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Oxalate and Mineral Contents of *Halogeton Glomeratus*[1]

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OXALIC acid and oxalates occur in many plants. Consumption of plants containing high concentration of oxalates can be poisonous to animals. This has been reported by several investigators (5, 7, 9). However, in only a few plants are oxalates found in sufficient quantities to be lethal. Some species with a relatively high oxalate content are: sorrel (*Rumex* spp.), rhubarb (*Rheum* spp.), greasewood (*Sarcobatus vermiculatus* Torr.), soursobs (*Oxalis cernus* Thunb.), and halogeton (*Halogeton glomeratus* C. A. Mey.).

Early literature makes no reference to the occurrence of oxalate in halogeton or of its possible poisonous effects upon animals. Following severe livestock losses in 1942, investigators at the University of Nevada Agricultural Experiment Station found large quantities of halogeton in the stomachs of poisoned animals. They (6) later found that halogeton contained oxalates equivalent to as high as 19 percent anhydrous oxalic acid and suggested oxalate as the toxic principle in halogeton. Their work showed also that the amount of halogeton required to kill a sheep was approximately 166 grams per 100 pounds of body weight (4). Studies in Utah (2) determined that 12 ounces or 342 grams of halogeton containing 8.7 percent soluble oxalates, or about 1 ounce of the soluble oxalates, were required to kill a sheep. This occurred after fasting sheep for 36 hours and giving the halogeton in a single feeding. However, 18 ounces of halogeton, equivalent to 1.6 ounces of the soluble oxalates, were required to produce lethal effects when the animal had been maintained on its usual ration.

Livestock losses due to halogeton poisoning have generally occurred during the fall and early winter, but some losses have

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occurred during the spring. Historically these losses have been sporadic and severe.

Dye (3) found that the leaf-seed-sepal fraction of the halogeton plant contained most of the soluble oxalate (19.53 to 32.81 percent) and that the stem fraction contained relatively small amounts (1.59 to 5.06 percent). He also found that the leaf-seed-sepal fraction collected in August contained 17.98 percent crude protein, 5.51 percent ether extract, 12.67 percent crude fiber, 22.25 percent nitrogen-free extract, and 41.59 percent ash; and that the stem fraction contained 7.83, 0.83, 29.32, 34.48, and 27.54 percent of these constituents, respectively. Cook and Stoddart (2) reported that halogeton plants contained up to 28 percent soluble oxalates during the early fall and decreased to a minimum of 5 percent by early spring, except in instances where the plants were covered with snow during the winter months.

Prior to 1950, only meager information was available concerning the accumulation and persistence of oxalate in halogeton plants throughout the entire year. Information on chemical constituents other than oxalates was lacking. No data were available concerning the composition of halogeton plants growing on soils in southern Idaho, where some of the major livestock losses have occurred.

The present investigations were initiated in southern Idaho in 1950 to determine the variations and trends in the chemical composition of halogeton as influenced by growth stages, weather conditions and soil types. Chemical analyses were made on samples collected at intervals throughout the year from several locations to determine seasonal variations in: (1) water-soluble and total oxalate content; (2) rate of oxalate loss under observed weather conditions; (3) oxalate and cation contents of plants grown in soils of varying soil salinity; and (4) ash content.

MATERIALS AND METHODS

Oxalate studies.

Two types of studies were conducted to determine the quantity of oxalates in halogeton and factors influencing concentration and persistence. The first was initiated in 1950 and continued as a combined study for three successive years. This study was designed to determine the oxalate content throughout the entire year, beginning with the young growth in June and continuing through to the following April. Collections were made in three sampling areas in the Raft River Valley of southern Idaho. These were progressively about 20 miles apart, namely, at the Idahome, Bridge, and Almo desert exclosures, all in Cassia County.

To obtain more detailed information on the influence of environmental site a second study was initiated in 1951. In it the analyses from the three sites were calculated and maintained separately. This study demonstrated the influence of environment on plant growth and subsequent oxalate persistence.

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same stiff upright position into the succeeding spring. In this study as in all succeeding phases the samples were obtained by severing the plants at the soil surface. They were weighed immediately, air dried, and stored for further analyses. Oxalate determinations were made by the method developed by Miller (6) and described by Dye (3).

A third study to determine influence of precipitation on oxalate loss in halogeton was initiated in the fall of 1951. Plants were obtained from a localized area near Idahome in mid-September. The plants were selected for uniformity of development and size. Twenty plants were protected indoors until November 3 when they were secured in a firm upright position in wooden flats and placed in the fenced weather station exclosure on the University of Idaho campus at Moscow.

Oxalate and cation studies.

To obtain more detailed information on chemical composition two additional studies were conducted. In the first, halogeton samples were collected at Bridge during the 1951 growing season. These were analyzed for the following constituents: water-soluble and total oxalates, and total sodium, potassium, calcium, and magnesium.

Still more detailed information on environmental influence upon chemical composition was derived from a vegetation type study. Plants were collected in September 1956 from sites representative of the sagebrush *(Artemisia tridentata* Nutt.), salt sage *(Atriplex Nuttallii* S. Wats.), and perennial Kochia *(Kochia vestita* S. Wats.) vegetational types and subjected to similar analyses. In addition, a collection was made from a site denuded of all perennial vegetation. Like many small desert sites this area had the perennial vegetation so completely removed that it was impossible to determine its original vegetal cover. This area is hereafter designated as the bare site.

Soil profile samples were taken from each of the mentioned collection sites. These were analyzed for pH of the soil paste; electrical conductivity; total, exchangeable, and water-soluble sodium; and for water-soluble potassium, calcium, and magnesium.

Analyses for total sodium and potassium in the plants were run according to flame photometric procedures. Total calcium and magnesium were determined by analyzing for the oxalate and phosphate precipitates of these ions respectively. Cations were determined as percent of air-dry plant materials. Soil and plant analyses were conducted as outlined in Agricultural Handbook No. 60 (8) and the Official Methods of Analysis of the Association of Official Agricultural Chemists (1).

Three major collections were used for ash determinations: (a) the 1951–52 collections; (b) plants collected at four stages of growth at Bridge, during the 1951 growing season; and (c) plants collected from the four vegetation types in September 1956. The ash determinations were made using a muffle furnace at a dull red heat until the samples were burned to a whitish-tan color. All determinations were made on air-dry plant materials.

RESULTS AND DISCUSSION

Influence of season and location on oxalate content.

Data on both the water soluble and the total oxalate contents of halogeton plants collected during 1950, 1951, and 1952 are contained in Table 1. These are expressed as the percentage of air-dry weight

Table 1. Average percentages of water-soluble and total oxalate content (air-dry basis) of halogeton plants collected at the Idahome, Bridge, and Almo exclosures during the 1950, 1951, and 1952 growing seasons and in the subsequent fall, winter, and spring months.

Collection month	Growth stage or condition	Average percent oxalate in halogeton							
		1950–51		1951–52		1952–53		3-year average	
		Water-soluble	Total	Water-soluble	Total	Water-soluble	Total	Water-soluble	Total
June	Cruciform	19.3	21.6	17.9	21.2	19.5	20.6	18.9	21.1
July	Mid-flowering	18.5	20.9	16.6	19.6	17.5	19.1	17.5	19.9
August	Late flowering	16.3	19.1	15.2	17.5	15.5	17.6	15.7	18.1
September	Seed maturation	18.1	20.6	15.5	17.5	16.7	17.8	16.8	18.6
November	Dead	14.9	20.6	14.9	16.4	16.2	16.5	15.3	17.8
December	Dead	8.9	11.9	16.7	17.0	15.6	17.4	13.7	15.4
January	Slightly weathered	6.5	9.7	—	—	12.6	16.4	9.6	13.1
February	Weathered	5.6	9.5	10.2	13.6	7.5	10.4	7.8	11.2
March	Extremely weathered	3.9	8.7	6.5	9.1	—	—	5.2	8.9
April	Extremely weathered	2.1	6.3	7.6	10.6	—	—	4.8	8.4

equivalent to anhydrous oxalic acid. The oxalate concentration was found to be consistently high throughout the growing season. It was usually highest in June, tending to decrease during July and August, with a slight increase occurring in September. Thereafter the oxalate content decreased progressively into spring.

As shown in Table 2, the rate of oxalate loss in 1951–52 was different at each of the three collection sites. Presumably this was due to differences in the size and growth habits of the plants and differences in the amount and type of precipitation. In these collections the plants at Idahome were tall and upright, those at Almo of intermediate growth, and those at Bridge short and prostrate. The September collections contained 18.7, 16.4, and 17.4 percent total oxalates respectively. By the following April few leaves remained on the tall Idahome plants while the short Bridge site plants retained

Table 2. Average percentage of water-soluble and total oxalate content (air-dry basis) of halogeton plants collected at the Idahome, Bridge, and Almo exclosures during the fall, winter, and spring months of 1951–1952.

Collection month	Percent oxalate in halogeton					
	Idahome		Bridge		Almo	
	Water-soluble	Total	Water-soluble	Total	Water-soluble	Total
September	16.6	18.7	15.1	17.4	14.8	16.4
November	15.1	17.9	16.7	18.4	14.7	15.0
December	8.7	11.3	16.7	17.8	22.9	23.6
February	6.0	8.8	9.8	14.3	14.7	17.6
March	2.8	3.5	7.1	13.9	9.7	9.9
April	5.6	5.9	10.0	14.5	7.2	11.4

most of theirs. The April 1952 collections yielded 5.9, 11.4, and 14.5 percent total oxalates for the Idahome, Almo, and Bridge samples respectively.

In the October collections a portion of the plants from the Idahome site were divided into stem, and leaf-seed-sepal fractions. These were found to have a total oxalate content of 2.0 percent in the stems and 24.6 percent in the leaf-seed-sepal fraction. These results confirm Dye's (3) report that most of the oxalate is contained in the leaf-seed-sepal fraction.

Since most of the oxalates occur in the leaf fraction, loss of leaves, seeds, and sepals probably accounts for the major differences in oxalate content among different sites as the seasons advanced. Therefore, high leaf retention at a certain site may account for livestock losses in early spring even though the mature halogeton has been assumed to have a uniformly low oxalate content. Likewise, the toxicity revealed in feeding trials may vary primarily according to the proportion of leaves present in the samples fed.

Halogeton is a very succulent plant containing as high as 85 percent moisture early in the growing season. A high moisture content is retained throughout the growing season, dropping to a minimum of 50 percent in September. The data show that young and mature plants contain practically equal concentrations of oxalates on a dry weight basis. However, the high moisture content of green halogeton may in part explain why no livestock losses have been reported during the summer. Due to the high moisture content of green plants a much greater volume would have to be consumed during the summer than in the winter to obtain equivalent amounts of oxalate. In addition, it appears that halogeton is relatively less palatable during the summer, and also, other forage plants are usually more abundant than in the fall and winter.

Rate of oxalate loss.

The percentage oxalate in halogeton plants exposed to weather conditions from November 3, 1951, to April 28, 1952, under the humid conditions at Moscow, Idaho, are shown in Table 3. From November 3 to December 1, 1951, relatively little precipitation occurred until the last two days of this interval. This precipitation was sufficient to thoroughly wet the plants. During the period December 1 to December 3 nearly all of the precipitation occurred in the form of rain and resulted in the largest oxalate loss per unit of precipitation during the study. From December 3 to December 20 precipitation occurred as both rain and snow but produced less oxalate loss per inch of precipitation than in the preceding interval. From December 20, 1951, to January 27, 1952, most of the precipitation was in the form of snow. Although precipitation during this interval totaled 4.5 inches, the decrease in total oxalate in the halogeton plants was only 0.6 percent per inch of precipitation. However, from January 27 to February 28, 1952, most of the precipitation occurred as rain. In this instance, the decrease in total oxalate was 1.9 percent per inch of precipitation. In the study of

oxalate contents in the field (Table 2) and in this study at Moscow snow appeared to be less effective than rain in reducing the oxalate content.

Table 3. Average content of halogeton plants (calculated on air-dry basis) exposed to weather conditions at Moscow, Idaho, from November 3, 1951, to April 28, 1952.

Sampling date	Precipitation between sampling dates		Oxalate content, percent		Percent of initial oxalate lost[a]		Oxalate loss/inch of precipitation, percent	
	Total inches	Snow inches	Water-soluble	Total	Water-soluble	Total	Water-soluble	Total
November 3, 1951			14.0	15.5				
December 1, 1951	1.7	0.0	11.8	13.7	15.7	11.6	1.3	1.1
December 3, 1951	0.4	Tr.	10.0	11.4	28.6	26.4	4.5	5.8
December 20, 1951	1.4	9.3	8.0	10.6	42.8	31.6	1.4	0.6
January 27, 1952	4.5	45.7	6.5	7.8	53.6	49.7	0.3	0.6
February 28, 1952	1.8	6.0	3.1	4.4	77.8	71.6	1.9	1.9
March 20, 1952	1.2	4.0	0.5	0.7	96.4	95.5	2.2	3.1
April 28, 1952	2.0	0.0	0.2	0.4	98.6	97.4	0.2	0.2
Total	13.0	65.0						

[a]Values calculated from initial water-soluble and total oxalate contents of 14.0 and 15.5 percent, respectively.

These studies demonstrated that the reduction of oxalate in halogeton is due primarily to leaf and seed drop expedited by precipitation. Since in October collections the combined leaves, seeds, and fruiting bracts contain about 12 times as much oxalate as the stems, the loss of these parts has a much greater effect upon the decrease in oxalate contents than the leaching of plants. The type of precipitation can be an important factor in the rate of oxalate loss, since heavy sleet or violent wind storm may contribute to leaf fall. Furthermore, the storms occurring in the halogeton-infested areas of the western United States are often localized. This can cause considerable variation in the rate of decline in oxalate contents in different localities. For example, when the plants are covered with snow during much of the winter, the plants may maintain a high oxalate concentration into early spring. This combined with the typical scarcity of late-winter forage increases the hazard of late-winter or early-spring poisoning. Conversely, precipitation in the form of rain and an open winter may decrease the hazard of livestock poisoning.

Interrelation of oxalate and cation contents and soil type.

Table 4 shows the oxalate and cation contents of halogeton plants collected at Bridge at several growth stages in 1951. Both the oxalate and sodium contents decreased from the early stages of growth through the mid-flowering stage. The potassium, calcium, and magnesium levels remained relatively constant. Samples collected at the seed maturation stage contained slightly greater amounts of oxalate and sodium than samples collected at the late-flowering stage. The sodium content was relatively high at all stages of growth.

Table 4. Average percentage of oxalate and cation content (calculated on air-dry basis) of halogeton plants collected at Bridge, Idaho, at four stages of growth in 1951.

Date	Growth stage	Oxalate content, percent		Cation contents, percent				
		Water-soluble	Total	Na	K	Ca	Mg	Total
June 22	Cruciform	21.4	24.3	11.3	3.8	1.4	0.6	17.1
July 23	Mid-flowering	18.6	21.2	10.0	3.7	1.2	0.5	16.4
August 22	Late flowering	17.1	19.2	9.3	3.9	1.3	0.5	15.0
September 21	Seed maturation	17.8	20.2	9.7	3.9	1.3	0.4	15.3

The oxalate and cation contents of plants collected from the four vegetation-type sites are shown in Tables 5. The sodium content was found to be extremely high in plants grown at all the sites, ranging from 8.0 percent at the sagebrush vegetational type to 12.5

Table 5. Average oxalate and cation content (calculated on air-dry basis) of halogeton plants collected in September 1956, from four vegetational types in southern Idaho.

Vegetational type	Oxalate content, percent		Cation content, percent				
	Water-soluble	Total	Na	K	Ca	Mg	Total
Bare[a]	16.8	18.3	11.9	3.0	0.6	0.4	15.9
Saltsage	18.0	19.4	10.4	4.1	0.8	0.5	15.8
Kochia	18.5	20.2	12.5	3.8	0.7	0.4	17.4
Sagebrush	14.8	17.5	8.0	5.0	1.3	0.7	15.0

[a]A site without perennial vegetation covered primarily with clasping-leaved peppergrass (*Lepidium perfoliatum* L.), halogeton, and other annuals.

percent at the kochia type. There appeared to be an inverse relationship between sodium and the other cations. The percentages of potassium, calcium, and magnesium from the different sites were greater in plants containing less sodium. Oxalates were found to be higher in plants containing the greatest percentage of sodium and the least percentage of other cations. Larger quantities of insoluble oxalates (differences between the total and water-soluble oxalates) were found in plants containing the greater quantities of calcium. These relations suggest that the oxalate content of halogeton may be associated with the mineral composition of the plant.

Soil analyses from the four vegetative-type sites appear in Table 6. The sample depth; pH; electrical conductivity; total, exchangeable, and water-soluble sodium; and other water-soluble cations are given. Samples from the entire soil profile at each site were analyzed; however, portions of the soil profile from approximately 4 to 13 inches were found to characterize the soil profiles. For the sake of brevity, only data from this portion of each soil profile are presented (Table 6). From these data it is evident that halogeton occurs under widely varying soil conditions and can grow on soils of very high salinity. It is also apparent that the concentration of cations in halogeton is not directly correlated to their relative concentration in the soil.

The large quantities of sodium found in plants grown on soils of both high and low sodium concentrations indicate that this plant is an accumulator of sodium.

The data suggest that with increasing soil pH there was a decrease in accumulation of sodium in the plants. Plants growing in soils with pH readings of 7.7, 7.9, 8.1, and 8.2 (Table 6) had sodium percentages (Table 5) of 12.5, 11.9, 10.4, and 8.0, respectively. The high sodium content in the soils of low pH readings undoubtedly influenced the accumulation of this ion in the plants; however, the plants did not accumulate sodium in proportion to the concentration of sodium in the soil.

Table 6. Cation content, electrical conductivity, and pH of soils collected in September, 1956, from four vegetational types in southern Idaho.

Vegetational type	Sample depth inches	Electrical conductivity ($ECX10^3$)[b]	pH[c]	Cations = milliequivalents per 100 grams of soil					
				Total Na	Exchangeable Na	Water-soluble cations			
						Na	K	Ca	Mg
Bare[a]	5–10	62.3	7.9	29.2	8.5	20.7	0.6	2.4	0.9
Saltsage	4–12	2.2	8.1	1.0	0.8	0.2	2.4	0.2	0.1
Kochia	6–12	45.3	7.7	21.9	5.8	16.1	0.7	3.4	1.6
Sagebrush	6–13	1.1	8.2	1.0	0.9	0.1	0.3	0.2	0.1

[a]A site without perennial vegetation covered primarily with clasping-leaved peppergrass (*Lepidium perfoliatum* L.), halogeton, and other annuals.
[b]Electrical conductivity is millimhos/cm ($ECX10^3$) at 25° C. of a saturated soil extract.
[c]pH determined on saturated soil paste.

Ash contents

Data on the ash contents of halogeton plants collected during the 1951 growing season and the fall, winter, and spring of 1951–52 are summarized in Table 7. The ash content was highest in June, when the plants were growing most rapidly, and lowest the following April. The ash content was found to be extremely high during the growing season.

The samples collected during the growing season fused when ashed at temperatures above 750° F. The fusion temperature progressively increased for the samples collected during the following fall, winter, and spring. This would indicate that the lighter metals were lost as the plants weathered.

The ash contents of plants collected in 1951 at Bridge in the cruciform, mid-flowering, late flowering, and seed maturation stages were 36.7, 35.2, 34.2, and 33.9 percent, respectively. These values are somewhat lower than those given in Table 7 for the samples

Table 7. Average ash content of halogeton plants collected from three sites during the 1951 growing season and the fall, winter, and spring of 1951–52, calculated on basis of air-dry plant material.

Collection month	Ash content %	Collection month	Ash content %	Collection month	Ash content %
June 1951	40.2	September 1951	35.3	February 1952	22.0
July 1951	37.7	November 1951	32.2	March 1952	21.2
August 1951	37.9	December 1951	25.6	April 1952	20.8

collected from June to September at other sites, but they show the same progressive decrease in ash content as the plants advance in maturity.

In addition to the elements listed in Tables 4 and 5, qualitative analyses of the ash revealed the presence of many other elements commonly found in plants. Quantitative analyses failed to show a large accumulation of other elements.

The halogeton plants collected from the kochia, bare, saltsage and sagebrush vegetational type sites (Table 6) contained 39.9, 39.5, 34.1 and 33.2 percent ash, respectively. These data suggest that with increasing soil pH there was a decrease in accumulation of total ash in the plants. This is probably due to the influence of pH upon the sodium accumulation in the plants.

The accumulation of large amounts of ash from throughout its root zone and especially large amounts of sodium suggests that the annually returning plant residues may increase salinity of the surface soil. While this may be only of minor importance in areas supporting the salt-desert shrub vegetational types, it could be of major importance in the sagebrush-grass and other types with non-saline soils in converting these to a saline-alkali type.

SUMMARY

The oxalate and mineral contents of halogeton plant material were studied by collecting plants at monthly intervals during three growing seasons and the subsequent fall, winter, and spring. Rate of oxalate loss from halogeton plants exposed to weather conditions at Moscow, Idaho, were determined. The oxalate and cation contents of halogeton plants were determined from collections made at different stages of growth and on various soil sites. It was found that:

1. The oxalate content of halogeton plants ranges from 18 to 21 percent on the air-dry weight basis, being highest in the early growing season when the plants are growing rapidly.
2. Most of the oxalate is contained in the leaves, seeds, and fruiting bracts, and relatively small amounts occur in the stems.
3. The rate of oxalate loss during the winter and spring months is affected more by factors which influence the loss of leaves, seeds, and fruiting bracts, than by total precipitation. However, rain appears to be more effective than snow in reducing the oxalate content of matured plants. These factors cause considerable differences in the oxalate contents of halogeton plants at different sites by late winter or early spring.
4. Halogeton plants accumulate large amounts of sodium. The sodium content is highest in young plants and declines steadily as the plants approach maturity. The content of potassium, calcium, and magnesium tends to vary inversely with the sodium content.
5. A relatively high oxalate concentration in the plants is associated with a high sodium content.
6. The ash content of halogeton is highest in young plants and

steadily declines during the growing season and the months following the plants maturity.

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