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SOIL-SALINITY STUDIES AS RELATED TO SUGARCANE GROWING IN SOUTHWESTERN PUERTO RICO[1]

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INTRODUCTION

A multiple-purpose project covering hydroelectric power, irrigation, drainage, and water supply, is being worked out for Lajas valley in the arid southwestern section of Puerto Rico. The estimated total cost of the project is $26,789,000 and water is expected to flow at the end of 1953 to begin the irrigation of about 24,000 acres in the valley, largely to be planted to sugarcane.

There are about 10,000 acres of additional land in Lajas valley where salinity problems affect the growth of sugarcane. This paper discusses such problems on the basis of surveys and experiments made by the author and his coworkers (2, 3)[3] before the irrigation works were started.

DEFINITIONS AND METHODS

The terms used in this report (table 1) are those adopted by the U. S. Regional Salinity Laboratory (6). "Saline" refers to the presence of excess salts and "alkali" as related to excessive exchangeable sodium. Nonsaline-alkaline soils are those found occasionally that contain exchangeable sodium, except for the soluble salts which have been removed by leaching. Saline-alkaline soils probably constitute the majority found containing excesses of both exchangeable sodium and soluble salts.

The "saturation extract" (6) reported in the second column of table 1 is a solution obtained by pressure or vacuum filtration of a soil paste that has been made up to a saturated condition by adding water while stirring. The electrical conductivity in that column is expressed as EC $\times 10^3$ in millimhos/cm.

Adequately spaced soil samples were taken throughout the whole area of Lajas valley, using an auger at 1-, 2-, 3-, and 4-foot depths. The samples

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[3] Numbers in parentheses refer to Literature Cited, p. 113.

were dried overnight in an oven kept around 60°C. The dry samples were ground by hand power in a corn mill No. 2. A 1:2 soil-water suspension was prepared by adding 80 ml. of distilled water to 40 gm. of soils in a 250-ml. beaker.

The suspensions were preferred to the saturation extracts because the preparation is simpler and quicker. Twelve suspensions were shaken for 30 minutes in a Ross-Kershaw stirring apparatus (No. 9235-D, A. H. Thomas Catalog) at about 185 revolutions per minute. Each suspension was poured into a 100-ml. test tube, 1.25 inch in diameter, and the conductivity value was determined with a Solu-bridge soil tester, model RD-15, using a heat-resistant rubber cell-4 with a constant value of 2.0. The scale markings in this Solu-bridge are expressed as specific electrical conductance or electrical conductivities, EC in mhos/cm. $\times 10^{-5}$ at 25°C. This value is equivalent to EC $\times 10^{-5}$ or K $\times 10^{5}$, used by the U. S. Regional Salinity Laboratory (6).

TABLE 1.—*Classification of saline and alkali soils used by the U. S. Regional Salinity Laboratory (6)*

Soil class	Electrical conductivity of saturation extract in millimhos/cm.	Exchangeable Na as percentage ESP[1]	pH
Saline	4 or higher	Less than 15	Usually less than 8.5
Saline-alkali	4 or higher	15 or higher	Seldom higher than 8.5
Nonsaline-alkali	Less than 4.0	15 or higher	Usually greater than 8.5
Soloth or degrated	Less than 4.0	15 or higher	Usually between 6.5 and 8.0 but may be below 6.0

[1] $\mathrm{ESP} = \dfrac{\text{Exchangeable sodium (m.e. per 100 gm. soil)}}{\text{Cation exchange capacity (m.e. per 100 gm. soil)}} \times 100.$

THE PROBLEM AND ITS SOLUTION

Quality of the Irrigation Water Supplies

The scale used to classify the water supplies with respect to their irrigation quality is reported in table 2.

Twenty-nine water samples supplied from wells used for irrigation, including two lagoons in Lajas valley, were analyzed and seven were found to be excellent to good for the irrigation of crops. Waters from seven rivers (2) that supply the reservoirs for the irrigation waters were also analyzed and found excellent to good. One of these rivers, the Río Loco, that has been used in the past for irrigation in Lajas valley, flows through a serpentine region and contains 26 p.p.m. in flood, and 41 p.p.m. of magnesium in normal flow, or from three to six times more magnesium than the other river waters.

The Salinity Problem

There is no danger of the intrusion of sea water through the south of the valley, since there is no direct connection through permeable rocks between the valley fill and the sea along the entire south of the valley.

The salinity problem of Lajas valley has developed by seepage caused by impeded drainage, and by surface-soil evaporation because of the salts from the salty wells used for irrigation and the run-off drain toward the lowlands. By this process the salt content of the ground water has been increased and salt flats have been formed, of which the low terrain known as the "Ciénaga el Anegado," comprising 1,931 acres, is typical. These salt flats are distributed sporadically, in an irregular pattern, in Lajas valley, and even the bottom soils of the two fresh-water lagoons, the Guánica lagoon with about 1,123 acres and the Cartagena lagoon with about 251 acres, are also salty.

TABLE 2.—*Standards for judging the quality of irrigation waters (4, 6)*

Water class No.	Water condition	Electrical conductivity in millimhos/cm.	Salt content—		Sodium	Boron
			Total	Per acre-foot		
			P.p.m.	*Tons*	*Percent total bases*	*P.p.m.*
1	Excellent to good	1	0–700	1	Below 60	Below 1
2	Good to injurious	1–3	700–2,000	1–3	60–75	1–2
3	Injurious to unsatisfactory	3+	Over 2,000	Over 3	Over 75	Over 2

Rainfall and Evaporation

The mean annual rainfall of Lajas valley is 31.35 inches. The drier period extends from December to April with a mean total rainfall of 6.82 inches; January is the driest month with 0.84 inch.

The mean monthly evaporation from a free water surface in the Lajas Agricultural Experiment Substation was 7.72 inches for the 6-month period, February to July 1949, and 11.23 inches for the 9-month period, July 1951 to March 1952. The monthly range for the 1949 records was from 6.04 to 8.87 inches and for the 1951–52 records, from 8.09 to 16.15 inches. There were 55 days with no evaporation for the latter period; the highest daily evaporation was 1.20 inches on December 9.

The Leaching Tests

Three leaching tests (3) with fresh waters were made in salty spots of Aguirre clay. This soil occurs in the low flat areas of Lajas valley. It occupies areas that are transitional in character between the soil of the well-drained river flood plains or alluvial fans and the poorly drained soils of the coastal lowlands. In a cultivated field, Aguirre clay has a 10- or 12-inch layer of very dark grayish-brown or nearly black plastic clay underlain by mottled grayish-brown and gray plastic clay that continues to a depth ranging from 30 to 36 inches. At a depth ranging from 5 to 6 feet is the substratum of bluish-gray plastic, sticky, wet clay. This layer continues to considerable depths and has the characteristics of estuarine deposits. Many areas are affected by salts. The best-drained areas that receive some irrigation are producing from 40 to 60 tons of Gran Cultura cane to the acre. The land is difficult to plow and cultivate, as it is plastic and sticky when wet and hard and cloddy when dry. There are about 7,881 acres of Aguirre clay, in Lajas valley.

Half an acre of land was divided into 24 plots, each 10 feet x 10 feet, separated crosswise and lengthwise by ditches 4 feet deep. Twelve randomized plots that were irrigated with fresh water were protected with bamboo canes to avoid landslide. In the third leaching tests, all the plots were irrigated; half of the randomized plots received sulfur at the rate of 8 pounds per plot, or 1.74 tons per acre. Half of these plots received the sulfur in one application and the other half at the same rate, but in four weekly applications.

In the first leaching test five separate soil samples were taken from each irrigated plot, one each at 1-, 2-, 3-, and 4-foot depths, and in the second and third tests they were taken at more convenient depths with the soil auger, at 8, 16, 24, 32, 40, and 48 inches, to be used for conductivity tests.

The first and second leaching tests lasted 73 and 63 days, and were leached with 78 and 84 inches of water, respectively. The third test lasted 130 days; the plots to which the sulfur was added in four applications and in one application were leached with 48 and 60 inches of water, respectively, and the untreated plots with 72 inches of water.

The three leaching tests revealed that irrigation with 48 inches of water washed out the excess of salts from the first foot of soil if adequate drainage was provided.

The Salty Land of Lajas Valley

The salty land was largely of two soil types, Aguirre clay and Guánica clay. There are about 4,518 acres of Guánica clay in Lajas valley. Guánica clay is similar to Aguirre clay, but it is more poorly drained and therefore is less well aerated and oxidized. It occupies lower positions than does

Aguirre clay, and it is more difficult to drain and to irrigate. The largest areas of Guánica clay occupy lagoonlike positions near Guánica Lagoon that have been filled with materials washed from the nearby hillsides, and consisting of tuffaceous rock and limestone. Only a small portion of this soil is irrigated with well water. Some of the water has a fairly high salt content. Unless the land is irrigated, the productivity depends to a very large extent on the yearly rainfall. An acre-yield of 40 tons of Gran Cultura cane is considered high on nonirrigated land, but in the irrigated areas yields ranging from 50 to 60 tons are not uncommon. This soil also requires good drainage. It is a good soil for rice.

The area of salty land that could be reclaimed with fresh waters, if good drainage is provided, based on the results obtained with the leaching tests, was found to be about 5,453 acres. The additional area of salty land that could be reclaimed with sulfur or gypsum and fresh waters, if good drainage is provided, was found to be about 5,028 acres.

A total of 6,822 soil samples were taken for conductivity tests at the 1-, 2-, 3-, and 4-foot depths, from 1,955 borings adequately spaced in the fields. The mean conductivities in the 1:2 soil-water suspensions for 1-foot layer of the salty lands planted to sugarcane varied from 8 to 320 mhos $\times 10^{-5}$ at 25°C. and for the upper 4-foot layer, from 10 to 400 mhos. The mean values for the uncropped land in range pastures varied from 10 to 1,000 mhos $\times 10^{-5}$ at 25°C. in the 1-foot layer and from 6 to 1,000 mhos $\times 10^{-5}$ at 25°C. in the 4-foot layer.

Chemical Data from the Salty Land

The cation-exchange capacity, and cations extractable with normal ammonium acetate, for 15 soil samples representing salty Aguirre clay and Guánica clay and nonsalty Fraternidad clay, Santa Isabel clay, Vayas silt loam, and San Antón clay loam, are reported in table 3.

The cation-exchange capacity of these soils varied from 28.0 to 60.3 milliequivalents per 100 gm. The extractable cations varied from 21.6 to 74.0 m.e. for Ca, from 0.14 to 0.41 m.e. for Mg, from 0.08 to 1.08 m.e. for Mn, from 1.4 to 26.7 m.e. for Na, and from 0.27 to 1.28 m.e. for K, per 100 gm. of soil.

The total cation-exchange capacity in six of the soils analyzed was saturated with calcium, and the remainder of the Ca, Mg, Mn, Na, and K extractable cations were combined as free salts. These salts, especially the harmful sodium salts, are leached out with fresh waters if good drainage is provided. This was corroborated in the three leaching tests, reported earlier where irrigation with fresh water washed out the excess of salts from the soil when adequate drainage was provided.

In the other nine soils analyzed, the extractable cations were exchange-

TABLE 3.—*Cation-exchange capacity and extractable cations[1] in soils of Lajas valley*

Lab. No.	Soil type and cover	Location	Cation-exchange capacity	Extractable cations in milliequivalents per 100 gm. soil, of— Ca	Mg	Mn	Na	K
140	Aguirre clay (0–36″), cane grows well	Hacienda Luz Dolores, Juan Angel Tió, Lajas	43.8	74.0	0.41	0.52	5.0	0.27
141	Aguirre clay (0–36″)—poor spot—cane does not grow well	A short distance N.E. sample 140	28.0	62.3	.41	.24	20.4	.84
143	Aguirre clay (0–30″)—trees	Antonio Matos farm, S.E. Anegado, Lajas-Guánica road	60.2	61.3	.31	.56	25.0	1.28
144	Aguirre clay (30–48″)—trees	do.	58.2	33.3	.16	.22	26.7	1.08
149	Aguirre clay (0–12″)—to be planted to cane	Recent plowed field, 250 m. W. Hda. Beatriz Soledad, Mario Mercado, Lajas	50.4	35.1	.14	.08	3.8	1.06
150	Aguirre clay (0–12″)—cane does not grow well	Recent plowed field, 500 m. S. Hda. Beatriz Soledad	45.0	27.4	.31	.64	9.0	.62
151	Aguirre clay (12–36″)—cane does not grow well	do.	45.8	24.0	.15	.12	9.5	.79
152	Aguirre clay (0–12″)—to be planted to cane	Plow working in field 2 Km. S. houses Hda. Beatriz Soledad	60.3	48.3	.15	.08	11.0	1.16
153	Do.	Plow working, 1 Km. E. Hda. Beatriz Soledad houses at Luis Irizarry's farm	54.4	48.8	.27	.24	4.5	.59
154	Aguirre clay (12–36″)—to be planted to cane	do.	48.2	51.9	.38	.28	8.3	.51
142	Fraternidad clay (0–24″)—pastures	Km. 11.9 bend, Lajas-Guánica road, Juan Angel Tió's farm	32.8	37.4	.15	.10	4.9	.72
146	Guánica clay (0–12″)	West Guánica lagoon	36.0	51.4	.15	.12	6.8	1.04
139	Santa Isabel clay (0–12″)—good cane soil	Hda. María Luisa. Padres Mercedarios, Bo. Palmarejo, Lajas	41.6	30.0	.16	.06	2.5	.43
147	Vayas silt loam (0–36″)—good cane soil	E. Guánica lagoon near outlet ditch to ocean, farm of Alfredo Ramírez	46.0	36.3	.51	1.08	2.9	.32
148	San Antón clay loam (0–30″)—good cane soil	1.5 Km. S.E. Guánica lagoon, Hda. María Antonia, Rusell & Co.; good cane soil, planted for over 40 years	31.4	21.6	.15	.08	1.4	.50

[1] Cations extracted with normal ammonium acetate (6).

able cations. Among these, in sample No. 144, the total exchange capacity of the soil was occupied by the exchangeable cations. This sample had an excessive amount of extractable or exchangeable sodium, 26.7 m.e. Na

TABLE 4.—*Available boron*[1], *sodium chloride, extractable sodium*[2], *calcium-sodium ratios, pH, electrical conductivities, and presence or absence of free carbonates in soils of Lajas valley reported in table 3*

Lab. No.	B	NaCl in soil	Extractable sodium	Ca/Na	pH	EC[3]	Free carbonates
	P.p.m.	*Percent*	*Percent*				
140	0.55	0.29	11.4	14.8	9.0	55	Yes
141	2.00	1.19	72.9	3.1	9.2	278	Yes
143	2.70	1.46	41.5	3.5	8.3	400	Yes
144	1.55	1.56	45.9	1.2	8.2	650	Yes
149	1.05	.22	7.5	9.2	7.7	60	No
150	.75	.53	20.0	3.0	8.3	108	No
151	1.00	.56	20.7	2.5	8.4	148	Yes
152	1.80	.64	18.6	4.4	8.1	370	Yes
153	.75	.26	8.3	10.8	7.7	100	No
154	1.00	.49	17.2	6.3	8.4	160	Yes
142	.55	.29	14.9	7.6	8.8	52	Yes
146	1.30	.40	18.7	7.6	8.9	50	Yes
139	.55	.15	6.0	12.0	7.5	36	No
147	1.30	.16	6.3	19.4	8.5	43	Yes
148	1.30	.08	4.5	15.4	8.1	34	No

[1] Available boron dissolved in boiling water (1).

[2] Extractable sodium percent = $\frac{\text{Extractable Na}}{\text{Cation Exchange Capacity}} \times 100.$

[3] Mhos. $\times 10^{-5}$ at 25°C. in 1:2 soil-water suspension.

TABLE 5.—*Range of available boron, sodium chloride, extractable sodium, calcium-sodium ratios, pH, and electrical conductivities in good and poor cane soils in Lajas valley*

Soil rating	Samples Nos.	B	NaCl in soil	Extractable Na	Ca/Na	pH	EC[1]
		P.p.m.	*Percent*	*Percent*			
Good	140, 139, 147, 148	0.55–1.30	0.08–0.29	4.5–11.4	12.0–19.4	7.5–9.0	34–55
Poor	141, 150, 151	.75–2.00	.53–1.19	20.0–72.9	2.5–3.1	8.3–9.2	148–370

[1] Mhos. $\times 10^{-5}$ at 25°C. in 1:2 soil-water suspension.

per 100 gms., that could not be leached out with fresh water only. Such chemicals as gypsum or sulfur, would be required in excess, besides fresh water and good drainage. The reclamation of excessive salty land under these conditions is not economical. The other samples (Nos. 149, 150, 151, 153, 146) of salty land in this group contained between 3.8 and 9.5 m.e. of extractable or exchangeable sodium per 100 gms. Under these conditions salty land may be reclaimed economically with chemicals. Soil sample No. 151 that contained 9.5 m.e., or 20.7 percent of exchangeable sodium, would require about 4 tons of gypsum per acre—6″ to reduce the exchangeable sodium one-half (6, p. 57).

The available boron in the soils of Lajas valley varied from 0.55 to 2.70 p.p.m. B, the sodium chloride from 0.08 to 1.56 percent, the extractable sodium from 4.5 to 72.9 percent, the calcium-sodium ratio from 1.2 to 19.4, the pH from 7.5 to 9.2, the conductivities of 1:2 soil-water suspensions from 34 to 650 mhos $\times 10^{-5}$ at 25°C., and 10 of the soils gave positive tests for free carbonates (table 4). In table 4 the salt content is expressed in terms of electrical conductivity, as EC in mhos $\times 10^{-5}$ at 25°C. The U. S. Regional Salinity Laboratory (table 1) expresses EC in terms of *millimhos/cm. for a saturation extract consisting of a solution obtained* by pressure or vacuum filtration of a soil paste that has been saturated by adding water while stirring.

The salty soils of Aguirre clay where sugarcane grew poorly (table 5) contained from 0.75 to 2.00 p.p.m. of available boron, from 0.53 to 1.19 percent of sodium chloride, from 20.0 to 72.9 percent of extractable sodium, from 2.5 to 3.1 in calcium-sodium ratios, and from pH 8.3 to pH 9.2.

Soil Drainage and the Infiltration Rate of the Salty Land

The Lajas valley project must be carried out under an efficiently controlled irrigation-drainage system.

Infiltration is the rate at which water enters the soil surface. Twenty-four quadruplicate tests (3) were performed on nine soil types of Lajas valley, including the salty Aguirre clay. The buffer-compartment method of Nelson and Muckenhirn (5) with three concentric rings, 9, 18, and 27 inches, respectively in diameter, 5 inches high, and a 2,000 ml. burette water reservoir was used. The test was run for eight consecutive hours and records were kept for every hour.

The maximum infiltration rate was obtained for all soils in the first hour, because they were dry and absorbed more water. From the second hour on the infiltration rate was reduced until the eighth hour, when the minimum was obtained. Salty Aguirre clay had very slow to slow minimum infiltration rates varying from 0.03 to 0.08 inch per hour.

Reclamation with Chemicals

A tract of high salty Aguirre clay with specific conductances in a 1:2 soil-water suspension varying from 186 to 445 mhos $\times 10^{-5}$ at 25°C., was chosen for the reclamation field experiment (2) with gypsum and sulfur.

Twenty square plots, each 20 feet x 20 feet, were separated by a ditch 2-feet wide followed by a pathway 5 feet wide and a second ditch. The plots were grouped into five blocks and each block was subdivided into four plots for the following randomized treatments: Check, leached, sulfur, gypsum.

Sulfur and gypsum were applied at rates of 1 and 2 tons per acre, respectively. The chemicals were hoed and mixed well with the surface soil. The plots were planted on January 19, 1948, with cane variety POJ 2878 and immediately irrigated by filling the furrows to the top with fresh water. The water was kept in the furrow by plugging its end with earth. The frequency of irrigation varied between 8 and 10 days until 1 month before harvest. Nitrogen as ammonium nitrate, at the rate of 283 lbs. of N per acre, was the only fertilizer applied. The crop was harvested at the age of 12½ months.

Discarding the results from two blocks affected by high water table and poor drainage at the drainage outlet, the data indicated that the gypsum treatment was significantly better than the check and leached treatments but that there were no significant differences between the sulfur, check, and leached treatments.

The cane juices from all treatments were salty, but were acid in reaction, around pH 5.7, and their mean specific conductance was found to be 697 mhos x 10^{-5} at 25°C., equivalent to an estimated 4,879 parts per million of soluble salts. Juices of 20 canes from nonsalty soils gave specific conductances, or electrical conductivities, ranging from 130 to 275 mhos $\times 10^{-5}$ at 25°C., equivalent to about 910 to 1,925 parts per million of salts, respectively. These good juices were slightly less acid, pH 5.8 to 6.0, than the ones from POJ 2878 cane grown in the highly salty land.

SUMMARY

The salinity problem of Lajas valley in southwestern Puerto Rico has developed from seepage caused by impeded drainage and by surface-soil evaporation because the salts from the salty wells used for irrigation and the run-off drain toward the lowlands. A project is under way in Lajas valley to irrigate about 24,000 acres of good cane land. Salts also affect adversely the growth of sugarcane on about 10,000 acres in addition.

The salty lands include saline, saline-alkali, and nonsaline alkaline soils. Saline soils contain excessive salts and alkaline soils contain excessive exchangeable sodium. The excess of salts in the saline and saline-alkali soils can be leached out by fresh water if good drainage is provided, as was shown by three leaching tests performed in the field. The excess of salts in the saline-alkali soils and the excess of sodium in the saline-alkali and nonsaline alkaline soils may be leached out with gypsum or sulfur

and fresh water, if good drainage is provided, and if the exchangeable sodium to be removed is not excessive, that is about 5 m.e. per 100 gms. of soil.

The high content of extractable or exchangeable calcium generally present in the salty lands of Lajas valley is a good asset for their successful reclamation with fresh water and chemicals such as gypsum or sulfur, if adequate drainage is provided. In a field test, an application of 2 tons of gypsum per acre produced a significant increase in cane yield, but the acid juice of the cane was salty.

Sugarcane grows poorly in the salty lands of Lajas valley that contain from 0.75 to 2.00 p.p.m. of available boron, from 0.53 to 1.19 percent of sodium chloride, from 20.0 to 72.9 percent of extractable sodium, from 2.5 to 3.1 calcium-sodium ratios, and the pH of which ranges 8.3 to 9.2. Good sugarcane growth was observed when the salty land contained 4.5 to 11.4 of extractable sodium and the calcium-sodium ratios were 12.0 to 19.4.

RESUMEN

El problema de la salinidad del Valle de Lajas, en la parte suroeste de Puerto Rico, ha sido el resultado del desagüe inadecuado y de la evaporación de las escorrentías del agua salada de los pozos, usada para el riego.

Estas aguas saladas han venido usandose, por muchos años, para regar la caña de azúcar en esta árida región. Toda la zona contiene alrededor de 10,000 acres de terrenos salados.

El sistema de riego del Valle de Lajas, actualmente en construcción, podrá proveer agua a 24,000 acres de terrenos fértiles.

Las tierras saladas de esta zona comprenden suelos salinos, salino-alcalinos y alcalinos no salinos.

Los suelos salinos contienen una cantidad excesiva de sales libres, mientras que los alcalinos tienen gran cantidad de sodio intercambiable.

Las sales libres en los terrenos se pueden lavar con agua de buena calidad, si el desagüe es adecuado. Esto quedó comprobado durante los experimentos que se llevaron a cabo en el campo.

Para eliminar el sodio intercambiable en los suelos alcalinos, es necesario, también, añadirles yeso o azufre. La adición de estos ingredientes resulta económica, cuando la cantidad de sodio intercambiable presente no exceda de 5 miliequivalentes, poco más o menos, por cada 100 gramos de suelo.

La presencia del calcio libre e intercambiable, en estos suelos salados, es abundante, y por lo tanto, favorable en cuanto a su eficaz reclamación.

En uno de los experimentos hechos, la aplicación de 2 toneladas de yeso por acre a un terreno salado, produjo un aumento significativo en el rendimiento de la caña de azúcar, pero los jugos resultaron salados.

Se observó que la caña creció pobremente en aquellas tierras saladas que

contenían de 0.75 a 2.00 partes por millón de boro asimilable; de 0.53 a 1.19 por ciento de cloruro sódico; de 20.0 a 72.9 por ciento de sodio; valores pH entre 8.3 y 9.2; y donde la razón entre el calcio y el sodio fluctuó de 2.5 a 3.1.

La caña de azúcar creció satisfactoriamente, cuando el terreno salado contenía de 4.5 a 11.4 por ciento de sodio y cuando la razón entre el calcio y el sodio fluctuó de 12.0 a 19.4.

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