Composition of Saline Residues on Leaves and Stems of Saltcedar (*Tamarix pentandra* Pallas)

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By JOHN D. HEM

STUDIES OF EVAPOTRANSPIRATION

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Analyses of saline deposits leached or washed from saltcedar plants

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COMPOSITION OF SALINE RESIDUES ON LEAVES AND STEMS OF SALTCEDAR (*TAMARIX PENTANDRA* PALLAS)

By JOHN D. HEM

ABSTRACT

Saltcedar leaves and stems collected along the Gila River in Safford Valley, Ariz., and at various locations in the Rio Grande and Pecos basins of New Mexico, were analyzed for inorganic ions. The total content of calcium, magnesium, sulfate, and chloride in the leaves generally ranged between 5 and 15 percent of their dry weight. From a few tenths of a percent to more than 3 percent of the dry weight of the leaves consisted of inorganic ions which could be washed off by rainfall. In most samples, the predominant inorganic anion was sulfate. Leaves highest in sodium and chloride content were obtained from trees growing where ground water had a high salinity.

The amounts and composition of inorganic solutes which are present in saltcedar leaves are influenced by numerous factors including composition of water available to the plant, the time of year, the rates of growth and transpiration before sampling, and the amount and frequency of antecedent rainfall.

UPTAKE AND CIRCULATION OF INORGANIC IONS BY PLANTS

The processes whereby plans absorb inorganic ions from soil solutions and the means which certain species of plants have for coping with excessive salinity in water and in soil have been studied for a long time. The published literature on these subjects, however, indicates that although some understanding has been gained, the details of the processes involved are far from being completely understood.

Some of the major constituents dissolved in natural water, in particular calcium, magnesium, sulfur, and carbon, are essential for plant growth. Most of the carbon required for carbohydrate synthesis is taken from atmospheric carbon dioxide, however, and the oxygen and hydrogen required are supplied from the water itself. Chlorine is required for plant growth only in small quantities and sodium apparently is essential for some but probably not all plants. Other essential elements such as iron are commonly present in smaller amounts in natural water (Sutcliffe, 1962, p. 6). It is to be expected that plant parts where metabolic processes are actively taking place, especially the leaves, would contain all the elements needed by the plants. Other elements extracted with the nutrients from the medium in which the plant is growing also might be present. Some plant species are noted for their tendency to accumulate elements present in minor amounts in the soil. Certain species of *Astragalus*, for example, accumulate selenium in large amounts (Anderson and others, 1961, p. 35).

Sutcliffe (1962, p. 5) presented data he had obtained from the literature showing that specimens of stonewort *Chara ceratophylla*, contained similar amounts of calcium, magnesium, and potassium regardless of the composition of the medium in which they were grown but that amounts of sodium and chloride taken up did depend to some extent on the concentration of these elements in the available water. He commented, "In particular, sodium is present at a low concentration in the above-ground parts of many plants, irrespective of the amount of sodium in the soil * * *." Evidently some plants reject sodium, and others may take it up only incidentally in obtaining other nutrient ions.

Saltcedar is the common name applied to two deciduous species of the genus *Tamarix* (*T. pentandra* Pallas and *T. gallica* Linneaus) which have become nuisance plants along streams in parts of the Western United States (Robinson, 1965). One of the distinctive traits of the saltcedar is its ability to thrive in areas where the ground water, from which its water requirements are met, has a rather high dissolved-solids concentration. The plant does not appear to be a true halophyte in the sense that it requires a saline environment, but it can thrive in places where the growth of most other vegetation is strongly inhibited and thus shares some of the properties of the halophytes.

The assimilation of water by plant roots involves the passage of water molecules through root membranes by osmosis, movement of water being toward the solution of higher solute concentration. Some solute ions pass with the water through the root membranes and generally supply the nutrient needs of the plant.

To obtain water from the soil, plants must overcome two forces. The first of these, soil-moisture tension, causes water films to adhere to soil particles. The other force is the osmotic pressure required to separate solvent molecules from a solution, and this force increases as the concentration of dissolved solids in the solution rises. Thus, as the salinity of available water around a plant's root system increases, the osmotic pressure required to extract water molecules becomes greater and greater. If the salinity of the soil water is too great, the plant will succumb from lack of water because it is unable to attain a high enough osmotic pressure.

Halophytic plants in general can exert a high osmotic pressure. According to Sutcliffe (1962, p. 156), this is mainly because of high sodium and chloride content of the cell sap. In some plants of this class, the salt concentration of the cell sap rises throughout the growing season, but in others the concentration is maintained at a fairly constant level by certain regulatory mechanisms. The presence of large amounts of water in the tissues of succulent plants is one mechanism for preventing excessively high dissolved-salt concentrations within the plant. Many halophytes are succulent plants.

More freely transpiring halophytic plants, however, require other mechanisms. Certain plants, including saltcedar (Decker, 1961), have organic structures termed "salt glands" on their leaves which can excrete fairly concentrated solutions. The salt in this solution is left behind on the leaf surface when the water is evaporated and may be washed from the plant by rain or blown off by wind.

The manner in which salt glands remove or concentrate salt from the internal solutions of the plant is not fully understood, although Sutcliffe (1962, p. 161) thought it probable that the glands perform osmotic work. If so, the plant actually expends energy in the process of eliminating salt. A fairly detailed anatomical description of the salt glands of saltcedar has been given by Campbell and Strong (1964).

Another process by which a plant may rid itself of saline material is the process of guttation. When transpiration ceases, at the end of the day, the solutions in the plant circulatory system may continue moving upward and outward to leaf surfaces, and drops of moisture may thus appear on the leaves. This moisture, although it has the appearance of dew condensed from the atmosphere, can be highly charged with salt derived from residues left in the leaf structures from the day's transpired solution, as well as from residues on the leaves from the activities of the salt glands and the evaporation of prior guttation.

The green leaves of saltcedar plants commonly carry small cubic crystals which are readily seen with the aid of a hand lens. Although the appearance of the crystals suggests they are nearly pure sodium chloride, the salt brought to the leaf surfaces also includes considerable amounts of other ions. The salt is transferred to the ground by rainfall or wind. Actual quantities of salt involved in such transfer mechanisms in areas of dense saltcedar growth have never been determined. Qualitative evidence includes the absence near saltcedar of vegetation having a low salt tolerance and the high corrosion rate of metals exposed in saltcedar thickets.

Decker (1961) noted the salt crystals on the foliage of saltcedar and the formation of whiskers of salt at the sites of the salt glands on the leaf surfaces. In his experiments, these salt deposits proved to be deliquescent and went into solution when the twigs were exposed to humid air. Drying caused cubic salt crystals to form on the leaves. Decker believed the liquid observed on saltcedar leaves in the field, which had been ascribed to guttation (Gatewood and others, 1950), was actually the result of the condensation of atmospheric moisture.

COLLECTION OF DATA

During investigations of water quality in Arizona and New Mexico in which the writer participated in the 1940's, the presence of salt crystals on saltcedar foilage was noted on many occasions, and from time to time several types of experiments were performed on samples of foilage to determine the quantity and nature of the saline material. The results of these experiments were not highly consistent or simply interpretable, and most of them were never published. Owing to increased interest in the processes whereby salt-tolerant plants are able to grow and in the details of the transpiration processes of the saltcedar, the data have been reexamined and are presented here as an aid in understanding some features of the solute circulation of the saltcedar and to aid in planning further studies of the process.

The samples usually consisted of green leaves and associated stems. Some collections were made after the end of the growing season when the leaves were no longer green, but most specimens were actively growing when collected. Generally, a sample of about 25 grams was obtained in the field by clipping leaves and stems from a single plant. In the studies of 1940 and 1944, the samples were brought to the laboratory and allowed to dry in the open air. About 2 g of this material was then oven dried at 110° C for 1 or 2 hours. The weight loss from oven drying, generally between 10 and 15 percent, was ascribed to moisture not removed by air drying. The plant material lost most of its green color during oven drying, however, so some breakdown of the organic material probably also took place. About 5.0 g of the air-dried material was placed in a beaker, 100 milliliters of distilled water was added, and the solution stood with occasional stirring for 16 to 24 hours. In some of the experiments, the leaching was done at room temperature; in others, the solutions were kept warm on a water bath. The temperature at which the leaching was performed did not affect the results significantly.

After the leaching, the solution was filtered and quantitatively transferred to a 250-ml volumetric flask. The flask was then filled to the mark with distilled water, and the solution was analyzed for calcium, magnesium, sulfate, chloride, and bicarbonate content and for total dissolved material. Results were calculated as percentages of the air-dried sample weight.

A large part of the material leached from the leaves and stems was organic, and the final solutions generally were strongly colored. The inorganic ions which were leached probably represented not only the saline deposits on leaf surfaces but also any ions that were present anywhere in the leaf tissues in combination with organic ligands. The analytical results are given in table 1.

TABLE 1. *Composition of solids leached from saltcedar leaves, 16 to 24 hours contact time*

Sample	Percent of air-dried sample: Residue after evaporation (heated for 1 hr at 180°C)	1 Calcium	2 Magnesium	3 Sulfate	4 Chloride	Sum (1-4)	Sulfate: chloride	Description
A.—Vegetation along Pecos River between Artesia and Carlsbad, N. Mex., sampled March 4-7, 1940								
1	29.5	----------	----------	4.9	2.7	----------	1.8	New growth on tree at bridge on New Mexico Highway 83, east of Artesia, N. Mex.
2	17.1	----------	----------	3.1	2.2	----------	1.4	New growth on tree on river bank near Carlsbad Spring, Carlsbad, N. Mex.
3	29.7	----------	----------	6.0	2.6	----------	2.3	Dead leaves from previous season on tree at bridge on New Mexico Highway 83, east of Artesia, N. Mex. Average of two samples.
B.—Vegetation in Safford Valley, Ariz., sampled November 1944								
4	28.5	1.7	0.7	5.2	0.8	8.4	6.5	Saltcedar growing in tank 16, Glenbar experiment station, Arizona. Water table held at 6.0 ft below surface.
5	26.5	2.4	.5	7.1	1.0	11.0	7.1	Saltcedar growing in tank 21, Glenbar experiment station, Arizona. Water table held at 6.0 ft below surface.
6	26.8	1.4	.6	4.7	.9	7.6	5.2	Saltcedar growing naturally near tank 16, Glenbar experiment station, Arizona.
7	26.8	1.3	.5	5.4	4.1	11.3	1.3	Saltcedar growing beside drain ditch from Knowles flowing well, Geronimo, Ariz.
8	23.2	.7	1.2	4.3	1.2	7.4	3.6	New growth on young saltcedar near well 18-79, SW¼NE¼ sec. 34, T. 4 S., R. 23 E. Graham County, Ariz.
9	24.2	1.1	1.0	4.8	1.0	7.9	4.8	Mature growth on saltcedar 16 ft tall, SW¼NE¼ sec. 34, T. 4 S., R. 23 E. Graham County, Ariz.
10	24.8	.6	.4	2.1	4.8	7.9	.4	New growth in area cleared 2 months previously, near Fort Thomas, Ariz.
11	26.8	.9	.8	3.2	4.2	9.1	.8	Mature growth just outside cleared area near Fort Thomas, Ariz.
12	26.0	1.4	.7	4.7	1.8	8.6	2.6	Mature growth on Gila River near Geronimo, Ariz.
C.—Vegetation in Pecos River basin, N. Mex., sampled November 1944								
13	28.9	2.8	0.9	9.4	1.6	14.7	5.9	Saltcedar on Pecos River near Frazier, N. Mex., bridge U.S. Highway 70.
14	31.0	2.2	1.9	8.7	4.3	17.1	2.0	Saltcedar on Pecos River near Artesia, N. Mex., New Mexico Highway 83 bridge.
15	29.9	2.7	1.1	9.3	2.3	15.4	4.0	Saltcedar on Pecos River near Major Johnson Springs below McMillan Dam, N. Mex.
16	23.2	1.5	.9	6.6	2.3	11.3	2.9	Saltcedar in Malaga Bend area, New Mexico, Pecos River.
17	23.9	.8	.3	4.1	3.0	8.2	1.4	Saltcedar in Malaga Bend area, New Mexico, 150 yds downstream from No. 16.
18	26.3	2.3	1.1	8.7	1.0	13.1	8.7	Saltcedar on Delaware River at U.S. Highway 285 bridge, south of Malaga, N. Mex.
D.—Vegetation in Rio Grande basin, N. Mex., sampled December 1944								
19	9.4	1.7	0.5	4.3	1.4	7.9	3.1	Saltcedar beside interior drain, San Acacia, N. Mex. Leaves brown from recent frost.
20	13.5	.8	.6	3.6	1.3	6.3	2.8	Saltcedar beside interior drain, San Acacia, N. Mex. Leaves still green.
21	22.8	.9	.7	5.3	2.0	8.9	2.6	Saltcedar on old U.S. Highway 85 in Bosque del Apache Wildlife Range near San Antonio, N. Mex.
22	18.6	.8	.2	2.7	1.3	5.0	2.1	Saltcedar in arroyo 1½ miles south of Truth or Consequences, N. Mex.
23	16.3	1.1	.3	2.9	1.4	5.7	2.1	Saltcedar by road 20 yd below No. 22, 1½ miles south of Truth or Consequences.
E.—Vegetation growing where permanent water table is very deep, sampled December 1944								
24	11.8	0.6	0.6	2.2	0.5	3.9	4.4	Lone saltcedar in highway borrow pit, 5 miles west of Hatch, N. Mex.
25	15.1	.8	.4	2.6	.7	4.5	3.7	Lone saltcedar tree by New Mexico Highway 26, 5 miles east of Florida, N. Mex.
F.—Vegetation in Safford Valley, Ariz., sampled December 1944								
26	25.7	1.9	1.1	6.5	2.6	12.1	2.5	Saltcedar beside Gila River at Solomon ford crossing, Solomon, Ariz.
27	22.3	1.5	.8	4.4	2.8	9.5	1.6	Saltcedar growing beneath U.S. Highway 70 bridge over San Simon Creek near Solomon, Ariz.
28	26.4	1.6	.6	6.5	5.0	13.7	1.3	Saltcedar growing beneath Safford, Ariz., bridge over Gila River; leaves brown from frost.
29	14.8	.6	.6	2.7	2.2	6.1	1.2	Green saltcedar sprouts on trees in Safford experiment plot, Arizona, at Safford bridge.
30	27.4	1.8	.7	5.2	5.1	12.8	1.0	Green leaves on saltcedar growing beneath Safford, Ariz., bridge.

Several times during the growing season of 1945, samples of foilage were obtained from saltcedars along the Pecos River in New Mexico and examined by a technique designed to determine only the saline material present on the outer surfaces of the leaves and stems. The collected samples were air dried, and solutes were washed from a weighed portion by pouring 125 ml of distilled water over the sample supported on filter paper in a large funnel. This filtrate was poured through the sample twice more and was then increased to a definite volume and analyzed. The analytical results are given in table 2. The sodium and potassium content was calculated from the difference between determined cations and anions. Very little organic matter was present in these solutions.

The chemical analyses also were computed where possible as percentages of the total weight of dissolved ions. This could be done only for the analyses which included all the major ions. Chemical analyses believed to represent the percentage composition of solutes in ground water in the vicinity of the plants are included in table 2.

The most mobile solute ions circulated by the plants are those dissolved in condensed water or guttation, or present as crystalline material on the leaf surfaces. The composition of solutions actually present on the leaves was determined on one occasion only. During studies of the use of water by bottom-land vegetation (described by Gatewood and others, 1950), it was often noticed that at night, during the growing season, branches of the thriving stands of saltcedar along the river were very wet with highly saline liquid. This effect was attributed to guttation, in the absence of complete explanation as to why the water was so saline. The diurnal range of air temperature and relative humidity was often wide. The temperature commonly dropped from an afternoon high in excess of 100°F to nighttime temperatures of 50° to 60°F, and the relative humidity at night often exceeded 90 percent. Whether guttation was a significant factor, however, is not a matter of particular concern here. The important fact is that the plants do exude saline material in considerable quantity.

The approximate composition of the liquid was determined by shaking the branches of a number of saltcedars near the Glenbar Experiment Station in the early morning of October 18, 1944, over a large shallow enamelware pan, to get a sample large enough for analysis. The composition of the shallow ground water in the vicinity was known from samples collected in the past from driven wells (Gatewood and others, 1950, p. 81). In table 3, the analyses of water shaken from the plants and of water pumped from a nearby shallow well are given.

TABLE 2.—*Composition of solids washed from saltcedar leaves, few minutes contact time, and of solids dissolved in nearby water*

[For tree samples, values in first column under each date are percent of air-dried foliage, and values in second column under each date are percent of determined constituents; for water samples, values are percent of determined constituents]

	Tree at Pecos River bridge at Frazier, N. Mex.						Pecos River near Acme, N. Mex. June 1–10, 1945
	May 24, 1945		July 10, 1945		October 22, 1945		
Specific conductance, in micromhos at 25°C	591		492		306		7,720
Foliage dry weight, grams	17.6		10.7		12.9		----
Calcium	0.06	11.6	0.13	18.9	0.06	18.6	13.7
Magnesium	.02	3.5	.02	2.7	.02	4.7	3.7
Sodium and potassium	.07	15.1	.06	8.1	.02	7.0	13.7
Bicarbonate	.02	3.5	.03	4.1	.02	4.7	2.3
Sulfate	.27	54.7	.37	54.1	.14	41.9	43.5
Chloride	.06	11.6	.08	12.2	.08	23.3	22.2
Sulfate: chloride	----	4.7	----	4.4	----	1.8	2.0
Sum of determined constituents	.50	----	.69	----	.34	----	----

	Tree at Pecos River bridge near Artesia, N. Mex.								Pecos River near Artesia, N. Mex. August 11–13, 17–21, 1945
	April 4, 1945		May 24, 1945		July 10, 1945		October 25, 1945		
Specific conductance, in micromhos at 25°C	757		416		356		1,140		14,900
Foliage dry weight, grams	31.7		7.0		9.0		10.0		----
Calcium	0.03	10.8	0.07	8.6	0.07	11.3	0.10	6.4	7.4
Magnesium	.01	4.3	.03	3.4	.01	1.9	.02	1.3	3.1
Sodium and potassium	.05	18.3	.17	20.7	.11	18.9	.45	28.2	23.4
Bicarbonate	----	----	.03	3.4	.03	5.7	.03	1.9	.8
Sulfate	.08	28.0	.27	32.8	.24	41.5	.28	17.9	28.1
Chloride	.11	38.7	.26	31.0	.12	20.8	.69	44.2	37.0
Sulfate: chloride	----	.72	----	1.1	----	2.0	----	.41	.76
Sum of determined constituents	.29	----	.83	----	.59	----	1.57	----	----

TABLE 2.—*Composition of solids washed from saltcedar leaves, few minutes contact time, and of solids dissolved in nearby water*—Continued

	Tree at Pecos River at Major Johnson Springs, N. Mex.								Spring at Major Johnson Springs area
	April 4, 1945		May 24, 1945		July 10, 1945		October 25, 1945		July 6, 1940
Specific conductance in micromhos at 25°C	1,480		1,560		525		676		5,230
Foliage dry weight grams	22.3		12.1		11.1		11.2		----
Calcium	0.15	16.5	0.33	15.4	0.11	14.6	0.12	13.0	15.0
Magnesium	.05	6.0	.10	4.6	.04	4.9	.04	5.0	3.4
Sodium and potassium	.06	7.0	.21	9.7	.07	9.8	.12	13.0	12.1
Bicarbonate	----	----	.05	2.3	.05	7.3	.06	7.0	2.9
Sulfate	.44	49.5	1.12	52.5	.36	48.8	.29	32.0	44.2
Chloride	.19	21.0	.33	15.4	.11	14.6	.27	30.0	20.7
Sulfate: chloride	----	2.4	----	3.4	----	3.3	----	1.1	2.1
Sum of determined constituents	.89	----	2.14	----	.74	----	.90	----	----

	Tree near well 5, Malaga Bend area near Malaga, N. Mex.								Well 5, Malaga Bend
	April 5, 1945		May 25, 1945		July 11, 1945		October 24, 1945		March 25, 1938
Specific conductance, in micromhos at 25°C	1,320		3,230		1,360		3,570		44,000
Foliage dry weight grams	26.7		10.3		16.1		16.3		----
Calcium	0.03	4.7	0.09	2.7	0.02	2.2	0.06	2.0	1.5
Magnesium	.01	1.7	.03	.9	.01	1.1	.02	.6	1.2
Sodium and potassium	.19	29.7	1.15	33.3	.38	33.9	1.04	34.2	34.9
Bicarbonate	----	----	.03	.9	.02	1.7	.07	2.4	.4
Sulfate	.12	18.6	.52	15.2	.12	11.1	.49	16.1	9.8
Chloride	.29	45.3	1.62	47.0	.56	50.0	1.36	44.7	52.2
Sulfate: chloride	----	.41	----	.32	----	.22	----	.36	.19
Sum of determined constituents	.64	----	3.44	----	1.12	----	3.05	----	----

	Tree on terrace near well 131, Malaga Bend area near Malaga, N. Mex.								Well 131, Malaga Bend
	April 5, 1945		May 25, 1945		July 11, 1945		October 24, 1945		October 18, 1938
Specific conductance, in micromhos at 25°C	349		873		179		450		9,840
Foliage dry weight grams	17.5		11.4		8.8		11.1		----
Calcium	0.03	11.6	0.10	8.4	0.02	7.1	0.04	6.0	11.6
Magnesium	.01	4.7	.03	2.3	.01	1.8	.01	1.5	4.0
Sodium and potassium	.03	14.0	.25	21.4	.07	21.4	.16	26.9	17.2
Bicarbonate	----	----	.04	3.1	.02	7.1	.02	3.0	1.7
Sulfate	.13	51.2	.55	48.1	.16	50.0	.17	28.4	33.7
Chloride	.05	18.6	.19	16.8	.03	10.7	.21	34.3	31.9
Sulfate: chloride	----	2.8	----	2.9	----	4.7	----	.83	1.1
Sum of determined constituents	.25	----	1.15	----	.32	----	.60	----	----

	Tree at Delaware River bridge on U.S. Highway 285 near New Mexico-Texas State line								Delaware River at U.S. Highway 285 bridge
	April 5, 1945		May 24, 1945		July 11, 1945		October 24, 1945		July 11, 1945
Specific conductance, in micromhos at 25°C	303		568		362		290		2,910
Foliage dry weight grams	22.6		14.5		7.3		11.1		----
Calcium	0.02	11.4	0.08	14.5	0.05	6.8	0.05	12.5	22.4
Magnesium	.01	5.7	.03	4.8	.03	3.4	.01	2.5	2.1
Sodium and potassium	.02	14.3	.06	10.8	.18	22.0	.06	17.5	4.1
Bicarbonate	----	----	.02	3.6	.03	3.4	.02	5.0	3.9
Sulfate	.06	40.0	.28	48.2	.33	40.7	.11	30.0	62.3
Chloride	.04	28.6	.10	18.1	.19	23.7	.12	32.5	3.6
Sulfate: chloride	----	1.4	----	2.7	----	1.7	----	.92	17.3
Sum of determined constituents	.15	----	.57	----	.81	----	.36	----	----

TABLE 3.—*Miscellaneous analyses of water associated with saltcedar*

[Values are percent of determined constituents]

	1	2
Calcium	2.3	7.5
Magnesium	.8	2.1
Sodium and potassium	33.6	23.1
Bicarbonate	.0	21.8
Sulfate	19.0	14.0
Chloride	44.3	31.5
Sulfate: chloride	.43	.44
Specific conductance, in micromhos at 25°C	55,500	3,260

1. Water accumulated on saltcedar foliage near Glenbar, Ariz., during night preceding Oct. 18, 1944.
2. Water from well 11-14 near Glenbar, Ariz., Aug. 30, 1943.

INTERPRETATION OF RESULTS

The analytical data should be capable of providing information bearing on the following three questions:

1. How much and what kinds of solutes are present in and on saltcedar leaves?
2. What relation does the amount and nature of solutes in the leaves have to the chemical quality of ground water in the vicinity of the plant?
3. What effects do other environmental or internal factors have on the composition of solutes in the leaves?

NATURE AND AMOUNT OF SOLUTES

The amount and composition of material leached from the saltcedar leaves obviously are functions both of the amounts present on the leaf surfaces or within the plant tissues and of the effectiveness of the method used to bring them into solution. The rather rigorous leaching used for samples listed in table 1 probably explains the fact that this procedure gave soluble contents from 9.4 percent to more than 30 percent of the dry-foliage weight. The simple washing of leaves used for samples listed in table 2 gave soluble contents ranging from a few tenths of a percent to a little over 3 percent, or about a tenth as much as the leaching treatment. The analysis in table 3 of the moisture naturally appearing on the leaves is obviously influenced by many extraneous factors and cannot be related to leaf weight or area. The solutes in this water are the most transient part, being subject to rapid removal by wind action.

The methods used to obtain the data in table 2 give results that are indicative of the amounts of soluble salt which might be washed from saltcedars by rainfall during the growing season. The more rigorous leaching procedure used for samples in table 1, however, probably approximates the total amount of the determined ions which can be extracted from leaves which fall to the soil surface and decompose.

The sodium content of the leaf extracts in table 1 was not determined; and because of the large amount of organic matter in the solutions, a meaningful value cannot be calculated from the ion balance. Therefore, ion percentages cannot be calculated for these data. The ratio of sulfate to chloride reported for the analysis, however, does have some usefulness in comparing data in table 1 with that in table 2.

The sum of inorganic ions reported in table 1 is generally no more than half the total soluble residue. Although sodium was not determined, it could account for only a small part of this difference. No significant concentrations of bicarbonate were found in those extracts which were analyzed for this constituent. For most samples, the four ions determined comprised from 5 to 15 percent of the dry weight of the leaves.

Although one might casually expect the inorganic solutes extracted from saltcedar leaves to be mostly sodium and chloride, the results of the leaching and washing experiments show that sulfate is generally the predominant anion. Surficial moisture from the leaves, however, may contain principally sodium and chloride as indicated by the single analysis of this material in table 3. It seems probable that sulfate is held to a greater extent within the leaf structure, and chloride to a greater extent is transported to the outer surface of the leaf from which it can be periodically removed by wind and rain. This inference is supported by the generally higher sulfate to chloride ratio for the more intensively leached samples (table 1) than for those simply washed with distilled water (table 2).

RELATION OF LEACHED SOLUTES TO GROUND-WATER QUALITY

The kinds and amounts of inorganic solutes on the surfaces of saltcedar leaves, as well as the amount present within the leaf structures and available for leaching, are influenced by numerous variables. In a general way, one would expect the composition of the leachings to be related to that of the water available to the plant roots, modified by whatever selective processes the plant might be able to exercise to absorb or reject certain solute ions. The composition observed would then be further modified by such factors in the sampled part of the plant as the rate at which water has been transpired and the rate of metabolic processes. More external but still important factors affecting the composition of leachings might include the length of time which has passed since the last rain or windstorm, the season of the year, and the manner in which the leaves for sampling are selected.

It probably is not surprising that very little can be deducted from the data in tables 1 to 3 to indicate the effect of the composition of the water supply. In many places, the composition of the water available to the plants, from which leaf samples were taken, is very imperfectly known. In table 2 an analysis of ground water or of low-flow water from the adjacent stream is included for each sample location. Somewhat similar information is available (Hem, 1950) for some of the sampling sites in Safford Valley. The actual composition of moisture available to plant roots may differ somewhat from the ground-water composition in the vicinity; however, until more is known about root-zone behavior of solutes, it is useless to speculate about this question.

Gross differences in ground-water composition do seem to be reflected to some extent in the composition of the extracts in table 1. Sample 7 was obtained from a saltcedar growing along a drainage ditch which had apparently been used for some years to convey the unused salty water from a small flowing well to a nearby wash channel. The chloride concentration of this water was 6,800 ppm (parts per million), and its dissolved solids were 14,000 ppm. The percentage of chloride in the leaf sample was higher than for most others in table 1, which represented for the most part trees having a less saline water supply. Samples 10 and 11, also having high chloride percentages, came from trees growing near Fort Thomas, Ariz., in an area where the ground water probably had between 3,000 and 4,000 ppm of chloride. The remaining two samples (Nos. 28 and 30) which showed very high chloride contents were from trees growing under a bridge, where the leaves were protected from rain, and therefore they are not really comparable to the others.

The total percentages of inorganic ions reported in table 1, although not including sodium, do seem to have a systematic trend. The highest totals generally are found in group C, which represents trees growing in the Pecos River basin. The dissolved-solids concentration of ground water available to the plants probably was considerably higher in that area than in the Rio Grande basin. The lower total ion contents of the leaves in group D are in accord with this interpretation.

Table 2 also shows some effects related to composition of the water supply. The tree growing near well 5 in the Malaga Bend area where the shallow ground water is very saline gave consistently higher chloride percentages in the leaves than did trees at other locations. It also had a sulfate to chloride ratio below 1.0 consistently through the growing season.

The sulfate to chloride ratio of the surficial moisture from saltcedar leaves (table 3) is nearly the same as that of ground water in the vicinity. Although this may be fortuitous, the ratio for leaf samples from nearby trees (table 1, sample 6) is much higher and suggests the sulfate is mostly present within the leaves.

EFFECTS OF OTHER FACTORS

Several analyses in table 1 give some indication that the younger, more vigorously growing leaves contain somewhat larger proportions of chloride than do mature leaves. Pairs of analyses showing this effect are those for samples 8 and 9 and samples 10 and 11. The first in each pair represents new growth and has a significantly lower sulfate to chloride ratio than the second, which represents mature growth.

The successive samples in table 2 give some general indications of effects of rainfall and passage of time during the growing season. A major factor affecting the results is the transfer of loose salt deposits from leaf surfaces to air or ground by wind movement, by rain, or by the drip of moisture accumulated on the plant leaves in other ways. Surficial deposits of sodium chloride, being loosely attached and readily soluble, probably are rather easily removed by wind and by dripping of condensed moisture or guttation. Salt exuded from salt glands in the form of so-called whiskers (Decker, 1961) would readily become airborne. Even in the absence of heavy rain, therefore, it might be expected that total content of soluble ions and the sulfate to chloride ratio would tend to increase with time.

The effect of rainfall is evident in some of the analyses. A moderate to heavy shower should remove all readily soluble material from the leaf surfaces; if some of this intercepted rainfall actually enters the plant directly, as may happen, the solution within the leaf tisues may be diluted somewhat. In any event, several days might have to pass after the rain before a normal deposit of saline material would again build up on the leaf surfaces. Leaves collected soon after a rain should contain a lower percentage of solute ions than leaves which had not been rained upon for some weeks.

Samples of leaves obtained July 10 and 11, 1945, from the locations at and downstream from Artesia, N. Mex. (table 2), were influenced by a general rainstorm which had occurred in that area a few days before. For all the sites where rain had occurred, the percentage of solute ions in the leaves obtained in July was lower than at the previous sampling. Very little precipitation occurred in the Pecos basin during the months of April, May, and June of 1945.

Figure 1 shows the average ratio of sulfate to chloride for each of the four sets of samples obtained during the growing season of 1945 (table 2). The general trend in the ratio was upward until after the July sampling. In common with other properties related to the plant-growth pattern, this ratio and the soluble percentage of the dry weight of the leaves would both be expected to increase most rapidly during the period of highest

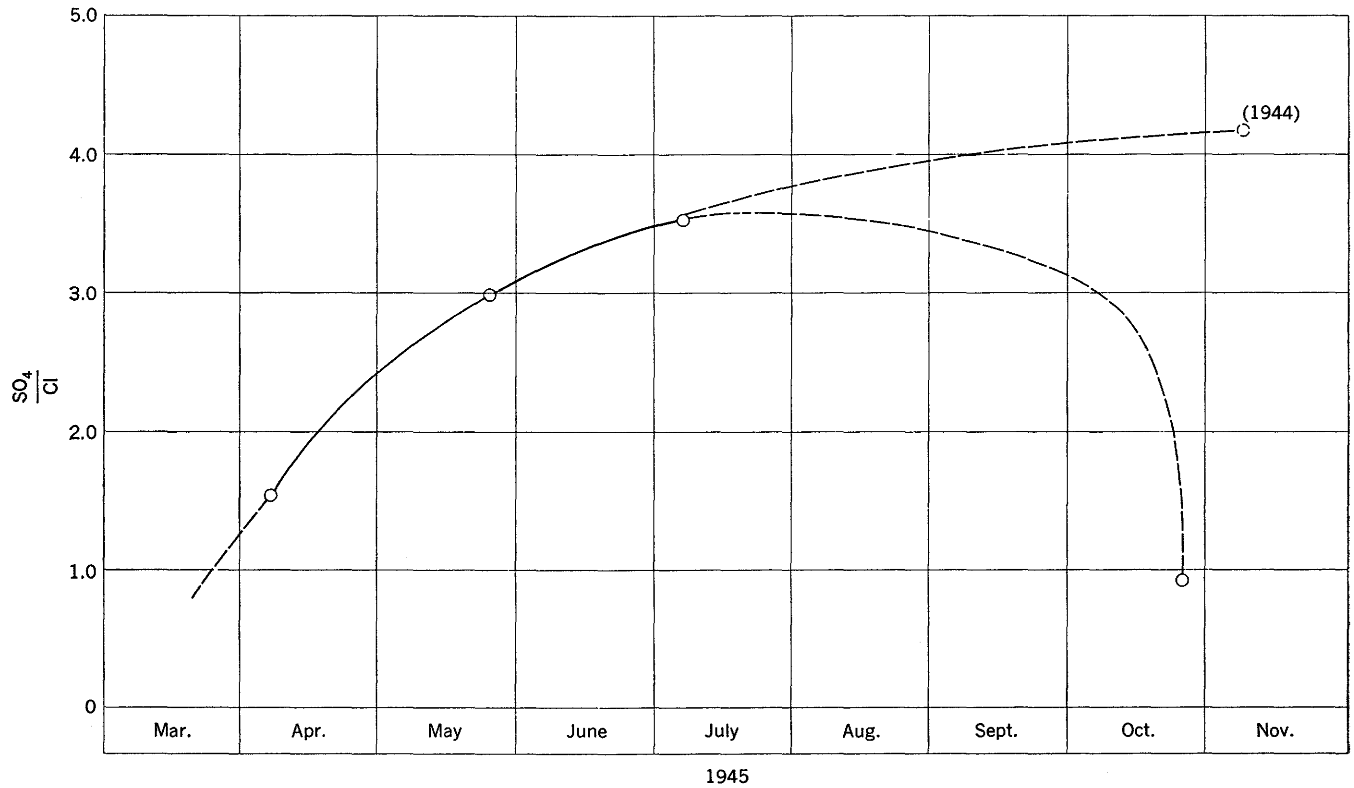

FIGURE 1.—Average sulfate to chloride ratio in solutes washed from saltcedar leaves, Pecos River basin, N. Mex. Heavy rainfall preceding October 1945 sampling probably caused an abnormally low sulfate:chloride ratio.

growth rate and to level off later in the growing season when growth rates are lower. The last sampling, however, which was made in late October, showed a very pronounced decrease in the ratio, to a little under 1.0. Precipitation in the Carlsbad-Artesia area in October 1945 was unusually heavy and probably accounted for the ratio decrease. From this rather fragmentary information, one cannot be certain that the decrease was the result of rainfall, but the average ratio of sulfate to chloride for samples obtained in November 1944 in the Pecos River basin (table 1) was a little over 4.0. The data probably are not completely comparable, but the general seasonal trend and the effect of rainfall would be interesting subjects for further study.

In table 1, there are two samples of leaves obtained from trees growing under the county highway bridge across the Gila River at Safford, Ariz. The trees in this location were protected from rain, although they were probably still losing salt from their leaves in other ways. Both samples 28 and 30 contained at least 5.0 percent of chloride and thus had the highest concentrations observed in any of the samples represented in the table.

CONCLUSIONS

The total inorganic solute content of saltcedar leaves and deciduous stems may exceed 15 percent of the air-dry weight. The predominant anion in the analyzed samples was generally sulfate, although chloride was also abundant and was the predominant anion in a few. The composition of total solute content of leaves was not closely related to composition of the ground water in the area where the plants were growing. It seems likely, however, that chloride must be strongly predominant in the water available to a plant to maintain a value below 1.0 for the sulfate to chloride ratio in the leaves.

The solutes which can be washed from the leaves by fairly brief contact with water, as during a rainstorm, constitute as much as 3.5 percent of the dry weight of foliage of plants growing where the water supply is high in dissolved solids. Where the available water is lower in dissolved solids, the solute content of the leaves is lower. More rigorous leaching may bring into solution as much as 30 percent of the dry weight of foliage, but a considerable part of the dissolved material is organic.

As the growing season advances, inorganic solutes tend to accumulate in and on the leaves. This trend may be interrupted or reversed by rainfall that is sufficiently heavy or prolonged to wash away some of the accumulated material. The available data suggest that the ratio of sulfate to chloride in the leaves usually tends to increase during the growing season. Except where the ground water in the vicinity was very high in chloride, the solute washed from the leaves contained more sulfate than chloride.

Moisture which collected on saltcedar leaves at night along the Gila River near Glenbar, Ariz., was strongly saline and contained mostly sodium and chloride. The cubic crystals, apparently sodium chloride, which occur on saltcedar leaves, are probably deposited when such saline solutions evaporate.

The chloride ion content of the solutes present in saltcedar leaves is probably affected more than the sulfate content by various processes that may remove salty fluids and dry salt crystals from the leaves.

Samples were obtained from trees growing in widely separated areas, and the composition of ground water available to them had a wide range. The range of composition of the solutes leached from the leaves, however, was narrower than the range of associated ground-water composition. One may thus conclude that selective processes within the plant strongly influence the composition of solutes which can be leached from the leaves.

Obviously the data presented here do no more than suggest some general tendencies in the movement of inorganic solutes from the ground water and soil moisture through the saltcedar plant. More detailed studies in which the environmental variables are more closely observed and can be controlled are needed before more firm conclusions can be reached.

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