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A. B. CONNER, DIRECTOR

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DIVISION OF CHEMISTRY

IODINE IN TEXAS SOILS

AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS

T. O. WALTON, President

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Iodine was determined in over 400 samples of soil from various parts of Texas. When the geographical divisions of the state are arranged in order of the increasing average iodine content of their soils, the divisions rank as follows, beginning with the lowest: Central Basin 1.7 parts per million, East Texas Timber Country 2.2, Gulf Coast Prairie 3.5, High Plains 3.9, West Cross Timbers 1.7 to 5.8, Blackland Prairies 5.8, Basins and Mountains 6.6, Rolling Plains 7.1, Rio Grande Plain 8.0, Grand Prairie 10.2, and Edwards Plateau 11.3 parts per million. Heavy textured soils contained more iodine than light textured soils. A high iodine content is usually associated with a high content of acid-soluble lime, and, to a much less marked and regular degree, with a high content of total phosphoric acid. The iodine content usually increased with an increase in depth. The soils of Texas are in general as high in iodine as soils of regions in which goiter is of minor importance, and higher than those from goiterous regions.

TABLE OF CONTENTS

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IODINE IN TEXAS SOILS

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For a long time, iodine in minute quantities has been recognized as necessary for the health of animals, including man. Deficiencies of iodine give rise to simple or endemic goiter, and also to other disturbances of health (17), though goiter is not always due to a deficiency of iodine alone. In the case of pigs, hairlessness is a common symptom of iodine deficiency; and the pigs are weak when born and may soon die. We know of no reports of the occurrence of hairless pigs in Texas. The wide interest in iodine is shown by the extensive use of iodized salt.

That the prevalence of goiter in humans is associated with very low quantities of iodine in the food and water supplies in a given area has been shown by the work of a large number of investigators. Simple goiter may occur anywhere and in any land or fresh water animal which has a thyroid gland, although there are species and individual differences in its incidence in animals living in the same general environment (23). The principal districts of endemic goiter in North America are the St. Lawrence Basin, the Great Lakes Basin extending through Minnesota, the Dakotas and adjacent Canadian provinces, and the Pacific Northwest, including Oregon, Washington, and British Columbia (24). Most of these regions are mountainous, but they include soils deposited from the last glacial period throughout northern United States and Canada.

Marine, Lenhart, and Kimball (23) state that iodine at the rate of 300 milligrams per year will control a large percentage of simple goiter in humans. The minimum quantity of iodine required per day by humans has been estimated by Meerburg (25) to be from 80 to 100 micrograms, by Cameron (6) from 35 to 70 micrograms, by Orr and Leitch (27) at about 45 micrograms for an adult male and 150 micrograms for a child, and by Levine, Remington, and von Kolnitz (16) at from 60 to 120 micrograms (a microgram is a millionth of a gram). Levine and Remington (15) and others have shown that the amount of iodine required by a person is determined to some extent by a number of factors besides the quantity of iodine ingested. These include the sexual age and condition of the individual, the quantity of lime, vitamins, and such foods as cabbage and fats in the diet, and also climatic factors such as light, temperature, and seasonal variations. The relation of geographic location to the iodine content of the thyroid gland in hogs was studied by Fenger, Andrew, and Vollertsen (9), who report that, when the iodine content was calculated on the desiccated fat-free basis, thyroid glands from hogs grown in North Dakota contained 0.32% iodine, while those from hogs grown in Texas contained 0.60% iodine; seasonal variations in the iodine content were most pronounced in the glands from North Dakota. Weston (35) has suggested that a complete survey of the iodine question in all areas of the country be made in order to determine more accurately the relation of the incidence of goiter to the quantity of iodine available. Such a study with respect to Texas was begun several years ago by the authors. This bulletin presents the results of the study of the iodine content of the soils of Texas.

Importance of the iodine content of soils

The iodine content of the soil is of considerable importance in connection with the provision of an ample supply of iodine for the proper development and functioning of man and animals, since the iodine in plants making up their food comes directly from the soil, and the iodine in their drinking water taken from the ground comes from the geological strata overlying the source of the water, of which the soil is the uppermost layer. The iodine content of soils of different regions has been studied by a number of investigators. A few workers (1, 13) found no relation between the incidence of goiter in a region and the iodine content of the soils, while many others (3, 4, 5, 12, 20, 26, 28, 29, 30, 34) concluded from their work that the incidence of goiter increases as the iodine content of the soil decreases. It is probable that the available supply of iodine is only one of a number of factors influencing the incidence of goiter, and that the bulk of the food eaten may not necessarily be grown on the soil in the immediate vicinity.

The relation between the iodine content of the soil and that of the plants grown on the soil seems to be influenced by a number of different factors, which includes the acidity of the soil, the species of the plant, and the relative availability of the iodine in the soil. Von Fellenberg (8) states that the liberation of iodine from iodides and the absorption of iodine by plants are much greater on acid soils than on alkaline soils. Balks (4) found that the effect of iodine fertilization of the soil on the iodine content of the plant was dependent both upon the nature of the soil and the species of plant fertilized. The iodine content of potatoes, white cabbage, and carrots appeared to be little affected by increasing the quantity of iodine in the soil, while the quantity of iodine in spinach bore a close relation to the quantity of iodine in the soil. The action of the added iodine differed with the kind of soil. Hercus and Roberts (12) state that loam has a marked retentive power for soluble iodides, while clay has considerably less and sand has none. Mack and Brasher (22) found no relation between the iodine content of potatoes, tomatoes, and sweet corn and the fertilizer used, the acidity of the soil, or the yield, while an application of potassium iodide equivalent to 1 part of iodine per million of soil increased the iodine content of beans and of turnips considerably. The maximum increase in iodine content occurred on soils rendered alkaline by hydrated lime and the minimum on the original soils or on soils acidified with sulfur. In general, the iodine content of turnips from soil not fertilized with potassium iodide increased with the acidity of the soil, while that of beans was little affected. McHargue, Roy, and Pelphrey (18) found that the iodine content of red clover was increased 16 times by moderate applications of such fertilizers as Chilean nitrate of soda and by phosphate rock, which may contain appreciable amounts of iodine. McHargue, Young, and Calfee (21) state that crude Chilean nitrate of soda, raw rock phosphate, and lime may contain sufficient iodine to change the iodine content of fertilized plants, and that the iodine contents of corn and of several vegetables were increased enormously by the addition of potassium iodide to the soil. Shore and Andrew (29) report that vegetables from different areas of the North Island of New Zealand were similar in iodine content, while the iodine content of milk and eggs varied with the iodine content of the soils; evidently, the iodine content of the soil had little effect upon the iodine content of the vegetables used as food by man but must have had considerable effect upon that of the forage plants grazed by cows and poultry. Von Wendt (34) reports that the soils of Finland are low in iodine, and that this low content of iodine in the soils results in an iodine deficiency in forage plants and as a result, a general occurrence of goiter in man and cattle.

Very little work has been done on the availability of the iodine of soils. The iodine content of the soils of various localities reported by the different workers represents the total quantity of iodine in the soil. Most of the work cited above was done by studying the effects of the addition of soluble salts of iodine to the soil. Many workers in soil chemistry have shown that the total quantity of nitrogen, phosphoric acid, and potash in the soil gives little indication as to the quantity of these constituents which may be available for plant use. They have developed methods by which an attempt is made to determine the quantity of these constituents which may be taken up by plants. No such work has been done in the case of iodine, and nothing is known concerning the proportion of the total iodine in the soil which may be available, nor factors which may influence the availability of the iodine in the natural soil. In general, there appears to be a relation between the iodine content of the soils of a given region and the incidence of common goiter, and that where goiter occurs, the soils are very low in iodine.

The iodine content of a large number of soils from Texas has been determined. The samples analyzed for iodine were those sent in by the Soil Surveyors from different areas throughout the state, and represented what they considered to be typical samples of the different soil types. The number of samples from some of the geographical regions of the state was small, but the samples were taken in the proper manner and are believed to represent the area concerned.

Method of analysis

Several methods (11) for the determination of iodine were tested during the early part of the work, but were unsatisfactory because the results of check analyses made at intervals of several days, did not agree well. Often there was wide difference when the work was repeated.

The procedure finally found to give consistent results, and used in most of the work reported in this paper is a colorimetric modification of the method of Trevorrow and Fashena (33) as later modified by Fashena and Trevorrow (7). The procedure may be briefly described as follows:

From 2 to 5 grams of soil in a 250 cc. beaker were digested in a mixture of 30 cc. of water and 30 cc. of 95% sulfuric acid containing 6 g. of potassium dichromate and about 10 mg. of cerous sulfate for about an hour over a low flame. Digestion was continued until the temperature had increased to 195°C. The insoluble material was filtered from the cooled solution through a mat of purified asbestos, and thoroughly washed with about 50 cc. of water. An excess (usually about 6 cc.) of 80% phosphorous acid was added to the solution after the latter had been transferred to the all-glass distilling apparatus described by Trevorrow and Fashena (33). The liberated iodine was distilled into 10 cc. of 0.02 N sodium hydroxide until the temperature in the solution had raised to 150° C. The distillate was made slightly acid with sulfuric acid, bromine vapor added until the color was brown, and evaporated to about 5 cc. The evaporated distillate was transferred quantitatively to a small separatory funnel, and 4 drops of 50% sulfuric acid, 1 cc. of 0.1% potassium hydroxide, and 1 cc. of carbon tetrachloride added in the order mentioned, with shaking between each addition. Water was then added to make a total volume of 10 cc. The liberated iodine was absorbed in the carbon tetrachloride by shaking vigorously for 2 minutes, the carbon tetrachloride centrifuged to remove turbidity, and the color compared in a Duboscq microcolorimeter with a standard containing approximately the same quantity of iodine and prepared in the same way.

This procedure is easily operated, requires a small amount of attention from the analyst, and gives results which agree very closely on repeated runs of the same sample. Tests made by reading the color of the iodine directly, gave results which agreed with those made by oxidation to iodate by means of the bromine by the method described above.

Iodine in Texas soils

The average iodine contents of a number of samples of important soil types in Texas, together with the number of samples analyzed and the range in iodine content of different samples within the types, are shown in Table 1. The soil types are arranged according to the geographic divisions in which they occur. The geographic divisions of the state are shown in Figure 1.

Table 1. Iodine in surface soils by soil types

	No.	High p. p. m.	Low p. p. m.	Average p. p. m.
East Texas Timber Country				
Upland soils with friable subsoils:				
Bowie fine sandy loam	4	2.7	1.1	2.0
Caddo fine sandy loam	1	....	....	1.1
Kirvin fine sandy loam	6	3.0	1.6	2.1
Nacogdoches fine sandy loam	4	14.0	2.5	6.1
Norfolk fine sand	7	1.8	0.8	1.4
Norfolk fine sandy loam	3	2.1	1.5	1.8
Norfolk sand	1	....	....	1.3
Ruston fine sand	1	....	....	1.0
Ruston fine sandy loam	8	2.3	1.1	1.9
Segno fine sand	1	....	....	1.7
Segno fine sandy loam	3	3.3	2.0	2.7

Table 1. Iodine in surface soils by soil types—Continued

	No.	High p. p. m.	Low p. p. m.	Average p. p. m.
East Texas Timber Country—Continued				
Upland soils with dense subsoils:				
Acadia clay loam	1	....	....	1.8
Lufkin clay	1	....	....	2.5
Lufkin fine sand	1	....	....	1.0
Lufkin fine sandy loam	7	3.4	0.9	2.1
Lufkin very fine sandy loam	3	2.1	0.9	1.4
Sesquehanna fine sandy loam	8	8.1	0.5	2.6
Sesquehanna silt loan	3	2.6	1.9	2.3
Leaf fine sandy loam	2	2.0	1.0	1.5
Flat stream bottom soils:				
Portland very fine sandy loam	1	....	....	1.3
Gulf Coast Prairie				
Dark-colored prairie soils:				
Lake Charles clay	6	8.5	2.4	4.8
Lake Charles clay loam	5	9.7	1.3	4.1
Lake Charles fine sandy loam	4	8.2	2.9	4.7
Light-colored prairie soils:				
Edna clay	1	....	....	4.4
Edna fine sandy clay loam	1	....	....	2.1
Edna fine sandy loam	3	6.5	1.2	3.3
Edna silty clay loam	1	....	....	3.3
Edna very fine sandy loam	1	....	....	1.0
Galveston fine sand	1	....	....	1.2
Hockley fine sandy loam	7	4.7	1.2	2.5
Katy fine sandy loam	4	4.3	0.9	2.1
Flat marshy to semi-marshy soils:				
Harris clay	1	....	....	9.6
Harris fine sandy loam	1	....	....	1.6
Flat stream bottom soils:				
Guadalupe fine sandy loam	1	....	....	9.3
Miller clay	2	3.1	2.3	2.7
Miller fine sandy loam	2	4.4	1.2	2.8
Miller silty clay loam	1	....	....	9.3
Miller very fine sandy loam	1	....	....	4.5
Ochlockonee fine sandy loam	2	12.0	2.4	7.2
Trinity clay	3	9.3	3.1	6.0
Yahola loamy fine sand	1	....	....	3.5
Yahola loamy very fine sand	1	....	....	1.9
Yahola very fine sandy loam	1	....	....	3.2
Blackland Prairies				
Calcareous upland prairie soils:				
Houston black clay	5	16.5	5.2	11.2
Houston clay	6	9.7	3.1	6.4
Houston clay loam	1	....	3.4	....
Bell Clay	6	16.3	4.9	8.1
Lewisville clay	3	6.9	2.6	4.2
Flat stream-bottom soils:				
Catalpa clay	5	7.3	2.5	4.5
Noncalcareous upland prairie soils:				
Crockett clay loam	6	13.3	2.7	7.0
Crockett fine sandy loam	6	8.2	1.4	4.0
Ellis clay	1	....	....	10.0
Wilson clay	4	6.2	2.8	4.8
Wilson clay loam	6	6.8	2.2	5.0
Wilson fine sandy loam	6	7.0	1.9	3.1
Wilson very fine sandy loam	1	....	....	6.6
Irving clay	3	6.6	3.5	5.2
Irving fine sandy loam	2	3.2	2.5	2.9

Table 1. Iodine in surface soils by soil types—Continued

	No.	High p. p. m.	Low p. p. m.	Average p. p. m.
Grand Prairie				
Rolling upland prairie soils:				
Brackett fine sandy loam	2	6.0	2.3	4.2
Brackett loam	3	7.4	5.5	6.4
Crawford clay	1	....	....	24.6
Denton clay	2	16.4	8.1	12.3
San Saba clay	3	20.2	7.1	11.8
West Cross Timbers				
Nimrod fine sand	2	1.2	1.0	1.1
Windthorst fine sandy loam	4	10.2	2.3	5.8
Bastrop silty clay loam	1	....	....	9.7
Central Basin				
Tishmingo sandy loam	3	2.6	1.1	1.7
Rio Grande Plain				
Upland plains, dark-colored soils:				
Goliad clay loam	2	23.7	17.0	20.4
Goliad fine sandy loam	4	14.3	6.0	8.9
Hidalgo clay loam	2	9.0	2.6	5.8
Hidalgo fine sandy loam	1	....	....	3.0
Orelia clay	1	....	....	14.1
Orelia clay loam	1	....	....	8.0
Orelia fine sandy loam	1	....	....	5.5
Victoria clay	2	11.2	11.2	11.2
Victoria clay loam	5	13.7	4.5	7.2
Victoria fine sandy loam	1	....	....	4.4
Victoria sandy clay loam	1	....	....	4.8
Willacy fine sandy loam	1	....	....	3.6
Upland plains, light-brown soils:				
Delfina fine sandy loam	1	....	....	4.7
Maverick fine sandy loam	1	....	....	22.7
Upland plains, light-colored soils:				
Brennan fine sandy loam	3	5.6	4.4	4.9
Nueces fine sand	3	8.5	1.7	4.0
Upland plains, red soils:				
Duval fine sandy loam	5	8.3	2.3	4.1
Webb fine sandy loam	4	4.4	1.9	3.1
Semi-marshy soils:				
Lomalto clay	3	24.0	7.3	14.0
Lomalto clay loam	1	....	....	18.9
Lomalta fine sandy loam	1	....	....	2.2
Point Isabel clay	2	15.3	13.0	14.2
Point Isabel fine sandy loam	2	10.6	3.9	7.3
Stream bottom soils:				
Cameron clay	1	....	....	3.6
Harlingen clay	1	....	....	3.1
Laredo clay	1	....	....	5.0
Rio Grande clay	1	....	....	2.7
Frio clay loam	1	....	....	5.5
Frio fine sandy loam	1	....	....	4.0
Frio very fine sandy loam	1	....	....	2.4
Frio silt loam	2	4.5	3.3	3.9
Frio silty clay loam	2	7.5	4.5	6.0
Edwards Plateau				
Valera clay	4	18.0	5.8	10.9
Denton clay	2	16.4	8.1	12.3

Table 1. Iodine in surface soils by soil types—Continued

	No.	High p. p. m.	Low p. p. m.	Average p. p. m.
Rolling Plains				
Dark-colored upland soils:				
Abilene clay loam	6	15.0	4.6	7.8
Abilene fine sandy loam	2	3.7	2.1	2.9
Abilene loam	2	6.5	3.9	5.2
Abilene silty clay loam	1	....	....	3.1
Abilene very fine sandy loam	1	....	....	2.7
Foard clay	2	13.0	3.4	8.2
Foard clay loam	1	....	....	4.7
Roscoe clay	2	8.7	4.2	6.5
Red soils:				
Vernon clay	3	7.0	4.1	5.2
Vernon clay loam	4	11.4	6.7	9.1
Vernon fine sandy loam	3	2.2	0.7	1.7
Vernon gravelly clay loam	1	....	....	3.7
Vernon very fine sandy loam	2	....	....	3.7
Brownish red soils:				
Miles clay loam	6	29.3	4.3	14.9
Miles fine sandy loam	7	3.2	1.3	3.1
Miles loam	2	6.1	4.8	5.5
Miles loamy fine sand	2	3.9	0.8	2.4
Wichita clay loam	1	....	....	9.5
Wichita fine sandy loam	1	....	....	6.1
Wichita sandy loam	1	....	....	2.2
Bottomland soils:				
Spur clay loam	1	....	....	2.6
Spur fine sandy loam	1	....	....	2.3
Spur very fine sandy loam	1	....	....	1.1
High Plains				
Dark-colored upland soils:				
Randall clay	2	3.5	2.6	3.1
Potter clay loam	3	14.3	9.9	11.4
Potter fine sandy loam	1	....	....	3.6
Pullman clay loam	1	....	....	1.9
Pullman fine sandy loam	1	....	....	1.6
Pullman silty clay loam	3	10.3	4.0	6.2
Richfield clay loam	1	....	....	3.3
Richfield silty clay loam	2	9.2	4.0	6.6
Red upland soils:				
Amarillo clay loam	3	....	....	4.6
Amarillo fine sandy loam	7	7.0	1.3	4.3
Springer fine sand	2	1.4	0.6	1.0
Springer fine sandy loam	3	2.5	1.6	2.2
Enterprise loamy fine sand	1	....	....	1.3
Enterprise loamy very fine sand	1	....	....	1.5
Mountains and Basins				
Reagan fine sandy loam	2	5.5	2.4	4.0
Reagan silty clay loam	2	10.6	3.3	7.0
Reeves fine sandy loam	2	4.7	1.6	3.2
Reeves gravelly loam	1	....	....	3.2
Reeves silty clay loam	5	16.2	4.2	8.7
Verhalen clay	2	9.1	7.9	8.5
Verhalen clay loam	1	....	....	2.7
Verhalen loamy fine sand	1	....	....	1.7
Flat stream bottom soils:				
Gila silt loam	1	....	....	3.0
Toyah clay loam	1	....	....	4.7

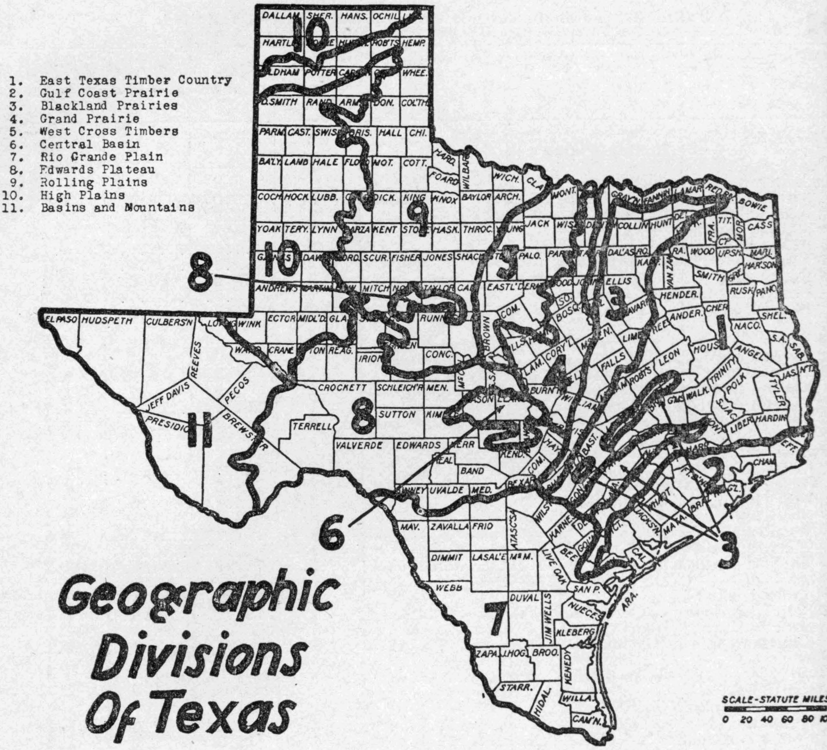

Figure 1. Geographic divisions of Texas.

The dominant soils of the East Texas Timber Country are yellow, red or gray in color, and are sandy and noncalcareous. The 62 samples of soil from this geographical division averaged 2.2 parts per million of iodine. Soils with freely permeable subsoils averaged 1.8 parts per million, when the Nacogdoches series (6.1 parts per million) is omitted from the average, while the soils with very slowly permeable subsoils averaged 2.1 parts per million. The iodine content of the soils, both with respect to the range of iodine content within a given series and also between series, was remarkably uniform. With the exception of the sandy soils of the Central Basin (which averaged 1.7 parts per million), the soils of the East Texas Timber Country averaged lower in iodine than the soils of any of the other geographic divisions of the state.

The soils of the Gulf Coast Prairie division are composed of two main groups—the dark-colored, heavy-textured soils of the Lake Charles and related series, and the light-colored sandy loam soils of the Hockley, Katy, and Edna series. The soils of the region as a whole averaged 3.5 parts of iodine per million, or about 60% higher than the soils of the East Texas Timber Country lying to the north. The dark-colored soils averaged 4.6 parts per million of iodine, while the light-colored soils averaged 2.6 parts per million, only slightly higher than the corresponding soils of the East Texas Timber Country. The Harris series is composed of flat, marshy to semimarshy soils lying along the coast, and averaged 5.6 parts per million, the highest series in the region. The Galveston soils are loose, incoherent sands of the sandbars lying along the coast; the iodine in these soils averaged only 1.2 parts per million of iodine, the lowest in the region.

The soils of the Blackland Prairies averaged 5.8 parts per million of iodine, or nearly three times as high as the soils of the East Texas Timber Country and, with the exception of the Lake Charles series, much higher than the upland soils of the Gulf Coast. This was true for all of the series in the region, whether calcareous or not. However, within the region, the calcareous soils averaged considerably higher in iodine than the noncalcareous soils. The calcareous, heavy-textured soils of the Houston, Bell, and Lewisville series averaged 7.1 parts per million of iodine, while the noncalcareous, lighter-textured soils of the Wilson, Crockett, and related series averaged 5.0 parts per million. The range between the minimum and maximum iodine contents of different samples of a given soil type was proportionately much greater in the Blackland Prairie region than in the other two divisions of the humid section of the state.

The soils of the Grand Prairie, composed chiefly of the heavy-textured dark-colored soils of the Denton and San Saba series, were relatively high in iodine, the general average for the region being 10.2 parts per million, nearly twice as high as the average for the Blackland Prairie and five times as high as the average for the East Texas Timber Country.

The sandy soils of the Nimrod series in the West Cross Timbers averaged 1.1 part per million and the Tishimingo series in the Central Basin averaged 1.7 parts per million. These are low compared with other Texas soils but high when compared with soils where goiter occurs frequently. The soils of the Windthorst series, which covers a large part of the West Cross Timbers, averaged 5.8 parts per million, while a single sample of the Bastrop series, a silty clay loam, contained 9.7 parts per million. The number of soils analyzed from the West Cross Timbers and the Central Basin was quite low, and the results are sufficient only to give indications as to the iodine content of the soils in these two regions.

The soils of the Rio Grande Plain were comparatively high in iodine, averaging 8.0 parts per million. The soils of this region are divided into a number of groups, differing markedly in texture, color, and general fertility; the iodine content of these groups also differs widely. The dark-colored, chiefly heavy-textured soils of the Victoria, Goliad, Orelia and related series averaged 8.9 parts per million, as compared with 4.4 parts per million for the light-colored sandy soils of the Brennan and Nueces series and 3.7 parts per million for the red fine sandy loams of the Duval and Webb series. The semi-marshy and associated soils of the Lomalta and Point Isabel soils along the coast were quite high in iodine, averaging 11.8 parts per million of iodine.

The heavy-textured, highly calcareous soils of the Edwards Plateau were high in iodine, averaging 11.3 parts per million, the highest average for any geographic division in the state.

The soils of the Rolling Plains averaged 7.1 parts per million of iodine, or slightly higher than the soils of the Blackland Prairies. The dark-colored, chiefly heavy-textured soils of the Abilene, Roscoe, Foard and related series averaged 6.1 parts per million, as compared with 5.2 parts per million for the Vernon series, the principal red soil of the region, and 7.5 for the Miles series, the principal series of the brownish-red soils. The range between minimum and maximum iodine contents within a given series was relatively large, the Miles soils ranging from 0.8 to 29.3 parts per million, and indicate a marked lack of uniformity in the soils of this division.

The soils of the High Plains averaged only 3.9 parts per million, considerably below the average for the soils of the Rolling Plains. The low average is partly due to the low iodine content of the sandy soils of the Springer and Enterprise series, which averaged only 1.6 parts per million. The red soils of the Amarillo and related series averaged 4.4 parts per million, while the heavy-textured, dark-colored soils of the Potter, Pullman, and Richfield series averaged 6.4 parts per million.

The calcareous soils of the Basins and Mountains region, in the extreme western part of the state and within the semi-arid area, averaged 6.0 parts per million, intermediate between the soils of the Rolling Plains and those of the High Plains and much lower than the soils of the Edwards Plateau. The data here presented are not in accord with the statements of some writers that soils nearest the coast are highest in iodine. The contrary is the case, since the sandy soils near the coast are low in iodine, compared with other soils of the state, though not low compared with soils of goiterous regions. This may be due to the greater rainfall in the coastal regions.

Relation of iodine content to soil texture

That there is a relation between the iodine content and the texture of soils is indicated by the figures in Table 1. In order to show this relation more clearly, the average iodine contents of different classes of soils of series of which more than one class was analyzed are shown in Table 2. The average relative quantity of iodine in the different soil classes, expressed as percentages of the next class containing a greater proportion of the fine soil separates, is shown at the bottom of Table 2. The average iodine content of clay loams was 89% as great as that in clays of the same series, that in sandy loams, only 45% as great as that in corresponding clay loams, and that in sands, only 75% as great as that in corresponding sandy loams. When the average iodine content of all classes of soils of all series listed in Table 2 are compared, the clay loams contained the same amount of iodine as the clays, the sandy loams less than half that amount, while the sands contained only about one-fifth as much iodine as the clays. Although there are exceptions, the iodine content of the soil in general increased significantly with an increase in the percentage of fine separates of the soil.

Table 2. The relation between iodine content and soil texture

Soil Series	Clay	Clay loam	Sandy loam	Sands
Norfolk	....	....	1.8	1.4
Ruston	....	....	1.8	1.0
Lufkin	2.5	....	1.9	1.0
Segno	....	....	2.7	1.7
Lake Charles	4.8	4.1	4.7	....
Edna	4.4	2.7	2.7	....
Houston	7.7	3.4	....	....
Wilson	4.8	5.0	3.6	....
Irving	5.2	....	2.9	....
Crockett	....	7.0	4.0	....
Victoria	11.2	6.8	4.4	....
Goliad	....	20.4	8.9	....
Orelia	14.1	8.8	5.5	....
Hidalgo	....	5.8	3.0	....
Lomalta	14.0	18.9	2.2	....
Point Isabel	14.2	7.3	....	....
Abilene	....	7.2	3.8	....
Foard	8.2	4.7	....	....
Vernon	5.2	8.0	2.5	....
Miles	....	14.9	3.6	2.4
Wichita	....	9.5	4.2	....
Potter	....	11.4	3.6	....
Pullman	....	5.3	1.6	....
Amarillo	....	4.6	4.3	....
Springer	....	....	2.2	1.0
Reagan	....	7.0	4.0	....
Reeves	....	8.7	3.2	....
Verhalen	8.5	2.7	....	1.7
Miller	2.7	9.3	3.4	....
Yahola	....	....	3.2	2.7
Frio	....	5.8	3.6	....
Spur	....	2.6	1.7	....
Relative averages:				
Clays to clay loams	100	89	....	....
Clay loams to sandy loams	....	100	45	....
Sandy loams to sands	....	....	100	75
Clays to all classes	100	100	44	21

Relation of iodine to geographical region

A comparison of the average iodine content of the several geographical regions of the state is given in Table 3. With the exception of the sandy soils of the Central Basin, the High Plains, and the West Cross Timbers, which are relatively low in iodine (Tables 1 and 2), the iodine in the soils of the subhumid section of the state averaged about 75% higher than the iodine in the soils of the humid section. In the humid section, 154 upland soils averaged 3.8 parts per million, while in the subhumid section, 173 upland soils averaged 6.7 parts per million.

Table 3. Average iodine content of Texas surface soils by regions

Region	Number analyzed					Iodine				
	Clay	Clay loams	Sandy loams	Sands	Total	Clay	Clay loams	Sandy loams	Sands	Average
						p. p. m.	p. p. m.	p. p. m.	p. p. m.	p. p. m.
East Texas Timber Country	1	1	49	11	62	2.5	1.8	2.1	1.4	2.2
Gulf Coast Prairie	8	7	20	1	36	5.4	3.7	2.9	1.2	3.5
Blackland Prairies	28	13	15	0	56	6.8	6.0	3.7	....	5.8
Grand Prairie	6	0	5	0	11	14.1	....	4.5	....	10.2
West Cross Timbers	0	1	4	2	7	....	9.7	5.8	1.1	5.0
Central Basin	0	0	3	0	3	....	....	1.7	....	1.7
Rio Grande Plain	8	14	23	3	48	13.4	8.6	6.2	4.0	8.0
Edwards Plateau	6	1	0	0	7	11.3	11.2	....	....	11.3
Rolling Plains	7	20	21	2	50	6.4	11.5	3.4	2.4	7.1
High Plains	2	13	12	4	31	3.1	6.6	3.5	1.2	3.9
Basins and Mountains	2	8	5	1	16	8.5	7.5	3.5	1.7	6.0
All upland soils	68	78	157	24	327	8.3	9.3	3.5	1.8	5.4
Alluvial soils	14	6	13	2	35	4.3	5.7	3.7	2.7	4.2
All soils	72	84	170	26	362	6.5	9.2	3.5	1.9	5.3

Table 4. Iodine in soil horizons of several important soil types

	Lowest depth of horizon				Iodine			
	1 inches	2 inches	3 inches	4 inches	1 p. p. m.	2 p. p. m.	3 p. p. m.	4 p. p. m.
East Texas Timber Country								
Bowie fine sandy loam	7	18	24	36	2.2	4.0	6.1	4.1
Caddo fine sandy loam	5	18	24	36	1.1	1.3	1.6	1.9
Kirvin fine sandy loam, Location No. 1	11	24	40	....	3.0	12.9	5.6	....
Kirvin fine sandy loam, Location No. 2	4	15	30	48	1.9	2.0	5.5	8.7
Norfolk fine sandy loam	7	20	40	....	1.5	3.8	2.2	....
Ruston fine sandy loam	7	14	60	....	1.7	2.2	10.0	....
Segno fine sandy loam	3	7	15	24	3.3	2.6	2.4	6.4
Lufkin fine sandy loam	7	19	30	....	2.4	5.3	7.5	....
Susquehanna fine sandy loam	7	18	36	....	8.1	3.1	10.7	....
Susquehanna silt loam	6	18	36	....	1.9	4.2	6.3	....
Gulf Coast Prairie								
Lake Charles clay loam	8	20	36	....	9.7	9.9	9.4	....
Lake Charles fine sandy loam	8	36	....	....	2.9	2.6	....	....
Hockley fine sandy loam	15	26	36	....	2.5	2.0	1.2	....
Katy fine sandy loam	8	24	36	....	0.9	2.0	1.5	....
Blackland Prairies								
Houston clay	7	20	36	....	4.8	6.1	3.8	....
Houston clay	7	24	36	....	9.0	9.5	7.5	....
Crockett fine sandy loam	12	24	....	....	3.7	5.8	....	....
Wilson clay	10	36	....	....	6.2	7.0	....	....
Wilson fine sandy loam	12	20	36	....	1.9	6.1	8.2	....
Rio Grande Plain								
Goliad fine sandy loam	7	10	20	24	6.0	20.8	28.1	35.4
Hidalgo clay loam	7	19	....	....	2.6	10.2	....	....
Hidalgo fine sandy loam	7	19	....	....	3.0	4.7	....	....
Victoria clay loam	7	19	....	....	6.9	15.6	....	....
Duval fine sandy loam	14	27	63	....	8.3	14.1	2.9	....
Cameron clay	18	36	....	....	3.6	4.9	....	....
Laredo clay	12	30	36	....	5.0	7.5	8.9	....
Rio Grande clay	15	36	....	....	2.7	2.2	....	....

Table 4. Iodine in soil horizons of several important soil types—Continued

	Lowest depth of horizon				Iodine			
	1 inches	2 inches	3 inches	4 inches	1 p. p. m.	2 p. p. m.	3 p. p. m.	4 p. p. m.
Rolling Plains								
Abilene clay loam, Location No. 1	4	12	24	....	7.5	6.2	12.0	....
Abilene clay loam, Location No. 2	7	19	30	42	6.1	14.2	20.6	18.5
Abilene fine sandy loam	7	19	31	....	3.7	6.1	5.5	....
Foard clay loam	8	16	24	36	4.7	9.1	11.2	12.6
Vernon clay	6	24	36	....	7.0	5.2	4.1	....
Miles clay loam	4	7	19	42	5.5	31.7	16.5	9.8
Miles fine sandy loam	7	12	24	54	2.5	5.4	6.9	11.9
Miles loamy fine sand	7	9	19	....	3.9	3.9	1.5	....
High Plains								
Potter clay loam	7	13	19	....	9.9	11.9	5.9	....
Amarillo clay loam	8	18	26	36	4.5	2.6	18.4	8.5
Amarillo fine sandy loam	6	15	24	36	2.6	1.7	5.2	4.8
Calculated Averages								
East Texas Timber Country	7	14	24	36	2.7	3.4	6.4	6.2
Gulf Coast Prairie	7	14	24	36	4.0	4.3	4.3	4.2
Blackland Prairies	7	14	24	36	5.1	5.9	6.9	6.6
Rio Grande Plain	7	14	24	36	5.4	12.8	15.1	....
Rolling Plains	7	14	24	36	6.4	8.3	8.5	10.6
High Plains	7	14	24	36	5.6	5.2	7.6	7.5
All upland soils	7	14	24	36	4.7	6.5	8.1	7.1

Relation of iodine content to depth of the soil

The change in the iodine content of a soil with increase in depth is of considerable importance. This question was studied by determining the iodine content of different horizons of 38 samples of important soil types of the different region. The results are given in Table 4. The depth of the soil represented by the different horizons varied widely with the different soil types, so that the actual depth represented by the different samples is also given in the same table.

The iodine content of the soil increased significantly with increase in depth up to about 24 inches in most of the soils. The iodine content of horizons lower than 24 inches, increased in about half of the samples and decreased slightly in the other half. The soils of the Gulf Coast Prairie changed much less than the soils of any of the other regions, while the soils of the High Plains and Rolling Plains were irregular, some soils increasing and others decreasing in iodine content with increase in depth. The calculated average iodine content (bottom of Table 4) for all of the samples of upland soils listed in Table 4 was 4.7 parts per million for the 0 to 7 inch layer, 6.5 for the 7 to 14 inch layer, 8.1 for the 14 to 24 inch layer, and 7.1 for the 24 to 36 inch layer. The results indicate that in most Texas soils, the iodine content of the soil increases significantly with increase in depth up to about 24 inches while beyond that depth the results are considerably more irregular but in general a slight decrease in iodine content occurs.

Relation of iodine to acid-soluble lime and total phosphoric acid

The relations between the iodine content and the acid-soluble lime content and total phosphoric acid content of surface soils of various soil groups of the state are shown in Table 5. In calculating the figures given in Column 5 of Table 5, the average iodine contents of all soil groups having the same grade of acid-soluble lime or of total phosphoric acid (10) were averaged. The range between the low iodine average and the high iodine average of the soil groups is also shown. No soil group was sufficiently low in lime to be placed in Grade 5, and no group was sufficiently high in total phosphoric acid to be placed in Grades 1 and 2. The average iodine content increased as the quantity of acid-soluble lime increased. The lowest iodine figure for iodine in a given grade for lime was in every case significantly higher than that for the next lower grade for lime, and the same is true for the highest and average iodine figure. The relation with respect to total phosphoric acid is not nearly so marked nor so regular. The lowest iodine figures for the three grades of phosphoric acid are not significantly different, and the highest iodine figure for Grade 4 for phosphoric acid is higher than that for Grade 3. However, the average figures (Column 5) increase significantly with an increase in total phosphoric acid. Thus, a high iodine content is usually associated with a high content of acid-soluble lime, and, to a much less marked and regular degree, with a high content of total phosphoric acid.

Table 5. Relation of average iodine content of soil groups to grades of acid-soluble lime and total phosphoric acid in surface soils.

	Number of soil groups	Iodine, parts per million		
		Low	High	Average
Acid-soluble lime:				
Grade 4, .11 to .20%	10	1.2	4.4	2.4
Grade 3, .21 to .40%	7	1.7	5.0	4.0
Grade 2, .41 to 2.00%	6	5.2	11.2	7.2
Grade 1, 2.01% and up	9	6.1	13.7	9.3
Total phosphoric acid:				
Grade 5, 0 to .025%	2	1.4	2.4	1.9
Grade 4, .026 to .050%	18	1.8	13.7	4.8
Grade 3, .051 to .100%	12	1.7	12.3	7.4

Comparison of iodine in Texas soils with that of soils in other localities

A comparison of the average iodine content of the soils of Texas with those of other localities is shown in Table 6. The general average is a trifle higher than the averages reported for Kentucky, Germany, and New Zealand, but somewhat lower than those reported from the North Island and other islands adjacent to the New Zealand group, and the Japanese islands. Orr and Leitch (27) state that the amount of iodine found in soils ranges from 0.6 to 6.0 parts per million, although amounts outside of these limits may be found. As shown by the data in connection with the soils of the subhumid section of Texas, many soils in Texas contain iodine well in excess of 6 parts per million. Noda (26) reported the percentages of incidence of endemic goiter in four sections of the Jehol Province of Manchukuo as being 7.8, 18.2, 27.7, and 43.4, while the corresponding figures for iodine in the soils were 1.2, 1.3, 1.8, and 0.8 parts per million. A considerable number of the light-textured soils of Texas

Table 6. Comparison of the iodine content of soils of various localities

Locality	Reference	Iodine		
		High	Low	Average
		p. p. m.	p. p. m.	p. p. m.
Czechoslovakia	32	6.5	0.2	3.4
Germany	3	19.3	1.5	3.8
Germany, South	30	12.2	0.6	3.7
Japan	14	56.5	0.5	7.4
Kentucky	20	17.0	0.8	4.6
New Zealand	5	9.6	0.7	3.5
North Island New Zealand	29	24.0	1.0	8.2
Manchukuo	26	5.9	0.3	1.4
Texas	....	29.3	0.5	5.4

contain similar quantities of iodine. On the other hand, Adolph and Prochaska (1) reported that the iodine content of the soils of Nebraska was very low, 5 of 8 samples showing no appreciable iodine, and the other 3 containing only about 3 parts per billion (.003 parts per million), and that even with this remarkably low content of iodine in the soil, goiter was rare in the state. The lowest quantity of iodine found in any of the Texas soils was 0.5 parts per million, which is 167 times the quantity found in the Nebraska soils. We can conclude that the soils of Texas are well supplied with iodine. The figures in Table 6 indicate that the soils of Texas compare favorably in iodine content with those from other localities.

Relation of iodine in the soil to iodine in forage

The relation between the iodine content of the soil and the iodine content of young Bermuda (Cynodon dactylon) and young and mature little bluestem (Andropogon scoparius) grasses was studied with sample from 12 locations, of which all but one were in the East Texas Timber Country. The results, shown in Table 7, are erratic. Ten of the 12 soils contained from 0.5 to 2.5 parts per million of iodine, while the iodine content of the young forage from these soils of similar iodine content varied widely, ranging from 17 to 521 parts per billion in the Bermuda and from 44 to 789 parts per billion in the young bluestem grass. The young bluestem from soils high in iodine contained less iodine than the samples from the soils low in iodine. The relation between the iodine contents of the different grasses from the same soil was also erratic, but as a rule young bluestem contained appreciably more iodine than Bermuda collected from the same soil at the same time; mature bluestem contained only about one-fourth as much iodine as the young bluestem. McHargue, Roy, and Pelphrey (19) reported single samples of timothy hay, orchard grass hay, and redtop hay from Kentucky as containing 71, 117, and 89 parts per billion of iodine; the results reported in this bulletin are thus in

Table 7. Relation of the iodine in the soil to that in forage

Soil Type	Soil	Bermuda	Bluestem young	Bluestem mature
	p. p. m.	p. p. b.	p. p. b.	p. p. b.
Susquehanna fine sandy loam	0.5	78	44	25
Lufkin fine sandy loam	0.9	120	123	24
Susquehanna fine sandy loam	1.0	521	256	52
Bowie fine sandy loam	1.1	34	209	173
Susquehanna fine sandy loam	1.5	121	61	40
Susquehanna fine sandy loam	1.8	161	151	90
Susquehanna silt loam	2.0	124	120	20
Norfolk fine sandy loam	2.1	126	789	53
Ruston fine sandy loam	2.3	162	347	34
Nacogdoches gravelly fine sandy loam	2.5	17	465	61
Ochlockonee fine sandy loam	12.0	35	35	31
Victoria clay loam	13.7	387	35	33
Average	3.4	157	220	53

good agreement with their results. Our results indicate very little relation between the iodine content of the soil and that of the forage from the soil.

The iodine content of most of the samples of forage is probably high enough to provide all of the iodine which the range animals need, especially when consideration is given to the fact that the water which they drink also contains some iodine. In order to provide sufficient energy for proper growth and maintenance, a range steer should consume approximately 25 pounds of dry matter per day. This quantity of dry matter, if it contained iodine similar in quantity to the averages shown in Table 7, would contain from about 600 micrograms to nearly 2,500 micrograms of iodine. These figures, when compared with the estimated daily requirements of 500 micrograms for a steer, based on a requirement of 100 micrograms per day for a man, indicate that in most cases, when other requirements of the animal are met, the quantity of iodine ingested by the range animal is more than sufficient for its needs. A few samples may not supply enough; the lowest iodine content reported in Table 7 is 17 parts per billion, and this forage would contain only about 125 micrograms in 25 pounds of dry matter. However, the deficiency would probably be made good by the drinking water.

SUMMARY

The iodine content of 362 samples of surface soil, representing 146 soil types in 64 upland and 13 alluvial soil series was determined. Most of the soils were well supplied with iodine, and there was no evidence of a deficiency.

The iodine content of the soils by regions ranged from 1.7 parts per million for the Central Basin to 11.3 parts per million for the Edwards Plateau. When the geographical regions of the state are arranged in order of the increasing average iodine content of their soils, the regions rank as follows, beginning with the lowest: Central Basin, East Texas Timber Country, Gulf Coast Prairie, High Plains, West Cross Timbers, Blackland Prairie, Basins and Mountains, Rolling Plains, Rio Grande Plain, Grand Prairie, and Edwards Plateau. With the exception of the small areas of sands in the western part of the state, the iodine in the soils of the subhumid section of the state averaged about 75% higher in iodine than the soils of the humid section.

Heavy textured soils contained more iodine than light-textured soils. Clays and clay loams contained about the same quantities, but sandy loams contained less than half and sands about one-fifth as much iodine as the clays.

A high iodine content is usually associated with a high content of acid-soluble lime, and, to a much less marked and regular degree, with a high content of total phosphoric acid. The average iodine content ranged from 2.4 parts per million in soils with lime contents in Grade 4 to 9.3 parts

per million in soils with lime contents in Grade 1, and from 1.9 parts per million in soils with total phosphoric acid in Grade 5 to 7.4 parts per million in soils with Grade 3 for total phosphoric acid.

In general, the iodine content of the soil increased with an increase in depth. The 0-7 inch layer averaged 4.7 parts per million, from 7 to 14 inches, 6.5 parts per million, from 14 to 24 inches, 8.1 parts per million, and 24 to 36 inches, 7.1 parts per million. The relative average iodine contents for 35 upland soils were 100 for the 0 to 7 inch layer, 138 for the 7 to 14 inch depth, 172 for the 14 to 24 inch depth, and 151 for the 24 to 36 inch depth.

A comparison of the general average iodine content of Texas soils with those reported by other workers from various localities shows that the soils of Texas are as high in iodine as most other regions, and higher than those from goiterous regions.

The results of a comparison of the iodine content of 12 soils with the quantity of iodine in young Bermuda and little bluestem and mature bluestem indicated little relation between the two, but showed that forage grown on Texas soils is almost certainly not deficient in iodine.

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