MANAGEMENT OF WESTERN SNOWBERRY aka WOLFBERRY AND BUCKBRUSH

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Preface

Western snowberry is a serious pasture weed, and its encroachment into North American grazinglands has been an increasing problem for over one hundred years. Traditional grazing management practices are antagonistic to the biological requirements of grass plants and to the biogeochemical processes in grassland ecosystems; the result of such antagonistic management is less than healthy grass plants. Because they have diminishing competitive abilities, these grass plants relinquish greater quantities of ecosystem natural resources that then become available for western snowberry colony expansion.

The aerial stems of western snowberry can be killed relatively easily with single burning, mowing, or herbicide application treatments. The belowground plant parts, however, are more persistent and not easily damaged. Western snowberry has biological mechanisms and processes that provide the shrub with capabilities to survive aerial stem removal treatments and to completely replace the aerial stem density and biomass by the third growing season following treatment.

Implementation of biologically effective grazing management like the twice-over rotation system improves the health and competitive abilities of the native grass plants but does not remove the aerial stems and reduce the size of preexisting western snowberry colonies. Additional management that uses burning, mechanical, or chemical treatments is needed to reduce western snowberry colonies.

This project summarizes available information about western snowberry with the intent to improve understanding of the shrub’s strengths and weaknesses so that management strategies to effectively reduce western snowberry colonies on grazinglands can be developed.

Western Snowberry Biology

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Introduction

Western snowberry has biological mechanisms and processes that provide the shrub with capabilities to develop dense colonies that can invade grasslands, eliminate existing native grass community species, and convert the area into brush habitat, creating an environment conducive to encroachment by taller shrubs and trees. This conversion of grassland habitat into brush habitat is difficult, if not impossible, to correct through a single application of any treatment type. Reduction of western snowberry colony density to a tolerable level requires multiple treatment strategies followed by repeated maintenance treatments.

Understanding how western snowberry grows and when it has vulnerable periods in its life cycle is necessary for the development of successful treatment practices. This report summarizes the biological information needed for the development of strategies to manage western snowberry colonies in grasslands.

Plant Description

The scientific name of western snowberry is *Symphoricarpos occidentalis* Hook., and the plant belongs to the honeysuckle family, Caprifoliaceae. The common name “snowberry” comes from the whitish color of the fruits. In the Northern Plains, the plant’s other common names are wolfberry, buckbrush, and badgerbrush.

Western snowberry is a native deciduous cool-season shrub that forms large colonies. Its rhizomes are long and sometimes branched (figure 1). Their diameter is usually 0.12 to 0.24 inches (3-6 mm). Clusters of stem bases or rhizome crowns develop at 1- to 3-foot (30-100 cm) intervals along interconnected rhizome systems. Roots with unequal growth develop as opposite pairs at rhizome nodes. Upright stems are 1 to more than 3 feet (0.3-1.0 m) tall. Stem diameter at 1 inch (3 cm) above the soil surface is 0.3 to 0.8 inches (0.8-2.0 cm). Lateral branches develop as opposite twig pairs at the nodes on the upper portions of stems after the first growing season. As the stem ages, the number of twigs and the complexity of branching pattern increase, and the pith becomes hollow. Leaves are simple, thick, opposite, oval to elliptical, 1 to 2.4 inches (2-6 cm) long, and 0.3 to 1.5 inches (1-3.5 cm) wide. Upper leaf surfaces are smooth and dark green to gray green. Leaf undersides have short hairs and are light green. Leaf edges are usually not toothed, but occasionally young or shaded stems can have leaves with wavy, blunt teeth. Short leaf stalks are 0.25 to 0.33 inches (6-8 mm) long. The small, pinkish, bell-shaped flowers develop from buds formed in clusters of 5 to 20 on a short spike and grow from twig ends and axils of upper leaves. Two to four slightly fragrant flowers of a cluster open at night or early morning each day. The flowering period of a colony is long and occurs during June and July, lasting until mid August in some years. The fruit, a fleshy greenish-white drupe 0.25 to 0.35 inches (6-9 mm) in diameter, contains two slightly flattened oval or elliptical yellowish to brown nutlets 0.08 to 0.12 inches (2-3 mm) long and 0.06 to 0.08 inches (1.5-2 mm) wide. The fruits persist on the stem through winter and turn dark blue to black when they are dry (Great Plains Flora Association 1986, Johnson and Larson 1999, Pelton 1953).

Habitats

Western snowberry is widely distributed throughout most of the interior of North America. The plant’s range extends from the southern portions of Northwest Territories to northern New Mexico and from central Washington to eastern Michigan and has expanded into the northern portions of New England (Pelton 1953).

Western snowberry grows in association with a great variety of plant communities and vegetation types on a wide variety of soils (Pelton 1953). It is commonly the ecotonal species on the transitional boundaries between two plant communities. It grows on the margins of openings or disturbed areas in woodlands and forests and on the borders of aspen bluffs and other types of groves with taller shrubs and trees; in grasslands, it can grow in large colonies as the only woody plant. Associated herbaceous plants tend to decrease as western snowberry stems increase. Shading of the understory by stem canopy cover of western snowberry reduces and eliminates native grass and forb species. Kentucky bluegrass is the last grass to die out under invading colonies of western snowberry (Weaver and Fitzpatrick 1934). Kentucky bluegrass is the only ubiquitous species under the partially shaded portions of western snowberry colonies in Minnesota (Pelton 1953), as it is across most of the United States and Canada (figure 2).

In the more humid parts of its range, western snowberry occurs on the drier topographic sites, such as exposed south- and west-facing slopes, where there is less competition from tall, dense vegetation. In the drier and arid parts of its range, the plant occurs on slopes having aspects where evapotranspiration is lower, in depressions or at the base of slopes where water runin is received from the upper slopes, or on sites where snowdrifts accumulate (Pelton 1953, Mastel 1983, Ransom-Nelson 1985).

Other Snowberries

There are several species of snowberry in North America, most of which are difficult to distinguish from western snowberry. Common white snowberry (*S. albus* (L) Blake) has wide distribution across North America, and its range overlaps that of western snowberry in the northern United States and in Canada. Common white snowberry has small, thin leaves about 1 inch (2.5 cm) long; flowers growing 2 or 3, sometimes 5, in a cluster; and hollow pith in older stems. It commonly grows as scattered individual plants and occasionally produces long rhizomes. Coralberry (*S. orbiculatus* Moeuch) is primarily an eastern species whose distribution overlaps that of western snowberry in the eastern portions of the Central and Southern Plains. The fruits are coral-pink to purplish. The pith of older stems is solid and white. Palmer's snowberry (*S. palmeri* G.N. Jones) is distributed in the western portions of the Southern Plains. It has climbing or sprawling stems to 10 feet (3 m) long (Great Plains Flora Association 1986). Several other snowberry species grow in the western and southwestern portions of the United States: longflower snowberry (*S. longiflorus*), spreading or trailing snowberry (*S. mollis*), mountain snowberry (*S. oreophilus*), roundleaf snowberry (*S. rotundifolius*), and whortleleaf snowberry (*S. vaccinioides*).

Vegetative Growth and Development

Western snowberry colonies can range from a small number of stems covering a few square feet to extensive growths covering hundreds of acres. Pelton (1953) found the colonies in Minnesota to range in size from 1.1 to 2.2 yards (1-2 m) to 55 to 82 yards (50-75 m) in diameter. In southcentral North Dakota, Roel (1983) and Ransom-Nelson (1985) found typical colonies to range in size from 22 to 55 yards (20-50 m) in diameter.

Stem height of western snowberry tends to be greater towards the center of the colony (Pelton 1953). Growth in stem height has been correlated to soil moisture but not to any other environmental factor (Pelton 1953). Mastel (1983) found that low precipitation during April and May, the period of growth initiation and rapid twig elongation, was important in determining the quantity of total annual growth even if the remainder of the growing season received near-normal precipitation. The stem height measured in Minnesota averaged 29.5 inches (75 cm), with a range from 16 to 45 inches (40-115 cm) (Pelton 1953). The average mature stem height measured in southcentral North Dakota was 17.0 inches (43.2 cm) (Roel 1983).

Stem density of western snowberry colonies varies considerably. The densest colonies are commonly located on topographic sites that are relatively moist and exposed to full sun (Pelton 1953). An average colony Pelton (1953) examined in Minnesota had a density of 38.5 stems/sq. yard (46/m^2). In southcentral North Dakota, Roel (1983) found average colony densities of 40.7 stems/sq. yard (48.7/m^2), and Ransom-Nelson (1985) found average colony densities of 61.8 stems/sq. yard (73.9/m^2).

Stem densities within a colony also vary. The lowest density typically occurs at the periphery of a colony (Pelton 1953). Roel (1983) systematically measured stem density every 16.5 feet (5 m) from the center of each of 12 colonies outward along four transects toward the periphery and found the greatest density, 49.5 stems/sq. yard (59.2/m^2), near the center. The density progressively decreased outward, reaching 28.1 stems/sq. yard (33.6/m^2) near the edge (table 1).

Pelton (1953) observed that portions of about one half of the 20 western snowberry colonies in his Minnesota study had canopy cover dense enough to shade out Kentucky bluegrass completely. In southcentral North Dakota, Roel (1983) studied 15 colonies that had an average canopy cover of 24.0%, with a range from 12.3% to 47.3%, and Ransom-Nelson (1985) studied 15 colonies that had an average canopy cover of 44.9%, with a range from

17.6% to 93.1%. In western North Dakota, Mastel (1983) studied 8 colonies that had an average canopy cover of 32.6%, with a range from 14.7% to 46.8%.

The successful distribution, survival, and abundance of western snowberry across extreme physical and environmental conditions depend on the persistence of the rhizomes and clusters of stem bases and their ability to produce numerous growing points with meristematic tissue that can generate new cells. The shrub's underground organs are long lived. Pelton (1953) found 40-year-old rhizomes in Minnesota colonies. An important factor that contributes to their longevity is the protection provided by the soil. Most rhizomes grow between 2 to 6 inches (5-15 cm) below the soil surface, but rhizomes can be found at any depth from 0.75 to 14 inches (2-35 cm) below ground (Pelton 1953). Western snowberry rhizomes grow at greater soil depths under areas that have grass sod (Pelton 1953).

Rhizome nodes comprising opposite pairs of growing points with meristematic tissue develop on young growing rhizomes about every 0.5 to 1.0 inch (1.25-2.5 cm). The length of the rhizomes between stem base clusters tends to be about 1.0 to 3.0 feet (30.5-91 cm). In a Minnesota colony that was less than 10 years old, Pelton (1953) found the cumulative rhizome length to be 4.4 times longer than the cumulative live aerial stem length, and the average diameter of rhizomes to be 0.16 inches (4 mm). In western North Dakota, rhizome diameter is usually between 0.12 and 0.24 inches (3-6 mm), increasing to 0.39 inches (1 cm) at junctions with rhizome branches and to 0.79 inches (2 cm) at junctions with stem bases.

Roots originate as opposite pairs at most of the nodes along the rhizomes. The root pairs have unequal growth. One root in each pair is larger than the mate, and some root pair mates fail to develop. A few roots along a section of rhizome grow considerably larger than the others. Pelton (1953) found these larger roots could penetrate the soil to a depth of 61 inches (155 cm).

Western snowberry's lateral buds, produced as opposite pairs at each rhizome node, have the potential to develop into a long rhizome branch or a short rhizome branch that turns upward and develops into erect stems. Most of the buds along the midsection of a rhizome, however, never develop, but atrophy with age. When rhizome buds do develop, the young rhizomes and the rhizome branches grow horizontally away from their original growing point for a distance, usually about 3 feet (91 cm) or less, turn upward, and develop into an erect aerial stem. Rhizome buds near a vertical stem base appear to have greater viability and can develop into long rhizomes, short rhizomes, and additional erect stems forming clusters of stem bases. These sections of vertical and horizontal rhizomes with several nodes actively producing rhizomes and aerial stems are rhizome crowns.

Aerial stems of western snowberry produced vegetatively from meristematic buds are suckers. Rhizome suckers develop from upturned rhizomes or rhizome branches, and crown suckers develop near stem base clusters. During the second year of growth, stems are young stems. During the third and subsequent years, stems are mature stems.

Sucker stems develop rapidly during the first growing season. The outer layer of young suckers is hairy or pubescent until bark develops during the latter portion of the first year or during the second year. Stem nodes comprising opposite pairs of growing points with meristematic tissue develop on sucker stems about every 1.0 to 2.0 inches (2.5-5.0 cm). Opposite pairs of leaves are produced at each node along the entire sucker stem. Lateral branches do not appear during the first year unless the lead apical meristem is damaged. The first lateral twigs usually appear from nodes along the upper portions of the young stem during the second year of growth. Most of the buds at the nodes along the lower portions of the stem never develop into twigs, but atrophy with age. Twigs originate as opposite pairs from meristematic buds located at the nodes that were the previous year's leaf axils. Twigs usually do not develop from every potential node. The uppermost undamaged pair of twig buds develops first. New leaves, produced as opposite pairs, develop at the nodes of only the current year's twigs, not on older twig material. Successive twigs growing from the previous year's leaf axils create a branch network that becomes more complex with each growing season. The age of intact stems can be determined from the pattern of twig branches.

Aerial stems do not survive as long as rhizomes and clusters of stem bases. Pelton (1953) determined the age of mature stems in Minnesota to average about 7.2 years, with the maximum age at 13 years. Portions of the twig branch system die as stems age. When more than 50% of the branch system no longer supports the growth of new twigs, the stem is considered to be decadent. This apparent twig senescence is not a symptom of reduced vigor of the stem (Pelton 1953) but is most likely the result of unfavorable environmental conditions, such as severe winter cold or growing-season water stress. Under some unfavorable conditions, the stem can be killed to ground level.

The loss of a few stems does not hurt the colony: the lost stems are replaced by vegetative growth of rhizome buds. Vegetative reproduction of sucker stems is regulated by apical dominance of a lead stem through the production of inhibitory hormones that block or suppress the activity of growth hormones. When a lead stem is killed or damaged by some unfavorable condition, such as low temperatures, fire, browsing, mowing, or drought, the production of inhibitory hormones is reduced or stopped, and the growth hormones activate meristematic tissue in rhizome buds; the activation results in the development of several new rhizomes and sucker stems. The distance from which hormones produced by lead stems can regulate or influence growth activity of rhizome buds may be reflected in the long length of the rhizomes between adjacent stem base clusters.

Sexual Reproduction

Changes in day length (photoperiod) regulate the growth and development of most plants in the middle latitudes by activating or stopping physiological processes (Leopold and Kriedemann 1975). In a study of transplanted stems placed in light-proof boxes and subjected to light periods of four different durations, Pelton (1953) determined that western snowberry required day lengths of at least 14 hours to initiate flower bud development. Once the flower buds had reached visible size, their subsequent development did not depend on photoperiod or temperature (Pelton 1953). Pinkish flower buds form near the growing tip of young twigs towards the end of rapid spring growth. Additional flower buds form at the leaf axils of the current year's twigs. Flower bud development progresses in a hierarchical sequence from twig ends downward to the lower leaf axils.

Flowering (anthesis) does not have a photoperiod requirement in addition to the 14 hours of day length the plant needs to initiate flower bud development (Pelton 1953). The flowers, which open during the night or early morning, are insect pollinated. The sticky pollen grains are accessible by numerous types of bees, butterflies, and moths because the structure of the flower is not specialized. Open flowers are slightly fragrant, and the lower portion of the wide corolla tube is filled with nectar to attract the insects (Pelton 1953). Flowering progress follows the sequence of flower bud development, from the flowers located at the twig ends downward to the flowers located at the lower leaf axils (figure 3). Western snowberry colonies can be in continuous bloom for much of the summer. Usually the flowering period occurs during June and July, but it can extend to mid August and sometimes later (Pelton 1953).

After a flower has been fertilized, the fruit develops for a period of several weeks as the ovary gradually enlarges. Fruit maturation does not depend on photoperiod or temperature requirements (Pelton 1953). Mature fruits are greenish white and contain two nutlets. Pelton (1953) measured fruit production of 500 stems collected from 6 colonies that included aerial stems of all age and size categories; he found the average number of fruits to be 32.5 per stem. Fruit production decreased from the center of a colony toward the periphery, where the stems were younger and competition from grass plants was more severe (Pelton 1953). Pelton (1953) also measured the fruit production of six healthy mature stems and found they developed an average of 160.3 flower buds that produced 119.6 mature fruits with 122.5 filled nutlets; about 48.8% of the nutlets were defective. Fruits composed 14.3% of the average total annual biomass production per mature stem in North Dakota (Roel 1983).

The stalk of the fruit does not have an abscission layer that would permit the fruit to drop shortly after it became ripe; as a result, the fruit remains attached to the stem over winter. The fruit stalks decay and the fruits drop during the following spring or summer (Pelton 1953).

Western snowberry nutlets have a complex double-dormancy mechanism that prevents the seed from germinating in the wrong place or at the wrong time of year. Germination of the seed cannot occur until after the seed coat has been broken down. The intact fruit and dried pulp are impervious to water and protect the seed coat while the fruit is attached to the stem. After the fruit drops and lands in warm, moist soil, the outer layers of the fruit decay in about one or two weeks. A physical restraint to embryo development, the seed coat is impervious to both water and gases and requires about one to two months to break down in response to fungal action in the soil. The afterripening process, the slow deterioration of the dormancy mechanism in the nutlet, can start after the seed coat has been broken down and usually requires one winter, sometimes two winters, to complete. Toward the final stages of the afterripening process, the embryo enlarges and expands to the full length of the nutlet (Pelton 1953).

The quantity of viable nutlets in the soil was investigated by Pelton (1953). He sampled 10 one-foot-square plots (30 cm^2) and found an average of 200 nutlets per sq. foot, but only about 1% were viable. The weight of 1000 viable nutlets collected from colonies in Minnesota was 6.53 grams (Pelton 1953); the weight of 1000 viable nutlets collected in North Dakota was 5.85 grams (Stevens 1932). Viable nutlets germinate soon after the soil thaws in spring. Germination occurs when the embryo root (radicle) breaks out of the nutlet. The optimum range of germination temperatures is between 41°F and 59°F (5°-15°C) (Pelton 1953). After germination, seedlings progress rapidly through several stages of juvenile growth. First-year seedlings do not produce flowers or rhizomes (Pelton 1953).

Mortality of seedlings is high because they have few defenses against insects, diseases, water stress, and competition from other plants. Over two growing seasons, Pelton (1953) carefully searched 20 colonies for seedlings. He found no seedlings during the first year; during the second year, he found no seedlings on 17 of the colonies and 50 seedlings on 3 colonies. Two seedlings were located on bare soil created from an animal disturbance. The other seedlings were located near the center of the colonies, where the canopy cover of the stems had completely shaded out the grasses and other herbaceous plants. No seedlings were found among the Kentucky bluegrass community growing in and around the colonies. Twenty of the seedlings survived through early July, and 7 seedlings survived to mid September: mortality rate of established seedlings was 86% (Pelton 1953). Western snowberry establishment by seed is rare (Pelton 1953). Seedlings probably do not become mature stems in and around existing colonies.

For seedlings to develop into adult plants, the nutlets must be transported to habitat sites that have sufficient soil water, few insects, low quantities of disease organisms, and little or no competition from dense grasses or canopy cover of shrubs. Western snowberry fruits are consumed by numerous types of birds and mammals. A few nutlets pass unharmed through the digestive tracts of some animals that inadvertently become important dispersal agents (Pelton 1953). Pelton (1953) force-fed nutlets to domesticated chickens and found that 10.7% passed intact. Pheasants, grouse, large herbivores, and livestock are known to have passed nutlets intact. However, rabbits and mice are known to pass only nutlet fragments. Despite the low viability of the nutlets and low seedling establishment, western snowberry is extremely successful and has wide distribution across North America.

Nonstructural Carbohydrates

Carbon is important to plants for energy transport and storage and as cellulose-based structural materials used in growth. Plants capture and fix carbon from atmospheric carbon dioxide during the process of photosynthesis. The assimilated carbon is combined in several ways to form various types of relatively simple sugars and starches that are collectively called carbohydrates (CHO). Some of the carbohydrates are used in growth as structural components, some are used in the formation of compounds of greater complexity, and some are used as energy in respiration; the remaining carbohydrates are stored as nonstructural carbohydrates for later use. The quantity of stored nonstructural carbohydrates is tied to plant growth and reproduction, and the amount of stored carbohydrates changes during the year, with periods of drawdown and replenishment (Coyne et al. 1995). Drawdown of stored nonstructural carbohydrates occurs when the rate of photosynthesis is insufficient to meet demands of the plant. During drawdown periods, material moves upward from the storage site in the rhizome crown to the active growing points. The plant replenishes stored nonstructural carbohydrates during periods when acquisition of carbon exceeds the flow to growth, reproduction, and maintenance of the plant so that an accumulation of carbohydrates results. During replenishment, material flows downward from the leaves to the rhizome crown (Coyne et al. 1995).

The nonstructural carbohydrate reserve cycle follows a typical pattern each growing season. The typical curve of the nonstructural carbohydrate cycle for western snowberry (figure 4) was adapted from data reported by Adams and Bailey (1983) and Krueger and Bedunah (1988). Nonstructural carbohydrates in rhizome crowns were collected from western snowberry (*S. occidentalis*) colonies every 10 days between 15 April and 16 October 1981, on rangeland near Ryley, Alberta, Canada (Adams and Bailey 1983), and from common white snowberry (*S. albus*) colonies every 14 days between 13 April and 20 October 1983, on rangeland clearcut from forested areas near Missoula, Montana, USA (Krueger and Bedunah 1988). In each study, the seasonal curve for stored nonstructural carbohydrates followed the same shape, starting in mid April with a sharp drawdown in carbohydrate reserves during the rapid growth of early spring. The low carbohydrate levels occurred for about 10 days between late May and early June (9

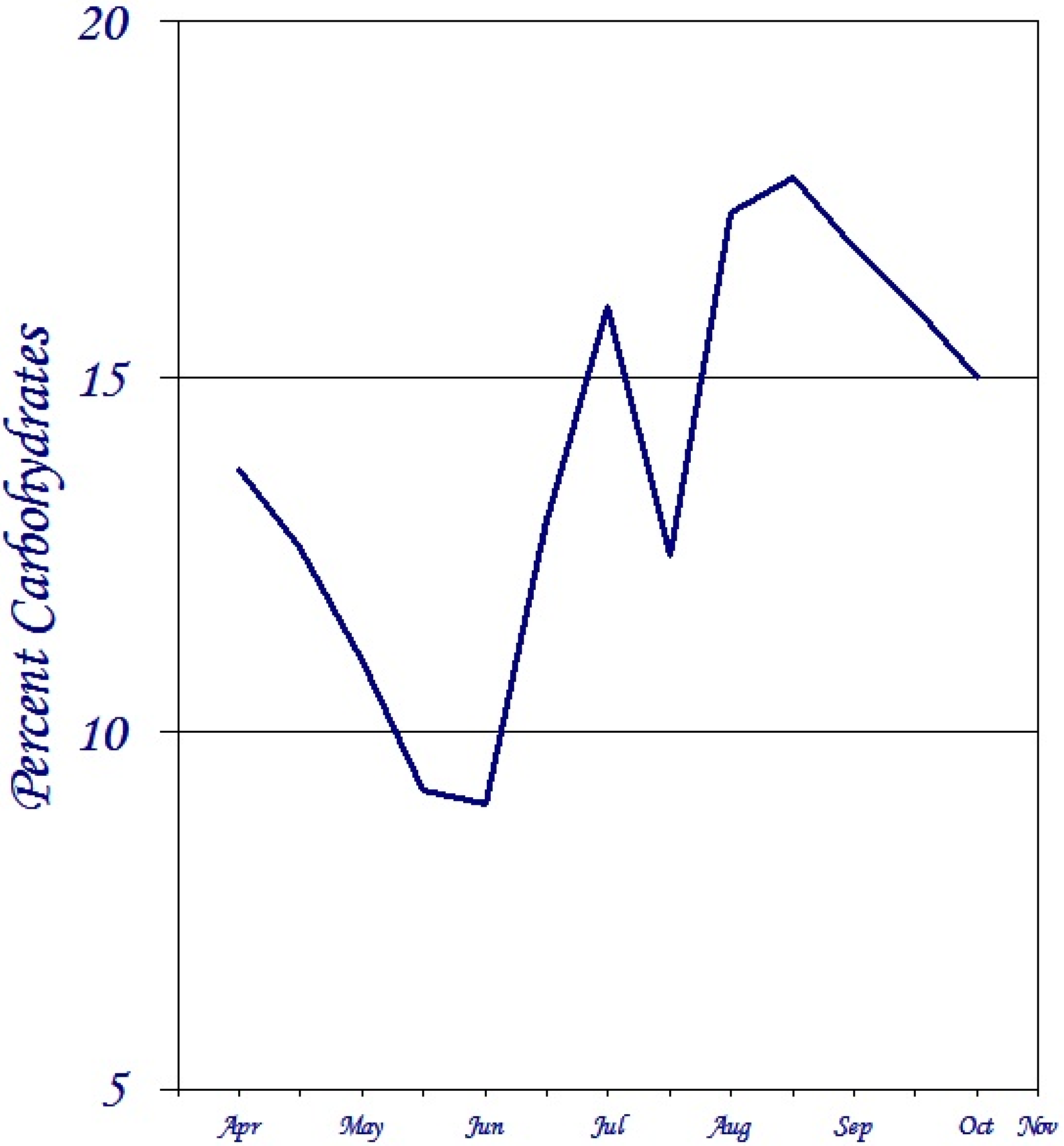

Fig. 4. Typical percent nonstructural carbohydrates in western snowberry, adapted from Adams and Bailey 1983 and Krueger and Bedunah 1988.

June), shortly after the full leaf growth stage and about the time the twigs had elongated to two-thirds of full length (Adams and Bailey 1983). Rapid replenishment occurred during a 40-day period from early June to mid July (10 June-20 July), which corresponded to the flowering stage. The carbohydrate levels of mid April were exceeded sometime around late June or early July. High levels of carbohydrates were reached in mid July, about two to three weeks after flowering commenced. A second drawdown occurred between mid July and early August. Both studies reported this carbohydrate decline to correspond to fruit fill. The Alberta data showed about a 3.5% carbohydrate decline, while the Montana data showed about a 1.5% decline. The greatest level of carbohydrate reserves was reached following the carbohydrate replenishment period that occurred between mid August and early September. A third drawdown occurred from early September to late October, a period of pre-winter root growth and bud development.

The three periods of carbohydrate drawdown--during rapid early spring growth, from mid April to early June; during fruit fill, from mid July to early August; and during fall growth, from early September to late October--indicate when western snowberry would have greater vulnerability to defoliation from natural events like hail or fire or from prescribed events like fire or mowing. Defoliation of western snowberry during early to mid June or early to mid August following drawdown periods would have greater negative effects on the colonies than defoliation during early to mid July following a replenishment period.

Phenology

Phenology is the relationship of 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 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.

The seasons and length of daylight in temperate zones change during the earth's annual revolution around the sun because of the tilt of the earth's axis. The sun's apparent path crosses the equator two times each year, once at the start of spring, on the vernal equinox, 20 March, and again at the start of fall, on the autumnal equinox, 22 September. During each equinox, the lengths of day and night are nearly uniform at 12 hours. The sun's apparent path moves northward during spring, and the day length in the Northern Hemisphere increases. The increase in day length is greater with increases in north latitude. The longest day length occurs at the start of summer, on the summer solstice, 21 June, when the sun's apparent path is farthest north of the equator. As the sun's apparent path moves southward, the length of daylight decreases. The decrease in day length is greater with increases in north latitude. The shortest day length in the Northern Hemisphere occurs at the start of winter, on the winter solstice, 21 December, when the sun's apparent path is farthest south of the equator.

The phenological development of western snowberry is triggered primarily by changes in the length of daylight, although other environmental factors produce secondary effects and cause variations in the pattern of phenological development. Changes in day length (photoperiod) function as the timer and trigger that activates or stops physiological processes initiating growth and flowering and activates the process of hardening for resistance to low temperatures that occur during the fall and winter. Vegetative growth is triggered by photoperiod and temperature (Dahl 1995), and reproductive development, which begins with the initiation of flower buds, is triggered primarily by photoperiod (Roberts 1939, Leopold and Kriedemann 1975, Dahl 1995) but can be slightly modified by temperature and precipitation (McMillan 1957, Leopold and Kriedemann 1975, Dahl and Hyder 1977, Dahl 1995).

Pelton (1953) did not find temperature requirements for bud formation and growth, but he did find that low temperatures, around 32°F (0°C), delayed shoot bud development. Photoperiod studies conducted by Pelton (1953) on western snowberry stems collected from Minnesota colonies found that day lengths shorter than 14 hours prevented normal vegetative growth and day lengths of at least 14 hours and longer strongly stimulated vegetative growth. The latitude at which a western snowberry colony grows determines the calendar date when day lengths greater than 14 hours occur. At the 46° 53' N latitude of Dickinson, in western North Dakota, long day lengths of 14 hours and longer occur between 20 April and 20 August (Manske 2005). Western snowberry has a wide latitudinal distribution, and Pelton (1953) expected colonies at locations north and south of Minnesota latitudes to show some genetic variations in photoperiod response.

During a phenological variation study that evaluated stems from plants growing in prairie habitat versus stems from the same plants growing in a uniform transplant garden separated by a distance of nine miles, McMillan and Pagel (1958) found genetic variation among 12 distinct colonies of western snowberry located within a single pasture in southeastern Nebraska. Because of genetic variation in the stems, leaf bud opening occurred over one week during favorable warm spring conditions. Genetic controls in the stems responded differently to adverse environmental conditions, and during cold spring conditions, leaf bud opening occurred over three weeks. McMillan and Pagel (1958) also found that habitat conditions and stem age affected the genetic material: the shorter young stems at the periphery of the colonies tended to open buds earlier than the older, taller stems towards the center. McMillan and Pagel (1958) concluded that phenological variation in western snowberry colonies resulted from variations in habitat conditions and year-to-year climatic differences and from genetic variations and differential responses of the genetic controls to environmental conditions.

Western snowberry has variation in its genetic material that responds differentially to environmental conditions, and it grows from about 35°N to almost 65°N latitude on a wide variety of habitats with a continental range in climates. In spite of all these variables, most of the reported phenological information from southern Nebraska to central Alberta is quite similiar (table 2).

Twig elongation usually starts around mid April and should be linked to calendar dates that have at least 14 hours of day length. In most of North and South Dakota, Minnesota, and Montana, 14 hours of daylight should occur within a few days of 20 April. Both twigs and leaves grow from the same buds located at the previous year's leaf axils. Rapid twig elongation and leaf opening occur at the same time and continue until late May or early June. Twig growth was measured in three North Dakota studies. Ransom-Nelson (1985) found that by early June (7 June) mature stems had completed 78% and young stems had completed 77% of their twig growth (table 4). Roel (1983) found that by mid June (14 June) mature stems had completed 90.2% and young stems had completed 90.4% of their twig growth and mature stems had completed 96.3% and young stems had completed 94.5% of their growth in height (table 3). Sucker stems develop at the same time as new twigs on mature stems but may not be obvious until a little later; sucker stems are reported to occur from late April to early June. Ransom-Nelson (1985) found that by early June (7 June) crown suckers had completed 87% and rhizome suckers had completed 69% of their growth in height (table 4). Roel (1983) found that by mid June (14 June) crown suckers had completed 95.3% and rhizome suckers had completed 90.4% of their growth in height (table 3).

Full-leaf stage is difficult to clearly identify. This stage is correctly understood to be the stage when all the leaves are fully expanded; plants reach this stage near the end of rapid twig elongation, around mid May or late May. However, when this stage is understood to be identified merely by the presence of leaves on all of the twigs, it would occur at an earlier time.

Flower bud appearance is a specific stage at which the pinkish buds are visible at the ends of the twigs. The appearance of the flower buds, which occurs during late May to early June, ends the rapid twig elongation stage. Flower buds continue to appear in the leaf axils until about late June.

Initial flowering stage (anthesis) begins when the first flowers located on the twig ends are visible. First flowers occur on plants in the southern colonies a little earlier than the first flowers on plants in the northern colonies (table 2). The average first flower date is around mid June; however, genetic variables and environmental conditions can alter first flower dates by about plus or minus 15 days. Flowering continues through July and sometimes lasts into mid August or later. The flowering process progresses downward from flowers on the twig ends to the flower clusters at the leaf axils. Fruit maturation requires several weeks following fertilization, and the process progresses downward from the twig ends to the leaf axils. Fruits fill and ripen during mid July to late August, becoming white as they mature.

The twigs continue to elongate slowly until about mid August (table 3). In southcentral North Dakota, total twig length per stem during August (table 4) was 36.7 inches (93.2 cm) for mature stems, 24.0 inches (61.0 cm) for young stems, 11.2 inches (28.4 cm) for crown suckers, and 9.8 inches (24.9 cm) for rhizome suckers (Ransom-Nelson 1985). In western North Dakota, total twig length per stem during August (table 5) was 8.4 inches (21.3 cm) for decadent stems, 24.7 inches (62.7 cm) for mature stems, 16.0 inches (40.6 cm) for young stems, 11.3 inches (28.7 cm) for crown suckers, and 10.1 inches (25.7 cm) for rhizome suckers (Mastel 1983). In southcentral North Dakota, biomass of twigs, leaves, and fruits during August (table 4) was 62.3 lbs/ac

(69.8 kg/ha) for decadent stems, 804.2 lbs/ac (901.6 kg/ha) for mature stems, 127.7 lbs/ac (143.2 kg/ha) for young stems, 310.4 lbs/ac (348.0 kg/ha) for crown suckers, and 140.9 lbs/ac (158.0 kg/ha) for rhizome suckers; total biomass production was 1445.5 lbs/ac (1620.5 kg/ha) (Ransom-Nelson 1985). In western North Dakota, biomass of twigs, leaves, and fruits during August (table 5) was 30.8 lbs/ac (34.5 kg/ha) for decadent stems, 255.8 lbs/ac (286.8 kg/ha) for mature stems, 42.0 lbs/ac (47.1 kg/ha) for young stems, 81.0 lbs/ac (90.8 kg/ha) for crown suckers, and 245.5 lbs/ac (275.2 kg/ha) for rhizome suckers; total biomass production was 655.1 lbs/ac (734.4 kg/ha) (Mastel 1983). The biomass produced by western snowberry in North Dakota (table 6) was 74.0% leaf, 19.6% twig, and 6.4% fruit for decadent stems; 64.1% leaf, 21.6% twig, and 14.3% fruit for mature stems; 66.5% leaf, 24.6% twig, and 8.9% fruit for young stems; 58.4% leaf, 33.7% twig, and 7.9% fruit for crown suckers; and 39.2% leaf, 49.0% twig, and 11.8% fruit for rhizome suckers (Roel 1983).

The stalks of the fruits do not separate from the plant, and most mature fruits remain attached all winter if they are not consumed by an animal. The start of leaf senescence can occur nearly any time of the growing season if the plant is in water stress, but it usually occurs during late August to October. Many of the leaves remain attached to the stems over the winter.

Nutrient Content

Williamson (1979) conducted a study to describe the seasonal variation in nutrient quality of shrubs. Western snowberry twigs, leaves, and fruits were collected from colonies in both western and eastern North Dakota on a biweekly or monthly schedule from June 1977 through May 1978, and the samples were analyzed for nutrient content of dry matter by standard wet laboratory methods. The results are summarized in tables 7, 8, and 9.

The diets of mule deer, whitetail deer, and pronghorn antelope consist of a high percentage of browse from shrubs (table 10). Williamson (1979) reported that most of the wild ungulate rumens examined in the Northern Plains during fall and winter contained western snowberry browse, and in some mule deer and whitetail deer rumens, western snowberry composed about 27% of the rumen volume.

The nutrient requirements for maintenance, growth, lactation, and antler or horn development of wild ungulates have had considerable study, and most of the parameters equal or exceed the requirements of domestic livestock (Williamson 1979). Western snowberry twigs (table 7) meet wild ungulates' requirements for calcium and potassium every month of the year, for magnesium during May and December, for phosphorus during May, for crude protein during May, and for in vitro dry matter digestibility during May. Western snowberry leaves (table 8) meet wild ungulates' requirements for calcium, magnesium, and potassium during June through October, for phosphorus during June, for crude protein during June and July, and for in vitro dry matter digestibility during June, July, and August. Western snowberry fruits (table 9) meet wild ungulates' requirements for calcium and potassium during July and August, for magnesium at no time, for phosphorus during July, for crude protein at no time, and for in vitro dry matter digestibility during July. Fresh fruits of western snowberry are very astringent, making skin and mucous membrane tissue tighter, and mammals and birds appear to prefer the dried fruits that remain attached to the shrubs (Pelton 1953). Although western snowberry twigs, leaves, and fruits do not meet wild ungulates' requirements for in vitro dry matter digestibility, crude protein, and phosphorus at any time during the fall and winter, western snowberry has traditionally been considered an important browse plant for wild ungulates.

Williamson (1979) used the rumen of a domesticated cow to determine in vitro dry matter digestibility and found digestible dry matter of western snowberry averaged 25.5% during fall and winter (table 7). Dietz (1972) determined in vitro dry matter digestibility by using the rumen fluid from a whitetailed deer and found western snowberry to be 41.0% digestible dry matter during the dormant season in western South Dakota. Dietz (1972) suggested deer require a minimum of 50% digestible dry matter. Both methods, whether using the rumen of a cow or of a deer, showed that digestible dry matter content of western snowberry was below the requirements of wild ungulates during fall and winter.

The digestibility of western snowberry was influenced by the high acid detergent fiber content, and the percent digestible dry matter was low during most of the year. Williamson (1979) found a negative relationship that showed that as acid detergent fiber increased, in vitro dry matter digestibility decreased. Percent acid detergent fiber is a measurement of the structural carbon content of western snowberry twigs, leaves, and fruits (tables 7, 8, and 9). Structural carbon gives strength and shape to growing plant tissue and is primarily cellulose (a complex carbohydrate) and lignin (a high-carbon-content complex alcohol), which are mostly nondigestible.

Evans and Dietz (1974) conducted a study that evaluated the nutritional value of winter food items consumed by sharp-tailed grouse. Western snowberry fruits collected during the fall and winter in western South Dakota were fed as a single-component diet to wild, trapped, captive male sharp-tailed grouse for a 4-day test period with 4 replications. The fruits and excreta were analyzed for gross energy and crude protein of dry matter; the differences in the respective values determined metabolizable energy and nitrogen balance.

Gross energy of western snowberry fruits was 4.92 kilocalories per gram of dry matter, and the metabolizable energy was 2.31 kilocalories per gram of dry matter. The grouse consumed an average of 39.9 grams of dry matter per day and metabolized an average of 92 kilocalories per day. During winter conditions, sharp-tailed grouse required an intake of at least 100 kilocalories of metabolizable energy per day to maintain a constant body weight (Evans and Dietz 1974). Western snowberry fruits consisted of 5.5 percent crude protein. The excreta of the grouse had an average of 0.84 grams of protein per day more than the 2.19 grams of protein per day in the ingested fruit. The nitrogen balance for the grouse in the feeding trial was -0.135 grams of nitrogen per day. A negative nitrogen balance indicates a loss of nitrogen from the body (Evans and Dietz 1974). The grouse fed air-dried western snowberry fruits lost weight. One male grouse lost 30.8 grams per day, about 3% of his body weight (Evans and Dietz 1974). Although the energy content and crude protein content of western snowberry fruits collected during fall and winter were inadequate for sharp-tailed grouse to maintain body weight, western snowberry has traditionally been considered an important food plant for birds.

Several neotropical birds, a few duck species, and sharp-tailed grouse use western snowberry colonies for escape cover and nesting habitat. Several small mammals use western snowberry during parts of the year for habitat and food. Wild ungulates use western snowberry for escape cover and as fall and winter food. Domesticated livestock browse leaves and twigs during late summer and fall, and calves find shelter from wind. Western snowberry is used by a wide variety of animals; however, none of the mammals and birds living in the Northern Plains depend exclusively on western snowberry during any portion of their life cycle.

Competition for Resources

The competitive ability of a plant to acquire aboveground and belowground resources determines that species' persistence and abundance in communities. Differences in competitive abilities between grasses and shrubs are related to growth form and biomass.

Grass vs. Shrubs

The degree of difference in competitive abilities between prairie grasses and western snowberry was investigated on an area of mixed grass prairie with colonies of western snowberry near Regina, Saskatchewan, Canada, in 1996 and 1997 (Kochy 1999, Kochy and Wilson 2000). The competitive abilities of grasses and western snowberry were compared by differences in biomass production and by differences in acquisition of sunlight, mineral (inorganic) nitrogen, and soil water. Data were collected from paired plots that consisted of a prairie habitat and a brush habitat, with four removal treatments on each habitat replicated at five sites. Selective herbicides were used to remove the shrubs, the grasses, or the shrubs and grasses from each habitat. Intact vegetation plots of each habitat with no removal treatments were used as reference controls. Aboveground biomass was harvested once each year during late August or early September. Shrub samples included previous years' woody stem accumulation. Grass samples included only current year's growth. Light was measured with a photon flux probe during August. Mineral nitrogen was measured by resin bags from May through August. Soil water was measured gravimetrically to a four-inch (10 cm) depth monthly (Kochy and Wilson 2000).

Shrub removal increased grass biomass production threefold on prairie habitat and sixfold on brush habitat. Grass removal increased shrub biomass production twofold on prairie habitat; however, grass removal had no effect on shrub production on brush habitat because the amount of grass growing on the brush habitat was small (Kochy 1999). Both growth forms were able to take up belowground resources not consumed by the removed growth form. The biomass production of grasses and shrubs decreased on both prairie habitat and brush habitat when the biomass production of the other growth form increased (Kochy 1999, Kochy and Wilson 2000).

Light was measured above the soil at a height of 1 inch (3 cm) and above the grass canopy at a height of 12 inches (30 cm). Light penetration to the ground was greater on prairie habitat than on brush habitat. Removal of grasses or shrubs increased light penetration to the ground on both prairie habitat and brush habitat. Shrubs and grasses reduced light penetration to a similar degree even through shrub leaves are flat and wide and grass leaves are erect and linear (Kochy 1999). Light penetration to the grass canopy was lower on the brush habitat than on the prairie habitat. Light levels above the grass canopy on brush habitat were about 30% of the light levels above the grass canopy on prairie habitat. Removal of shrubs increased light penetration to the grass canopy on both prairie habitat and brush habitat (Kochy and Wilson 2000).

Unshaded grasses attenuated more light per gram of biomass than did shrubs. However, the taller shrubs preempted sunlight and shaded the grasses (Kochy 1999). The reduced quantity of light reaching the grass canopy was below the light saturation point of most open grassland species, and the shading reduced grass biomass production severely. Shading has a greater effect on warm-season (C_4) grasses because they have a higher light compensation point than cool-season (C_3) species (Kochy and Wilson 2000).

The quantity of mineral nitrogen was the same on prairie habitat and on brush habitat. Shrub removal increased available mineral nitrogen on both prairie habitat and brush habitat. Grass removal on both prairie habitat and brush habitat did not change the mineral nitrogen quantities. Grasses took up more mineral nitrogen per gram of biomass than did shrubs (Kochy and Wilson 2000). Insufficient nitrogen availability limits productivity more often than water in temperate grasslands (Tilman 1990).

Soil water was lower on prairie habitat than on brush habitat. Greater soil water on brush habitat suggests that western snowberry colonies increase soil water by snow trapping, hydraulic lift from lower levels, or reduced evapotranspiration. Grasses took up more soil water per gram of biomass than did shrubs (Kochy and Wilson 2000).

Grasses and western snowberry compete for sunlight, mineral nitrogen, and soil water. The per gram of biomass effects on resources are smaller for shrub growth forms than for grass growth forms. Grasses have a 1.4 times greater per gram of biomass effect than shrubs. Western snowberry requires six times greater aboveground biomass than the grasses before grass production is decreased as a result of competition from the shrubs (Kochy 1999). Shrubs must use a portion of the photosynthates produced in the leaves to build and maintain their unproductive woody stems; the result is a great reduction in resource uptake efficiency. Grass aboveground biomass is primarily productive photosynthetic leaves; the result is a high resource uptake efficiency. Because grasses have high root : shoot ratios and no woody stems to maintain; grasses are good competitors for belowground resources and superior competitors for mineral nitrogen. Shrubs' taller growth makes the plants superior competitors for aboveground resources (Kochy and Wilson 2000).

During early stages of western snowberry expansion into prairie habitat on the periphery of the colonies, competition is primarily for belowground resources of nutrients and soil water; under these conditions, grasses have the advantage and the shrubs are suppressed. The taller shrubs shade some of the shorter grasses. Reductions in sunlight decrease grass biomass production; these decreases result in reductions in competitive effect of grasses for belowground resources. Shrubs take up the belowground resources not consumed by the smaller, less vigorous grasses. As shrub stem density increases, the competition is primarily for the aboveground resource of light; under these conditions, shrubs have the advantage and the grasses are strongly suppressed. Competition on brush habitat is strongest for sunlight. Competition on prairie habitat is strongest for mineral nitrogen (Kochy and Wilson 2000).

The study that Kochy (1999) conducted to evaluate the competitive abilities of prairie grasses and western snowberry was continued by Peltzer and Kochy (2001), with the same treatments on the same plots at the same location near Regina, Saskatchewan, Canada. Peltzer and Kochy (2001) also evaluated the competitive effects from prairie grasses and western snowberry on grass and shrub seedlings.

Selective herbicides were used to remove the shrubs, the grasses, or the shrubs and grasses on prairie habitat and brush habitat paired plots for a third year (1998). Intact vegetation plots of each habitat with no removal treatments were used as reference controls. Aboveground biomass was harvested once each year during late July. Light was measured with a photon flux probe during July. Mineral nitrogen was measured by resin bags from May through mid September. Soil water was measured gravimetrically to an eight-inch (20 cm) depth in late July. Ten seedlings each of blue grama and silverberry were transplanted into each competition plot during early June. Shoots of seedlings were harvested and weighed in mid September (Peltzer and Kochy 2001).

Three years of shrub removal increased grass biomass production to equal the total biomass production of the intact vegetation treatments on both prairie habitat and brush habitat. Three years of grass removal increased shrub biomass production to equal the total biomass production of the intact vegetation treatment on prairie habitat. Shrub biomass production on the grass removal treatment was equal to the total biomass production of the intact vegetation treatment on brush habitat (Peltzer and Kochy 2001). Grass removal on brush habitat had no effect on shrub production because the amount of grass growing there was small (Kochy 1999). Belowground biomass on the treatments with three years of shrub removal or of grass removal was equal to the belowground biomass on the intact vegetation treatments on both prairie habitat and brush habitat (Peltzer and Kochy 2001). After three years of selective herbicide treatments for shrub removal and grass removal, the remaining respective growth forms produced the same total quantities of aboveground and belowground biomass as the intact vegetation treatments produced.

Light penetration to the ground on the treatments with three years of shrub removal or of grass removal was equal to the light penetration on the intact vegetation treatments on prairie habitat. Light penetration to the ground on the treatments with three years of shrub removal on brush habitat was equal to light penetration on the treatments on prairie habitat. Light penetration to the ground on the treatments with three years of grass removal was equal to the light penetration on the intact vegetation treatments on brush habitat. Light levels penetrating the shrub canopy on brush habitat were low, at about 20% of the light levels above the plant canopy (Peltzer and Kochy 2001).

Available mineral nitrogen on the treatments with three years of shrub removal was greater than that on the intact vegetation treatments on both prairie habitat and brush habitat. Available mineral nitrogen on the treatments with three years of grass removal was not changed and was equal to that on the intact vegetation treatment on both prairie habitat and brush habitat (Peltzer and Kochy 2001).

Soil water in July was the same on the treatments with three years of shrub removal and of grass removal as on the intact vegetation treatments on both prairie habitat and brush habitat. Both grasses and shrubs decreased soil water to about the same extent (Peltzer and Kochy 2001).

Seedlings of blue grama and silverberry that were growing in established plant communities were unable to compete effectively for resources. Competition for resources from prairie grasses or western snowberry strongly reduced the growth of blue grama and silverberry seedlings on both prairie habitat and brush habitat. Growth of blue grama and silverberry seedlings was greater on treatments with no competition (Peltzer and Kochy 2001).

Competition for sunlight, nutrients, and soil water from prairie grass or from western snowberry can suppress growth of the other growth form. Selective removal of grass or shrub growth forms from plant communities reduces competition for resources. The aboveground and belowground resources become available for use by the growth form that remains in the community. After three successive years of selective herbicide application, both remaining prairie grasses and western snowberry were able to use these additional available resources to produce biomass equal to the total amount of biomass produced on the intact vegetation treatments.

Grass vs. Rhizome Suckers

Shrub establishment in grasslands frequently occurs in clumps. A study was conducted to determine whether young shrub vegetative rhizome suckers' growing at high density increases the shrubs' ability to compete against grasses. Sections of western snowberry rhizomes were transplanted into small plots in an old field of smooth bromegrass near Regina, Saskatchewan, Canada, in 1994 and 1995 (Li and Wilson 1998). Small plots with 27.4 sq. inches (176.7 cm^2) of soil surface were defined by placing individual solid galvanized steel tubes, 6 inches (15 cm) in diameter and 6 inches (15 cm) deep, into the soil along transects at 39.4 inch (1 m) intervals. Western snowberry rhizomes were transplanted at low and high densities of one or five per plot, respectively. Twenty replicated plots of each rhizome density had the grass removed with a herbicide treatment. Forty replicated plots of each rhizome density had the grass remain intact. Fifteen replicated plots without transplanted rhizomes were used to evaluate performance of grass alone (Li and Wilson 1998).

Aboveground and belowground biomass of transplanted suckers and grass plants of each plot was harvested during early September after two growing seasons. Mineral nitrogen was measured in soil samples collected four times using an ion selective electrode. Soil water was measured gravimetrically to a four-inch (10 cm) depth four times (Li and Wilson 1998).

Soil mineral nitrogen was lower in the experimental old field of smooth bromegrass than in a nearby mixed grass prairie. The soil of the previously cultivated old field had relatively little organic matter remaining to be mineralized. Removal of grass on the old field increased available mineral nitrogen (Li and Wilson 1998).

Soil water was higher in the experimental old field of smooth bromegrass than in a nearby mixed grass prairie. The soil of the mixed grass prairie was sandy and unsuitable for annual crop agriculture. Soil water was consistently lower on the high transplant density plots than on the low density plots (Li and Wilson 1998).

Competition from grass decreased growth of western snowberry rhizome suckers at both high and low transplant densities. Shoot growth was suppressed more than root growth on plots with grass present; the result was greater root : shoot ratios than on plots with grass removed. Survival rates of rhizome suckers were lower on plots with grass present than on plots with grass removed. Growth rates of transplanted rhizome suckers were higher on plots with grass removed. High transplant densities reduced growth rates of rhizome suckers on plots with grass removed. Growth rates of rhizome suckers were greater at low transplant densities on plots with grass removed. Rhizome sucker survival rates were lower at high transplant densities. Growth rates of rhizome suckers were greater at high transplant densities than at low transplant densities on plots with grass present. High transplant density enhanced the ability of western snowberry rhizome suckers to compete against grasses. Grass biomass and grass root : shoot ratios were not affected by the presence of transplanted western snowberry rhizome suckers (Li and Wilson 1998).

Expansion of western snowberry into grassland habitat at the periphery of the colonies is slowed or suppressed by competition for belowground resources of mineral nitrogen and soil water from grass plants. Competition from grasses reduces growth rates of western snowberry rhizome suckers and causes a relatively high mortality rate of young suckers. When grass competition is present, mortality rates of rhizome suckers are higher when stems are clustered and densities are high; however, the surviving rhizome suckers have greater growth rates at high stem densities than at low stem densities. When grass competition for belowground resources is reduced or removed, rhizome suckers have increased growth rates. Single rhizome suckers have higher survival rates and greater growth rates than clusters of rhizome suckers when grass competition is removed.

Rhizosphere Fungi

Grassland soils sampled at any single point in time reveal low levels of mineral nitrogen, but grassland soils are not low in nitrogen. Grassland soils contain abundant quantities of nitrogen, although most of it is in the organic form and unavailable for direct use by plants. Rhizosphere soil organisms can convert organic nitrogen to mineral nitrogen.

The soil rhizosphere around perennial roots is the zone where a symbiotic relationship occurs between the roots of plants and microorganisms living in the soil. Grassland rhizosphere organisms interact in a complex trophic web and play a major role in the biogeochemical nutrient cycles that are necessary for an ecosystem to function properly (Manske 1999).

One of the major organisms of the rhizosphere is fungi. Rhizosphere fungi are primarily vesicular arbuscular mycorrhizae that form endomycorrhiza in which the vesicles, arbuscules, and hyphae of the fungus enter the cells and tissue of the host plant (Harley and Smith 1983). The symbiotic function of endomycorrhiza fungi in grassland plant rhizospheres is the nitrification of ammonia (Ingham et al. 1985, Clarholm 1985, Biondini et al. 1988, Frederick and Klein 1994, Frank and Groffman 1998) and the enhancement of the absorption of phosphorus, other mineral nutrients, and water (Moorman and Reeves 1979, Harley and Smith 1983, Allen and Allen 1990, Koide 1993, Marschner and Dell 1994, Smith and Read 1997). Rhizosphere organism activity results in increased conversion of organic nitrogen into mineral nitrogen and in greater availability of water, minerals, and nutrients for the grassland plants.

Pelton (1953) excavated the root system of a western snowberry stem and rhizome following methods used by John E. Weaver. Pelton (1953) observed that the roots were mycorrhizal in appearance, with the concentration increasing towards the tips, and that the roots had a fine covering of closely adherent soil particles.

Williams and Aldon (1976) collected snowberry (*Symphoricarpos spp.*) roots in northern New Mexico between August and October 1972 and examined them for infection by fungi. Glomus type vesicular arbuscular endomycorrhizal fungi were found in association with young snowberry roots. The glomus endomycorrhizal fungi produced round to ovoid vesicles 12 to 80 microns in diameter, arbuscules, coiling hyphae, and chlamydospores 40 to 135 microns in diameter within the tissue of the roots (Williams and Aldon 1976).

Manske (1992) evaluated mycorrhizal fungi infection of grass and shrub roots of plants growing in western snowberry colonies that had not been burned in over 80 years at a mixed grass prairie location in northwestern North Dakota. Roots of three plants of each species were collected from each of 6 replicated sites and analyzed individually. Roots of western snowberry, smooth bromegrass, western wheatgrass, and blue grama were cleared and stained, then assessed for fungi infection by presence or absence on a grid-intersect method (Manske 1992).

Western snowberry had encroached and expanded into idle prairie and developed dense colonies that covered over 50% of the upland landscape. The brush habitat consisted mainly of western snowberry and Kentucky bluegrass. Smooth bromegrass, an introduced species, had become established and increased on the decadent portions at colony centers. The native grasses, western wheatgrass and blue grama, had been greatly reduced in abundance and were only small components of the mature brush community (table 11).

Nearly all of the western snowberry (93.8%) roots were infected with fungi. Most of the roots of western wheatgrass (66.0%) and blue grama (78.8%) were infected. The roots of smooth bromegrass (32.3%) were only partially infected with fungi (table 11).

The symbiotic relationship between roots of perennial plants and soil organisms in the rhizosphere enhances the plants' abilities to compete for belowground resources. Native grassland shrubs and grasses have well developed rhizospheres and are effective at acquiring needed resources.

Summary

Western snowberry is a native shrub that forms large dense colonies. This biologically successful shrub is widely distributed throughout most of the interior of North America and it grows in association with a great variety of plant communities and vegetation types on a wide variety of soils. The shrub has a long interconnected branching rhizome system with clusters of stem bases at the crowns. The aerial stems are one to three feet tall and are readily replaced by vegetative growth from meristematic buds on the rhizomes and crowns when unfavorable environmental conditions or management practices destroy any aerial stems. Vegetative growth is regulated by apical dominance with hormones. Sexual reproduction in western snowberry has a low success rate and establishment by seed is rare because the nutlets have low viability and seedlings have high mortality.

Western snowberry starts growing in mid to late April when there is at least 14 hours of daylight. Rapid twig elongation and leaf growth and expansion occur at the same time and continue until late May or early June when the pinkish flower buds appear at the twig tips. By early June, the twigs are about 75% of full growth and the leaves are near full expansion. Twigs continue growing at a slower rate and by mid June they have completed about 95% of their annual growth. Flower buds continue to appear in the leaf axils until about late June. The first flowers begin to open around mid June, with new flowers opening at lower leaf axils through July and sometimes extending into mid August. After fertilization, the fruits fill and ripen during mid July to late August. Most of the fruits remain attached to the stems all winter. Leaf senescence usually occurs during late August to October.

The quantity of stored nonstructural carbohydrates is related to plant growth and reproduction, with the cycles of drawdown and replenishment following a typical pattern each growing season. A sharp drawdown in carbohydrate reserves occurs during the rapid growth of early spring, from mid April to early June. Rapid replenishment occurs during the flowering stage, from early June to mid July. A second drawdown period occurs during fruit fill, between mid July and early August. A second replenishment period occurs between mid August and early September. A gradual third drawdown occurs during pre-winter root growth and bud development, from early September to late October.

Western snowberry competes with grasses for sunlight, mineral nitrogen, and soil water. Healthy grasses are superior competitors for the belowground resources of mineral nitrogen and soil water; their presence retards and reverses the shrub's encroachment. Less than healthy grasses have diminished competitive abilities and relinquish proportional quantities of belowground resources to the shrubs. The additional resources available for western snowberry growth facilitate the enlargement and spreading of the colonies and the increase in stem density. Increases in aerial stem canopy cover increase the competitiveness of the shrubs for the aboveground resources of sunlight. Reductions in sunlight reaching the understory vegetation cause severe reductions in grass biomass production. Effects from shading by dense aerial stems can completely eliminate the understory vegetation.

Development of treatment practices to effectively manage western snowberry using biological, burning, mechanical, and chemical methods requires an understanding of how the plant grows, its strong characteristics, and its weaknesses and periods of vulnerability.

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Table 1. Western snowberry stem density at systematic distances from the center of 12 colonies in southcentral North Dakota, 1981.

	Distance from center of colony				
	16.5 feet	33.0 feet	49.5 feet	66.0 feet	82.5 feet
Density					
Stems per sq. yard	49.5	47.8	43.1	40.1	28.1

Data from Roel 1983

Table 2. Reported phenological information for western snowberry.

Phenological Stages	Nebraska McMillan and Pagel 1958	Nebraska McCarthy 1967	Minnesota Pelton 1953	North Dakota Stevens 1972	North Dakota Manske 1980	North Dakota Roel 1983	Montana Krueger and Bedunah 1988	Wyoming Ferrell 1986, 1992	Alberta Adams and Bailey 1983	Compiled Summary
Bud Swell							Apr			Apr
Twig Elongation	mid Apr	early May	same as most shrubs				late Apr to early Jun			mid Apr to early Jun
Leaf Opening	13-21 Apr	early May 4-6 leaf				14 May	late Apr to early Jun		mid Apr	mid Apr to early Jun
Sucker Development		before early May							late Apr to early Jun	late Apr to early Jun
Full Leaf		late May	mid May to late May					before 7 Jun	late May	mid May to late May
Flower Buds Appear	30 May		20 May							late May to late Jun
Initial Flowering (Anthesis)	16-18 Jun		12 Jun	26 Jun 9 yr Mean	21 Jun 3 yr Mean	22 Jun			late Jun	mid Jun to late Jun
Flower Development	mid Jun to Jul		mid Jun to 15 Aug			6 Jul	mid Jun to mid Aug	before 4 Jul		mid Jun to mid Aug
Fruit Development	22 Jul to 28 Aug		several weeks each						late Jun to mid Aug	late Jul to mid Aug
Fruit Mature							Aug to Sep			Aug to Sep
Leaf Senescence						10 Aug	Sep to Oct			late Aug to Oct

Table 3. Western snowberry current year's growth in stem height and twig length of stem types on 15 colonies in southcentral North Dakota, 1981.

Stem Types	Sample Periods			
	14 Jun	5 Jul	26 Jul	16 Aug
Decadent Stems				
Height (inches)	-	-	-	-
% of peak				
Twig Length (inches)	-	-	-	-
% of peak				
Mature Stems				
Height (inches)	16.4	16.7	16.9	17.0
% of peak	96.3	98.3	99.7	100.0
Twig Length (inches)	3.4	3.6	3.7	3.8
% of peak	90.2	95.8	98.9	100.0
Young Stems				
Height (inches)	11.4	11.8	12.0	12.1
% of peak	94.5	97.4	99.3	100.0
Twig Length (inches)	3.8	4.0	4.1	4.2
% of peak	90.4	94.7	98.8	100.0
Crown Suckers				
Height (inches)	12.6	13.0	13.2	13.3
% of peak	95.3	98.2	99.3	100.0
Twig Length (inches)	3.4	3.6	3.7	3.8
% of peak	90.7	95.7	99.2	100.0
Rhizome Suckers				
Height (inches)	11.6	12.3	12.7	12.8
% of peak	90.4	96.1	99.6	100.0.
Twig Length (inches)	11.6	12.3	12.7	12.8
% of peak	90.4	96.1	99.6	100.0

Data from Roel 1983

Table 4. Western snowberry current year's growth of stem types on 15 colonies in southcentral North Dakota, 1982.

Stem Types	Density stems per square yard	Percent Twig Growth Completed 7 Jun (%)	Total Twig Length per Stem 7 Aug (inches)	Biomass of Twigs, Leaves, and Fruits (lbs/ac)
Decadent Stems	8.4	-	-	62.3
Mature Stems	15.6	78	36.7	804.2
Young Stems	11.0	77	24.0	127.7
Crown Suckers	15.9	87	11.2	310.4
Rhizome Suckers	10.8	69	9.8	140.9
	61.8 stems/sq. yd			1445.5 lbs/ac

Data from Ransom-Nelson 1985

Table 5. Western snowberry current year's growth of stem types on 8 colonies in western North Dakota, August 1981.

Stem Types	Number Twigs per Stem	Total Twig Length per Stem (inches)	Mean Twig Length (inches)	Biomass of Twigs, Leaves, and Fruits (lbs/ac)
Decadent Stems	4.1	8.4	2.1	30.8
Mature Stems	11.2	24.7	2.2	255.8
Young Stems	4.5	16.0	3.5	42.0
Crown Suckers	1.4	11.3	8.1	81.0
Rhizome Suckers	1.2	10.1	8.3	245.5
				655.1 lbs/ac

Data from Mastel 1983

Table 6. Western snowberry current year's biomass of leaves, twigs, and fruits per stem on 15 colonies in southcentral North Dakota, mid August 1981.

Stem Types	Plant Parts			
	Leaf	Twig	Fruit	Total
Decadent Stems				
Weight (gm)	1.5	0.4	0.1	2.0
% of total	74.0	19.6	6.4	
Mature Stems				
Weight (gm)	3.1	1.1	0.7	4.9
% of total	64.1	21.6	14.3	
Young Stems				
Weight (gm)	1.6	0.6	0.2	2.4
% of total	66.5	24.6	8.9	
Crown Suckers				
Weight (gm)	2.4	1.4	0.3	4.2
% of total	58.4	33.7	7.9	
Rhizome Suckers				
Weight (gm)	1.2	1.5	0.4	3.1
% of total	39.2	49.0	11.8	

Data from Roel 1983

Table 7. Mean percent nutrient content of western snowberry twigs in North Dakota.

	Calcium Ca	Magnesium Mg	Phosphorus P	Potassium K	Acid Detergent Fiber ADF	Crude Protein CP	In Vitro Dry Matter Digestibility IVDMD
Apr	0.69	0.13	0.08	0.90	57.3	4.8	22.5
May	0.39	0.20	0.43	2.16	19.7	21.6	73.4
Jun	0.51	0.12	0.12	1.15	45.6	5.1	39.2
Jul	0.56	0.16	0.09	1.09	51.2	3.8	27.8
Aug	0.48	0.11	0.09	1.02	52.1	3.9	27.6
Sep							
Oct	0.54	0.11	0.07	0.90	54.2	4.0	28.9
Nov	0.60	0.15	0.09	0.96	53.8	4.4	26.7
Dec	0.76	0.14	0.08	0.91	53.2	5.1	27.4
Jan	0.69	0.14	0.08	0.88	54.7	4.9	23.7
Feb	0.59	0.14	0.07	0.70	53.9	4.4	23.0
Mar	0.65	0.13	0.05	0.81	56.4	4.4	23.5

Data from Williamson 1979

Table 8. Mean percent nutrient content of western snowberry leaves in North Dakota.

	Calcium Ca	Magnesium Mg	Phosphorus P	Potassium K	Acid Detergent Fiber ADF	Crude Protein CP	In Vitro Dry Matter Digestibility IVDMD
Apr							
May							
Jun	0.65	0.26	0.20	1.97	31.5	12.6	56.7
Jul	0.76	0.30	0.14	1.31	20.8	10.5	64.5
Aug	0.90	0.30	0.14	1.33	21.6	9.2	62.9
Sep							
Oct	1.31	0.26	0.14	1.11	28.8	6.8	51.7
Nov							
Dec							
Jan							
Feb							
Mar							

Data from Williamson 1979

Table 9. Mean percent nutrient content of western snowberry fruits in North Dakota.

	Calcium Ca	Magnesium Mg	Phosphorus P	Potassium K	Acid Detergent Fiber ADF	Crude Protein CP	In Vitro Dry Matter Digestibility IVDMD
Apr							
May							
Jun							
Jul	0.37	0.16	0.21	1.71	18.9	8.3	63.0
Aug	0.28	0.11	0.16	1.44	19.9	6.5	53.7
Sep							
Oct							
Nov							
Dec							
Jan							
Feb							
Mar							

Data from Williamson 1979

Table 10. Percent diet comprised of browse from shrubs for wild ungulates in the Northern Plains.

Wild Ungulates	Spring Apr, May, Jun	Summer Jul, Aug, Sep	Fall Oct, Nov, Dec	Winter Jan, Feb, Mar	Mean for Year
Mule Deer	59	43	81	60	61
Whitetail Deer	43	45	81	65	59
Pronghorn Antelope	18	25	50	43	34

Data from Holechek, Pieper, and Herbel 1995

Table 11. Percent shoot frequency of plants growing in western snowberry colonies and percent fungi infection of roots.

		Western Snowberry	Kentucky Bluegrass	Smooth Bromegrass	Western Wheatgrass	Blue Grama
Shoot frequency in brush habitat	%	58.3a	59.5a	17.5b	15.5b	8.0b
Root infection by mycorrhizal fungi	%	93.8a		32.3c	66.0b	78.8ab

Data from Manske 1992

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

Fig. 1. Excavated western snowberry rhizomes and rhizome crowns with clusters of aerial stems.

Fig. 2. Kentucky bluegrass associated with western snowberry colonies.

Fig. 3. Flowering western snowberry.

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Biological Management of Western Snowberry

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Biological management is the use of an agent organism to cause an intentional reduction of an undesirable organism. A recent example of biological management is the reduction of leafy spurge, an introduced undesirable plant, by the flea beetle, a natural enemy that was brought into North America from the weed's original habitat. Biological management of problem native plants is not as straightforward or as dramatic as that of introduced plants. Effective biological management of western snowberry requires the identification and enhancement of an agent organism whose detrimental action leads to the reduction or containment of western snowberry colonies.

A number of biotic agents are injurious to western snowberry. Many insects attack the vegetative parts. Several butterfly and moth larvae chew the leaves, and aphids injure leaves and shoots. At least 42 genera and 50 species of fungi are known to occur on various parts of the plant (Pelton 1953). A wide variety of animals use western snowberry as food. Mice and other rodents girdle stems. Rabbits browse the stems. Wild ungulates and domesticated cattle, sheep, and goats browse the leaves and twigs (Pelton 1953). Despite the high number of organisms that use this shrub, no biotic agents are known to damage the plant severely enough or remove enough biomass that their action directly results in the restriction or death of rhizome-stem base clusters and in the subsequent reduction of western snowberry colonies.

Western snowberry appears to have adequate mechanisms to resist insect and fungus attacks, and the shrub appears to be quite resistant to browsing attacks because of its comparative unpalatability and active vegetative reproduction (Pelton 1953). In an analysis of browse survey data collected by North Dakota Game and Fish Department personnel over a 19 year period, Volesky (1982) found that western snowberry stems received low incidence of heavy hedging (>40%) except in one year that had considerable growing season water stress. McCarty (1967) reported that although young sucker stems were consumed following mowing treatments and vegetative sprouts were livestock feed in degenerate pastures heavily infested with western snowberry, the shrub was not commonly utilized by livestock. Banister (1991) observed that cows will not eat much snowberry until pasture utilization reaches 65% to 70% during spring and 50% during fall; at these high utilization levels, pasture recovery requires two growing seasons of rest.

Grasses are superior competitors for belowground resources and can suppress western snowberry encroachment (Kochy 1999, Kochy and Wilson 2000, Peltzer and Kochy 2001). Because of these competitive abilities, grasses are the sought-after agent organisms that can be manipulated to successfully manage western snowberry colonies biologically. Coordinating grazing periods with appropriate grass growth stages can promote grass growth, improve the health status of grass plants, and increase grass herbage production by stimulating both beneficial activity of soil organisms and vegetative reproduction by tillering and by enhancing biological and ecological processes in grassland ecosystems (Manske 2000a). Strengthening the competitiveness of grass plants reduces the quantity of belowground resources available for western snowberry; the reduction of resources retards or reverses the shrub's encroachment into grasslands.

The degree of competitiveness from grasses is not constant under all types of management practices. The positive or negative response of grasses to defoliation depends on the amount of leaf material removed and the growth stage of the plant. Removing too much leaf area or grazing too early or too late in the seasonal development of the plant diminishes the plant's competitive abilities and permits greater quantities of belowground resources to become available for western snowberry colonies. These conditions facilitate the enlargement and spread of western snowberry colonies on pastures managed by traditional grazing practices, on land managed by overgrazing practices (Pelton 1953), and on idle land managed with no defoliation (Smith 1985).

Grass plants evolved 20 million years ago with early herbivores that are now extinct. During this time, grasses developed biological processes that help the plants withstand and recover from defoliation

(Manske 2000a). This complex of processes (McNaughton 1979, 1983, Briske 1991, Briske and Richards 1995), called defoliation resistance mechanisms, accelerates both the growth rate of the grazed plant and its development of foliage and roots. Two biological processes of primary concern to grassland managers are the increased beneficial activity of soil organisms (Coleman et al. 1983) and the stimulation of vegetative reproduction by secondary tiller development from axillary buds (Briske and Richards 1995). Grazing that removes a small amount of leaf area from the grass plant between the third-leaf stage and flowering stage can trigger these beneficial responses (Manske 1999).

There is a mutually beneficial relationship between the grass plant's root system and soil organisms. The narrow zone of soil around the roots of perennial grassland plants, the rhizosphere, contains bacteria, protozoa, nematodes, mites, springtails, and endomycorrhizal fungi (Elliot 1978, Anderson et al. 1981, Harley and Smith 1983, Curl and Truelove 1986, Whipps 1990, Campbell and Greaves 1990). The grass plant's roots release carbon compounds (Campbell and Greaves 1990), including sugars, to these rhizosphere organisms, and the organisms release mineral nitrogen that the plant's roots absorb (Ingham et al. 1985, Clarholm 1985, Biondini et al. 1988, Frederick and Klein 1994, Frank and Groffman 1998). The endomycorrhizal fungi also provide phosphorus, other mineral nutrients, and water that the plant needs for growth (Moorman and Reeves 1979, Harley and Smith 1983, Allen and Allen 1990, Koide 1993, Marschner and Dell 1994, Smith and Read 1997). Activity of the soil microorganisms increases with the availability of carbon compounds in the rhizosphere (Curl and Truelove 1986, Whipps 1990), and the elevated microorganism activity results in an increase in nitrogen available to the grass plant (Coleman et al. 1983, Klein et al. 1988, Burrows and Pfleger 2002, Rillig et al. 2002, Bird et al. 2002, Driver et al. 2005).

Grazing lead tillers between the third-leaf stage and the flowering stage can increase the quantity of carbon compounds the defoliated plant releases into the rhizosphere (Hamilton III and Frank 2001). The increase in nitrogen produced by elevated rates of microorganism activity allows the plant to accelerate growth and recover more quickly from defoliation. This beneficial activity does not seem to occur when grazing is conducted during the middle and late growth stages of the grass plant.

Grazing grass plants prior to the third-leaf stage negatively affects grass growth (Manske 2000b). Early seasonal growth of grass plants depends on carbohydrates stored in the roots, rhizomes, and stem bases (Trlica 1977), and prematurely grazed plants are unable to replenish adequate amounts of carbohydrates to support active growth (Coyne et al. 1995, Manske 1999). Starting grazing after the third-leaf stage and before the flowering stage allows plants to establish sufficient leaf area to produce adequate photosynthetic assimilates to meet leaf growth requirements and allows all leaf bud primordia in the apical meristem to develop into leaf buds (Manske 1999).

Management strategies that defer grazing until after the flowering stage were intended to enhance sexual reproduction and increase the quantity of seeds produced. However, deferred grazing does not improve grass plant density (Sarvis 1941, Manske et al. 1988). Most young grass plants in grassland ecosystems start not as seedlings but as vegetative tillers that grow from axillary buds on the crowns of an established plant. These vegetative tillers make up the majority of the plant population because they have a competitive advantage over seedlings. Tillers initially draw support from the root systems of parent tillers, while seedlings rely on their own less-developed structures.

Tiller development from axillary buds is regulated by lead tillers (Briske and Richards 1995) through a process called lead tiller dominance. The lead tillers produce an inhibitory hormone that prevents the growth hormone from activating growth within axillary buds (Briske and Richards 1995). Grazing that removes a small amount of young leaf tissue from the aboveground portion of lead tillers after the three-leaf stage and before the flowering stage reduces the amount of the inhibitory hormone in the plant (Briske and Richards 1994). With that inhibitory hormone reduced, the growth hormones stimulate vegetative reproduction (Murphy and Briske 1992, Briske and Richards 1994), and secondary tillers develop from the previous year's axillary buds (Langer 1972).

If no defoliation occurs before the flowering stage, as on a deferred grazing strategy, the lead tiller inhibits vegetative tiller development until the inhibitory hormone production naturally declines during the flowering stage. This hormone reduction permits one axillary bud to grow and develop into a secondary tiller, which in turn produces inhibitory hormones that prevent growth of the other six to eight axillary crown buds (Mueller and Richards 1986).

These dormant axillary buds are never activated and become senescent with the lead tiller. No evidence has been found to suggest that grazing the lead tiller after it has reached the flowering stage has beneficial stimulatory effects on vegetative tiller development (Manske 2000a).

All grass species in the Northern Plains have strong lead tiller dominance except Kentucky bluegrass and meadow bromegrass, which have low levels of inhibitory hormones and relatively higher levels of tiller development. Plants with these growth characteristics have greater demands for water than grasses with strong lead tillers and cease growth processes during minor water deficiency periods.

Grasses with strong lead tillers produce one set of lead tillers and one set of secondary tillers. Proper grazing management can increase the number of secondary tillers that develop, but the growing season length does not permit the development of a third set of tillers. The number of sets of tillers determines the number of times each pasture in a rotation system can be grazed. Two sets of tillers permit two rotation grazing periods. Rotation systems that graze each pasture more than two times are not coordinated with grass plant growth and do not meet grass plants' biological requirements (Manske 2000a).

The twice-over rotation system was designed to meet the biological requirements of the plants and to coordinate two grazing periods with grass growth stages. This coordinated defoliation stimulates biological and ecological processes within grass plants and the ecosystem so that beneficial changes to plant growth, soil organisms, and biogeochemical cycles in the ecosystem result (Manske 2000a).

A 3- to 6-pasture rotation system is used on native rangeland from early June until mid October, with each pasture grazed for two periods. Each native range pasture is grazed for 7 to 17 days during the first period, the 45-day interval from 1 June to 15 July. The length of the first period on each pasture is the same percentage of 45 days as the percentage of the total season's grazeable forage each pasture contributes (Manske 2000a).

During the first period, grasses are between the third-leaf and flowering stages, the stages of plant development at which grazing produces beneficial effects by stimulating the defoliation resistance mechanisms that increase tillering from axillary buds and enhance activity of rhizosphere organisms. Increased vegetative reproduction by tillering contributes to the development of greater plant basal cover and to the production of greater grass herbage weight; increased activity of the soil organisms in the rhizosphere supplies the plant with greater quantities of nutrients to support additional growth (Manske 2000a).

During the second period, after mid July and before mid October, each pasture is grazed for double the number of days it was grazed during the first period. Removing livestock from native rangeland pastures in mid October, during the early fall, allows native grasses to store nutrients that will maintain plant processes over the winter and to retain the fall vegetative growth that will become next season's lead tillers (Manske 2003). This practice ensures healthy plants in the spring and greater herbage production during the next growing season (Manske 2000a).

Grazing effects on grass

Grazing effects are often simplistically perceived to be just the removal of leaf material from grass plants. However, defoliation by grazing produces complex effects on grass plants. Different grazing management treatments cause diverse changes in plant growth, plant density, herbage biomass produced, and soil organism activity on grassland ecosystems.

The effects from different grazing management treatments on vegetative tillering and soil rhizosphere organism activity were investigated on an area of mixed grass prairie near Dickinson, North Dakota, USA, in 2002 (Gorder, Manske, and Stroh 2004). Tiller density and rhizosphere volume of western wheatgrass plants were used to evaluate the different effects from four grazing management treatments on stimulation of the vegetative tillering process and of the soil organism activity in the rhizosphere, respectively. The four management treatments were 1) 4.5-month twice-over rotation system, 2) 4.5-month seasonlong, 3) 6.0-month seasonlong, and 4) long-term nongrazed control. Livestock on the 4.5-month twice-over rotation management treatment grazed each of three pastures for two periods from early June until mid October. Livestock on the 4.5-month seasonlong management treatment grazed one pasture from early June until mid October. Livestock on the 6.0-month seasonlong management treatment grazed one pasture from mid May until mid November. The long-term nongrazed management treatment had not been grazed, mowed, or burned for more than 30 years before the initiation of these research treatments (Gorder, Manske, and Stroh 2004). Two replicated plant and soil samples were collected monthly from silty range sites on each of the four defoliation treatments. Plastic PVC pipe 3 inches (7.62 cm) in diameter and 4 inches (10.16 cm) long was forced into sample site soil, and the soil-plant cores were excavated intact. The matrix soil was separated from the rhizospheres of western wheatgrass plants. The tillers of each plant were categorized as lead, secondary, or fall types, and the densities per square meter were determined. The length and diameter of the rhizosphere around each root of every plant were measured with a vernier caliper, and volume was determined (Gorder, Manske, and Stroh 2004).

Total tiller density on the 4.5-month twice-over rotation treatment was greater than that on the 4.5-month seasonlong and 6.0-month seasonlong treatments during June, August, and September and greater than that on the long-term nongrazed treatment during June (table 1, figure 1). Total rhizosphere volume per cubic meter of soil on the 4.5-month twice-over rotation treatment was greater than that on the 4.5-month seasonlong and 6.0-month seasonlong treatments during July, August, and September and greater than that on the nongrazed treatment during August and September (table 2, figure 2) (Gorder, Manske, and Stroh 2004).

Stimulation of vegetative reproduction from the twice-over rotation grazing treatment during the previous year increased western wheatgrass tiller density. Most of the increased tillers carried over through the winter and the result was greater tiller density on that treatment than on the other treatments in June of the study year. The tiller stimulation that resulted from the twice-over rotation grazing treatment during the year of the study increased the western wheatgrass tiller density so that during the entire latter portion of the growing season the density was greater on that biologically effective treatment than on the other grazing treatments.

The activity of symbiotic soil organisms, as indicated by the volume of the rhizosphere, increased on the twice-over rotation system following defoliation during the stimulation grazing period, which occurred on the sample area from early July to mid July during the year of the study. The rhizosphere volume per plant increased on the twice-over rotation treatment following the stimulation grazing period, and the total rhizosphere volume in the soil increased following the stimulation period and remained greater during the entire latter portion of the growing season.

The twice-over rotation system matches defoliation periods with grass phenological stages of growth, stimulating grass defoliation resistance mechanisms that meet the biological requirements of plants and enhance the biogeochemical processes in grassland ecosystems. Stimulation of these biological and ecological mechanisms increases the vegetative tillering process and the rhizosphere organism activity. Traditional management practices that are designed for other priorities than to meet plant requirements or enhance ecosystem processes impede the function of defoliation resistance mechanisms. Inhibition of these mechanisms reduces the development of grass vegetative tillers and the activity of rhizosphere organisms (Gorder, Manske, and Stroh 2004).

Grazing effects on western snowberry

The effects of grazing treatments on western snowberry plants in the mixed grass prairie were studied in southcentral North Dakota, USA, at the North Dakota State University Central Grasslands Research and Extension Center (Sturn 1987, Kirby et al. 1988). Study sites were selected based on similar criteria prior to the implementation of the grazing treatments. Shrub stem density, shrub canopy cover, and current year shrub biomass production data were collected along the same permanently marked transects in 1982 and again in 1986. Precipitation rates were favorable for plant growth during the five-year study period, with average annual precipitation at 118.4% of the long-term mean of 17.9 inches (45.6 cm). The idle control treatment had been last grazed in 1979. The seasonlong and short duration grazing treatments were started in 1982, and the twice-over rotation grazing treatment was started in 1983 (Sturn 1987, Kirby et al. 1988).

The initial shrub stem densities were not similar on all treatments (table 3) and western snowberry response was not the same on the different grazing treatments. The densities of sucker and young stems decreased on the control and twice-over rotation treatments and increased on the short duration treatment; the densities of sucker stems significantly increased on the seasonlong treatment between 1982 and 1986. The short duration treatment had significantly greater sucker stem densities in 1986 than the control and twice-over rotation treatments. The densities of mature stems increased on the control and short duration treatments and decreased on the seasonlong treatment between 1982 and 1986. The short duration treatment had significantly greater mature stem densities in 1986 than the seasonlong treatment. The densities of total stems increased on the seasonlong and short duration treatments and decreased on the control and twice-over rotation treatments between 1982 and 1986. The short duration treatment had significantly greater total stem densities in 1986 than the control treatment.

Shrub percent canopy cover (table 3) increased on the short duration treatment and decreased significantly on the control, seasonlong, and twice-over rotation treatments between 1982 and 1986. The short duration treatment had significantly greater percent canopy cover in 1986 than the seasonlong and twice-over rotation treatments.

Shrub current year twig and leaf production (table 3) increased significantly between 1982 and 1986 on the short duration treatment. The short duration treatment had significantly greater shrub production in 1986 than the seasonlong treatment. The seasonlong treatment had significantly greater shrub production in 1986 than the twice-over rotation treatment.

After five years of management on the idle control treatment, western snowberry communities had decreased sucker and young stem densities and increased mature stem densities that resulted in decreased total stem densities, significantly decreased percent canopy cover, and only slightly increased shrub twig and leaf production.

After five years of management on the seasonlong treatment, western snowberry communities had significantly increased sucker stem densities and decreased mature stem densities that resulted in increased total stem densities and increased shrub twig and leaf production, but because young stems have less canopy than old stems, there was a significant reduction in percent canopy cover.

After five years of management on the short duration treatment, western snowberry communities had increased sucker stem densities and increased mature stem densities that resulted in increased total stem densities, increased percent canopy cover, and significantly increased shrub twig and leaf biomass production.

After five years on the twice-over rotation management treatment, western snowberry communities had decreased young stem densities and no change in mature and decadent stem densities; the result was decreased total stem densities, significantly decreased percent canopy cover, and only slightly increased shrub twig and leaf production.

Management Implications

Livestock grazing has only a relatively small direct effect on aerial stems of western snowberry and the size and densities of the colonies. However, the effects from grazing management practices on the adjacent grassland community can regulate the rate at which the western snowberry colonies increase and spread.

Grazing management practices that do not meet grass biological requirements or enhance ecosystem processes impede vegetative tillering and activity levels of rhizosphere organisms; as a result, the competitive abilities of grass plants are weakened. The degree to which biological and ecological processes are inhibited by antagonistic grazing practices will be reflected inversely by the rate of western snowberry invasion.

Grazing management practices that meet the biological requirements of plants and enhance the biogeochemical processes in grassland ecosystems increase the amount of vegetative tillering and rhizosphere organism activity. The result is a healthy, dense, productive grass population that is highly competitive for belowground resources and creates the strongest possible biological barrier to western snowberry encroachment.

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Table 1. Total tiller density of western wheatgrass per square meter.

Grazing Management	June	July	August	September	Growing Season
4.5-m Twice-over rotation	2412.09a	1206.04a	1973.53a	1425.32a	1754.25a
4.5-m Seasonlong	548.20b	657.84a	767.48b	657.84b	657.84b
6.0-m Seasonlong	767.48b	548.20a	822.30b	767.48b	726.37b
Nongrazed	548.20b	548.20a	877.12ab	1206.04a	794.89b

Data from Gorder, Manske, and Stroh 2004

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

Table 2. Rhizosphere volume (cm^3) per cubic meter of soil.

Grazing Management	June	July	August	September	Growing Season
4.5-m Twice-over rotation	3214.75a	3867.54a	7183.27a	6586.06a	5212.91a
4.5-m Seasonlong	1800.93a	692.21b	1963.02b	1802.97b	1564.78bc
6.0-m Seasonlong	1695.21a	1087.08b	1128.08b	658.29c	1142.17c
Nongrazed	1725.24a	2804.61a	2391.97b	2438.47b	2340.07b

Data from Gorder, Manske, and Stroh 2004

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

Table 3. Western snowberry response to grazing treatments after five years.

Treatments	Idle Control	Seasonlong	Short Duration	Twice-over Rotation
Years				
	Sucker and young stem density (stems/m^2)			
1982	34b	14a	43b	32b
1986	26b	27b	49a	28b
% change/5 yr	-23.5%	92.9%*	14.0%	-12.5%
	Mature stem density (stems/m^2)			
1982	22a	18ab	19ab	15b
1986	25a	12c	21ab	15bc
% change/5 yr	13.6%	-33.3%	10.5%	0.0%
	Decadent stem density (stems/m^2)			
1982	6b	5b	11a	5b
1986	4b	3b	9a	5b
% change/5 yr	-33.3%	-40.0%	-18.2%	0.0%
	Total stem density (stems/m^2)			
1982	62ab	37c	73a	52b
1986	55b	42c	79a	48bc
% change/5 yr	-11.3%	13.5%	8.2%	-7.7%
	Shrub canopy cover (%)			
1982	59a	41b	40b	39b
1986	46a	25b	46a	25b
% change/5 yr	-22.0%*	-39.0%*	15.0%	-35.9%*
	Shrub twig and leaf biomass production (lbs/ac)			
1982	1917.8a	1257.7bc	1516.4ab	1034.7c
1986	1989.2ab	1703.7b	2337.0a	1168.5c
% change/5 yr	3.7%	35.5%	54.1%*	12.9%

Data from Sturn 1987 and Kirby et al. 1988

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

*Percent change after five years is significantly different ($P<0.05$).

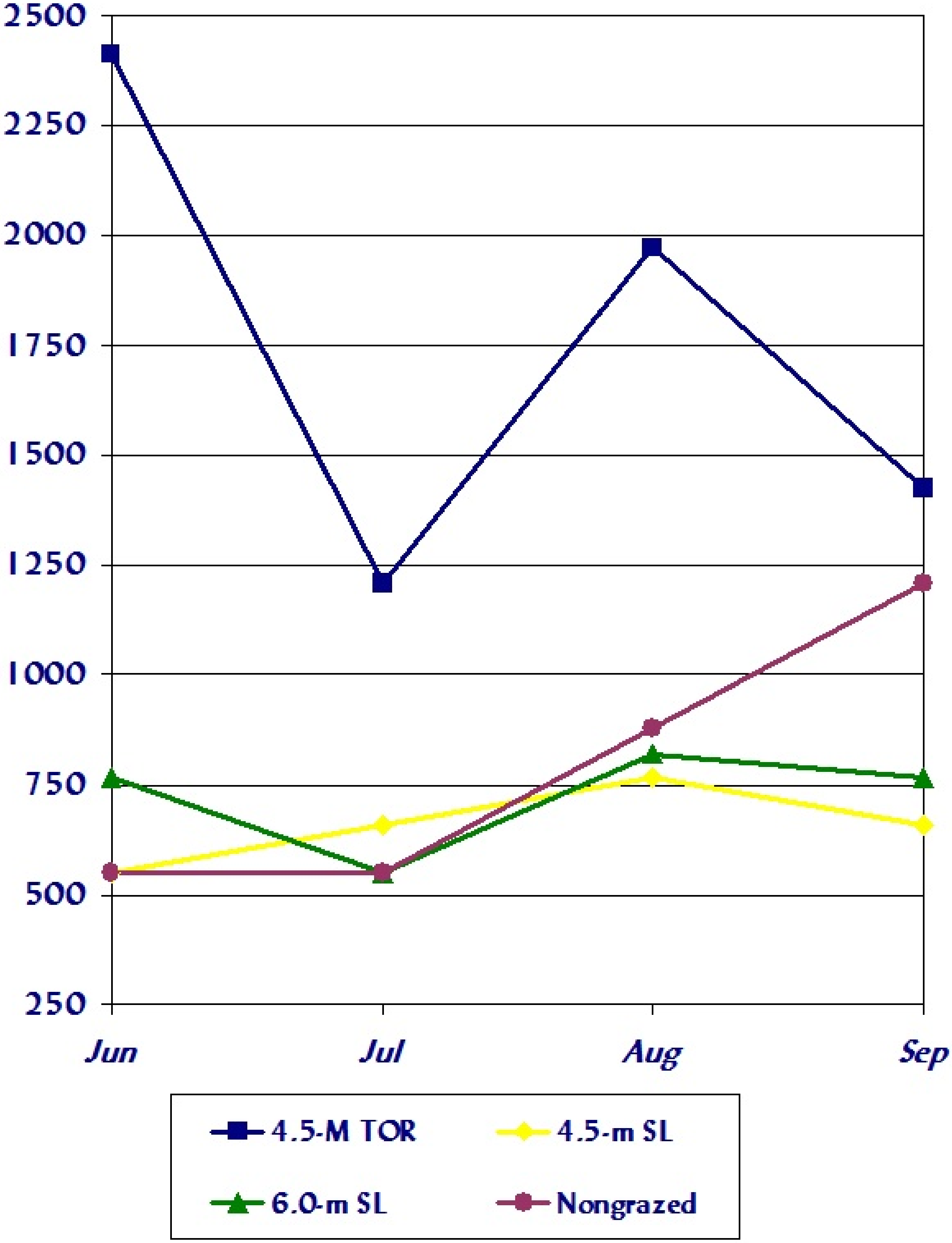

Figure 1. Total Tiller Density of western wheatgrass per square meter, data from Gorder, Manske, and Stroh 2004.

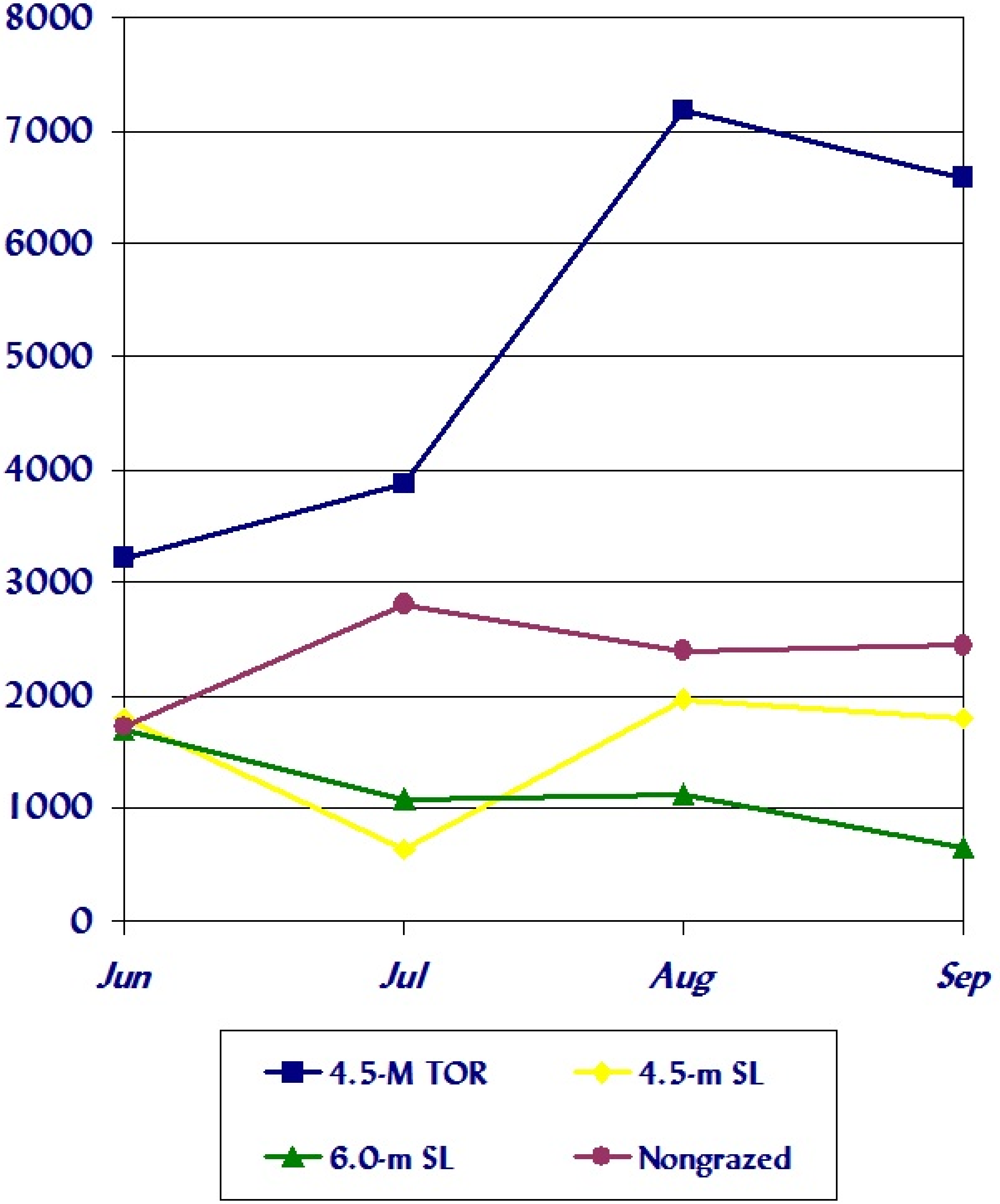

Figure 2. Rhizosphere volume (cm^3) per cubic meter of soil, data from Gorder, Manske, and Stroh 2004.

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Burning Management of Western Snowberry

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Western snowberry is one of the few woody plants that can successfully invade grasslands by means of rhizomes that produce aerial stems in quantities sufficient to shade out grasses and permit expansion of the colonies (Pelton 1953). The invasion of western snowberry colonies into grassland habitat may have been facilitated by the widespread practice of suppressing grassland wildfires to protect valuable pasture forage. Unlike growth from frequently burned western snowberry colonies, growth from unburned colonies accumulates aboveground stem biomass and enlarges the total leaf area. With these increases of plant material, the unburned colonies can produce greater quantities of nonstructural carbohydrates, which can be used to support growth of more rhizome suckers. Western snowberry colonies in grasslands protected from fire increase progressively in density and size, and after several years can render major portions of pastures relatively useless for forage production (Pelton 1953). Encroachment of western snowberry colonies has become a serious pasture problem across most of the areas that suppress grassland wildfires and do not practice prescribed burning for woody plant control. Controlled fire can be used as an important tool in the management of western snowberry colony expansion. Effective use of prescribed burning requires an understanding of fire's effects on western snowberry.

Fire was historically a natural environmental factor on grasslands of North America (Wright and Bailey 1982), and, presumably, frequent fires helped check western snowberry encroachment (Pelton 1953). Historical fire frequency was not the same across all of the grassland regions. The fire return interval (Wright and Bailey 1982, Bragg 1995) was 3 to 4 years for tallgrass prairie, 5 to 10 years for moist mixed grass prairie, and around 25 years for dry mixed grass prairie. The seasonal period during which grassland fires occurred was interpreted by Higgins (1986) from historical information about Indian- and lightning-set fires. The Indian-set fires occurred primarily during two periods: March through May, with a peak in April, and July through early November, with a peak in October. The probable practice was burning the mixed grass prairie in late summer and fall and the tallgrass prairie in spring. Lightning-set fires occurred during summer and early fall, with 73% occurring in July and August. The historical frequency and seasonal period of Indian-set and lightning-set fires are considered to be natural forces that have influenced how western snowberry responds to prescribed burning.

Pelton (1953) compared burned and unburned treatments for two growing seasons after a mid April fire in Minnesota to assess the effect of fire on western snowberry colonies. The aerial stems were not completely consumed by the fire but were charred sufficiently to kill all stems to ground level. The sucker shoots grew rapidly from the stem bases at an average of 2.5 suckers for each killed stem. The number of vegetative shoots that develop following a fire is affected by the length of daylight during the time of the fire. Day lengths shorter than 14 hours prevent normal vegetative growth, and day lengths longer than 14 hours stimulate vegetative growth (Pelton 1953). The numerous vegetative sucker shoots grew to about half the height and diameter of the unburned stems during the first growing season. Most of the stronger sucker shoots reached three-fourths of the unburned stem height during the second growing season. During that growing season, the stem density on the burned treatment was greater than that on the unburned treatment; however, competition had reduced the stem density from that occurring during the first growing season.

Pelton (1953) found that the aerial stems of western snowberry are sensitive to fire and are easily killed. The rhizomes and stem bases are unharmed by fire, probably because of their depth in the soil, which ranges from 1 to 14 inches (2 to 35 cm). Recovery of aerial stems by vegetative development of lateral buds on rhizomes and stem bases is moderately rapid during the first and second growing seasons following a spring fire. The responses of the vegetation suggest that annual or very frequent fires are probably detrimental to western snowberry (Pelton 1953).

Anderson and Bailey (1979) evaluated the effects from two prescribed single spring burns conducted during May 1970 and May 1971 in western snowberry communities of central Alberta. The study analyzed frequency, canopy cover, and woody stem density data collected in August along landscape transects on both burned and unburned treatments and assessed the responses of western snowberry and of other vegetation categories.

Responses varied among vegetation categories. Single burns during May resulted in an increase in frequency and canopy cover for annual and perennial forbs (tables 1 and 2). Annual forbs were prominent only during the first year after the fire; their invasion was in response to increased nutrients, a favorable seedbed, and reduced competition. The perennial forb increase remained high for 3 years after burning. Perennial forbs responded to the temporary reduction in competition from shrubs, higher light intensity at the soil surface, warmer soil temperatures, a release of nutrients, and a favorable seedbed (Anderson and Bailey 1979). Frequency of grasses and sedges decreased (tables 1 and 2) after a single burn. Canopy cover increased (table 1) for grasses and sedges after the 1970 burn, but decreased after the 1971 burn (table 2). Shrub frequency and canopy cover (tables 1 and 2) increased after a single spring burn. Most of this increase was the result of a great increase in red raspberry density following the fire (Anderson and Bailey 1979).

Western snowberry frequency and canopy cover were about the same in burned and unburned treatments three months following the spring burns (tables 1 and 2). Western snowberry vegetative suckers were visible two weeks after the fire and grew rapidly, maintaining dominance in the stand. The rhizomes of western snowberry are resistant to spring fires. The lateral buds on rhizomes are hormonally controlled from active growth by apical dominance of the stems. The fire consumed the aerial stems and removed the growth-inhibiting hormone control, releasing rhizome bud development into vegetative sucker shoots (Anderson and Bailey 1979). Western snowberry stem density per m^2 increased 174.4% and 363.6% during the first year after a May burn in 1970 and 1971, respectively. Stem density decreased during the second and third growing seasons after burning (Anderson and Bailey 1979).

Bailey and Anderson (1980) conducted a study to determine the range in temperatures reached during prescribed burning grassland communities of rough fescue-western porcupine grass and shrubland communities of western snowberry in the central Alberta aspen parkland. Commercial temperature pellets that melt at specific temperatures were placed on asbestos cards attached at different heights to metal posts randomly located within the grassland and shrubland communities. Spring burns were conducted in 1971 and 1972, with areas of each community type burned by both backfires and headfires (Bailey and Anderson 1980).

The grasslands burned rapidly but at comparatively low temperatures ranging from 199.4° F to 800.6° F (93° C - 427° C) (table 3). Temperatures of grassland backfires were lower than temperatures of grassland headfires. The temperature at the soil surface was 278.6° F (137° C) for the backfires and 402.8° F (206° C) for the headfires. The hottest temperature of grassland backfires was 449.6° F (232° C), at a height of 2 inches (5 cm) above the soil surface (table 3). The hottest temperature of grassland headfires was 800.6° F (427° C), at a height of 6 inches (15 cm) above the soil surface (table 3).

The shrublands burned at higher temperatures than the grasslands, with a range of temperatures from 399.2° F to 1299.2° F (204° C - 704° C) (table 3). Temperatures of shrubland backfires were lower than temperatures of shrubland headfires. The temperature at the soil surface was 617° F (325° C) for the backfires and 815° F (435° C) for the headfires. The hottest temperature of shrubland backfires was 800.6° F (427° C), at a height of 3.2 inches (8 cm) above the soil surface (table 3). The hottest temperature of shrubland headfires was 1299.2° F (704° C), at a height of 3.2 to 7.9 inches (8-20 cm) above the soil surface (table 3).

Microrelief, type of fire, weather conditions before and during burning, and the kind, quantity and spatial distribution of fuels influence fire temperatures. The hottest fire temperatures are not at the soil surface. Woody fuels burn hotter than grass fuels. The temperature of fire increases with the density of western snowberry stems (Bailey and Anderson 1980).

All of the temperatures measured at or above the soil surface were greater than the lethal temperature for leaf tissue, which is approximately 140° F (60° C). Green grass shoots became conspicuous on burned grassland about a week after the fire (Bailey and Anderson 1980), and western snowberry shoots became visible on burned shrubland about two weeks after the fire (Anderson and Bailey 1979). The wet soil prevented penetration of lethal temperatures to the depth of perennial plant meristematic buds or growing points. Wet soils apparently dissipate heat more effectively than do dry soils (Bailey and Anderson 1980).

Western snowberry lateral buds on stem bases and rhizomes would not be expected to be damaged by lethal temperatures during prescribed burns conducted under wet soil conditions. However, near the center of western snowberry colonies, where the stem density and total fuels are greater, long periods of high fire temperatures would be experienced, and under dry soil conditions, lethal temperatures could be expected to cause considerable mortality to the growing points on the shallower rhizomes and stem bases (Bailey and Anderson 1980).

Romo et al. (1993) evaluated the effects from prescribed single spring burns and fall burns conducted from fall 1986 to spring 1988 in western snowberry communities of a relict rough fescue prairie in central Saskatchewan that had not been burned, mowed, or grazed for about 20 years. The study analyzed stem densities per m^2 data collected during four successive years on permanent plots in both burned and unburned treatments.

Single burns during early spring and early fall resulted in increases in western snowberry stem density (table 4). The majority of the new shoots developed from crowns or stem bases, and some shoots arose from rhizomes. The increase in stem density on the spring burn (221%) was greater than that on the fall burn (90%) during the first growing season. Stem density during the second growing season was greater on the burned treatments than on the unburned treatments (table 4); however, density-dependent mortality had reduced stem density on the burned treatments from the density occurring during the first growing season. After the first year, the spring burns had a greater rate of stem mortality than the fall burns. Stem densities on the spring burns and fall burns were similar to those on the unburned reference controls during the third and fourth growing seasons after burning (table 4) (Romo et al. 1993).

Romo et al. (1993) presented a direct and an indirect possible explanation for the difference in the quantity of sucker sprouts developing after the spring burns compared to the fall burns. The possible direct explanation is related to the difference in the fire temperature. The fuels on the fall burned treatments were loose and fine, with oxygen pockets throughout; the fall fire would be hotter than a fire consuming the compacted fine fuels on the spring burned treatments. The hotter temperatures of fall burns may cause damage to meristematic tissue on crowns and a resulting reduction in the number of new shoots that develop the following growing season. The possible indirect explanation is related to modification of the microenvironment. The fall fire consumed the aerial stems that would have trapped insulating snow; during the winter the unprotected crowns would be exposed to temperature extremes that might cause damage to meristematic tissue and a resulting reduction in the number of new shoots that develop the following growing season.

A single burn during spring or fall should not be expected to reduce stem density of western snowberry colonies. Aerial stem dominance is rapidly reestablished because of prolific sucker sprouting in combination with increased productivity following burning (Romo et al. 1993).

Anderson and Bailey (1980) evaluated the effects from annual early spring burning conducted during April for 24 years in aspen parkland of east central Alberta. The study analyzed frequency, canopy cover, and woody stem density data collected in August of 1976 along landscape transects on both burned and unburned treatments.

Annual early spring burning resulted in a considerable expansion of grassland habitat and a reduction in the proportion of aspen groves. Annual burning for 24 years resulted in increased frequency and canopy cover of grasses, sedges, and perennial forbs (table 5). Competition for sunlight was temporarily reduced after each annual fire consumed the aerial stems of western snowberry. Annual burning caused an increase in the number of grass, sedge, and forb species, with a change towards plants adapted for more arid regions. Fringed sage increased in frequency (133.3%) and in canopy cover (50.0%) on the burned treatments. The early spring fires were deleterious to cool-season grasses. Rough fescue and western porcupine grass increased in frequency but decreased in canopy cover. The annually burned areas had lower soil moisture than the unburned areas; this condition resulted from reduced infiltration rates and greater evaporation loss. Water stress in grasses and sedges on the burned areas caused a reduction of leaf blade length (43.8%) and herbage biomass production (48.9%). Annual burning prevented litter accumulation; the greater area of exposed soil surface in burned areas resulted in a more favorable seedbed. Organic matter was greater in the top 6 inches (15 cm) of soil on the burned areas than on the unburned areas. Total mineral nitrogen (NH_4-NO_3) and other nutrients were not different on the burned and unburned areas (Anderson and Bailey 1980).

Annual burning during April for 24 years resulted in an increase in shrub frequency (64.7%)

(table 5); however, burning reduced shrub canopy cover (56.3%) (table 5), shrub height, and shrub herbage biomass (94.6%). Because of the vast quantity of vegetative suckers produced by shrubs after fire, annual early spring burning did not eliminate any woody species from the plant community. The stem density of shrubs was 245.5% greater on the burned areas than on the unburned areas. Annual burning during early spring for 24 years resulted in a grassland with a high frequency of small shrubs (Anderson and Bailey 1980).

Annual early spring burning resulted in a small decrease in frequency (7.1%) and a large decrease in canopy cover (93.5%) for western snowberry (table 5). Western snowberry stem density was 28.8% lower on the burned areas than on the unburned areas. The annual burning killed many aerial stems each year, but the rhizome systems were not killed. The rhizome system made western snowberry resistant to early spring fires (Anderson and Bailey 1980).

Manske (1992) evaluated the effects from the every-other-year burning strategy developed by refuge manager Karen A. Smith. During the thirteen-year period from 1978 to 1990, burning was conducted during early spring (mid-late April), spring (May-mid June), early summer (mid June-July), and mid summer (early-mid August), with burning repeated one, two, three, and four times on mixed grass prairie invaded by western snowberry in northwestern North Dakota (figure 1). The study analyzed shoot frequency and current year's live biomass production data collected in 1990 along landscape transects on both burned and unburned treatments.

The total current year's production of aboveground biomass was not different after one, two, three, and four repeated prescribed burns compared to the biomass of the unburned treatment (table 6). However, the composition of the aboveground biomass changed remarkably. The contribution of grasses to the total biomass changed from 24.2% on treatments with no burns to 65.6% after four burns (table 6), an increase of 171.1%. Grass biomass decreased 24.7% after one burn and increased 109.3% after four burns (table 6). The contribution from sedges changed from 13.2% on treatments with no burns to 11.1% after four burns. Sedge biomass increased 61.6% after one burn and decreased 35.1% after four burns (table 6). The contribution from forbs changed from 15.0% on treatments with no burns to 20.3% after four burns. After one burn, the forb contribution to total aboveground biomass was 139.7% greater than that on the unburned treatments. After two and three burns, the weedy forbs decreased and the ecological status of perennial forbs improved. The forb contribution to the total biomass production after four burns was 35.3% greater than that on the unburned treatments. Forb biomass increased 78.0% after one burn and increased 4.4% after four burns (table 6). The biomass contribution from shrubs changed from 47.5% on treatments with no burns to only 3.0% after four burns (table 6), a 93.7% decrease. Shrub biomass decreased 83.1% after one burn and decreased 95.1% after four burns (table 6).

Native grass shoot frequency increased significantly as a result of repeated burning. The average increase after one, two, and three burns was 79.6%, and after four burns native grass shoot frequency increased 94.7% (table 7). Sedge shoot frequency increased an average of 58.4% after repeated burning. Introduced grass shoot frequency decreased an average of 49.4% after one, two, and three burns and decreased 65.1% after four burns. Four burns were required to reduce introduced grasses significantly (table 7). Kentucky bluegrass shoot frequency decreased an average of 36.2% after one, two, three, and four burns. Quackgrass shoot frequency decreased an average of 84.0% after one and two burns and decreased an average of 90.9% after three and four burns. Smooth bromegrass shoot frequency decreased an average of 90.0% after one and two burns and decreased an average of 96.7% after three and four burns.

Perennial forb shoot frequency increased 39.3% after one burn (table 7) and increased an average of 7.5% after additional repeated burns of two, three, and four times. Early succession and weedy forb shoot frequency increased 8.2% after one burn, decreased an average of 7.5% after two and three burns, and decreased 50.9% after four burns (table 7). Four burns were required to reduce weedy forbs significantly (table 7).

Shrub shoot frequency decreased 36.4% after one burn, decreased an average of 46.1% after two and three burns, and decreased 58.2% after four burns (table 7). Four burns were required to reduce shrubs significantly (table 7).

Western snowberry shoot frequency decreased 62.7% after one burn, decreased an average of 55.8% after two and three burns, and decreased 64.0% after four burns. Shoot frequency of western snowberry changed little from repeated burning after the first burn. However, the aboveground biomass produced by the shrubs was greatly reduced after the third and fourth burns.

All burns cause some damage to plants, but the seasonal period that prescribed burns are conducted affects the biomass production and shoot frequency of plant biotypes differently. Effective prescribed burns are conducted during appropriate seasonal periods so that the greatest reduction to the undesirable plants is caused and the damage to the desirable plants is minimized.

Grass biomass greatly increased after spring (May-mid June) and mid summer (early-mid August) burns but decreased after early summer (mid June-July) burns (table 8). Grass shoot frequency increased significantly after burns conducted during all seasonal periods. The greatest increases occurred after spring (May-mid June) and mid summer (early-mid August) burns (table 9). Shoot frequency of native cool-season grasses increased significantly after burns conducted during all seasonal periods (table 10). Shoot frequency of western wheatgrass increased significantly after early spring (mid-late April) burns and decreased after spring (May-mid June) burns (table 10). Shoot frequency of native warm-season grasses increased significantly after burns conducted during spring (May-mid June) (table 10). Blue grama shoot frequency increased significantly after spring (May-mid June) burns (table 10). Shoot frequency of introduced grasses decreased significantly after spring (May-mid June) burns (table 9). Kentucky bluegrass shoot frequency decreased significantly after spring (May-mid June) burns (table 10) and increased after early spring (mid-late April) burns (table 10). Smooth bromegrass and quackgrass shoot frequency decreased after burns conducted during all seasonal periods. Smooth bromegrass shoot frequency decreased most after early spring (mid-late April) burns (table 10). Quackgrass shoot frequency decreased most after spring (May-mid June) burns (table 10).

Sedge biomass increased after burns conducted during early spring (mid-late April) and early summer (mid June-July) and decreased after spring (May-mid June) and mid summer (early-mid August) burns (table 8). Shoot frequency of sedges increased significantly after spring (May-mid June) burns (table 9).

Forb biomass increased after burns conducted during all seasonal periods. The greatest increases occurred after early spring (mid-late April) and spring (May-mid June) burns (table 8). Shoot frequency of perennial forbs increased after early spring (mid-late April) and early summer (mid June-July) burns and decreased slightly after spring (May-mid June) burns (table 9). Shoot frequency of weedy forbs increased significantly after early spring (mid-late April) burns and decreased after spring (May-mid June), early summer (mid June-July), and mid summer (early-mid August) burns (table 9).

Shrub biomass decreased after burns conducted during all seasonal periods. The greatest decreases occurred after early spring (mid-late April), spring (May-mid June), and mid summer (early-mid August) burns (table 8). Shoot frequency of shrubs decreased significantly after early spring (mid-late April), spring (May-mid June), and mid summer (early-mid August) burns (table 9). Shrub shoot frequency did not decrease significantly after early summer (mid June-July) burns (table 9). Silverberry shoot frequency decreased significantly after early spring (mid-late April) and mid summer (early-mid August) burns (table 11). Western rose shoot frequency decreased significantly after early spring (mid-late April) and spring (May-mid June) burns (table 11) and increased slightly after early summer (mid June-July) and mid summer (early-mid August) burns. Shoot frequency of western snowberry decreased significantly after early spring (mid-late April), spring (May-mid June), and mid summer (early-mid August) burns (table 11). Western snowberry shoot frequency did not decrease significantly after early summer (mid June-July) burns (table 11).

The effects of every-other-year burning treatments on mycorrhizal fungi infection were evaluated from roots of three plants of western snowberry, smooth bromegrass, western wheatgrass, and blue grama collected at each replicated site and analyzed individually. The number of repeated burns and the seasonal period of burns did not significantly change the level of fungal infection (tables 12 and 13).

The effects of every-other-year burning treatments on the quantity of available mineral (inorganic) nitrogen (NH_4-NO_3) were evaluated. The number of repeated burns and the seasonal period of burns did not significantly change the level of mineral nitrogen (tables 12 and 13).

The average quantity of soil water during the growing season was not significantly different on the unburned and burned treatments (Manske 1992).

Prior to the initiation of the every-other-year prescribed burn strategy in 1978 by refuge manager

Karen Smith, the Lostwood National Wildlife Refuge had not been burned in over 80 years (Smith 1985b). Western snowberry invasion had progressed unchecked in the absence of fire, and the expanded colonies covered over 50% of the upland landscape. Kentucky bluegrass was the dominant grass associated with western snowberry colonies. Native grasses and forbs were still present but greatly suppressed. Large portions of the western snowberry colonies were extremely dense and had no herbaceous understory. Decadent centers of old western snowberry colonies had been invaded by smooth bromegrass, quackgrass (Smith 1985a), and Canada thistle (Smith 1985b). The management strategy designed to reduce the invading western snowberry and exotic grasses and renovate the prairie ecosystem was a regime of burning on alternate years. Annual burns were not possible because of insufficient production of plant biomass for fuel (Smith 1985a).

Four burns conducted every other year were required to significantly reduce the undesirable plants of introduced grasses, early succession and weedy forbs, and shrubs from mixed grass prairie habitat. Native grasses, sedges, and perennial forbs were not reduced by repeated burning and benefitted from the reduction in competition for sunlight from the taller shrubs. The long period of native species suppression by western snowberry colonies had greatly diminished plant numbers. The quantity of basal area for native species was not well developed even after four burns. Grazing management based on the twice-over rotation system was implemented to stimulate vegetative tillering and activity of rhizosphere organisms to increase native species stem density (Smith 1997).

The prescribed burns conducted during early spring (mid-late April), spring (May-mid June), and mid summer (early-mid August) resulted in decreased western snowberry shoot frequency and shrub biomass production. These burns coincided with the first two carbohydrate drawdown periods of western snowberry. The first carbohydrate drawdown period occurs during early spring, from mid April to early June (9 June), when the plants are in rapid growth to full leaf expansion stages. The second carbohydrate drawdown period occurs during the major portion of fruit fill stage, from mid July to mid August.

The prescribed burns conducted during early summer (mid June-July) caused the least reduction in western snowberry shoot frequency and shrub biomass production. These burns coincided with western snowberry's major carbohydrate replenishment period, which occurs from full leaf expansion stage through most of the flowering stage, from early June to mid July. Burns conducted during carbohydrate drawdown periods had greater success at western snowberry reduction than burns conducted during carbohydrate replenishment periods.

Management Implications

Western snowberry aerial stems are sensitive to fire, and even if they are not completely consumed by the fire, they usually die to ground level. The belowground rhizomes and rhizome crowns with clusters of aerial stems are usually not damaged by fire. The belowground parts have large quantities of buds that have the potential to develop into new aerial sucker stems.

Historically, fire has been an environmental factor on mixed grass prairie, with an estimated fire return interval of 5 to 10 years on the moist portions and around 25 years on the dry portions. Most lightning-set fires occurred in July and August, and a large portion of the Indian-set fires occurred between July and early November. The Northern Plains has probably had considerably more late season fires, occurring after mid July, than spring or early summer fires.

A prescribed fire during August causes the least damage to native cool- and warm-season grasses and perennial forbs. An August fire removes all or most of the top growth of western snowberry and results in fewer sucker shoots the following year than a spring burn. August burns can be nearly nondetrimental to desirable plants when the soil is not dry, and August burns can cause considerable damage to the undesirable woody plants.

June and early July burns are usually detrimental to native grass plants and hurt western snowberry plants only a little. Spring burns during late April or May are severely detrimental to native cool-season grasses because of the removal of the valuable growth of the fall tillers and overwintering secondary tillers. Kentucky bluegrass is increased by earlier burns and decreased by later spring burns. Weedy forbs are increased greatly by spring burns. Western snowberry top growth is usually removed completely if sufficient fine fuel is present; however, spring burns result in great quantities of sucker stems, which become visible about two weeks following the burn, and because carbohydrates stores can be completely replenished by the new plant material in one growing season, spring burns do not decrease stem frequency even after 24 years. Late April and May prescribed burns are less likely to escape control measures compared to August burns; however, the growth pattern and biological requirements of the herbaceous vegetation in the mixed grass prairie match the August burns more closely. Prescribed burning can be used to remove western snowberry aerial stems, and four every-other-year burns can reduce shrub stem frequency, but fire alone will not remove western snowberry from the northern mixed grass prairie.

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Table 1. Frequency % and canopy cover % of vegetation in unburned and burned western snowberry colonies from a single May 1970 burn treatment.

	Frequency %						Canopy Cover %					
	Unburned			Burned			Unburned			Burned		
	1970	1971	1972	1970	1971	1972	1970	1971	1972	1970	1971	1972
Annual Forbs	0	0	0	61	29	4	0	0	0	15	4	4
Perennial Forbs	26	26	30	96	68	82	5	2	9	29	31	30
Grass and Sedge	57	78	83	64	57	75	19	19	34	42	60	64
Shrubs	56	80	70	72	90	90	2	17	7	8	16	13
Western snowberry	100	100	100	100	100	100	95	90	89	95	90	89

Data from Anderson and Bailey 1979

Table 2. Frequency % and canopy cover % of vegetation in unburned and burned western snowberry colonies from a single May 1971 burn treatment.

	Frequency %		Canopy Cover %	
	Unburned	Burned	Unburned	Burned
	1971	1971	1971	1971
Annual Forbs	5	14	<1	2
Perennial Forbs	36	94	4	41
Grass and Sedge	46	8	7	<1
Shrubs	35	106	7	35
Western snowberry	99	100	87	78

Data from Anderson and Bailey 1979

Table 3. Range in temperatures reached during prescribed burning of grassland and shrubland habitats.

	Grassland Habitat		Shrubland Habitat	
Backfire				
Soil surface Temperature	278.6° F	(137° C)	617° F	(325° C)
Range of fire Temperatures	199.4°-449.6° F	(93°-232° C)	399.2°-800.6° F	(204°-427° C)
Height of hottest Temperature	2 inches	(5 cm)	3.2 inches	(8 cm)
Headfire				
Soil surface Temperature	402.8° F	(206° C)	815° F	(435° C)
Range of fire Temperatures	199.4°-800.6° F	(93°-427° C)	449.6°-1299.2° F	(232°-704° C)
Height of hottest Temperature	6 inches	(15 cm)	3.2-7.9 inches	(8-20 cm)

Data from Bailey and Anderson 1980

Table 4. Stem density (stems/m^2) for western snowberry on spring and fall burn treatments during four years following burning and percent change from preburn control.

		No Burns 2 reps	Early Spring (late Apr-early May) 4 reps	Early Fall (mid Oct) 4 reps
Preburn	(stems/m^2)	38a	38a	38a
Year 1	(stems/m^2)	39b	122c	72bc
% change	(%)	2.6	221.1	89.5
Year 2	(stems/m^2)	43d	111e	67de
% change	(%)	13.2	192.1	76.3
Year 3	(stems/m^2)	46f	95f	62f
% change	(%)	21.1	150.0	63.2
Year 4	(stems/m^2)	46g	51g	57g
% change	(%)	21.1	34.2	50.0

Data from Romo et al. 1993

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

Table 5. Frequency % and canopy cover % of vegetation in unburned and burned western snowberry colonies from 24 years of annual April burn treatment.

	Frequency %		Canopy Cover %	
	Unburned	Burned	Unburned	Burned
	1976	1976	1976	1976
Annual Forbs	0	0	0	0
Perennial Forbs	204	348	13.1	49.9
Grass and Sedge	207	437	67.4	109.8
Shrubs	68	112	16	7
Western snowberry	56	52	31	2

Data from Anderson and Bailey 1980

Table 6. Live biomass production of plant biotypes on every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	One Burn 4 reps	Two Burns 4 reps	Three Burns 4 reps	Four Burns 3 reps
Grass						
Biomass	(lbs/ac)	411.61a	310.12a	762.75a	512.87a	861.51a
% change	(%)		-24.7	85.3	24.6	109.3
Sedge						
Biomass	(lbs/ac)	224.59b	362.93b	74.34b	238.58b	145.81b
% change	(%)		61.6	-66.9	6.2	-35.1
Forb						
Biomass	(lbs/ac)	255.33c	454.35c	445.14c	587.41c	266.49c
% change	(%)		78.0	74.3	130.1	4.4
Shrub						
Biomass	(lbs/ac)	806.83d	136.00d	237.09d	52.00d	39.57d
% change	(%)		-83.1	-70.6	-93.6	-95.1
Total Live						
Biomass	(lbs/ac)	1698.36e	1263.39e	1519.19e	1390.87e	1313.38e
% change	(%)		-25.6	-10.6	-18.1	-22.7

Data from Manske 1992

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

Table 7. Shoot frequency of plant biotypes on every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	One Burn 4 reps	Two Burns 4 reps	Three Burns 4 reps	Four Burns 3 reps
Native Grass						
Shoot frequency	(%)	107.0a	194.3b	183.3ab	198.8b	208.3b
% change	(%)		81.6	71.3	85.8	94.7
Sedge						
Shoot frequency	(%)	56.7c	95.5d	97.0d	77.8cd	89.0cd
% change	(%)		68.4	71.1	37.2	57.0
Introduced Grass						
Shoot frequency	(%)	86.7e	46.3ef	31.8ef	53.5ef	30.3f
% change	(%)		-46.6	-63.3	-38.3	-65.1
Perennial Forbs						
Shoot frequency	(%)	120.5g	167.8h	125.5gh	137.5gh	125.7gh
% change	(%)		39.3	4.1	14.1	4.3
Weedy Forbs						
Shoot frequency	(%)	85.5i	92.5i	80.3ij	78.0ij	42.0j
% change	(%)		8.2	-6.1	-8.8	-50.9
Shrubs						
Shoot frequency	(%)	111.7k	71.0kl	58.5kl	62.0kl	46.7l
% change	(%)		-36.4	-47.6	-44.5	-58.2

Data from Manske 1992

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

Table 8. Live biomass production of plant biotypes on the seasonal period of every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	Early Spring (mid-late Apr) 1 rep	Spring (May-mid Jun) 3 reps	Early Summer (mid Jun-Jul) 7 reps	Mid Summer (early-mid Aug) 4 reps
Grass						
Biomass	(lbs/ac)	411.61a	571.59a	748.93a	347.88a	918.49a
% change	(%)		38.9	82.0	-15.5	123.1
Sedge						
Biomass	(lbs/ac)	224.59b	366.79b	48.88b	316.29b	103.33b
% change	(%)		63.3	-78.2	40.8	-54.0
Forb						
Biomass	(lbs/ac)	255.33c	771.40c	587.21c	451.17c	263.97c
% change	(%)		202.1	130.0	76.7	3.4
Shrub						
Biomass	(lbs/ac)	806.83d	0.0d	0.0d	226.43d	58.52d
% change	(%)		-100.0	-100.0	-71.9	-92.8
Total Live						
Biomass	(lbs/ac)	1698.36e	1709.78e	1385.02e	1341.77e	1344.18e
% change	(%)		0.7	-18.5	-21.0	-20.9

Data from Manske 1992

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

Table 9. Shoot frequency of plant biotypes on the seasonal period of every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	Early Spring (mid-late Apr) 1 rep	Spring (May-mid Jun) 3 reps	Early Summer (mid Jun-Jul) 7 reps	Mid Summer (early-mid Aug) 4 reps
Native Grass						
Shoot frequency	(%)	107.0a	189.0b	219.7b	182.9b	200.5b
% change	(%)		76.6	105.3	70.9	87.4
Sedge						
Shoot frequency	(%)	56.7c	39.0c	97.3d	93.4cd	90.8cd
% change	(%)		-31.2	71.6	64.7	60.1
Introduced Grass						
Shoot frequency	(%)	86.7e	73.0e	23.7f	43.4ef	42.3ef
% change	(%)		-15.8	-72.7	-49.9	-51.2
Perennial Forbs						
Shoot frequency	(%)	120.5g	157.0g	116.7g	154.6g	127.8g
% change	(%)		30.3	-3.2	28.3	6.1
Weedy Forbs						
Shoot frequency	(%)	85.5h	129.0i	43.3h	79.3h	78.8h
% change	(%)		50.9	-49.4	-7.3	-7.8
Shrubs						
Shoot frequency	(%)	111.7j	15.0l	22.0l	81.7jk	63.3k
% change	(%)		-86.6	-80.3	-26.9	-43.3

Data from Manske 1992

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

Table 10. Shoot frequency of grasses on the seasonal period of every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	Early Spring (mid-late Apr) 1 rep	Spring (May-mid Jun) 3 reps	Early Summer (mid Jun-Jul) 7 reps	Mid Summer (early-mid Aug) 4 reps
Native Grass						
Cool Season Grass						
Shoot frequency	(%)	89.2a	177.0b	166.0b	168.9b	169.0b
% change	(%)		98.4	86.1	89.3	89.5
Warm Season Grass						
Shoot frequency	(%)	17.8c	12.0c	53.7d	14.0c	31.5cd
% change	(%)		-32.7	201.0	-21.5	76.7
Western wheatgrass						
Shoot frequency	(%)	15.5e	42.0c	13.7e	16.4e	19.5e
% change	(%)		170.1	-11.8	6.0	25.8
Blue grama						
Shoot frequency	(%)	8.0f	4.0f	39.3g	7.4f	14.8fg
% change	(%)		-50.0	391.6	-7.1	84.4
Introduced Grass						
Smooth bromegrass						
Shoot frequency	(%)	17.5h	0.0h	2.3h	0.3h	2.3h
% change	(%)		-100.0	-86.7	-98.3	-87.1
Quackgrass						
Shoot frequency	(%)	7.8i	1.0i	0.0i	0.4i	2.8i
% change	(%)		-87.2	-100.0	-94.5	-64.7
Kentucky bluegrass						
Shoot frequency	(%)	59.5j	72.0j	21.3k	42.0j	37.3jk
% change	(%)		21.0	-64.2	-29.4	-37.3

Data from Manske 1992

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

Table 11. Shoot frequency of shrubs on the seasonal period of every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	Early Spring (mid-late Apr) 1 rep	Spring (May-mid Jun) 3 reps	Early Summer (mid Jun-Jul) 7 reps	Mid Summer (early-mid Aug) 4 reps
Western snowberry						
Shoot frequency	(%)	58.3a	5.0b	10.3b	33.4ab	21.5b
% change	(%)		-91.4	-82.3	-42.7	-63.1
Western rose						
Shoot frequency	(%)	35.8c	8.0d	4.3d	41.7c	41.3c
% change	(%)		-77.7	-87.9	16.4	15.1
Silverberry						
Shoot frequency	(%)	17.3e	2.0f	7.3e	6.6e	0.5f
% change	(%)		-88.5	-57.7	-62.1	-97.1

Data from Manske 1992

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

Table 12. Mycorrhizal fungi infection of plant roots and soil mineral nitrogen (NH_4-NO_3) on every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	One Burn 4 reps	Two Burns 4 reps	Three Burns 4 reps	Four Burns 3 reps
Western snowberry						
Fungi infection	(%)	93.8a	84.7a	84.3a	85.2a	85.9a
% change	(%)		-9.7	-10.7	-9.2	-8.4
Smooth bromegrass						
Fungi infection	(%)	32.3b	55.0b	50.0b	31.4b	40.1b
% change	(%)		70.3	54.8	-2.8	24.1
Western wheatgrass						
Fungi infection	(%)	66.0c	67.0c	61.3c	76.8c	63.8c
% change	(%)		1.5	-7.1	16.4	-3.3
Blue grama						
Fungi infection	(%)	78.8d	77.1d	84.9d	79.9d	73.5d
% change	(%)		-2.2	7.7	1.4	-6.7
Mineral Nitrogen						
NH_4-NO_3	(ppm)	9.56e	9.65e	9.41e	5.54e	8.36e
% change	(%)		0.9	-1.6	-42.1	-12.6

Data from Manske 1992

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

Table 13. Mycorrhizal fungi infection of plant roots and soil mineral nitrogen (NH_4-NO_3) on the seasonal period of every-other-year burn treatments and percent change from nonburned control.

Plant Biotypes		No Burns 6 reps	Early Spring (mid-late Apr) 1 rep	Spring (May-mid Jun) 3 reps	Early Summer (mid Jun-Jul) 7 reps	Mid Summer (early-mid Aug) 4 reps
Western snowberry						
Fungi infection	(%)	93.8a	92.3a	85.5a	82.7a	86.6a
% change	(%)		1.6	-8.8	-11.8	-7.7
Smooth bromegrass						
Fungi infection	(%)	32.3b	33.7b	40.0b	37.2b	65.7b
% change	(%)		4.3	23.8	15.2	103.4
Western wheatgrass						
Fungi infection	(%)	66.0c	74.7c	48.0c	73.7c	69.5c
% change	(%)		13.2	-27.3	11.7	5.3
Blue grama						
Fungi infection	(%)	78.8d	70.7d	79.6d	82.0d	76.2d
% change	(%)		-10.3	1.0	4.1	-3.3
Mineral Nitrogen						
NH_4-NO_3	(ppm)	9.56e	3.64e	8.47e	9.42e	7.09e
% change	(%)		-61.9	-11.4	-1.5	-25.8

Data from Manske 1992

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

Fig. 1. Western snowberry colony before (left) and after (right) four every-other-year prescribed burns during mid summer (August).

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Mechanical Management of Western Snowberry

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Western snowberry can invade grasslands by shading the understory plants with an enlarging canopy cover of aerial stems. Native grass species require near full sunlight and are reduced by low sunlight conditions. A replacement community consisting primarily of Kentucky bluegrass develops in the areas of diminished light. The rate of shrub encroachment can be decreased or increased by the beneficial or detrimental effects caused by different grazing management practices on the competitive abilities of grass plants. Grazing practices, however, will not decrease aerial stems, and some other type of management is needed to reduce western snowberry aerial stem density (figure 1).

The woody stems of western snowberry can be cut with typical farm mowing equipment. Two basic types of machines are used for general purpose agricultural mowing: the rotary mower and the sickle-bar mower. Rotary mowers are equipped with one or two horizontally rotating blades that have each end sharpened to cut on the leading edge. Sickle-bar mowers have a cutter bar with stationary guards, and a sickle with knife-edged sections moves back and forth, cutting against the blunt edges of the guards. Mechanical removal of the aerial stem top growth of western snowberry eliminates competition for sunlight and reduces stored carbohydrate energy, resulting in improved plant species composition of the ecosystem and reduced shrub stem density. Mechanical mowing equipment is effective on most western snowberry colonies; however, steep slopes, rough terrain, and large rocks may restrict mechanical equipment usage in some areas.

Pelton (1953) conducted an experiment of cutting individually marked mature western snowberry aerial stems at monthly intervals in dry and moist habitats in Minnesota. Severity or height of cutting seemed to have little or no effect on stem survival, but season of cutting and quantity of soil moisture influenced the results from the cutting treatments. Stems lightly topped in June or July frequently died partly or all the way to the ground. Stems lightly topped in August, after shoot buds had become dormant, died completely. While most of the stems cut in June and July under dry soil conditions delayed resprouting until the following year, most stems cut under moist soil conditions resprouted the same season. None of the stems cut in August, after normal dormancy of the lateral buds on the stem bases, resprouted during the same season. Pelton (1953) determined that day lengths shorter than 14 hours prevented normal vegetative growth of sucker shoots from lateral buds on crowns or stem bases and rhizomes. The only single cut treatment that was partially effective at stem kill was an August cutting on a dry site (Pelton 1953).

McCarty (1967) conducted two experiments in southern Nebraska that estimated percent reduction of western snowberry aerial stems of colonies mowed with a tractor-mounted sickle-bar mower. The mowing was repeated for 2 or 3 consecutive single annual spring treatments conducted on three dates in May, and the results were evaluated one year after final treatment.

All of the single annual spring mowing treatments repeated for two or three years resulted in some reduction of western snowberry stems. Two mowings during late May, when stems were at the full foliage stage, reduced aerial stems only 13%, and three mowings during late May caused a 30% reduction in stems (table 1). Two mowings conducted between 12 and 21 May, when new shoots were 4 to 8 inches (10-20 cm) tall, with four to six leaf pairs, reduced stems about 30%, and three mowings during mid May caused a reduction of about 50% in stem numbers (table 1). McCarty (1967) did not evaluate the understory species composition in the Kentucky bluegrass pasture for potential changes resulting from the mowing treatments' removal of the shrub canopy and the elimination of competition for sunlight. The slow rate of aerial stem reduction that resulted from repeated single annual spring mowing treatments led McCarty (1967) to conclude that mowing was an ineffective method for western snowberry control and that the impracticality of mowing extensive areas caused severe limitation of the practice as a weed control measure.

Western snowberry has an extensive belowground interconnected rhizome system that has the ability to replace destroyed or damaged aboveground stems. Vegetative suckers develop from lateral buds on the crowns and rhizomes, and the buds' growth depends on stored nonstructural carbohydrates. The potential for repeated aerial stem replacement is contingent on the replenishment of the carbohydrate reserves from photosynthetic activity of the replacement leaves on the new sucker stems.

The objective of mechanical mowing treatments is to deplete the stored nonstructural carbohydrate energy by cutting aerial stems at the times when the carbohydrate reserves are low. Energy reserves will be further reduced when vegetative sucker regrowth is produced. Repeated cutting is required to prevent replenishment of reserves used in producing new growth (Adams and Bailey 1983).

Adams and Bailey (1983) compared the nonstructural carbohydrate reserve cycle for western snowberry colonies mowed in May to that of nonmowed colonies in Alberta. Nonmowed colonies have a sharp drawdown in carbohydrate reserves from the rapid growth of early spring until shortly after full leaf, from mid April to early June (9 June). Rapid replenishment occurs during the flowering stage, from early June to mid July. A second drawdown period occurs during fruit fill, between mid July and early August. A second replenishment period occurs between mid August and early September. A gradual third drawdown occurs during pre-winter root growth and bud development, from early September to late October (Adams and Bailey 1983).

The nonstructural carbohydrate reserve cycle for western snowberry colonies mowed with a gyro-mower on 8 May was different from that of the nonmowed colonies. The drawdown in carbohydrate reserves during the rapid growth in early spring was greater on the mowed treatment than on the nonmowed control. The carbohydrate low was reached in late May and was prolonged for six weeks (until 10 July) as a result of the vigorous flush of sucker regrowth. A period of carbohydrate replenishment started when there were 9 to 13 leaf pairs on the new sucker stems. By the time the first flowers opened in mid to late June, the carbohydrates were fully recharged to levels that exceeded the quantities of mid April. After a single mowing treatment in May, western snowberry colonies were able to reestablish high carbohydrate reserve levels during the same growing season.

Adams and Bailey (1983) analyzed percent nonstructural carbohydrate reserves remaining in crowns or stem bases of western snowberry colonies during October following single, double, and triple mowing treatments conducted on 8 May, 24 June, and 13 August in Alberta. The carbohydrate reserves in the stem bases were lower on all of the mowing treatments than the reserves on the nonmowed control (table 2). The triple mow treatment with cutting in May, June, and August caused the greatest reduction in carbohydrate reserves. The double mow treatments with cutting in June and August or in May and August caused substantial reductions in carbohydrate reserves (table 2). The single mow treatment in August caused greater reductions in carbohydrate reserves than the single mow treatments in May or in June (table 2).

Vigorous sucker regrowth occurred after cutting on 8 May or 24 June (Adams and Bailey 1983). The replenishment of carbohydrate reserves from the leaves on the new sucker stems diminished the negative effects from the single mow treatments in May or in June and the double mow treatment with cutting in May and June (table 2).

No visible signs of resuckering were observed after the 13 August mowing treatments (Adams and Bailey 1983). However, excavation of stem bases in October showed that many sprouts had been produced after August mowing and were between 0.4 to 2.0 inches (1-5 cm) long. About 30% of the stimulated sprouts had broken the soil surface and had been injured by frost (Adams and Bailey 1983).

Practical Mowing Treatments

The mowing height of western snowberry colonies in grazed pastures should not be close to the ground, at the height that hay is cut, but the mowing height should be raised to about 8 or 9 inches (20-30 cm) above the ground. The cutting height should be set so most of the leaves and branches on the typical stems are removed and a relatively tall, flexible, bare stem remains. Stems one year old and older are usually killed to ground level when the tops are removed by mowing. When only a portion of the top is removed, young sucker stems do not die; branches are produced from the undamaged leaf axils, and the stems continue to develop.

Mature stems of western snowberry are flexible and can be bent to the ground without breakage (Pelton 1953). However, short stems that have been cut by mowing machines are not as flexible as uncut stems. The shorter the stems are cut, the greater their rigidity. Stems cut at 1- to 3-inch (2.5-7.6 cm) heights by sharp sickle sections are very rigid and have sharp points. These short, rigid, sharp stems can be serious problems for cattle walking through the mowed western snowberry colony areas. The stiff stems can puncture the sole of the hoof, causing an injury open to infection that can possibly result in hoof rot. These hazardous conditions can be avoided by raising the cutting height of the mower so that tall, flexible stems are left and by using dull or unsharpened mower blades so the contact between blade and stem creates a frazzled end rather than a straight, sharp point.

A single mowing treatment does not control western snowberry colonies. Repeated single annual mowing treatments reduce stem numbers slowly, and numerous years of retreatment are needed to develop substantial results. The reduction in stem numbers results from the annual removal of accumulated aboveground biomass. The annual mowing deprives western snowberry colonies of a valuable resource and disrupts growth mechanisms that require longer than one growing season to recover. Repeated single annual mowing treatments conducted in August should be expected to have greater effect on aerial stem reduction than single mowing treatments conducted during other times. Because the regrowth of sucker stems after mowing treatments conducted in May or June can replenish the carbohydrate reserves during one growing season, these early season single mowing treatments may result in a decrease of only a few stems each year.

Reduction of stem numbers is not the only benefit from mowing treatments, however. Annual mowing treatments remove the shrub canopy cover and eliminate the competition for sunlight. The increased sunlight causes changes in plant species composition toward the grassland species that were present in the ecosystem prior to the western snowberry invasion. The desirable changes in plant species alone may be adequate justification for conducting single annual mowing treatments in grazinglands invaded by western snowberry.

The triple mowing treatment with cutting in mid May, late June, and August results in the fewest growing-season days in which western snowberry colonies can replenish carbohydrate reserves. Because the cutting height of the June and August mowings must be low to remove most of the biomass of the new sucker stem growth and recutting the older stems at short heights produces hazardous stiff stems, the triple mowing treatment may require the removal of cattle for more than one growing season. The annual costs for triple mowing treatments are greater than the costs for double or single annual treatments. However, the triple mowing treatment may reduce the number of growing seasons that the treatments need to be repeated.

The double mowing treatment can be as effective as the triple mowing treatment, when mowing periods are conducted for maximum carbohydrate depletion. Because the cutting height of both mowings can be at the taller levels, cattle do not need to be removed from pastures with double mowing treatments. The seasonal low carbohydrate reserves for western snowberry occur during the period from rapid growth until near the start of flowering, between mid May and mid June. The first mowing treatment conducted during the last week in May through the third week in June should cause considerable depletion of stored carbohydrates. Growth of sucker shoots should continue to deplete carbohydrate reserves for nearly six weeks, until the new sucker stems develop about ten leaf pairs. A second mowing treatment conducted sometime during late July through August is needed to prevent full carbohydrate replenishment. Mowing in late July or August causes a substantial amount of winter injury to late-season lateral bud sprouts on the stem bases. The double mowing treatments will need to be repeated two, three, or more seasons, depending on the quantity of stored carbohydrates of the western snowberry colonies at the start of the mowing treatments.

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Table 1. Percent reduction of western snowberry stems from repeated single annual mowing with a sickle-bar mower, evaluated one year after final treatment.

	Treatment Dates		
Number of repeated single annual treatments	12-14 May	19-21 May	26-28 May
2	27	33	13
3	50	53	30

Data from McCarty 1967

Table 2. Percent nonstructural carbohydrates of stem bases in October following mowing treatments and percent change from nonmowed control.

		Treatments							
		Control	Single Mow			Double Mow			Triple Mow
		No Mow	8 May	24 Jun	13 Aug	8 May & 24 Jun	8 May & 13 Aug	24 Jun & 13 Aug	8 May, 24 Jun, & 13 Aug
		4 reps	4 reps	4 reps	4 reps	4 reps	4 reps	4 reps	4 reps
Nonstructural Carbohydrates	(%)	20	17	16	15	18	13	12	8
% change	(%)		-15	-20	-25	-10	-35	-40	-60

Data from Adams and Bailey 1983

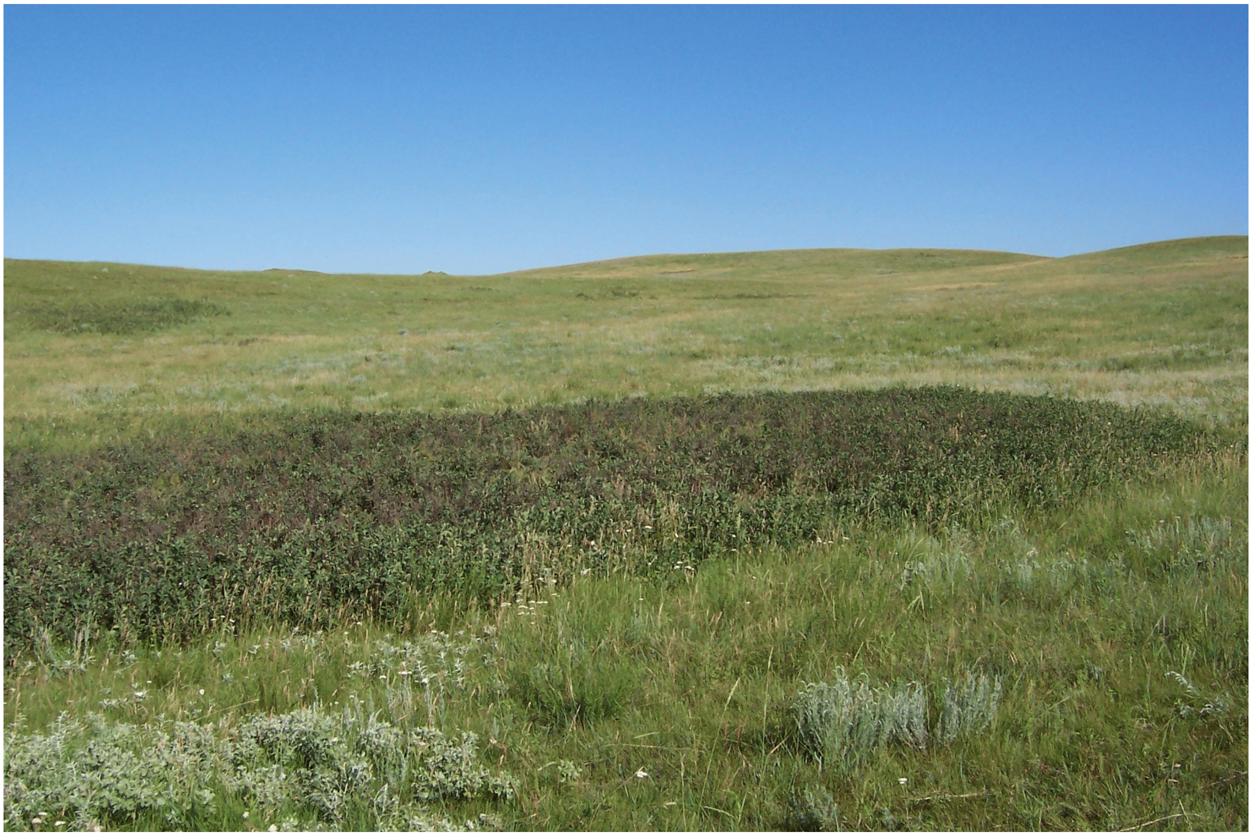

Fig. 1. Western snowberry colony in pasture grazed seasonlong.

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Chemical Management of Western Snowberry

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Western snowberry colonies invade and spread rapidly by means of extensive rhizome systems in pastures managed by traditional grazing practices that weaken the competitive abilities of grass plants. The aerial stem canopy cover of healthy western snowberry colonies shades sunlight from the grass understory, reducing the forage biomass production in a pasture and decreasing the livestock carrying capacity. Chemical management with herbicide treatments can reduce or eliminate the shrubs from the grassland ecosystem and permit full sunlight to reach the grass. Two years after shrub removal by herbicide treatment, the grass biomass production can increase three to six times greater than the pretreatment production, depending on the previous density of the shrubs. After three years with shrub removal, the increase in grass biomass production can equal the weight of the shrubs on an untreated area. Chemical management of western snowberry uses herbicides that interfere with vital physiological processes within the plant. Herbicide active ingredients from different chemical groups affect various plant processes. Effective chemical management requires an understanding of the general properties and characteristics of the herbicides approved for woody plant control or suppression on grazingland.

Herbicide Classification

Herbicides are classified by their general route of entry and their method of activity in plants. The mode of entry is categorized as either foliage-active or soil-active. The type of activity is categorized as either nonselective, with chemical activity on contact of any plant, or selective, with chemical translocation from entry point to site of activity.

Foliage-active herbicides are applied directly to leaves and stems of plants by spraying or wiping and usually have limited residual activity in the soil. Contact foliage-active herbicides are nonselective and kill the plant tissue directly contacted by the chemical. Translocated foliage-active herbicides penetrate the leaves and stems of plants, move through the phloem vascular system, and are translocated to the roots and other organs some distance from the point of entry (Scifres 1980).

Soil-active herbicides are applied directly to the soil within the vicinity of the root zone of target plant species. Translocated soil-active herbicides must be moved into the soil by rainfall, absorbed by the plant roots, and then moved upward through the xylem vascular system, which consists of nonliving vessel cells (Scifres 1980). A few herbicides can be transported both downward through the phloem from the leaves and upward though the xylem from the roots. Nonselective soil-active herbicides are used in some industrial areas to remove all vegetation. This type of herbicide is not used on grazinglands.

Most of the herbicides labeled for rangelands and grasslands were developed for other markets first. Development of new herbicide active ingredients is expensive for chemical companies, and there is a low profit potential for herbicides specific for grazinglands. As a result, there are relatively few chemicals available for use as woody plant control on grazinglands. Some improvements in herbicide efficacy and reductions in application rates and in total costs per acre have resulted from the development of synergistic mixtures of existing herbicides. One new active ingredient (aminopyralid) was developed by Dow AgroSciences in 2005. The new herbicide, Milestone, is labeled for control of broadleaf herbaceous plants in rangelands, pasturelands, and noncroplands. This herbicide can be safely applied right up to water's edge or in areas with a high water table.

A list of herbicides and synergistic mixtures of herbicides used in western snowberry management is on table 1. The herbicides are sorted by the mechanisms of action; the chemical group, trade name, and production company name for each herbicide are also included on table 1.

Herbicide Toxicity

Herbicides are intended to be toxic to undesirable plants, but they also may have varying degrees of toxicity to humans and other organisms. The toxicity of herbicide chemicals is measured by the lethal dose (LD) or lethal concentration (LC) that kills 50% of the test animals, which are usually rats or rabbits (table 2). Toxic quantities that are ingested orally, exposed to the dermal layer of skin, and inhaled as vapor are measured separately. The oral and dermal lethal dosages are expressed as milligrams (mg) of toxicant per kilogram (kg) of body weight (mg/kg), and the inhaled lethal concentration is expressed as milligrams (mg) of toxicant per liter (l) of aerosol (mg/l).

Highly toxic herbicides have an LD_{50} of 50 to 500 mg/kg for a single oral dose and an LD_{50} of 200 to 1000 mg/kg for a single dermal dose. Moderately toxic herbicides have an LD_{50} of 500 to 5000 mg/kg for a single oral dose and an LD_{50} of 1000 to 2000 mg/kg for a single dermal dose. Slightly toxic herbicides have an LD_{50} of 5000 to 15000 mg/kg for a single oral dose and an LD_{50} of 2000 to 20000 mg/kg for a single dermal dose (Hamilton et al. 2004). None of the herbicides used in the chemical management of western snowberry are highly toxic. The herbicides are either moderately or slightly toxic to humans and other mammals, and generally a one-time exposure results in minimal irritation. Herbicide applicators need to wear appropriate personal protective equipment described on the respective product labels.

Beef Animal Restrictions

The grazing and haying restrictions for beef animals on grazinglands treated with herbicides used in western snowberry management are on table 3. These herbicides are either nontoxic or have low toxicity to domesticated animals and have no grazing restrictions at the application rates labeled for pasture use. Glyphosate (Roundup) that is applied by wiper technique at less than 3 quarts product per acre requires seven days without livestock grazing for maximum performance of the chemical, but the chemical does not pose any toxicity problems for the livestock. The restriction period between herbicide application and harvest of treated vegetation for hay ranges from zero days to one year (table 3). The restriction period required between slaughter of animals and their removal from herbicide treated pastures ranges from zero days to thirty days (table 3).

Table 1. Chemical name, chemical group, trade name, and company name of herbicides used in western snowberry management.

Mechanism of Action Herbicide Chemical Name	Chemical Group	Trade Name	Producer Company Name
Growth Regulates or Synthetic Auxins			
2,4-D low volatile ester	Phenoxy	2,4-D LVE	Several
2,4-D amine	Phenoxy	2,4-D A	Several
dicamba	Benzoic acid	Banvel	Micro Flo Co.
dicamba	Benzoic acid	Clarity	BASF
dicamba + 2,4-D	Benzoic acid + Phenoxy	Weedmaster	BASF
triclopyr	Pyridine	Garlon 3A	Dow AgroSciences
triclopyr + 2,4-D	Pyridine + Phenoxy	Crossbow	Dow AgroSciences
triclopyr + fluroxypyr	Pyridine + Pyridine	PastureGard	Dow AgroSciences
picloram	Picolinic acid	Tordon 22K	Dow AgroSciences
picloram + 2,4-D	Picolinic + Phenoxy	Grazon P+D	Dow AgroSciences
ALS Enzyme Inhibitors			
metsulfuron	Sulfonylurea	Ally XP	Dupont
metsulfuron	Sulfonylurea	Cimarron	Dupont
metsulfuron +chlorsulfuron	Sulfonylureas	Cimarron X-tra	Dupont
ALS Enzyme Inhibitor + Growth Regulators			
metsulfuron + dicamba + 2,4-D	Sulfonylurea + Benzoic acid + Phenoxy	Cimarron Max	Dupont
EPSP Synthase Inhibitor			
glyphosate	Aliphatic	Roundup	Monsanto
Photosystem II Inhibitor			
tebuthiuron	Amide	Spike 20P	Dow AgroSciences

Table 2. Toxicological test data of herbicides used in western snowberry management.

Trade Name	Chemical Name	Ingestion Oral LD_{50} (rat) (mg/kg)	Skin Dermal LD_{50} (rabbit) (mg/kg)	Inhalation Vapor LC_{50} (rat) (mg/L-4h)
2,4-D LVE	2,4-D low volatile ester	1161	>2000	N/E
2,4-D A	2,4-D amine	837-1492	2871	N/D
Banvel	dicamba	2629	>2000	>5.4
Clarity	dicamba	3512	>2000	>5.3
Weedmaster	dicamba + 2,4-D	1150	>2000	>20.3
Garlon 3A	triclopyr	1847-2574	>5000	N/E
Crossbow	triclopyr + 2,4-D	1000-2589	>5000	>5.0
PastureGard	triclopyr + fluroxypyr	2389-2675	>5000	>5.6
Tordon 22K	picloram	>5000	>5000	>8.11
Grazon P+D	picloram + 2,4-D	2598	>2000	N/E
Ally XP	metsulfuron	>5000	>2000	>5.3
Cimarron	metsulfuron	>5000	>2000	>5.3
Cimarron X-tra	metsulfuron + chlorsulfuron	>5000 >5000	>2000 >2000	>5.3 >5.9
Cimarron Max	metsulfuron (ptA) + dicamba + 2,4-D (ptB)	>5000 1497	>2000 >2000	>5.3 >2.07
Roundup	glyphosate	>5000	>5000	2.6
Spike 20P	tebuthiuron	>2000	>2000	N/A

Data from Material Safety Data Sheets

Table 3. Grazing and haying restrictions for beef animals on grazinglands treated with herbicides used in western snowberry management.

		Restrictions for beef animals		
Chemical Name	Trade Name	Period before grazing	Period before haying	Removal before slaughter
2,4-D low volatile ester	2,4-D LVE	0d	30d	3d
2,4-D amine	2,4-D A	0d	30d	3d
dicamba	Banvel	0d	7d	30d
dicamba	Clarity	0d	0d	30d
dicamba + 2,4-D	Weedmaster	0d	37d	30d
triclopyr	Garlon 3A	0d	14d	3d
triclopyr + 2,4-D	Crossbow	0d	14d	3d
triclopyr + fluroxypyr	PastureGard	0d	14d	3d
picloram	Tordon 22K	0d	14d	3d
picloram + 2,4-D	Grazon P+D	0d	30d	3d
metsulfuron	Ally XP	0d	4hr	0d
metsulfuron	Cimarron	0d	4hr	0d
metsulfuron + chlorsulfuron	Cimarron X-tra	0d	4hr	0d
metsulfuron + dicamba + 2,4-D	Cimarron Max	0d	37d	30d
glyphosate	Roundup	7d	7d	0d
tebuthiuron	Spike 20P	0d	1yr	0d

Data from product labels

Herbicide Properties and Characteristics

Phenoxy Herbicides

All of the numerous formulations of 2,4-D are phenoxy herbicides that are synthetically produced growth hormones similar to auxin. The ester forms of 2,4-D are more toxic per unit of acid equivalence for most plants and do not mix with water unless emulsified. The amine forms of 2,4-D are generally less toxic than the ester forms, but they have no volatility hazard and they are directly soluble in water. The exact mode of action is virtually impossible to ascertain because the physiological effects are so complex. The phenoxy herbicides cause changes in nitrogen metabolism, respiration, photosynthesis, and nucleic acid metabolism; they effect changes in the composition of carbohydrates, lipids, organic acids, ethylene alkaloids, steroids, aromatics, vitamins, pigments, minerals, hormones, nucleic acids, and enzymes; and they stimulate meristematic activity that results in abnormal morphological changes and twisting and curling of stems (Scifres 1980). Phenoxy herbicides are short lived in the environment and have limited mobility, with movement through soil to groundwater unlikely. Phenoxy herbicides are rapidly decomposed by soil microbes, sunlight, and plant metabolism (Hamilton et al. 2004).

2,4-D low volatile ester (LVE) is manufactured by several companies for control of annual, biennial, and perennial weeds and brush on pastures, rangeland, CRP acres, and noncropland. This herbicide is toxic to aquatic invertebrates and cannot be applied directly to water. This product contains 66.2% 2,4-D, with the acid equivalent (ae) of 3.8 lbs per gallon. Nonionic surfactants may be added to the spray mixture, and their use is recommended for application to woody plants on pasture and rangeland. The label rates for control or suppression of buckbrush on grazingland are 2.14 to 2.85 lb ae 2,4-D (2.25 to 3.0 qt product) per acre. Repeat treatments may be required (data from product label).

2,4-D amine is manufactured by several companies for control of annual, biennial, and perennial weeds and brush on pastures, rangeland, CRP acres, and noncropland. This herbicide is toxic to aquatic invertebrates and cannot be applied directly to water. This product contains 47.3% 2,4-D, with the acid equivalent (ae) of 3.8 lbs per gallon. Nonionic surfactants may be added to the spray mixture, and their use is recommended for application to woody plants on pasture and rangeland. The label rate for control or suppression of buckbrush on grazingland is 1.9 lb ae 2,4-D (2 qt product) per acre. Repeat treatments may be required (data from product label).

Benzoic Acid Herbicides

Dicamba is a broad spectrum benzoic acid herbicide. The exact mode of action has not been defined; however, the complex reactions in plants to benzoic acid phytotoxicity are similar to those caused by the phenoxy herbicides. Benzoic acid herbicides also disrupt the physiological processes of nucleic acid metabolism and photosynthesis (Scifres 1980). Dicamba is degraded by microbial activity and remains only a short time in the environment. In warm, moist soil, dicamba has a half-life of <14 days, and in native grasses and litter, the half-life is only 3 to 4 weeks (Hamilton et al. 2004).

Banvel is a water-soluble liquid manufactured for Micro Flo Co. for control of annual, biennial, and perennial broadleaf weeds and woody brush and vine species on pasture, hay, rangeland, noncropland, and CRP acres. This herbicide cannot be applied directly to water. This product contains 48.2% dicamba, with the acid equivalent (ae) of 4.0 lbs per gallon. Agriculturally approved adjuvants, emulsifiers, surfactants, wetting agents, drift control agents, and penetrants may be used for wetting, penetration, or drift control. The specific application rates of this herbicide that control western snowberry have not been determined through research. The label rates for control or suppression of woody species on grazingland are 0.5 to 1.0 lb ae dicamba (1 pt to 1 qt product) per acre broadcast applied and no more than 2.0 lb ae dicamba (2 qt product) per acre as a spot treatment. The amount of herbicide applied cannot exceed a total of 2.0 lb ae dicamba (2 qt product) per treated acre per growing season (data from product label).

Clarity is a water-soluble liquid manufactured by BASF for control of annual, biennial, and perennial broadleaf weeds and woody brush and vine species on CRP acres, noncropland, pasture, and rangeland. This herbicide cannot be applied directly to water. This product contains 56.8% dicamba, with the acid equivalent (ae) of 4.0 lbs per gallon. Agriculturally approved nonionic surfactants and crop oil concentrates may be added to spray mixtures. The specific application rates of this herbicide that control western snowberry have not been determined through research. The label rates for control or suppression of woody species on grazingland are 0.5 to 1.0 lb ae dicamba (1 pt to 1 qt product) per acre broadcast applied and no more than 2.0 lb ae dicamba (2 qt product) per acre as a spot treatment. The amount of herbicide applied cannot exceed a total of 2.0 lb ae dicamba (2 qt product) per treated acre during a growing season (data from product label).

Weedmaster is a selective postemergence mixture manufactured by BASF for control of annual, biennial, and perennial weeds and brush on CRP acres, noncropland, grass (hay or silage), pastures, and rangeland. This herbicide is toxic to aquatic invertebrates and cannot be applied directly to water. This product contains 12.4% dicamba and 35.7% 2,4-D, with the acid equivalents (ae) of 1.0 lb dicamba per gallon and 2.87 lb 2,4-D per gallon. Nonionic surfactants may be added to the spray mixture. The specific application rates of this herbicide that control western snowberry have not been determined through research. The label rates for control or suppression of woody species on grazingland are no more than 0.5 lb ae dicamba and 1.44 lb ae 2,4-D (2 qt product) per acre broadcast applied and 0.5 to 1.0 lb ae dicamba and 1.44 to 2.87 lb ae 2,4-D (2 to 4 qt product) per acre as a spot treatment. The amount of herbicide applied cannot exceed a total of 1.0 lb ae dicamba and 2.87 lb ae 2,4-D (4 qt product) per treated acre during a growing season (data from product label 2004).

Pyridine Herbicides

Triclopyr and fluroxypyr are pyridine herbicides. The complex reactions in plants to pyridine phototoxicity are similar to those caused by the phenoxy herbicides (Scifres 1980). Breakdown of pyridine herbicides occurs in soil by leaching, photodegradation, and microbial activity, with the rate of breakdown related to temperature. Movement through soil to groundwater is unlikely, and mobility in runoff water is limited (Hamilton et al. 2004).

Garlon 3A is a speciality herbicide manufactured by Dow AgroSciences for control of woody plants, broadleaf weeds, vines, and deciduous trees on noncropland and forests, including grazing areas. Use within production forests may include herbicide applications to control target vegetation in and around standing water sites if no more than one-third to one-half of the water area is in a single treatment. This product contains 44.4% triclopyr, with the acid equivalent (ae) of 3.0 lbs per gallon. Addition of an agriculturally labeled nonionic surfactant to the spray mixture is recommended for all foliar applications. The specific application rates of this herbicide that control western snowberry have not been determined through research. The label rates for treatment of woody plants on range and pasture sites where grazing is allowed are no more than 2.0 lb ae triclopyr (two-thirds gallon product) per acre per growing season. Spot treatments of problem plants in grazed areas may be conducted when the treated sites compose no more than 10% of the total grazable area (data from product label 2003).

Crossbow is a speciality herbicide mixture manufactured by Dow AgroSciences for control of trees and brush, and annual, biennial, and perennial broadleaf weeds on rangeland, permanent grass pastures, CRP acres, and noncropland. This product may not be applied to forage that is to be cut and sold for commercial purposes. This herbicide is toxic to fish and cannot be applied directly to water. This product contains 16.5% triclopyr BEE and 34.4% 2,4-D LVE, with the acid equivalents (ae) of 1.0 lb triclopyr per gallon and 2.0 lb 2,4-D per gallon. Continuous agitation of spray mixture is necessary because this herbicide forms an emulsion in water, not a solution, and separation may occur. The specific application rates of this herbicide that control western snowberry have not been determined through research. The label instructions and rates for suppression of buckbrush on grazingland are to use the 1.5% mixture (2.0 fl oz product per gallon of water) at 1.0 lb ae triclopyr and 2.0 lb ae 2,4-D (4 qt product) per acre. The amount of herbicide applied cannot exceed a total of 1.0 lb ae triclopyr and 2.0 lb ae 2,4-D (4 qt product) per acre per growing season. Hard to control species will require retreatment or a double rate application. Spot treatments of problem plants in grazed areas may be conducted when the treated sites compose no more than 10% of the total grazable area (data from product label 2005).

PastureGard is a herbicide mixture manufactured by Dow AgroSciences for control of broadleaf herbaceous and woody plants in rangeland, permanent pastures, and noncropland. This herbicide is toxic to fish and cannot be applied directly to water. This product contains 25.0% triclopyr and 8.6% fluroxypyr, with the acid equivalents (ae) of 1.5 lb triclopyr and 0.5 lb fluroxypyr per gallon. Using a nonionic surfactant may improve weed control. The specific application rates of this herbicide that control western snowberry have not been determined through research. The label rates for the control of woody plants on grazingland are 0.56 lb to 1.5 lb ae triclopyr and 0.19 lb to 0.5 lb ae fluroxypyr (3 pt to 8 pt product) per acre broadcast applied. The amount of herbicide applied cannot exceed a total of 1.5 lb ae triclopyr and 0.5 lb ae fluroxypyr (4 qt product) per treated acre per growing season (data from product label 2005).

Picolinic Acid Herbicides

Picloram is a picolinic acid herbicide that interferes with a multitude of vital processes and enzyme systems, disrupts nucleic acid metabolism, and stimulates abnormal meristematic activity that causes twisted stems and death of growing points (Scifres 1980). Picloram is an effective broad spectrum herbicide because it is readily absorbed both by upper and lower leaf surfaces and by the roots, and it can move through either the phloem or the xylem vascular systems. Picloram degrades rapidly by sunlight; however, degradation by soil microorganisms and plant metabolism is slow and may require 3 to 6 months, with the half-life depending on rainfall and soil temperature. The persistence is longer in cooler climates, and some of the chemical may leach to lower soil depths (Hamilton et al. 2004).

Tordon 22K is a restricted use pesticide manufactured by Dow AgroSciences for control of broadleaf weeds and woody plants and vines on rangeland, permanent grass pastures, CRP acres, and noncropland. This herbicide cannot be applied directly to water. This product contains 24.4% picloram, with the acid equivalent (ae) of 2.0 lbs per gallon. The addition of a surfactant may improve efficacy during drought conditions or when plant surfaces are dusty. The specific application rates of this herbicide that control western snowberry have not been determined through research. The label rates for the control of woody species on grazingland are 0.5 lb to 1.0 lb ae picloram (1 qt to 2 qt product) per acre broadcast applied and no more than 1.0 lb ae picloram (2 qt product) per acre as a spot treatment. The amount of herbicide applied cannot exceed a total of 1.0 lb ae picloram (2 qt product) per acre per growing season (data from product label 2005).

Grazon P+D is a restricted use pesticide mixture manufactured by Dow AgroSciences for control of annual and perennial broadleaf weeds and woody plants on CRP acres, rangeland, and permanent grass pastures. This herbicide cannot be applied directly to water. This product contains 10.2% picloram and 39.6% 2,4-D amine, with the acid equivalents (ae) of 0.54 lb picloram per gallon and 2.0 lbs 2,4-D per gallon. Grazon P+D is a water-soluble liquid, and a nonionic surfactant may be used to provide more complete wetting and coverage of the foliage. The specific application rates of this herbicide that control western snowberry have not been determined through research. The label rates for the control of woody species on grazingland are 0.14 lb to 0.54 lb ae picloram and 0.5 lb to 2.0 lb ae 2,4-D (1 qt to 4 qt product) per acre. The amount of herbicide applied cannot exceed a total of 0.54 lb ae picloram and 2.0 lb ae 2,4-D (4 qt product) per acre per growing season (data from product label 2002).

Sulfonylurea Herbicides

Metsulfuron and chlorsulfuron are sulfonylurea herbicides that disrupt enzyme systems, rapidly inhibiting growth; within 1 to 3 weeks the meristemetic tissue at the growing points dies (product label). Sulfonylurea herbicides are moderately persistent in soil, with a typical half-life of 30 days. Degradation by soil microbes is generally slow, with increased rates at high soil temperatures and high soil moisture. Nonmicrobial hydrolysis degrades the herbicides slowly at high pH and relatively rapidly at lower pH (Hamilton et al. 2004).

Ally XP is manufactured by DuPont for control of broadleaf weeds and woody species on pastures and rangeland. This herbicide cannot be applied directly to water. This dry flowable product contains 60% metsulfuron methyl. Use of a nonionic surfactant is recommended. The label rates for suppression of western snowberry are 0.2 to 0.3 oz product per acre broadcast applied and 1.0 oz product per 100 gallons of water as a spot treatment. The amount of herbicide applied cannot exceed a total of 0.75 oz product per acre (data from product label 2001).

Cimarron is manufactured by DuPont for control or suppression of broadleaf weeds and brush on pastures, rangeland, CRP, and noncropland. This herbicide cannot be applied directly to bodies of water. This dry flowable product contains 60% metsulfuron methyl. A nonionic surfactant should be used. The label rates for control or suppression of western snowberry are 0.12 oz to 0.60 oz metsulfuron (0.2 to 1.0 oz product) per acre broadcast applied and 0.60 oz metsulfuron (1.0 oz product) per 100 gallons of water as a spot treatment. The degree of suppression varies with the rate used, the size of the weeds, and the environmental conditions following treatment. The amount of herbicide applied cannot exceed a total of 1.0 oz metsulfuron (1.67 oz product) per acre per year (data from product label 2005).

Cimarron X-tra is a herbicide mixture manufactured by DuPont for control of weeds and brush on pastures, rangeland, CRP acres with established grasses, and noncropland. This herbicide cannot be applied directly to water. A 20-ounce unit pack of this product contains 30.0% metsulfuron and 37.5% chlorsulfuron in separate compartments. A nonionic surfactant must be used in the spray mixture. The specific application rates of this herbicide that control western snowberry have not been determined through research. The label instructions and rates for control or suppression of western snowberry on grazingland are to use Rate I–0.15 oz metsulfuron and 0.19 oz chlorsulfuron (0.5 oz product) per acre. The amount of herbicide applied cannot exceed a total of 1.0 oz chlorsulfuron (2.67 oz product) per acre and cannot exceed a total of 1.0 oz of metsulfuron (3.33 oz product) per acre per year (data from product label 2005).

Cimarron Max is a two-part product mixture manufactured by DuPont for control of weeds and brush on pastures, rangeland, CRP acres with established grasses, and noncropland. This herbicide is toxic to aquatic invertebrates and cannot be applied directly to water. Part A of this product contains 60% metsulfuron. Part B of this product contains 10.3% dicamba, with the acid equivalent (ae) of 1.0 lb per gallon and 29.6% 2,4-D, with the acid equivalent (ae) of 2.87 lb per gallon. A crop oil concentrate or a nonionic surfactant must be used in the spray mixture. The specific application rates of this herbicide that control western snowberry have not been determined through research. The label instructions and rates for control or suppression of western snowberry are to use Rate I–0.15 oz metsulfuron (0.25 oz part A) and 0.125 lb dicamba and 0.359 lb 2,4-D (1 pt part B) per acre. The amount of herbicide applied cannot exceed a total of 1.0 oz metsulfuron (1.67 oz part A) per acre per year (data from product label 2005).

Aliphatic Herbicides

Glyphosate is an aliphatic herbicide that is nonselective and it can kill in about 2 to 7 days from application all types of plants contacted by the chemical by inhibiting an enzyme essential for amino acid formulation (product label 2004). Glyphosate is strongly adsorbed to soil, so it is virtually biologically unavailable and immobile. The chemical is degraded by microbial activity (Hamilton et al. 2004).

Roundup is a nonselective broad spectrum systemic herbicide manufactured by Monsanto for control of annual and perennial weeds, woody brush, and trees on pastures, rangeland, CRP acres, and noncropland. Application of this product may be as spot treatments or over-the-top wiper treatments where the chemical does not come in contact with the desirable understory vegetation. Surfactants cannot be added to the herbicide solution when wiper applicators are used. This herbicide cannot be applied directly to water. This product contains 41.0% glyphosate, with the acid equivalent (ae) of 3.0 lb per gallon and 4.0 lb active ingredient (ai) per gallon. The specific application rates of this herbicide that control western snowberry have not been determined through research. The label rates for control or suppression of woody brush on grazingland are 2.0 to 3.0 lb ai glyphosate (2 to 3 qt product) per acre. The amount of herbicide applied onto pasture and rangeland cannot exceed a total of 3.0 lb ai glyphosate (3 qt product) per acre per year (data from product label 2004).

Amide Herbicides

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 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 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). This product contains 20% tebuthiuron. The specific application rates of this herbicide that control western snowberry have not been determined through research. 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. 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 (data from product label 2003). At low rates of 0.25 lb ai tebuthiuron per acre, additional time for control may be required.

Period of Vulnerability

In order to kill belowground plant parts, foliage-applied herbicides must enter leaf tissue through the stomata openings or penetrate the cuticle on the outer layer of the leaf and then be translocated downward through the bidirectional phloem vascular system to metabolically active organs of the rhizome crown (Scifres 1980). Young leaf tissue has a thin cuticle layer and the cell walls have low levels of cellulose and lignin; this young tissue presents low resistance to foliage-active herbicide penetration. The cuticle thickens and the cell walls stiffen as leaves mature; this aging process increases the resistance to herbicide penetration and absorption. Surfactants (or adjuvants) increase herbicidal activity. Adding surfactants to herbicide spray mixtures improves penetration and absorption of foliage-active herbicides into maturing leaves. The quantity of herbicide translocated downward is related to the rate at which carbohydrates are used for plant growth (Scifres 1980) and whether the source of carbohydrates is derived from current photosynthate or stored reserves (Leopold and Kriedemann 1975). When the rate of photosynthesis is insufficient to meet demands of plant growth, stored nonstructural carbohydrates move upward from the storage site in the rhizome crown to the active growing points of the twigs and leaves. When photosynthetic rates exceed plant growth demands, nonstructural carbohydrates move downward from the leaves to the storage site in the rhizome crown (Coyne et al. 1995). Greater quantities of foliar-applied herbicides are translocated downward to belowground plant parts during replenishment periods, when carbohydrates are moving downward from leaves to the storage site, than during drawdown periods, when carbohydrates are moving upwards from the storage site to actively growing aerial parts (Adams and Bailey 1983). Changes in the amount of stored carbohydrates follow a typical pattern each growing season, with periods of drawdown and replenishment (Coyne et al. 1995).

Adams and Bailey (1983) conducted a study in Alberta to determine when drawdown and replenishment periods occur in western snowberry. Rhizome crowns were collected every ten days during the growing season and analyzed for nonstructural carbohydrate content. The resulting pattern of carbohydrate drawdown and replenishment indicates the time periods and plant growth stages when foliar application of herbicides would be expected to produce greater kill of belowground plant parts.

The major carbohydrate drawdown period occurs during the rapid growth of early spring, starting in mid April and continuing until early June, shortly after full leaf stage and about the time the sucker stems have elongated to two-thirds of full length. Two other periods of carbohydrate drawdown occur, one during fruit fill, from mid July to early August, and the other during fall growth, from early September to late October (Adams and Bailey 1983). Herbicides applied during the early drawdown period would likely penetrate the young foliage and cause high rates of top kill (Adams and Bailey 1983). However, only small amounts of herbicide would reach the roots because the upward flow of carbohydrates during this period interferes with the downward movement of herbicides; the result is low levels of kill of belowground plant parts.

The main carbohydrate replenishment period occurs from early June to mid July, starting during the final stages of sucker stem elongation and continuing through the flower bud stage into the early stages of flower development. A second carbohydrate replenishment period occurs between mid August and early September (Adams and Bailey 1983). Much of the herbicide applied during the early replenishment period would be expected to be carried downward to the rhizome crowns, with the downward flow of carbohydrates moving from the leaves to the belowground storage sites; the result would be kill of both aboveground and belowground plant parts (Adams and Bailey 1983). Herbicides applied during the earlier portions of the first replenishment period would possibly have greater kill levels than herbicides applied during the latter portions because herbicide penetration into leaf tissue tends to decrease as the leaves mature (Scifres 1980).

Chemical Management Research

Pelton (1953) projected that chemical herbicide use would increase as a method to control western snowberry and indicated that 2,4-D was the most promising herbicide, even though western snowberry was one of the more resistant shrubs to this chemical.

McCarty (1967) conducted three experiments in southern Nebraska that compared one, two, or three repeated annual applications of chemical herbicides to replicated western snowberry colonies on different dates in May, June, and July and estimated percent control of aerial stems one year after final treatment.

McCarty (1967) considered the timeliness of herbicide application to be important for good western snowberry control. The phenological growth of western snowberry in Nebraska is similar to that of western snowberry colonies across North America. Most of the growth occurs during May. New shoots are 4 to 8 inches (10-20 cm) long, with the first four to six leaves full size in early May, and by late May the plants have completed full foliar development (McCarty 1967). The results of the herbicide experiment indicated that herbicide application during early to mid May was more effective for western snowberry aerial stem control than herbicide application in late May and that herbicide application during late June or mid July was much less effective than the May applications (McCarty 1967). The June and July application treatments were discontinued during the second and third experiments.

Favorable moisture conditions and multiple retreatments appeared to improve western snowberry control (McCarty 1967). Three applications of 2,4-D HV ester on the 14 and 21 May treatment dates gave excellent control of aerial stems (table 4). Three applications of 2,4-D HV ester on the late June and mid July treatment dates were much less effective at aerial stem control than the May application dates (table 4). Herbicide penetration into mature leaf tissue is much less than herbicide penetration into young leaf tissue (Scifres 1980). The low levels of aerial stem control during the late June and mid July treatment dates may reflect low herbicide penetration into mature leaf tissue. The greater levels of aerial stem control during the May treatment dates may reflect high herbicide penetration into young leaf tissue.

The 2,4-D ester treatment was consistently more effective than the 2,4-D amine treatment on all application dates (table 4). The 2,4-D amine did not kill a large portion of the aerial stems. These surviving stems were able to reinfest the area quickly by respouting during subsequent growing seasons (McCarty 1967).

Two applications of 2,4-D HV ester at both the 1.0 lb/ac and 2.0 lb/ac rates gave excellent control of western snowberry aerial stems on all three treatment dates in May (table 4). Percent control of aerial stems with two applications of 2,4-D LV ester at both the 1.0 lb/ac and 2.0 lb/ac rates was only slightly lower than the percent control of aerial stems from 2,4-D HV ester at the respective rates (table 4).

One application of 2,4-D HV ester at the 2.0 lb/ac rate resulted in greater percent control of aerial stems than one application at the 1.0 lb/ac rate on all three treatment dates in May (table 4). Treatments with one application of herbicide had lower percent control of western snowberry aerial stems than treatments with multiple annual applications of herbicide.

The high percent control of aerial stems during the three May application dates indicates high levels of herbicide penetration and effective top kill. However, the increase in the presence of living western snowberry stems on study plots during the second growing season after the final treatment indicates that only low levels of control of the belowground plant parts had been achieved. McCarty (1967) concluded that because western snowberry can quickly reinfest an area, the use of 2,4-D every second or third year will be necessary for long-term pasture management.

Ferrel (1986, 1992a, 1992b) and Ferrel and Whitson (1987) conducted four experiments to evaluate various formulations of herbicides for the control of western snowberry. Research was conducted near Aladdin, Wyoming, on an unimproved pasture that had a heavy infestation of western snowberry. Experimental plots of around 10 by 20 ft. (3 X 6 m) were arranged in a randomized complete block design with three replications. Liquid herbicide treatments were broadcast applied with a CO_2 pressurized six-nozzle knapsack spray unit. Granular formulations were applied by hand. Percent control of aerial stems was evaluated by visual estimates one year following treatment (Ferrel 1986, 1992a, 1992b; Ferrel and Whitson 1987).

The phenological growth of western snowberry in Wyoming is similar to that of western snowberry colonies across North America. Most of the growth occurs during May, and by late May the stems are 6 to 20 inches (15-51 cm) tall and near full leaf development. Stems are at full leaf stage and 12 to 20 inches (31-52 cm) tall in early June and at bud to full bloom growth stages and 12 to 20 inches (31-51 cm) tall in early July. In mid September, stems are 15 to 36 inches (38-91 cm) tall, and leaves are beginning to drop (Ferrel 1986, 1992a, 1992b; Ferrel and Whitson 1987).

The objective of these four experiments was to perform a rapid screening of herbicides and identify chemicals that showed promise for the control of western snowberry. Most of the chemicals or chemical mixtures were evaluated at more than one application rate.

Spring application of triclopyr, fluroxypyr, fluroxypyr + triclopyr, tebuthiuron, and fosamine at 6.0 lb ai/ac, and summer application of triclopyr, Dowco 290 + 2,4-D A, Dowco 290 + picloram, metsulfuron, and metsulfuron + 2,4-D LVE did not show promise for controlling western snowberry aerial stems at the rates and application dates evaluated (table 5). Spring application of 2,4-D LVE and summer application of picloram provided 70% and 73% control of aerial stems at 2.0 lb ai/ac, respectively (table 5). Spring application of fosamine at 12.0 lb and 24.0 lb ai/ac, and glyphosate at 1.125 lb ai/ac provided 82%, 96%, and 95% control of aerial stems, respectively (table 5). Spring application of chlorsulfuron, metsulfuron, and metsulfuron + 2,4-D LVE provided 100% control of aerial stems at the rates evaluated, respectively (table 5), and showed considerable promise for western snowberry control.

Experiment #4 evaluated two herbicide application dates; one date was successful, and the other date was not successful. The differences in the percent control of western snowberry aerial stems between the two herbicide application dates are most likely related to differences in the quantities of herbicide penetration into the leaves and differences in the quantities of herbicide translocated to belowground plant parts. Greater quantities of herbicide penetrate young leaves than penetrate mature leaves, and greater quantities of foliar-applied herbicide are translocated downward during carbohydrate replenishment periods than during drawdown periods. On the early June application date, western snowberry has fully developed young leaves and is just starting the first carbohydrate replenishment period. On the mid September application date, western snowberry has mature leaves near senescence and is in a late season carbohydrate drawdown period. The early June herbicide application date resulted in 100% control of aerial stems, and the mid September application date resulted in 50% control of aerial stems one year after treatment (table 5).

Bowes (1991) conducted two chemical management experiments northeast of Regina, Saskatchewan, to evaluate the effects of herbicide mixtures on reducing western snowberry regrowth suckers in the aspen parkland vegetation zone following bulldozer treatments that sheared aspen poplar trees at the surface of frozen soil. Herbicide treatments of dicamba plus 2,4-D LVE (ester) and plus 2,4-D A (amine) applied at the rates of 1.34 + 1.96 lb ai/acre (1.5 + 2.2 kg/ha) in experiment #1 and 1.34 + 1.78 lb ai/acre (1.5 + 2.0 kg/ha) in experiment #2 were applied with a hand-held compressed-air sprayer one, two, and three times every year or every-other-year on 6 June 1981, 16 June 1982, and 16 June 1983 in experiment #1 and on 16 June 1983, 19 June 1984, and 27 June 1985 in experiment #2. The study analyzed data for percent canopy cover of western snowberry collected during mid August for nine years and data for aboveground herbage biomass of grasses and forbs collected during late June to mid July for eight years from plots replicated four times.

Bowes (1991) considered western snowberry effectively controlled when the canopy cover was reduced to less than 1%. Herbicide mixtures of dicamba + 2,4-D LVE and dicamba + 2,4-D A had similar effects in reducing canopy cover of western snowberry (Bowes 1991); however, sucker regrowth was greater five years after final treatment on the dicamba + 2,4-D A plots than on the dicamba + 2,4-D LVE plots (table 6). Dicamba + 2,4-D LVE and dicamba + 2,4-D A applied two and three times during early to mid June were more effective at reducing western snowberry canopy cover than dicamba + 2,4-D LVE and dicamba + 2,4-D A applied one time during early June (table 6). No differences in canopy cover one year or five years after final treatment were found between treatments with herbicide mixtures applied two times every year or every-other-year (table 6). Dicamba + 2,4-D LVE applied two times during mid to late June was more effective than dicamba + 2,4-D LVE applied two times during early to mid June (table 6). Dicamba + 2,4-D LVE applied one time during mid June was more effective than dicamba + 2,4-D LVE applied one time during early June (table 6).

Grass biomass production was greater on the herbicide treated plots than on the untreated control plots (Bowes 1991) (table 7). Herbicide mixtures of dicamba + 2,4-D LVE and dicamba + 2,4-D A had similar effects on grass biomass production; however, five years after final treatment, grass biomass production was greater on the dicamba + 2,4-D LVE plots than on the dicamba + 2,4-D A plots (table 7). Dicamba + 2,4-D LVE and dicamba + 2,4-D A applied two and three times were more effective at increasing grass biomass production than dicamba + 2,4-D LVE and dicamba + 2,4-D A applied one time (table 7). No differences in grass biomass production one year or five years after final treatment were found between treatments with herbicide mixtures applied two times every year or every-other-year (table 7). Dicamba + 2,4-D LVE applied two times during mid to late June was more effective at increasing grass biomass production than dicamba + 2,4-D LVE applied two times during early to mid June (table 7).

Both dicamba + 2,4-D LVE and dicamba + 2,4-D A herbicide mixtures reduced forb biomass production. Two and three applications of the herbicide mixtures reduced forb biomass production more than a single application of the herbicide mixtures (Bowes 1991).

Western snowberry was not completely eradicated by the herbicide mixtures of dicamba and 2,4-D tested (Bowes 1991). Dicamba + 2,4-D LVE and dicamba + 2,4-D A have similar effects on western snowberry canopy cover and grass and forb herbage biomass production one year after final treatment; however, five years after final treatment, the effects from dicamba + 2,4-D A had diminished further than those from dicamba + 2,4-D LVE. Two and three applications of herbicide mixtures are more effective than a single application. Multiple applications every year or every-other-year have similar effects following the final treatment. Herbicide mixtures applied during mid to late June are more effective than mixtures applied during early to mid June.

Bowes and Spurr (1995) conducted two chemical management experiments southeast of Regina, Saskatchewan, to evaluate the effects from herbicide treatments on reducing western snowberry in mixed grass prairie that had not been grazed for ten years. Single herbicide treatments of metsulfuron, metsulfuron + 2,4-D LVE (ester), and 2,4-D LVE alone were applied with a hand-held compressed-air sprayer when western snowberry sucker stems were at or near full expansion growth stage on 16 June 1986 in experiment #1 and on 12 June 1987 in experiment #2. The study analyzed data for percent canopy cover of western snowberry collected during mid August for six years and data for aboveground biomass of western snowberry aerial stems and aboveground herbage biomass of grasses collected between mid June and mid July each year of the study from plots replicated four times.

Bowes (1991) considered western snowberry effectively controlled when the canopy cover was reduced to less than 1%. All herbicide treatments applied 16 June in experiment #1 and all treatments applied 12 June in experiment #2, with the exception of one treatment, resulted in 95% or better reduction of western snowberry canopy cover during the year of treatment. The low rate with 0.04 oz/acre (3 g/ha) of metsulfuron + 2,4-D LVE treatment in experiment #2 resulted in only 85% reduction in canopy cover (table 8).

All herbicide treatments applied 16 June in experiment #1, with the exception of one treatment, resulted in 95% or better reduction of canopy cover five years after treatment. The 2,4-D LVE alone treatment resulted in only 86% reduction in canopy cover five years after treatment (table 8). Two treatments applied 12 June in experiment #2 resulted in 95% or better reduction of canopy cover five years after treatment. The treatments with the 0.21 oz/acre (15 g/ha) rate of metsulfuron alone and the 0.21 oz/acre (15 g/ha) rate of metsulfuron + 2,4-D LVE resulted in 95% or better reduction in canopy cover five years after treatment (table 8). The treatments with lower rates of 0.11, 0.07, and 0.04 oz/acre (7.5, 5, and 3 g/ha) metsulfuron alone and metsulfuron + 2,4-D LVE, and with 2,4-D LVE alone applied 12 June in experiment #2 resulted in western snowberry canopy cover reductions of less than 95% five years after treatment (table 8). Percent canopy cover reductions were similar among the high rates of 0.21, 0.43, and 0.86 oz/acre (15, 30, and 60 g/ha) metsulfuron alone and metsulfuron + 2,4-D LVE one year and five years after treatment. Metsulfuron applied at the 0.43 and 0.86 oz/acre (30 and 60 g/ha) rates was no more effective than metsulfuron applied at the 0.21 oz/acre (15 g/ha) rate.

All herbicide treatments applied 16 June in experiment #1 resulted in 95% or better reduction of western snowberry aboveground biomass one year after treatment (table 9). All treatments applied 12 June in experiment #2, with the exception of two treatments, resulted in 95% or better reduction of western snowberry aboveground biomass one year after treatment. The treatments with the low rate of 0.04 oz/acre (3 g/ha) metsulfuron + 2,4-D LVE and with 2,4-D LVE alone resulted in aerial stem biomass reductions of less than 95% one year after treatment (table 9).

All herbicide treatments applied 16 June in experiment #1, with the exception of one treatment, resulted in 95% or better reduction of western snowberry aerial stem biomass five years after treatment. The 2,4-D LVE alone treatment resulted in aerial stem biomass reduction of only 89% five years after treatment (table 9). Two treatments applied 12 June in experiment #2 resulted in high reductions of aerial stem biomass five years after treatment. These two treatments were the 0.21 oz/acre (15 g/ha) rate of metsulfuron alone and the 0.21 oz/acre (15 g/ha) rate of metsulfuron + 2,4-D LVE (table 9). The herbicide treatments with the low rates of 0.04, 0.07, and 0.11 oz/acre (3, 5, and 7.5 g/ha) metsulfuron alone and metsulfuron + 2,4-D LVE, and with 2,4-D LVE alone applied 12 June in experiment #2 had considerable western snowberry aerial stem biomass production from regrowth of rhizome suckers, crown suckers, and new growth on existing stems five years after treatment, and these treatments were considered not to be successful long-term control of western snowberry (Bowes and Spurr 1995).

All treatments with herbicide applied 16 June in experiment #1 had greater grass production than the untreated control plots one year and five years after treatment (table 10). Grass biomass production on the treatments with herbicide applied 12 June in experiment #2 was not much different from grass production on the untreated control plots one year after treatment. However, all treatments with herbicide applied 12 June in experiment #2 had greater grass production than the untreated control plots five years after treatment (table 10). Reduction of western snowberry canopy cover resulted in greater quantities of sunlight reaching the herbaceous layer and caused an increase in grass herbage biomass production.

The time of herbicide application is important (Bowes and Spurr 1995). Foliar-applied herbicides are translocated through the phloem vascular system when materials are moving downward. The carbohydrate reserves in the crowns of western snowberry are drawn down during the rapid growth of early spring and are at the lowest level about the time the sucker stems have elongated to two-thirds of full length, during the ten days prior to 9 June (Adams and Bailey 1983). From early June to mid July, the energy reserves in the crowns are replenished with surplus carbohydrates produced in the leaves and moved down into belowground plant parts. That the herbicide treatments applied 16 June were more effective than the treatments applied 12 June indicates that greater quantities of herbicide were translocated to the crowns on the later application date.

Western snowberry was not eradicated by the metsulfuron and 2,4-D treatments tested (Bowes and Spurr 1995). Metsulfuron was more effective at killing western snowberry crowns than 2,4-D because a greater percent of the metsulfuron than of the 2,4-D was translocated through the phloem (Bowes and Spurr 1995). The addition of 2,4-D to metsulfuron did not improve the effectiveness. At the low chemical rates, metsulfuron was more effective alone than when 2,4-D was present in the mixture. Bowes and Spurr (1995) concluded that the effective herbicide treatment for the control of western snowberry through the fifth year after treatment was metsulfuron applied alone at the rate of 0.21 oz ai/acre (15 g/ha) during mid June.

Bowes and Spurr (1996) conducted two chemical management experiments northeast of Regina, Saskatchewan, to evaluate the effects of herbicide treatments on reducing western snowberry regrowth suckers in the aspen parkland vegetation zone following bulldozer treatments that sheared aspen poplar trees at the surface of frozen soil. Single herbicide treatments of metsulfuron, metsulfuron + 2,4-D LVE (ester), and 2,4-D LVE alone were applied with a hand-held compressed-air sprayer on 19 June 1985 in experiment #1 and on 10 June 1986 in experiment #2. The study analyzed data for percent canopy cover of western snowberry collected during mid August for seven years and data for aboveground herbage biomass of grasses and forbs collected during late June to mid July for five years from plots replicated four times.

All herbicide treatments applied 19 June in experiment #1 and 10 June in experiment #2 reduced western snowberry canopy cover to less than 1% during the year of treatment (table 11). Bowes (1991) considered western snowberry effectively controlled when the canopy cover was reduced to less than 1%. Percent canopy cover changed very little on the untreated and treated areas of both experiments six years after treatment (Bowes and Spurr 1996).

All treatments with herbicide applied 19 June in experiment #1 and 10 June in experiment #2 had greater five year mean grass biomass production than the untreated controls (table 12). Treatments with metsulfuron applied at 0.21, 0.43, and 0.86 oz/acre (15, 30, and 60 g/ha) rates on 19 June in experiment #1 and 10 June in experiment #2 had lower five year mean forb biomass production than the untreated controls. The addition of 2,4-D LVE to metsulfuron resulted in greater reductions in the five year mean forb biomass production for the three rates of metsulfuron, respectively (table 12). Treatments with application of 2,4-D LVE alone on 19 June in experiment #1 had greater five year mean forb biomass production than the untreated controls. Treatments with application of 2,4-D LVE alone on 10 June in experiment #2 had lower five year mean forb biomass production than the untreated controls (table 12).

Western snowberry was not completely eradicated by the metsulfuron and 2,4-D LVE treatments tested (Bowes and Spurr 1996). Metsulfuron applied at the high rates of 0.21, 0.43, and 0.86 oz/acre (15, 30, and 60 g/ha) effectively killed western snowberry crowns and controlled rhizome sucker canopy cover at less than 1% six years after treatment. Application of 2,4-D LVE alone at the 1.78 lb/acre (2 kg/ha) rate effectively killed western snowberry and controlled canopy cover at 1% six years after treatment. The addition of 2,4-D LVE to metsulfuron did not improve the effectiveness. Differences from the application dates were not found between respective herbicide treatments of metsulfuron and metsulfuron + 2,4-D LVE. Metsulfuron applied at 0.43 and 0.86 oz/acre (30 and 60 g/ha) was no more effective than the 0.21 oz/acre (15 g/ha) rate. Metsulfuron applied alone at the rate of 0.21 oz/acre (15 g/ha) during mid June is an effective herbicide treatment for the control of western snowberry.

Management Implications

Successful chemical management of western snowberry depends on terminating the regenerative capabilities of the rhizomes and the cluster of stem bases on the crowns. Two critical factors must occur in order for sufficient quantities of foliage-active herbicides to reach the site of activity in the belowground plant parts and interfere with their respective specific physiological processes. First, the herbicides must enter the leaf tissue through the stomata openings or penetrate the outer cuticle layer, be absorbed through leaf tissue by diffusion, and be moved to the vascular system within the leaf. Second, the herbicides must be translocated from the leaves downward though the phloem vascular system to the metabolically active sites of the crowns and rhizomes. The vulnerable stage when the leaf tissue absorbs herbicides and the phloem system translocates herbicides downward is remarkably narrow, during mid June.

Spring growth of western snowberry starts in mid to late April, with rapid twig elongation and leaf growth and expansion occurring simultaneously until late May or early June, when the appearance of flower buds at the twig tips ends both rapid twig growth and the possibility for additional new leaves. Nonstructural carbohydrates move from the storage site in the rhizomes and the crowns upward through the phloem vascular system to the active growing points during the spring growth period of mid April to early June. By early June, the twigs have completed about 75% of their growth and the leaves are near full expansion. Herbicides can readily penetrate young western snowberry leaves during May and early June. However, when western snowberry colonies are at that stage of growth, carbohydrate movement upward through the phloem prevents downward movement of herbicides. The twigs continue to grow at a slower rate, and by mid June the twigs have reached about 95% of their annual growth. Sometime between early June and mid June, processes within the plant shift from using stored carbohydrates at the growing points to using the carbohydrates produced by leaf photosynthesis. As the rate of growth slows and leaf photosynthesis increases, a surplus of carbohydrates is produced and must be moved downward through the phloem for storage in the rhizomes and crowns. This change in direction of carbohydrate flow permits the translocation of herbicides from the leaves downward to the belowground plant parts. Meanwhile, maturation of the leaves has been continuing with development of a thicker cuticle layer and denser cell walls; the result is an increasing resistance to herbicide penetration and absorption. The two critical factors required for successful chemical management of western snowberry occur coincidentally during only a brief vulnerable stage, from about 10 June until 20 June, when herbicide penetration into leaf tissue is decreasing and herbicide translocation downward is increasing. Greater quantities of herbicide are translocated downward during mid to late June than during early to mid June. Leaf penetration by herbicides is improved with wetting agents, and these surfactants should be added to all foliage-active herbicide spray mixtures.

Soil-active herbicides have a relatively wide window of opportunity for treatment and require only that application be ahead of a rainy period. The herbicides move into the roots anytime the roots are absorbing water. Movement upward in the xylem vascular system is not as complex as movement within the phloem system. Plants have few resistance mechanisms to restrict activity of soil-applied herbicides. Usually lower rates are quite effective, but a longer period of time may be required to produce the desired results.

Comparisons and evaluations of the herbicide costs for chemical management of western snowberry should include the treatment cost per acre and the frequency of retreatment. None of the herbicides approved for control of woody plants on grazingland are known to eradicate western snowberry from grassland ecosystems. Retreatment will be required. Unfortunately, the frequency rate of retreatment for the various herbicides is currently not known.

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Table 4. Percent reduction of western snowberry live aerial stems from chemical herbicides estimated one year after final treatment.

Number of Repeated Annual Applications	Rate lbs ai/ac	Treatment Dates 12-15 May	19-22 May	26-29 May	28 Jun	16 Jul
3 Applications						
2,4-D HVE	na	97	96	82	65	26
2,4-D A	na	65	61	45	45	20
2 Applications						
2,4-D HVE	1.0 lb	99	100	99		
2,4-D HVE	2.0 lb	100	100	100		
2,4-D LVE	1.0 lb	90	92	87		
2,4-D LVE	2.0 lb	94	97	85		
1 Application						
2,4-D HVE	1.0 lb	62	24	84		
2,4-D HVE	2.0 lb	87	71	85		

Data from McCarty 1967

Table 5. Percent control of western snowberry live aerial stems from chemical herbicides estimated visually one year following final treatment.

Herbicide Treatment	% Aerial Stem Control	
	Spring Application	Summer Application
Experiment #1, 4 Jul 84		
Triclopyr		
1.0 lb ai/ac		0
2.0 lb ai/ac		0
Dowco 290 + 2,4-D A		
0.25 + 1.0 lb ai/ac		10
0.38 +1.5 lb ai/ac		20
Dowco 290 + picloram		
0.25 + 2.25 lb ai/ac		20
Picloram		
2.0 lb ai/ac		73
Experiment #2, 30 May 85		
Triclopyr		
1.0 lb ai/ac	0	
2.0 lb ai/ac	0	
Fluroxypyr		
2.0 lb ai/ac	0	
3.0 lb ai/ac	0	
Fluroxypyr + Triclopyr		
1.0 + 1.0 lb ai/ac	0	
1.5 + 1.5 lb ai/ac	0	
Tebuthiuron		
0.25 lb ai/ac	0	
0.50 lb ai/ac	0	
0.75 lb ai/ac	0	
1.0 lb ai/ac	0	
2,4-D LVE		
2.0 lb ai/ac	70	

Table 5. (Cont.). Percent control of western snowberry live aerial stems from chemical herbicides estimated visually one year following final treatment.

Herbicide Treatment	% Aerial Stem Control Spring Application	 Summer Application
Experiment #3, 7 Jun 89		
Glyphosate		
1.125 lb ai/ac	95	
Fosamine		
6.0 lb ai/ac	13	
12.0 lb ai/ac	82	
24.0 lb ai/ac	96	
Metsulfuron		
0.3 oz ai/ac	100	
0.6 oz ai/ac	100	
1.2 oz ai/ac	100	
Chlorsulfuron		
0.4 oz ai/ac	100	
0.8 oz ai/ac	100	
2.2 oz ai/ac	100	
Experiment #4, 7 Jun 90, 13 Sep 90		
Metsulfuron		
0.2 oz ai/ac	100	50
0.3 oz ai/ac	100	50
0.4 oz ai/ac	100	50
Metsulfuron + 2,4-D LVE		
0.2 oz + 1.0 lb ai/ac	100	50
0.3 oz + 1.0 lb ai/ac	100	50
0.4 oz + 1.0 lb ai/ac	100	50

Data from Ferrell 1986, 1992a, 1992b, and Ferrell and Whitson 1987

Table 6. Percent canopy cover of western snowberry and percent change from control treatment resulting from herbicide treatments evaluated one year and five years after final treatment.

	one year after final treatment		five years after final treatment	
Herbicide Treatment	canopy cover %	% change from control	canopy cover %	% change from control
Experiment #1, 1981-1989				
No Herbicide				
Control	6		6	
Dicamba + 2,4-D LVE 1.34 + 1.96 lb ai/ac				
3 applications 6 Jun 81, 16 Jun 82, 16 Jun 83	0	-100.0	<1	>-83.3
2 applications 6 Jun 81, 16 Jun 82	<1	>-83.3	1	-83.3
6 Jun 81, 16 Jun 83	<1	>-83.3	<1	>-83.3
1 application 6 Jun 81	2	-66.7	5	-16.7
Dicamba + 2,4-D A 1.34 + 1.96 lb ai/ac				
3 applications 6 Jun 81, 16 Jun 82, 16 Jun 83	<1	>-83.3	2	-66.7
2 applications 6 Jun 81, 16 Jun 82	<1	>-83.3	3	-50.0
6 Jun 81, 16 Jun 83	<1	>-83.3	3	-50.0
1 application 6 Jun 81	2	-66.7	6	0.0

Table 6. (Cont.). Percent canopy cover of western snowberry and percent change from control treatment resulting from herbicide treatments evaluated one year and five years after final treatment.

	one year after final treatment		five years after final treatment	
Herbicide Treatment	canopy cover %	% change from control	canopy cover %	% change from control
Experiment #2, 1983-1989				
No herbicide				
Control	3		3	
Dicamba + 2,4-D LVE 1.34 + 1.78 lb ai/ac				
2 applications 16 Jun 83, 19 Jun 84	0	-100.0	<1	>-66.7
16 Jun 83, 27 Jun 85	0	-100.0	<1	>-66.7
1 application 16 Jun 83	0	-100.0	1	-66.7

Data from Bowes 1991

Table 7. Grass biomass production and percent change from control treatment resulting from herbicide treatments evaluated one year and five years after final treatment.

	one year after final treatment		five years after final treatment	
Herbicide Treatment	Grass Biomass Production lbs/ac	% change from control	Grass Biomass Production lbs/ac	% change from control
Experiment #1, 1981-1989				
No Herbicide				
Control	276.52		276.52	
Dicamba + 2,4-D LVE 1.34 + 1.96 lb ai/ac				
3 applications 6 Jun 81, 16 Jun 82, 16 Jun 83	1195.28	332.3	927.68	235.5
2 applications 6 Jun 81, 16 Jun 82	1079.32	290.3	749.28	171.0
6 Jun 81, 16 Jun 83	1141.76	312.9	749.28	171.0
1 application 6 Jun 81	838.48	203.2	526.28	90.3
Dicamba + 2,4-D A 1.34 + 1.96 lb ai/ac				
3 applications 6 Jun 81, 16 Jun 82, 16 Jun 83	1266.64	358.1	695.76	151.6
2 applications 6 Jun 81, 16 Jun 82	936.60	238.7	561.96	103.2
6 Jun 81, 16 Jun 83	1239.88	348.4	660.08	138.7
1 application 6 Jun 81	544.12	96.8	517.36	87.1

Table 7. (Cont.). Grass biomass production and percent change from control treatment resulting from herbicide treatments evaluated one year and five years after final treatment.

	one year after final treatment		five years after final treatment	
Herbicide Treatment	Grass Biomass Production lbs/ac	% change from control	Grass Biomass Production lbs/ac	% change from control
Experiment #2, 1983-1989				
No herbicide				
Control	338.96		338.96	
Dicamba + 2,4-D LVE 1.34 + 1.78 lb ai/ac				
2 applications 16 Jun 83, 19 Jun 84	1355.84	300.0	1284.48	278.9
16 Jun 83, 27 Jun 85	1257.72	271.1	1382.60	307.9
1 application 16 Jun 83	722.52	113.2	660.08	94.7

Data from Bowes 1991

Table 8. Percent canopy cover of western snowberry and percent change from control treatment resulting from herbicide treatments evaluated two months and five years after treatment.

	two months after treatment		five years after treatment	
Herbicide Treatment	Canopy cover %	% change from control	Canopy cover %	% change from control
Experiment #1, 1986-1989 16 June 1986				
No Herbicide				
Control	32.1		72.2	
Metsulfuron				
0.11 oz/ac	0.1	-99.7	0.7	-99.0
0.21 oz/ac	<0.1	>-99.7	<0.1	>-99.9
0.43 oz/ac	<0.1	>-99.7	0.5	-99.3
0.86 oz/ac	<0.1	>-99.7	<0.1	>-99.9
Metsulfuron + 2,4-D LVE				
0.11 oz/ac +1.78 lb/ac	<0.1	>-99.7	0.5	-99.3
0.21 oz/ac +1.78 lb/ac	<0.1	>-99.7	0.4	-99.4
0.43 oz/ac +1.78 lb/ac	<0.1	>-99.7	0.3	-99.6
0.86 oz/ac +1.78 lb/ac	<0.1	>-99.7	<0.1	>-99.9
2,4-D LVE 1.78 lb/ac	1.1	-96.6	9.0	-87.5

Table 8. (Cont.). Percent canopy cover of western snowberry and percent change from control treatment resulting from herbicide treatments evaluated two months and five years after treatment.

	two months after treatment		five years after treatment	
Herbicide Treatment	Canopy cover %	% change from control	Canopy cover %	% change from control
Experiment #2, 1987-1992 12 June 1987				
No Herbicide				
Control	32.2		76.4	
Metsulfuron				
0.04 oz/ac	0.2	-99.4	19.9	-74.0
0.07 oz/ac	0.2	-99.4	7.6	-90.1
0.11 oz/ac	<0.1	>-99.7	8.1	-89.4
0.21 oz/ac	<0.1	>-99.7	2.1	-97.3
Metsulfuron + 2,4-D LVE				
0.04 oz/ac +1.78 lb/ac	4.8	-85.1	31.3	-59.0
0.07 oz/ac +1.78 lb/ac	1.1	-96.6	7.9	-89.7
0.11 oz/ac +1.78 lb/ac	0.1	-99.7	4.7	-93.8
0.21 oz/ac +1.78 lb/ac	0.1	-99.7	0.3	-99.6
2,4-D LVE				
1.78 lb/ac	0.3	-99.1	49.1	-35.7

Data from Bowes and Spurr 1995

Table 9. Western snowberry aboveground biomass and percent change from control treatment resulting from herbicide treatments evaluated one year and five years after treatment.

	one year after treatment		five years after treatment	
Herbicide Treatment	Western snowberry aboveground biomass lbs/ac	% change from control	Western snowberry aboveground biomass lbs/ac	% change from control
Experiment #1, 1986-1989 16 June 1986				
No Herbicide				
Control	1873.11		2470.48	
Metsulfuron				
0.11 oz/ac	0.09	-99.9	<0.09	>-99.9
0.21 oz/ac	<0.09	>-99.9	<0.09	>-99.9
0.43 oz/ac	<0.09	>-99.9	<0.09	>-99.9
0.86 oz/ac	<0.09	>-99.9	<0.09	>-99.9
Metsulfuron + 2,4-D LVE				
0.11 oz/ac +1.78 lb/ac	<0.09	>-99.9	<0.09	>-99.9
0.21 oz/ac +1.78 lb/ac	0.09	-99.9	19.09	-99.2
0.43 oz/ac +1.78 lb/ac	3.03	-99.8	1.34	-99.9
0.86 oz/ac +1.78 lb/ac	3.03	-99.8	<0.09	>-99.9
2,4-D LVE 1.78 lb/ac	2.23	-99.9	267.60	-89.2

Table 9. (Cont.). Western snowberry aboveground biomass and percent change from control treatment resulting from herbicide treatments evaluated one year and five years after treatment.

	one year after treatment		five years after treatment	
Herbicide Treatment	Western snowberry aboveground biomass lbs/ac	% change from control	Western snowberry aboveground biomass lbs/ac	% change from control
Experiment #2, 1987-1992 12 June 1987				
No Herbicide				
Control	1071.02		3597.44	
Metsulfuron				
0.04 oz/ac	50.13	-95.3	354.03	-90.2
0.07 oz/ac	6.33	-99.4	125.06	-96.5
0.11 oz/ac	21.76	-98.0	349.84	-90.3
0.21 oz/ac	1.34	-99.9	20.43	-99.4
Metsulfuron + 2,4-D LVE				
0.04 oz/ac +1.78 lb/ac	99.01	-90.8	794.95	-77.9
0.07 oz/ac +1.78 lb/ac	44.96	-95.8	281.34	-92.2
0.11 oz/ac +1.78 lb/ac	3.84	-99.6	222.02	-93.8
0.21 oz/ac +1.78 lb/ac	3.84	-99.6	8.83	-99.8
2,4-D LVE 1.78 lb/ac	260.55	-75.7	1672.59	-53.5

Data from Bowes and Spurr 1995

Table 10. Grass biomass production and percent change from control treatment resulting from herbicide treatments evaluated one year and five years after treatment.

	one year after treatment		five years after treatment	
Herbicide Treatment	Grass Biomass Production lbs/ac	% change from control	Grass Biomass Production lbs/ac	% change from control
Experiment #1, 1986-1989 16 June 1986				
No Herbicide				
Control	359.48		643.13	
Metsulfuron				
0.04 oz/ac	759.98	+111.4	1740.29	+170.6
0.07 oz/ac	536.98	+49.4	1486.07	+131.1
0.11 oz/ac	591.40	+64.5	1567.24	+143.7
0.21 oz/ac	733.22	+104.0	1744.75	+171.3
Metsulfuron + 2,4-D LVE				
0.04 oz/ac +1.78 lb/ac	753.74	+109.7	1581.52	+145.9
0.07 oz/ac +1.78 lb/ac	732.33	+103.7	1659.12	+158.0
0.11 oz/ac +1.78 lb/ac	619.05	+72.2	1660.90	+158.3
0.21 oz/ac +1.78 lb/ac	759.98	+111.4	1424.52	+121.5
2,4-D LVE				
1.78 lb/ac	765.34	+112.9	1678.74	+161.0

Table 10. (Cont.). Grass biomass production and percent change from control treatment resulting from herbicide treatments evaluated one year and five years after treatment.

	one year after treatment		five years after treatment	
Herbicide Treatment	Grass Biomass Production lbs/ac	% change from control	Grass Biomass Production lbs/ac	% change from control
Experiment #2, 1987-1992 12 June 1987				
No Herbicide				
Control	317.55		1577.06	
Metsulfuron				
0.04 oz/ac	397.83	+25.3	2580.56	+63.6
0.07 oz/ac	424.59	+33.7	2370.04	+50.3
0.11 oz/ac	340.74	+7.3	2630.51	+66.8
0.21 oz/ac	333.61	+5.1	2567.18	+62.8
Metsulfuron + 2,4-D LVE				
0.04 oz/ac +1.78 lb/ac	322.01	+1.4	2231.78	+41.5
0.07 oz/ac +1.78 lb/ac	302.39	-4.8	2799.99	+77.5
0.11 oz/ac +1.78 lb/ac	382.67	+20.5	2180.05	+38.2
0.21 oz/ac +1.78 lb/ac	390.70	+23.0	2326.34	+47.5
2,4-D LVE 1.78 lb/ac	338.07	+6.5	2167.56	+37.4

Data from Bowes and Spurr 1995

Table 11. Percent canopy cover of western snowberry and percent change from control treatment resulting from herbicide treatments evaluated two months and six years after treatment.

	two months after treatment		six years after treatment	
Herbicide Treatment	Canopy cover %	% change from control	Canopy cover %	% change from control
Experiment #1, 1985-1991 19 June 1985				
No Herbicide				
Control	9		9	
Metsulfuron				
0.21 oz/ac	<1	>-88.9	2	-77.8
0.43 oz/ac	<1	>-88.9	<1	>-88.9
0.86 oz/ac	<1	>-88.9	<1	>-88.9
Metsulfuron + 2,4-D LVE				
0.21 oz/ac +1.78 lb/ac	<1	>-88.9	<1	>-88.9
0.43 oz/ac +1.78 lb/ac	<1	>-88.9	<1	>-88.9
0.86 oz/ac +1.78 lb/ac	<1	>-88.9	<1	>-88.9
2,4-D LVE 1.78 lb/ac	<1	>-88.9	1	-88.9
Experiment #2, 1986-1992 10 June 1986				
No Herbicide				
Control	8		8	
Metsulfuron				
0.21 oz/ac	<1	>-87.5	<1	>-87.5
0.43 oz/ac	<1	>-87.5	<1	>-87.5
0.86 oz/ac	<1	>-87.5	<1	>-87.5
Metsulfuron + 2,4-D LVE				
0.21 oz/ac +1.78 lb/ac	<1	>-87.5	<1	>-87.5
0.43 oz/ac +1.78 lb/ac	<1	>-87.5	1	-87.5
0.86 oz/ac +1.78 lb/ac	<1	>-87.5	1	-87.5
2,4-D LVE 1.78 lb/ac	<1	>-87.5	1	-87.5

Data from Bowes and Spurr 1996

Table 12. Grass and forb biomass production and percent change from control treatment resulting from herbicide treatments evaluated as five year means.

Herbicide Treatment	Five year mean Grass Biomass Production lbs/ac	% change from control	Five year mean Forb Biomass Production lbs/ac	% change from control
Experiment #1, 1985-1991 19 June 1985				
No Herbicide				
Control	634.21		245.30	
Metsulfuron				
0.21 oz/ac	966.93	+52.5	227.46	-7.3
0.43 oz/ac	1342.46	+111.7	110.61	-54.9
0.86 oz/ac	1400.44	+120.8	33.00	-86.5
Metsulfuron + 2,4-D LVE				
0.21 oz/ac +1.78 lb/ac	1089.13	+71.7	92.77	-62.2
0.43 oz/ac +1.78 lb/ac	1144.44	+80.5	37.46	-84.7
0.86 oz/ac +1.78 lb/ac	1377.25	+117.2	29.44	-88.0
2,4-D LVE 1.78 lb/ac	891.11	+40.5	298.82	+21.8
Experiment #2, 1986-1992 10 June 1986				
No Herbicide				
Control	379.99		565.53	
Metsulfuron				
0.21 oz/ac	1012.42	+166.4	225.68	-60.1
0.43 oz/ac	940.17	+147.4	279.20	-50.6
0.86 oz/ac	1263.96	+232.6	190.00	-66.4
Metsulfuron + 2,4-D LVE				
0.21 oz/ac +1.78 lb/ac	1286.26	+238.5	198.92	-64.8
0.43 oz/ac +1.78 lb/ac	1129.27	+197.2	148.96	-73.7
0.86 oz/ac +1.78 lb/ac	1275.56	+235.7	151.64	-73.2
2,4-D LVE 1.78 lb/ac	758.20	+99.5	460.27	-18.6

Data from Bowes and Spurr 1996

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Effective Management of Western Snowberry

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Western snowberry colonies invade and expand in grazingland managed by traditional grazing practices because of the reduced competitive abilities of the grass plants. Enlarging western snowberry colonies use increasing quantities of ecosystem natural resources of soil water, mineral nitrogen, and sunlight to produce biomass that is not nutritious forage for livestock or wildlife. Depending on the shrub's stem density and whether the location is in the moist or dry portions of the mixed grass prairie, the proper stocking rate of a pasture is reduced by about one animal unit for each 1.5 to 5.0 acres of land with western snowberry colonies.

Aerial stems of western snowberry are relatively easy to kill to the ground with single burning, mowing, or herbicide application treatments. The rhizomes and crowns are not easily killed and have biological mechanisms and processes that enable the shrub to survive aerial stem removal and to completely replace the aerial stem density and biomass by the third growing season following the treatment.

Development and implementation of management practices that effectively reduce western snowberry colony size and stem density require the understanding of how the shrub grows, when phenological growth stages occur, when the shrub has vulnerable periods in its life cycle, and when treatments can deplete the nonstructural carbohydrate reserves or damage the capabilities of the rhizomes and crowns for vegetative regeneration of aerial stems.

Growth and Development

Western snowberry, *Symphoricarpos occidentalis* Hook. (a member of the honeysuckle family, Caprifoliaceae), is a native deciduous cool-season shrub that forms large colonies. This biologically successful shrub is widely distributed throughout most of the interior of North America, and it grows at the transitional boundaries of a great variety of plant communities and vegetation types on a wide variety of soils. In grasslands, it can grow in colonies as the only woody plant in association with Kentucky bluegrass and other shade-tolerant plants.

The size of western snowberry colonies can range from a small number of stems covering a few square feet to extensive growths covering hundreds of acres. Typical colonies range from 22 to 82 yards in diameter. Stem height of western snowberry tends to be greater towards the center of the colony, with a range from 16 to 45 inches. Stem density of western snowberry colonies varies considerably, with average density ranging from 39 to 62 stems/sq. yard. Typically, the lowest densities occur at the periphery of a colony, at about 28 stems/sq. yard. Canopy cover of typical western snowberry colonies ranges from 12% to 93%.

Western snowberry has an extensive interconnected rhizome system with clusters of stem bases at about 1.0- to 3.0-foot intervals. The cumulative rhizome length can be 4.4 times greater than the cumulative live aerial stem length. Rhizomes grow at a soil depth from 0.75 to 14 inches below ground. The protection the soil provides for the belowground plant parts contributes to their longevity of about 40 years. Nodes develop on the rhizomes about every 0.5 to 1.0 inch. The nodes are sites with meristematic tissue that forms into growing points for opposite pairs of roots that have unequal growth in length and opposite pairs of lateral buds that have the potential to develop vegetatively into long or short rhizome branches.

The growth of rhizome buds is regulated by apical dominance of a lead aerial stem through the production of inhibitory hormones that block or suppress the activity of growth hormones. When a lead stem is killed or damaged by unfavorable environmental conditions or by management treatments, the production of inhibitory hormones is reduced or stopped, and the growth hormones activate meristematic tissue in rhizome buds; the activation results in the development of several new rhizomes and sucker stems. The long length of the rhizome between adjacent stem base clusters reflects the distance from which hormones produced by lead stems can regulate or influence growth activity of rhizome lateral buds.

Rhizomes and rhizome branches grow horizontally away from their original growing point for a distance, usually about 3 feet or a little less; turn upward; and develop into an erect aerial stem. Rhizome buds near a vertical stem base appear to have greater viability and can develop into long rhizomes, short rhizomes, or additional erect stems forming clusters of stem bases. These sections of vertical and horizontal rhizomes with several nodes actively producing rhizomes and aerial stems are rhizome crowns.

Aerial stems that western snowberry produces vegetatively from meristematic buds are suckers. Rhizome suckers develop from upturned rhizomes or rhizome branches, and crown suckers develop near stem base clusters. During the second year of growth, stems are young stems. During the third and subsequent years, stems are mature stems.

Sucker stems grow rapidly during the first growing season. Stem nodes comprising opposite pairs of growing points with meristematic tissue develop on sucker stems about every 1.0 to 2.0 inches. Opposite pairs of leaves are produced at each node along the entire sucker stem. Lateral branches do not appear during the first year unless the lead apical meristem is damaged. During the second year of growth, pairs of lateral twigs appear from nodes that were the previous year's leaf axils along the upper portions of the stem. Nodes along the lower portions of the stem do not develop twigs. New leaves develop as opposite pairs at the nodes of only the current year's twigs, not on older twig material. Successive twigs growing from the previous year's leaf axils create a branch network that becomes more complex with each growing season. The age of intact stems can be determined from the pattern of twig branches.

Aerial stems, which live to the maximum age of about 13 years, do not survive as long as rhizomes and clusters of stem bases, which are protected by a layer of soil. Portions of mature stems may die each year. This decadence of aerial stems is most likely the result of unfavorable environmental conditions rather than a symptom of reduced vigor of aging stems.

Phenological Growth Stages

Western snowberry starts growing in mid to late April, when there are at least 14 hours of daylight. Rapid twig elongation and leaf growth and expansion occur at the same time and continue until late May or early June, when pinkish flower buds appear at the twig tips. By early June, the twigs have reached about 75% of full growth, and the leaves are near full expansion. Twigs continue growing at a slower rate, and by mid June they have completed about 95% of their annual growth. Flower buds continue to appear in the leaf axils until about late June. The shrub starts the anthesis growth stage when the first flowers begin opening at the twig tips around mid June; subsequent new flowers open at lower leaf axils through July and sometimes into mid August. The slightly fragrant flowers are insect pollinated and open during the night or early morning. After fertilization, the fruits fill and ripen during mid July to late August. Leaf senescence can occur any time the plant is in water stress, but it usually occurs during late August to October. Many of the leaves remain attached to the stems over the winter. The greenish white mature fruits are the feature for which "snowberry" was named. The stalk of the fruit does not have an abscission layer and most fruits remain attached to the stems all winter. The fruits that have not been consumed by an animal drop to the ground during the following spring or summer. Each fruit contains two nutlets, but about half of the nutlets are defective. The nutlets have a complex double-dormancy mechanism that must be satisfied before germination can occur. Germination rate is low because only about 1% of the nutlets reaching the soil are viable. Mortality of seedlings is high because they have few defenses against insects, diseases, water stress, and competition from other plants. Seedlings probably do not become mature stems in and around existing colonies. For seedlings to develop into adult plants, the nutlets must be transported inadvertently in the digestive tracts of animals to habitat sites that have sufficient soil water, few insects, low quantities of disease organisms, and little or no competition from dense grasses or canopy cover of shrubs. Western snowberry establishment by seed is rare.

Nutrient Content

Western snowberry fruits are consumed by numerous types of birds and mammals. A few nutlets pass unharmed through the digestive tracts of some animals. About 10.7% of the nutlets force-fed to domesticated chickens passed intact. Pheasants, grouse, large herbivores, and livestock are known to pass intact nutlets. Rabbits and mice are known to pass only nutlet fragments.

A wide variety of animals consumes portions of western snowberry shoots. Several insects chew parts of leaves and stems. Mice and other rodents girdle stems. Rabbits browse the stems. Wild ungulates and domesticated cattle, sheep, and goats browse the leaves and twigs. Western snowberry, however, is not important as food for wildlife. The nutrient content of western snowberry twigs, leaves, and fruits does not meet the requirements for in vitro dry matter digestibility, crude protein, and phosphorus of wild ungulates during fall and winter. The energy content and crude protein content of western snowberry fruits do not meet the nutrient requirements of sharp-tailed grouse during fall and winter.

Nonstructural Carbohydrate Cycle

Carbon is important to plants for energy transport and storage and as cellulose-based structural materials used in growth. Plants capture and fix carbon from atmospheric carbon dioxide during the process of photosynthesis. The assimilated carbon forms into various simple sugars and starches that are collectively called carbohydrates. The surplus carbohydrates that are not used as energy or for structural growth are stored as nonstructural carbohydrates. The quantity of stored nonstructural carbohydrates is related to plant growth and reproduction, with cycles of drawdown and replenishment following a typical pattern each growing season. A sharp drawdown in carbohydrate reserves occurs during the rapid growth of early spring, from mid April to early June. The lowest carbohydrate levels occur for about 10 days between late May and early June. Rapid replenishment occurs during the flowering stage, from early June to mid July. A second drawdown period occurs during fruit fill, between mid July and early August. A second replenishment period occurs between mid August and early September. A gradual third drawdown occurs during pre-winter root growth and bud development, from early September to late October.

Biological Management

The persistence and abundance of a species in a community is determined by that species' competitive ability to acquire aboveground and belowground resources. Western snowberry and native grasses compete for sunlight, mineral nitrogen, and soil water. The taller aerial stems of the shrub shade sunlight from the grass understory, reducing the quantity of light reaching the grass canopy by 70% to 80%. The quantity of light reaching the grass plants is below the light saturation point of most native grassland species, and the shading reduces grass biomass production severely. Shading has a greater effect on warm-season grasses because of their higher light compensation point than on cool-season species. Effects from shading by dense aerial stems can completely eliminate the understory vegetation.

Implementation of traditional grazing practices that are antagonistic to the biological requirements of grass plants and the biogeochemical processes in grassland ecosystems weakens the competitive abilities of grasses and facilitates the encroachment and enlargement of western snowberry colonies. Less than healthy grasses have diminished competitive abilities; these grass plants relinquish quantities of belowground resources in proportion to the reduced competitiveness. The additional resources then become available for western snowberry growth and facilitate the enlargement and spread of the colonies and the increase in stem density. Increases in aerial stem canopy cover improve the competitiveness of the shrubs for the aboveground resource of sunlight.

Healthy grass plants are superior competitors for soil water and mineral nitrogen; these grass plants reduce the quantity of belowground resources available for western snowberry and thereby retard or reverse the shrub's encroachment into grazinglands. Grass competition for belowground resources reduces the quantity of western snowberry vegetative buds with activated meristematic tissue, reduces the growth rates of developing rhizome suckers, and causes a relatively high mortality rate of young sucker stems. The effect of competition from grasses causes a decrease in the density of rhizome and crown suckers, young stems, and total aerial stems and a decrease in the canopy cover of western snowberry colonies. Implementation of biologically effective management, like the twice-over rotation system, that is designed to meet the biological requirements of the plants and to coordinate two grazing periods with grass growth stages, activates the defoliation resistance mechanisms in grazed grass plants. The coordinated defoliation stimulates biological and ecological processes within grass plants and the ecosystem so that beneficial changes to plant growth, soil organisms, and biogeochemical cycles in the ecosystem result. The increase in vegetative reproduction by tillering from axillary buds contributes to the development of greater grass basal cover and to the production of greater herbage weight. The increase in activity of the soil organisms in the rhizosphere supplies the plant with greater quantities of nutrients to support additional growth. The result is a healthy, dense, productive grass population that is highly competitive for belowground resources and creates the strongest possible biological barrier to western snowberry encroachment.

Biologically effective management practices improve the health and competitive abilities of the native grass plants but do not remove the aerial stems and reduce the size of preexisting western snowberry colonies. Additional management practices that use burning, mechanical, and chemical methods are needed to diminish existing colonies of western snowberry on grazinglands.

Burning Management

Western snowberry aerial stems are sensitive to fire, and even if they are not completely consumed by the fire, the stems usually die to ground level. Because of the protection provided by soil, the belowground rhizomes and rhizome crowns with clusters of stem bases are usually not damaged by fire. The belowground parts have large quantities of buds that have the potential to develop into new aerial sucker stems.

Historically, fire has been an environmental factor on mixed grass prairie, with an estimated fire return interval of 5 to 10 years on the moist portions and around 25 years on the dry portions. Both lightning-set fires and Indian-set fires have influenced how western snowberry responds to prescribed burning. Most lightning-set fires occurred in July and August, and a large portion of the Indian-set fires occurred between July and early November. The Northern Plains has probably had considerably more late season fires, occurring after mid July, than spring or early summer fires.

Western snowberry top growth is usually removed completely by fire if sufficient fine fuel is present; however, spring burns result in great quantities of sucker stems, which become visible about two weeks following the burn, and because carbohydrate stores can be completely replenished by the new plant material in one growing season, spring burns do not decrease stem frequency even after 24 years. Shrub stem densities recover during the first and second growing season following a burn treatment, and during the third growing season following burning, stem densities on burn treatments are similar to stem densities on the unburned reference areas.

Management strategies with four every-other-year burns are required to reduce western snowberry aboveground biomass production and shrub frequency and to increase grass biomass production. Prescribed fires during August cause the least damage to native cool- and warm-season grasses and perennial forbs. August fires remove all or most of the top growth of western snowberry and result in fewer sucker shoots the following year than spring burns. The growth pattern and biological requirements of the herbaceous vegetation in the mixed grass prairie match the defoliation pattern of August burns more closely than burns at other periods. When the soil is not dry, August burns can be nearly nondetrimental to desirable plants and can cause considerable damage to the undesirable woody plants. Prescribed burning alone, however, will not remove western snowberry from the northern mixed grass prairie.

Mechanical Management

Mechanical mowing treatments can effectively reduce western snowberry stem densities by causing depletion of stored nonstructural carbohydrate energy from repeated cutting of aerial stems at the times when the carbohydrate reserves are low. Energy reserves are reduced when vegetative sucker regrowth is produced. Repeat cutting is required to prevent replenishment of reserves when the replacement suckers produce greater quantities of carbohydrates than they use for growth. Plant growth requirements cause carbohydrate drawdown during rapid spring growth, from mid April to early June; during fruit fill, from mid July to early August; and during pre-winter root growth and bud development, from early September to late October.

The mowing height of western snowberry colonies in grazed pastures should not be close to the ground, at the height that hay is cut, but the mowing height should be raised to about 8 or 9 inches above the ground. Young and mature stems topped by cutting frequently die all the way to the ground. The cutting height should be set so most of the leaves and branches on the typical stems are removed and a relatively tall, flexible, bare stem remains. Intact mature stems are flexible and can be bent to the ground without breakage. Stems cut short are very rigid and do not bend when stepped on. Short, rigid, sharp stems can be serious problems for cattle walking through mowed western snowberry colony areas. The stiff stems can puncture the sole of the hoof, causing an injury open to infection that can possibly result in hoof rot.

Single annual mowing treatments do not reduce stem numbers, because the regrowth of sucker stems can replenish the carbohydrate reserves during one growing season. Double mowing treatments can be effective at reducing stem numbers when mowing periods are conducted for maximum carbohydrate depletion. The seasonal low carbohydrate reserves for western snowberry occur from the period of rapid growth until near the start of flowering, between May and mid June. The first mowing treatment conducted during the last week in May through the third week in June should cause considerable depletion of stored carbohydrates. Growth of sucker shoots should continue to deplete carbohydrate reserves for nearly six weeks, until the new sucker stems develop about ten leaf pair. A second mowing treatment conducted sometime during late July through August is needed to prevent full carbohydrate replenishment. Mowing in late July or August causes a substantial amount of winter injury to late-season lateral bud sprouts on the stem bases. Double mowing treatments will need to be repeated two, three, or more seasons, depending on the quantity of stored carbohydrates of western snowberry colonies at the start of the mowing treatments.

Chemical Management

Successful chemical management of western snowberry depends on terminating the regenerative capabilities of the rhizomes and the clusters of stem bases on the crowns. Two critical factors must occur in order for sufficient quantities of foliage-active herbicides to reach the site of activity in the belowground plant parts and interfere with their physiological processes. First, the herbicides must enter the leaf tissue through the stomata openings or penetrate the outer cuticle layer, be absorbed through leaf tissue by diffusion, and be moved to the vascular system within the leaf. Second, the herbicides must be translocated from the leaves downward through the phloem vascular system to the metabolically active sites of the crowns and rhizomes. During the period of rapid twig elongation, from mid April to early June, nonstructural carbohydrates move from the storage site in the rhizomes and the crowns upward through the phloem vascular system to the active growing points. The upward movement of carbohydrates through the phloem prevents downward movement of herbicides. Herbicides can readily penetrate young western snowberry leaves during May and early June but cannot be translocated downward. Sometime between early June and mid June, the carbohydrate production by leaf photosynthesis exceeds the demands from growth, and the surplus carbohydrates are moved downward through the phloem for storage in the rhizomes and crowns. This change in direction of carbohydrate flow permits the translocation of herbicides from the leaves downward to the belowground plant parts. The leaves have continued to mature, developing a thicker cuticle layer and denser cell walls; the result is an increased resistence to herbicide penetration and absorption. The two critical factors for successful chemical management of western snowberry occur coincidentally during only a brief vulnerable stage, from about 10 June until 20 June, when herbicide penetration into leaf tissue is decreasing and herbicide translocation downward is increasing. Leaf penetration by herbicides is improved with wetting agents, and these surfactants should be added to all foliage-active herbicide spray mixtures.

Implementing management practices that effectively reduce western snowberry colony size and stem density using biological, burning, mechanical, and chemical methods requires an understanding of how the plant grows, its strong characteristics, and its weaknesses and periods of vulnerability.

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