Multiple Defoliation Effects on Herbage Yield, Vigor, and Total Nonstructural Carbohydrates of Five Range Species

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Highlight: Western wheatgrass (*Agropyron smithii*), blue grama (*Bouteloua gracilis*), and fourwing saltbush (*Atriplex canescens*) were subjected to multiple defoliations at moderate and heavy intensities during a 2-year period. Most heavy defoliation treatments drastically reduced herbage yield, vigor, and total nonstructural carbohydrates (TNC) of western wheatgrass. Multiple defoliations were detrimental to vigor and herbage yield of blue grama; however, defoliation treatments did not detrimentally affect root TNC levels. All defoliation treatments severely reduced the number of seedstalks, live crown cover, and TNC of fourwing saltbush, but seedstalk length and live crown diameter were less affected by the defoliation treatments. Both fringed sagewort (*Artemisia frigida*) and antelope bitterbrush (*Purshia tridentata*) subjected to two moderate defoliations during quiescence and rapid growth (or flowers developing) remained in fair to good vigor at the end of the growing season. However, both species were detrimentally affected if utilized during the later part of the growing season. Defoliation effects were generally more severe when plants were defoliated at a heavy intensity than when defoliated at a moderate intensity during the same phenological stages. Five- and six-pasture rest-rotation grazing systems were proposed to ensure that grazed plants would receive rest following critical late summer foliage utilization.

Factors that reduce the capacity of a plant to manufacture food will cause a depletion of stored total nonstructural carbohydrates (TNC) and might lead to changes in range condition. Frequent and severe clippings or grazing depletes TNC and lowers herbage yield and plant vigor. The season of grazing or clipping often influences the success or failure of a grazing practice. Therefore, it is necessary to know the period when key forage species are less susceptible to foliage removal (Heady 1974). This study was undertaken to determine the effects of frequency, intensity, and season of defoliations on herbage yield, vigor, and TNC levels of blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), fourwing saltbush (*Atriplex canescens*), antelope bitterbrush (*Purshia tridentata*), and fringed sagewort (*Artemisia frigida*).

Literature Review

Defoliation of plants during susceptible periods can reduce the ability of plants to maintain growth and vigor. Intensive defoliation often lowers the TNC levels in the storage organs (Cook 1966; Everson 1966; Willard and McKell 1973; Perry and Chapman 1974; Owensby et al. 1974). Trlica and Cook (1971) reported that TNC levels were a good indicator of the effects of clipping on many desert plants.

The time of defoliation can significantly influence the severity of a clipping treatment. Trlica and Cook (1971) found that salt desert plants defoliated late in the spring and at a near maturity phenological stage made little regrowth and stored little TNC. Cook (1971) stated that defoliation was more detrimental in the late spring or mid-summer than in the fall, winter, or early spring for several salt desert species. McCarty and Price (1942) reported that defoliation was most detrimental from flowerstalk formation through the seed ripening stage for some mountain forage species. Laycock and Conrad (1969) reported that defoliation of tall bluebell (*Mertensia arizonica*) was most detrimental during the flowering and fruit developing stages. Currie (1970) found that spring or spring and fall grazing of a seeded crested wheatgrass (*Agropyron cristatum*) pasture caused greater invasion by other species than did fall grazing.

Frequent clippings of blue grama greatly reduced herbage yields (Reed and Dwyer 1971). Dwyer et al. (1963) reported that frequent defoliations greatly reduced herbage yields of several Oklahoma range grasses. Holscher (1945) found frequent, intensive defoliations reduced herbage yields of blue grama and western wheatgrass.

Methods and Procedures

The study was carried out from 1972 through 1974 at two locations in northern Colorado: the Central Plains Experiment Range (CPER), located about 50 km northeast of Fort Collins, and the Maybell location, about 6 km west of Maybell. The CPER location is typical of the shortgrass type of the Central Great Plains region. The Maybell location is in the intermountain sandhills region of northwestern Colorado. This location is characterized by gently rolling hills with occasional steeper slopes. The climate at both study locations is semiarid with warm summers and cold winters. A more detailed site description was given by Trlica et al. (1977).

Three exclosures were built in the fall of 1972 at the CPER to exclude livestock grazing. Blue grama, western wheatgrass, and fourwing saltbush included within these exclosures were clipped from the fall of 1972 through the late summer of 1974. Antelope bitterbrush and fringed sagewort were enclosed within three exclosures that were built in the spring of 1973 at the Maybell location. Clipping of these two species was from the fall of 1973 through the late summer of 1974. The current photosynthetic tissues of the five species were clipped at two intensities, heavy (90% of the current year's growth removed) and moderate (60% of the current year's growth removed). Small twigs

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supporting the foliage of antelope bitterbrush and fourwing saltbush were also clipped.

Four replications at each exclosure and for both clipping intensities were used for each defoliation treatment of the three species at the CPER location. A replication was defined for the two grasses, blue grama and western wheatgrass, as a 0.23 m^2 plot. Replications of fourwing saltbush were defined as the individual plants included in a defoliation treatment for each intensity at each exclosure. In each Maybell exclosure, four antelope bitterbrush plants and eight fringed sagewort plants were clipped under each clipping intensity for each multiple defoliation treatment. All treatments were randomly assigned to each species.

Since species grow at different times and rates, clippings were made at certain phenological stages. Clipping of plants at the CPER location was made at quiescence (November 1–25); rapid growth (May 6–June 4); and seedset (August 1–18). Fringed sagewort and antelope bitterbrush at the Maybell location were defoliated during two of the following phenological stages: quiescence (in late October); rapid growth or flowers developing (in early June); and near maturity or seed shatter in early August). Plants were clipped when the desired phenological stage of unclipped control plants was attained. The responses of all species to the clipping treatments were evaluated in the fall of 1974 by obtaining data on herbage yield, vigor, and TNC levels. Data were obtained on both clipped and unclipped plants. Little regrowth occurred for plants clipped late in the 1974 growing season, as indicated by reduced herbage yields and vigor at the end of the growing season.

Vigor of the two grasses was evaluated using percentage basal cover, plant height, and plant vigor category. Vigor for the browse and suffretescent species was measured by percentage live crown cover (ocular estimate), number and length of seedstalks (or twig lengths), live crown diameter, average plant height, and plant vigor category. Vigor measurements were made on all replications for each species. Plant vigor category was visually estimated and categorized by assigning numbers as follows: 1 = very high vigor; 2 = high vigor; 3 = medium vigor; 4 = low vigor; and 5 = very low vigor. The plant vigor category integrated other vigor observations into a single number. In other words, plants with a large number of seedstalks, high live crown cover, and good plant height would be rated as having very high vigor (1). If some of these vigor measurements were low, a lower vigor category would have been assigned.

Herbage yield data for both grasses and fringed sagewort were collected in the fall of 1974 by clipping the standing biomass to ground level. For fourwing saltbush, herbage yield represented the total dry weight of seeds, leaves, and current twig growth. Herbage yield of antelope bitterbrush represented the total weight of leaves and current twig growth. A double sampling technique (Pechanec and Pickford 1937) was used to obtain herbage yields of antelope bitterbrush and fourwing saltbush. Actual herbage yields were obtained for one-half of the clipped and unclipped plants of both species, while herbage yields of the remaining plants were estimated. All herbage samples were dried at 70°C for 24 hours and then weighed.

Roots of blue grama, western wheatgrass, and fringed sagewort and live basal stems of 0.5 to 1 cm diameter of antelope bitterbrush and fourwing saltbush were sampled to determine the TNC levels in both clipped and unclipped plants. Rhizomes were included in the western wheatgrass root samples. Roots were excavated to a depth of 30 cm. Samples were washed with water, covered with 95% ethanol to reduce enzyme activity, dried at 70°C for approximately 10 days, and then ground to pass through a 40-mesh screen. Extraction and determination of total nonstructural carbohydrates were made using procedures previously described by Heinze and Murneek (1940), Smith et al. (1964), and Trlica and Cook (1971), with modifications as described by the Association of Official Agricultural Chemists (1965). A total of six replications (two per exclosure) for each defoliation treatment and each clipping intensity were used for TNC determinations for all species.

All data were analyzed using standard analysis of variance techniques (Steel and Torrie 1960). Significant differences were accepted at the 0.05 level of probability. When significant F-values were found, Duncan's new multiple range test was utilized to separate significant ($p<0.05$) mean differences.

Results and Discussion

Effects of multiple defoliations on western wheatgrass, blue grama, and fourwing saltbush were evaluated by obtaining data on herbage yield, vigor, and TNC levels during the fall of 1974. Treatment 1 refers to the undefoliated control plants; whereas defoliation treatments 2 through 8 refer to the phenological stages at which the species were defoliated during 1972, 1973, and 1974. These treatments are defined in the column for phenological stages when defoliated as shown in the tables.

Western Wheatgrass

All multiple defoliation treatments drastically reduced herbage yield and vigor of western wheatgrass below that of the control plants (Table 1). Root and rhizome TNC levels were depressed by all the heavy defoliation treatments, but most moderately defoliated western wheatgrass plants had TNC levels that were similar to those of the undefoliated control plants.

Basal cover of western wheatgrass was severely reduced below that of the control plants by both moderate and heavy defoliations (Table 1). Western wheatgrass defoliated at the moderate intensity had greater basal cover than did plants defoliated heavily during the same phenological stages, but the differences were not always significant. Defoliated plants had 20 to 60% less basal cover than did undefoliated plants. Basal cover was most affected by heavy defoliations over a 2-year period during the rapid growth and seedset phenological stages (defoliation treatment 7).

All multiple defoliation treatments reduced plant heights of western wheatgrass (Table 1). Defoliation effects on plant heights were most pronounced when western wheatgrass plants were defoliated at a heavy intensity during the seedset period of the second growing season (treatments 4, 5, and 7) since little time remained between clipping and data collection. Holscher (1945) reported that frequent intensive defoliations of western wheatgrass severely reduced plant height. Goebel and Cook (1960) showed that a decline in range condition was usually accompanied by a decrease in leaf and stem length. The present study showed that multiple defoliations greatly reduced height of western wheatgrass plants.

Undefoliated western wheatgrass plants had good vigor at the end of the 1974 growing season (Table 1). Plants moderately defoliated in defoliation treatments 3, 6, and 8 remained in fair vigor at the end of the growing season. However, all heavily defoliated western wheatgrass plants had poor plant vigor category values at the end of the 1974 growing season. Drawe et al. (1972) showed that vigor of crested wheatgrass decreased with increased intensity of defoliation.

Herbage yields of western wheatgrass were drastically lowered by the 2-year multiple defoliations (Table 1). Defoliated plants showed more than a 60% reduction in herbage yields below that of the undefoliated control plants. Herbage yields of western wheatgrass were generally less affected by moderate defoliations in defoliation treatments 3, 6, and 8.

Defoliation effects on root and rhizome TNC levels were most pronounced when western wheatgrass plants were heavily defoliated (Table 1). Kinsinger and Hopkins (1961) earlier reported that frequent heavy defoliations of western wheatgrass for two consecutive years drastically reduced root TNC levels below that of the undefoliated control plants. In the present

Table 1. Average herbage yield, vigor, and total nonstructural carbohydrates (TNC) for western wheatgrass (*Agropyron smithii*) subjected to multiple defoliations during various phenological stages and at two intensities during 1972, 1973, and 1974. Measurements and collections were made during the fall of 1974.

			Vigor				
Treatment number	Phenological stages when defoliated	Intensity of foliage removal	Basal cover (%)	Plant height (cm)	Plant vigor category	Herbage yield (g/m²)	TNC in roots and rhizomes (mg/g)
1	Control (undefoliated)	None	19 a[1]	24 a	1.8 a	212 a	128 a
2	Quiescence, 1972; Rapid growth and quiescence, 1973; Rapid growth, 1974.	Moderate	10 de	13 cd	3.5 cd	40 bcd	116 abc
		Heavy	9 e	13 cd	3.8 cde	17 d	105 bcde
3	Quiescence, 1972; Seedset and quiescence, 1973; Rapid growth, 1974.	Moderate	14 b	17 b	2.8 b	79 b	124 ab
		Heavy	9 e	12 de	4.0 de	26 cd	83 f
4	Quiescence, 1972; Seedset and quiescence, 1973; Seedset, 1974.	Moderate	11 cde	10 ef	3.8 cde	40 bcd	114 abc
		Heavy	9 e	8 fg	4.8 g	12 d	89 ef
5	Quiescence, 1972; Rapid growth, 1973; Rapid growth and seedset, 1974.	Moderate	11 cde	10 ef	3.9 de	38 bcd	106 bcde
		Heavy	9 e	7 g	5.0 g	21 cd	92 def
6	Rapid growth, seedset, and quiescence, 1973; Rapid growth, 1974.	Moderate	12 bcd	14 cd	3.3 bc	67 bc	109 bcde
		Heavy	9 e	13 cd	4.1 e	31 cd	106 bcde
7	Rapid growth and seedset, 1973; Rapid growth and seedset, 1974.	Moderate	14 b	14 cd	3.6 cde	40 bcd	111 abcd
		Heavy	6 f	6 g	5.0 g	7 d	103 cde
8	Rapid growth, seedset, and quiescence, 1973.	Moderate	13 bc	15 bc	2.8 b	65 bc	124 ab
		Heavy	10 de	14 cd	3.7 cde	38 bcd	106 bcd

[1] Means in the same column followed by a similar letter are not significantly different at the 0.05 level of probability.

study, moderately defoliated western wheatgrass plants had slightly higher TNC levels than did heavily defoliated plants when clippings were made during the same phenological stages. However, the differences in TNC levels among moderately and heavily defoliated plants were not always significant. The only moderate intensity defoliations to severely reduce western wheatgrass TNC levels below that of the control plants were treatments 5 and 6.

Blue Grama

All multiple defoliation treatments reduced herbage yield and vigor of blue grama below that of the undefoliated control plants (Table 2). However, root TNC levels were not severely reduced by any of the defoliation treatments.

Defoliated blue grama plants had less basal cover than that of the control plants (Table 2). In general, basal cover was less for heavily defoliated plants than for moderately defoliated plants. Most moderately defoliated plants had about 30% more basal cover than plants that were heavily defoliated during the same phenological stages. All heavily defoliated blue grama plants had at least a 50% reduction in basal cover as compared with the undefoliated control plants.

Undefoliated blue grama plants were taller than were the defoliated plants (Table 2). Defoliation treatments reduced plant heights 40 to 80% below that of the undefoliated control plants. In general, plant heights were most affected by defoliation during the seedset period of the second growing season. This was anticipated, as blue grama plants defoliated late in the growing season had little chance for regrowth prior to fall collection. Albertson et al. (1953) reported that frequent, intensive defoliations reduced blue grama leaf length more than 40% below that of control plants.

Most defoliated blue grama plants were in low vigor at the end of the 1974 growing season (Table 2). Plant vigor category was less affected by moderate defoliations in defoliation treatments 2, 3, 6, and 8.

Herbage yields of blue grama were reduced by all the 2-year multiple defoliations below that of the control plants (Table 2). Herbage yields were reduced more by heavy defoliations than by moderate defoliations during the same phenological stages, but the differences were not always significant. Lang and Barnes (1942) reported that herbage yields of frequently defoliated blue grama plants were drastically reduced below that of the control plants. Similar results were reported by Branson (1956) and Bekele et al. (1974).

Root TNC levels of blue grama were little affected by any of the defoliation treatments (Table 2). However, blue grama plants defoliated three times at a moderate intensity in defoliation treatment 8 had higher root TNC levels than did the undefoliated control plants. Fisher (1966) had also found TNC levels of blue grama roots to be little affected by clipping treatments. The failure of the defoliation treatments to severely reduce blue grama root TNC levels might be related to the ability of the defoliated plants to remain in a semidormant stage throughout most of the growing season, while unclipped control plants were utilizing their stored TNC for growth. Defoliated plants, therefore, may not attain the same phenological stage as the unclipped control plants.

Cook (1966) suggested that species that grew slowly and did not extensively utilize stored TNC were probably more resistant to grazing or defoliation damage than were those species that grew rapidly and utilized stored TNC extensively. It appeared that blue grama may follow this pattern and did not make any

Table 2. Average herbage yield, vigor, and total nonstructural carbohydrates (TNC) for blue grama (*Bouteloua gracilis*) subjected to multiple defoliations during various phenological stages and at two intensities during 1972, 1973, and 1974. Measurements and collections were made during the fall of 1974.

Treatment number	Phenological stages when defoliated	Intensity of foliage removal	Vigor: Basal cover (%)	Vigor: Plant height (cm)	Vigor: Plant vigor category	Herbage yield (g/m^2)	TNC in roots (mg/g)
1	Control (undefoliated)	None	28 a[1]	9 a	2.0 a	116 a	47 bcde
2	Quiescence, 1972; Rapid growth and quiescence, 1973; Rapid growth, 1974.	Moderate	15 cd	5 b	3.7 bc	35 cde	43 de
		Heavy	14 d	4 bc	4.0 cde	31 de	48 abcde
3	Quiescence, 1972; Seedset and quiescence, 1973; Rapid growth, 1974.	Moderate	21 b	5 b	3.5 b	48 bc	48 abcde
		Heavy	13 de	3 cd	4.8 h	25 ef	44 de
4	Quiescence, 1972; Seedset and quiescence, 1973; Seedset, 1974.	Moderate	19 b	4 bc	4.0 cde	46 bc	55 abc
		Heavy	12 def	3 cd	4.7 gh	13 f	53 abcd
5	Quiescence, 1972; Rapid growth, 1973; Rapid growth and seedset, 1974.	Moderate	15 cd	3 cd	4.3 efg	30 de	45 cde
		Heavy	13 de	2 d	4.9 h	25 ef	41 e
6	Rapid growth, seedset, and quiescence, 1973; Rapid growth, 1974.	Moderate	18 bc	4 bc	3.8 bcd	43 bcd	43 e
		Heavy	10 ef	3 cd	4.8 h	29 e	42 e
7	Rapid growth and seedset, 1973; Rapid growth and seedset, 1974.	Moderate	15 cd	3 cd	4.6 fgh	30 de	49 abcde
		Heavy	9 f	2 d	5.0 h	15 f	43 e
8	Rapid growth, seedset, and quiescence, 1973.	Moderate	18 bc	5 b	3.8 bcd	51 b	58 a
		Heavy	14 d	4 bc	4.2 def	37 cde	56 ab

[1] Means in the same column followed by a similar letter are not significantly different at the 0.05 level of probability.

Table 3. Average herbage yield, vigor, and total nonstructural carbohydrates (TNC) for fourwing saltbush (*Atriplex canescens*) subjected to multiple defoliations during various phenological stages and at two intensities during 1972, 1973, and 1974. Measurements and collections were made during the fall of 1974.

Treatment number	Phenological stages when defoliated	Intensity of foliage removal	Vigor: Live crown cover (%)	Vigor: Number seed-stalks per plant	Vigor: Twig or seed-stalk length (cm)	Vigor: Plant hieght (cm)	Vigor: Live crown diameter (cm)	Vigor: Plant vigor category	Herbage yield (g/plant)	TNC in basal stems (mg/g)
1	Control (undefoliated)	None	74 a[1]	102 a	10 a	59 a	74 a	1.8 a	240 a	41 a
2	Quiescence, 1972; Rapid growth and quiescence, 1973; Rapid growth, 1974.	Moderate	45 cd	18 b	9 ab	44 bcd	47 cd	3.6 cd	80 bcde	38 abc
		Heavy	42 de	6 b	8 abc	38 def	50 bcd	4.3 ef	74 def	29 abcde
3	Quiescence, 1972; Seedset and quiescence, 1973; Rapid growth, 1974.	Moderate	43 de	15 b	9 ab	42 bcd	54 abcd	3.9 de	78 cde	36 abcd
		Heavy	40 de	5 b	10 a	39 cde	51 bcd	4.2 e	58 efg	23 de
4	Quiescence, 1972; Seedset and quiescence, 1973; Seedset, 1974.	Moderate	37 e	7 b	6 cd	37 def	50 bcd	4.7 fg	35 fg	32 abcde
		Heavy	30 f	0 b	5 d	32 ef	45 d	4.9 g	23 g	26 bcde
5	Quiescence, 1972; Rapid growth, 1973; Rapid growth and seedset, 1974.	Moderate	40 de	16 b	6 cd	39 cde	55 abcd	4.1 e	42 efg	33 abcde
		Heavy	26 f	1 b	5 d	31 f	68 abc	4.9 g	27 g	24 cde
6	Rapid growth, seedset, and quiescence, 1973; Rapid growth, 1974.	Moderate	52 b	21 b	9 ab	46 bc	66 abcd	3.4 c	100 bcd	31 abcde
		Heavy	40 de	0 b	9 ab	39 cde	58 abcd	4.2 e	55 efg	24 bcde
7	Rapid growth and seedset, 1973; Rapid growth and seedset, 1974.	Moderate	41 de	6 b	7 bcd	43 bcd	60 abcd	4.3 ef	75 def	38 abc
		Heavy	27 f	1 b	6 cd	39 cde	54 abcd	4.8 g	21 g	19 e
8	Rapid growth, seedset, and quiescence, 1973.	Moderate	55 b	23 b	9 ab	49 b	64 abcd	2.8 b	120 b	29 ab
		Heavy	51 bc	6 b	8 abc	43 bcd	69 ab	3.4 c	116 bc	35 abcd

[1] Means in the same column followed by a similar letter are not significantly different at the 0.05 level of probability.

substantial regrowth following severe defoliations during later phenological stages.

Fourwing Saltbush

Most multiple defoliation treatments lowered herbage yield, vigor, and basal stem TNC levels of fourwing saltbush plants below that of the undefoliated control plants (Table 3). Defoliation effects were less severe on basal stem TNC levels than they were on herbage yield and vigor of fourwing saltbush.

All the defoliated fourwing saltbush plants had less live crown cover than did the undefoliated control plants (Table 3). However, live crown diameters for some of the defoliated plants were similar to that of the control plants. Live crown cover was less affected by four moderate defoliations in defoliation treatment 6 or three defoliations at both intensities in defoliation treatment 8. Heavy defoliations during the seedset period of the second growing season (defoliation treatments 4, 5, and 7) caused the greatest reductions in live crown cover of fourwing saltbush among the various defoliation treatments. This was anticipated, as little chance for regrowth remained following the last late summer defoliation.

All multiple defoliation treatments severely reduced the number of seedstalks for fourwing saltbush (Table 3). Twig or seedstalk lengths, however, were less affected by defoliation treatments than were seedstalk numbers. Twig or seedstalk lengths were reduced below that of the control plants only when fourwing saltbush plants were defoliated during the seedset period of the second growing season (defoliation treatments 4, 5, and 7). Mueggler (1967) reported that 3 years of consecutive defoliations resulted in an 80% reduction in the number of flowerstalks produced by *Aster intergifolius* and *Potentilla gracilis*. Garrison (1953) also found that the number of seedstalks produced in clipped browse plants was greatly reduced below those of unclipped plants.

Defoliated fourwing saltbush plants were shorter than were the undefoliated control plants (Table 3). Heavily defoliated plants were usually shorter than were plants that were moderately defoliated during the same phenological stages, but the differences were not always significant.

Plant vigor category was better for the control plants than it was for any of the defoliated plants (Table 3). Fourwing saltbush plants defoliated at a moderate intensity during rapid growth, seedset, and quiescence (defoliation treatment 8) were in a good state of vigor at the end of the 1974 growing season. In general, plant vigor was reduced most by heavy defoliations during the later part of the 1974 growing season (defoliation treatments 4, 5, and 7).

Herbage yields of fourwing saltbush were lower for all defoliated plants than they were for the control plants (Table 3). Multiple defoliations were less detrimental to herbage yields when plants were given four moderate defoliations in defoliation treatments 2 and 6 or given three defoliations at both intensities during rapid growth, seedset, and quiescence (defoliation treatment 8).

All defoliated fourwing saltbush plants had lower basal stem TNC levels than did the control plants, but the differences were not always significant (Table 3). Heavy defoliations drastically reduced basal stem TNC levels below that of the undefoliated control plants, except for heavy defoliations in defoliation treatments 2 and 8.

Antelope Bitterbrush

Both live crown cover and live crown diameter were lower for defoliated antelope bitterbrush plants as compared with control plants (Table 4). Live crown cover was most severely reduced by heavy defoliation during the flowers developing and seed shatter stages, or by defoliation at quiescence and seed shatter. Live crown diameter of antelope bitterbrush plants was most affected by defoliation at the flowers developing and seed shatter stages.

Antelope bitterbrush plants defoliated during quiescence and flower developing had longer twigs than did the control plants (Table 4). Twig length was reduced most by heavy defoliations during the flowers developing and seed shatter stages or defoliations at both moderate and heavy intensities during the quiescence and seed shatter phenological stages. Garrison (1953) found single defoliation treatments to remove tips of twigs during inactive growth periods stimulated several browse species to produce longer twigs.

All defoliated antelope bitterbrush plants were shorter than were control plants (Table 4). Plant heights were most drastically reduced by heavy defoliations during the flowers developing and seed shatter or quiescence and seed shatter stages. Antelope bitterbrush plants heavily defoliated in 1974 during the seed shatter phenological stage showed about 40% reduction in plant height below that of control plants.

Plant vigor categories were detrimentally affected by all the defoliation treatments (Table 4). Antelope bitterbrush plants

Table 4. Average herbage yield, vigor, and total nonstructural carbohydrates (TNC) for antelope bitterbrush (*Purshia tridentata*) subjected to two defoliations during various phenological stages and at two intensities during 1973 and 1974. Measurements and collections were made during the fall of 1974.

		Vigor						
Phenological stages when defoliated	Intensity of foliage removal	Live crown cover (%)	Twig length (cm)	Plant height (cm)	Live crown diameter (cm)	Plant vigor category	Herbage yield (g/plant)	TNC in basal stems (mg/g)
Control (not defoliated)	None	72 a[1]	12 b	60 a	82 a	2.0 a	273 a	45 a
Quiescence, 1973 flowers developing, 1974	Moderate	54 b	16 a	48 bc	61 b	2.6 b	121 b	21 b
	Heavy	46 c	15 a	48 bc	56 bc	3.3 c	84 bc	29 b
Quiescence, 1973 and seed shatter, 1974	Moderate	46 c	6 c	51 b	60 b	4.1 d	63 cde	25 b
	Heavy	31 d	5 c	37 de	54 bc	5.0 e	27 e	28 b
Flowers developing and seed shatter, 1974	Moderate	47 c	10 b	42 cd	50 c	3.6 c	69 cd	28 b
	Heavy	33 d	5 c	34 e	48 c	4.9 e	32 de	32 b

[1] Means in the same column followed by a similar letter are not significantly different at the 0.05 level of probability.

defoliated at the heavy intensity during the flower developing and seed shatter stages had very poor vigor at the end of the 1974 growing season. Vigor of antelope bitterbrush was fair when plants were moderately defoliated during quiescence and flower developing phenological stages. Shepherd (1971) reported that heavy defoliations greatly reduced antelope bitterbrush vigor. Several other workers have shown intensive defoliations reduced plant vigor (Goebel and Cook 1960; Julander 1968).

Herbage yields of all defoliated antelope bitterbrush plants were lower than those of control plants (Table 4). However, yields of antelope bitterbrush plants defoliated at moderate and heavy intensities during the same phenological stages were not found to be significantly different. As expected, herbage yields were most affected by defoliations made during the seed shatter period.

Basal stem TNC levels of antelope bitterbrush were severely reduced below that of the control plants by all the defoliation treatments (Table 4). The TNC levels, however, were similar among the various defoliation treatments. Willard and McKell (1973) also found TNC levels of clipped little rabbitbrush (*Chrysothamnus vicidiflorus*) to be below those of unclipped control plants.

Fringed Sagewort

Fringed sagewort was detrimentally affected by any two multiple defoliation treatments (Table 5). Plants were most affected by heavy defoliations during rapid growth and near maturity. Defoliations were least severe when fringed sagewort plants were moderately defoliated during the quiescence and rapid growth phenological stages.

All of the defoliation treatments reduced live crown cover of fringed sagewort below that of the control plants, but live crown diameter was detrimentally affected by only some defoliation treatments (Table 5). Both live crown diameter and live crown cover of fringed sagewort were reduced most by two heavy defoliations during quiescence and near maturity, or during rapid growth and near maturity stages. Heavily defoliated fringed sagewort plants had less live crown cover and live crown diameter than did plants moderately defoliated during the same phenological stages. Fringed sagewort plants that were moderately defoliated during quiescence and rapid growth or during quiescence and near maturity had live crown diameters similar to those of the undefoliated plants.

Defoliated fringed sagewort plants were shorter than were the undefoliated control plants (Table 5). All multiple defoliations at the heavy intensity resulted in more than a 75% reduction in plant heights. Defoliation effects on plant height were less pronounced when fringed sagewort was defoliated at the moderate intensity during quiescence and rapid growth, or quiescence and near maturity phenological stages.

Plant vigor category was much better for the control fringed sagewort plants than it was for any defoliated plants (Table 5). Vigor of fringed sagewort was poor at the end of the 1974 growing season for all defoliated plants, except when plants were defoliated at a moderate intensity during quiescence and rapid growth or quiescence and near maturity stages. Plants defoliated under these two treatments had a fair vigor rating at the end of the growing season.

Herbage yields of fringed sagewort plants were less for all defoliated plants than they were for the control plants (Table 5). Herbage yield was reduced 40 to 90% below that of the control plants by the various defoliation treatments. Defoliations were more detrimental when plants were defoliated at a heavy intensity than when they were defoliated at a moderate intensity during the same phenological stages.

Root TNC levels of fringed sagewort were reduced by the multiple defoliations, except when plants were defoliated at a moderate intensity during quiescence and rapid growth (Table 5). Some fringed sagewort plants defoliated at the heavy intensity had TNC levels similar to plants defoliated at the moderate intensity.

It appeared that fringed sagewort could withstand multiple defoliations at a moderate intensity only during quiescence and rapid growth. Therefore, complete rest from grazing or clipping during later phenological stages during some years may be required to maintain fringed sagewort vigor, production, and carbohydrate reserve levels.

Grazing Systems

Grazing management should be based on important forage species of an area. Although some species can withstand heavy utilization, it may be necessary to give some important forage species periodic rest to ensure that these species are not replaced by less desirable species that might be capable of withstanding intensive, frequent defoliations or that might not be utilized as heavily by the grazing animals. Several workers have discussed various rotation grazing systems (Hyder and Sawyer 1951; Smoliak 1960; Freeman 1961; Hormay and Talbot 1961; Hormay 1970; Ratliff and Repper 1974). A six-pasture and a five-pasture rest-rotation grazing system are proposed for possible use on these semiarid ranges (Figs. 1 and 2).

In the six-pasture grazing system, pastures would be grazed during the fall (September through mid-December), winter (mid-December through March), spring (April through May), early summer (June through mid-July), and late summer (mid-July through August) periods. This system would ensure that plants grazed during the early summer or late summer period would receive two consecutive summer seasons of rest follow-

Table 5. Average herbage yield, vigor, and total nonstructural carbohydrates (TNC) for fringed sagewort (*Artemisia frigida*) subjected to two defoliations during various phenological stages and at two intensities during 1973 and 1974. Measurements and collections were made during the fall of 1974.

Phenological stages when defoliated	Intensity of foliage removal	Vigor: Live crown cover (%)	Vigor: Plant height (cm)	Vigor: Live crown diameter (cm)	Vigor: Plant vigor category	Herbage yield (g/plant)	TNC in roots (mg/g)
Control (not defoliated)	None	73 a[1]	31 a	5 a	1.6 a	10 a	140 a
Quiescence, 1973 and rapid growth, 1974	Moderate	51 b	17 b	6 a	3.3 b	6 b	118 a
	Heavy	27 c	7 c	3 b	4.7 c	2 cd	44 c
Quiescence, 1973 and near maturity, 1974	Moderate	44 b	14 b	5 a	3.7 b	4 bc	83 b
	Heavy	17 d	5 c	2 bc	5.0 c	2 cd	28 c
Rapid growth and near maturity, 1974	Moderate	28 c	6 c	3 b	4.6 c	4 bc	47 c
	Heavy	11 d	3 c	1 c	4.9 c	1 d	27 c

[1] Means in the same column followed by a similar letter are not significantly different at the 0.05 level of probability.

YEARS	PASTURES 1	2	3	4	5	6
1	Rest	Late summer	Spring	Winter	Early summer	Fall
2	Fall	Rest	Late summer	Spring	Winter	Early summer
3	Early summer	Fall	Rest	Late summer	Spring	Winter
4	Winter	Early summer	Fall	Rest	Late summer	Spring
5	Spring	Winter	Early summer	Fall	Rest	Late summer
6	Late summer	Spring	Winter	Early summer	Fall	Rest

Fig. 1. *A proposed six-pasture rest-rotation grazing system designed to give plants a rest period following grazing during the critical late summer period.*

YEARS	PASTURES 1	2	3	4	5
1	Rest	Late summer	Spring	Early summer	Fall & winter
2	Fall & winter	Rest	Late summer	Spring	Early summer
3	Early summer	Fall & winter	Rest	Late summer	Spring
4	Spring	Early summer	Fall & winter	Rest	Late summer
5	Late summer	Spring	Early summer	Fall & winter	Rest

Fig. 2. *A proposed five-pasture rest-rotation grazing system designed to give plants a rest period following grazing during the critical late summer period.*

ing the summer grazing.

In the five-pasture system, plants would be grazed during quiescence (September through March), early spring growth (April through May), rapid growth (June through mid-July), and near maturity (mid-July through August) phenological stages. Pastures grazed in the early summer in one year (June through mid-July) would be rested during the next summer period. Two consecutive summer seasons of rest following critical late summer grazing (mid-July through August) would be attained by utilizing this five-pasture grazing system.

Trlica et al. (1977) reported that several species made good recovery after one year of rest following a single, heavy defoliation. Therefore, the rest periods illustrated in Figures 1 and 2 should be adequate to restore herbage yield, vigor, and TNC levels of moderately grazed plants. These grazing systems might, however, require a great deal of fencing, water development, and animal movement. In addition, supplemental feeding would probably be required during the fall and winter extended grazing period under the five-pasture system to avoid over utilization of plants. However, the long-term benefits to the vegetation resource through use of one of these grazing systems might outweigh the possible capital expenditures and labor costs necessary to utilize these rest-rotation plans. In addition, use of one of these rest-rotation grazing systems might result in improved range condition through time.

Summary and Conclusions

The effects of foliage removal on herbage yield, vigor, and TNC levels of fringed sagewort and antelope bitterbrush were studied on an intermountain shrubland range near Maybell, Colo. Blue grama, western wheatgrass, and fourwing saltbush were studied on a shortgrass prairie site at the Central Plains Experimental Range (CPER) in northeastern Colorado. All species were defoliated at 60% (moderate) and 90% (heavy) foliage removal during several phenological stages. Plants were clipped three or four times over a 2-year period at the CPER; plants at the Maybell location were clipped only twice.

Three moderate defoliations during rapid growth, seedset, and quiescence were less severe for fourwing saltbush than they were for western wheatgrass and blue grama. Fourwing saltbush subjected to three moderate defoliations remained in good vigor at the end of the 1974 growing season. However, four multiple defoliations during several phenological stages were extremely detrimental to vigor of fourwing saltbush.

Fourwing saltbush given three moderate defoliations during rapid growth, seedset, and quiescence resulted in stimulations of twig growth. Herbage yields of fourwing saltbush plants moderately defoliated three times over a 2-year period were 20 to 80% greater than were herbage yields of plants that had received four defoliations during the 2-year period. Moderate utilization during the fall and spring or fall and early summer may have little effect on fourwing saltbush plants. However, fourwing saltbush could not withstand four heavy defoliations. Continuous use at this intensity and frequency might kill the plants. The present study indicated that fourwing saltbush would probably benefit from rotation grazing that would allow for complete rest during some growing seasons.

In general, live crown cover of fourwing saltbush was severely reduced by heavy defoliations during the seedset period of the second growing season. However, live crown diameters for most defoliated fourwing saltbush plants were similar to those of the control plants. All defoliation treatments severely reduced the number of seedstalks, but seedstalk lengths were less affected by multiple defoliation treatments.

Undefoliated blue grama and western wheatgrass plants were taller and had greater basal cover than did any of the defoliated plants. Plant heights were severely reduced by all multiple defoliation treatments. Defoliations made late in the growing season of the second year were most detrimental to herbage yield and vigor of blue grama and western wheatgrass. The data indicated that both basal cover and plant height were good indicators of the effects of defoliation treatments on the welfare of these two species.

All heavy defoliations drastically reduced TNC levels of western wheatgrass and fourwing saltbush, except when fourwing saltbush received three heavy defoliations during rapid growth, seedset, and quiescence. The effects of the multiple defoliations on the TNC levels of these two species were less severe when plants were defoliated at a moderate intensity. Blue grama root TNC levels were not severely reduced by any multiple defoliation treatment. The resistence of blue grama to defoliations may be related to its ability to remain semidormant when environmental conditions are unfavorable following defoliation, thereby reducing grazing or clipping effects.

Results of the study showed that fringed sagewort and antelope bitterbrush were most detrimentally affected when defoliated during the later part of the growing season. Little possibility existed for regrowth at that time. In general, heavy defoliations resulted in greater reductions of herbage yield and vigor than did moderate defoliations during the same phenological stages. However, differences among heavy and moderate defoliation intensities were small when defoliations were made during the later part of the growing season.

Antelope bitterbrush plants defoliated at a moderate intensity during quiescence and flowers developing remained in good vigor at the end of the growing season. Twigs of antelope bitterbrush defoliated at a moderate intensity during those phenological stages were longer than twigs of the undefoliated control plants. In general, herbage yield and vigor measurements were lower for antelope bitterbrush defoliated during flowers developing and seed shatter or during quiescence and seed shatter. All defoliation treatments severely reduced basal stem TNC levels of antelope bitterbrush.

Most defoliation treatments greatly reduced herbage yields, vigor, and TNC levels of fringed sagewort below that of the control plants. Defoliation effects, however, were less severe when fringed sagewort was moderately defoliated during quiescence and rapid growth than at other phenological stages. The TNC levels in roots of fringed sagewort defoliated at a moderate intensity during quiescence and rapid growth were similar to those of the control plants. It appeared that fringed sagewort could only withstand multiple defoliations during quiescence and rapid growth at a moderate intensity.

Five- and six-pasture rest-rotation grazing systems were proposed for possible use on these semiarid ranges. These grazing systems would insure that plants utilized during the critical late summer period would receive two consecutive summer seasons of rest following grazing.

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