986 total shrubs	2004 surviving plants	2004 plants from seedlings
Control	35.25	23.58	17.13	11.12	29.66	1.46
change from 1983	-	-33.11%	-51.40%	-68.45%	-15.86%	-95.86%
0.25 lb ai/ac 20%	45.28	22.30	9.69	4.72	30.63	0.51
change from 1983	-	-50.75%	-78.60%	-89.58%	-32.35%	-98.87%
0.25 lb ai/ac 40%	33.13	18.28	5.58	3.75	29.87	1.61
change from 1983	-	-44.82%	-83.16%	-88.68%	-9.84%	-95.14%
0.50 lb ai/ac 20%	30.03	14.10	3.05	1.36	14.80	0.88
change from 1983	-	-53.05%	-89.84%	-95.47%	-50.72%	-97.07%
0.50 lb ai/ac 40%	35.54	15.27	2.20	1.46	16.02	0.73
change from 1983	-	-57.03%	-93.81%	-95.89%	-54.92%	-97.95%
0.75 lb ai/ac 20%	44.34	22.92	1.86	0.22	19.93	1.61
change from 1983	-	-48.31%	-95.81%	-99.50%	-55.05%	-96.37%
0.75 lb ai/ac 40%	37.74	16.72	2.68	0.93	23.50	1.28
change from 1983	-	-21.02%	-92.90%	-97.54%	-37.73%	-96.61%

Table 20. Long-term plant survival/mortality effects from tebuthiuron treatments.

Treatments		% plants with aerial branches surviving	% plants with belowground parts surviving	% plants with topgrowth killed	% plants totally killed
Control		33.63	22.12	66.37	44.25
0.25 lb ai/ac	20%	26.44	18.39	73.56	55.17
0.25 lb ai/ac	40%	28.33	29.17	71.67	42.50
0.50 lb ai/ac	20%	11.11	9.09	88.89	79.80
0.50 lb ai/ac	40%	20.43	10.75	79.57	68.82
0.75 lb ai/ac	20%	20.75	22.65	79.25	56.60
0.75 lb ai/ac	40%	24.14	8.04	75.86	67.82

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