Zerban, F W

The salt marshes of the north coast of Porto Rico

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SUGAR PRODUCERS' ASSOCIATION OF

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RIO PIEDRAS, P. R.

The Salt Marshes of the North Coast of Porto Rico.

By F. W. Zerban.

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PREFACE

In this publication are presented the results of an investigation which was proposed by Mr. Crawley, Director of this Station, and the writer wishes to express his thanks to him for many valuable suggestions made during the progress of the work.

As probably some of the readers for whom this bulletin is primarily intended may not be familiar with chemistry, the author has endeavored to use chemical terms as little as possible. But the very nature of the subject is such that they cannot be entirely avoided; and for the benefit of those who have only a slight knowledge of such terms, a few explanations may not be out of place. Most agricultural workers nowadays know what is meant by those terms which designate the different chemical substances that form the important parts of soils, such as lime, nitrogen, phosphoric acid and potash. But they may not be so well acquainted with some words from the chemical vocabulary which the writer has had to make use of in this publication. It would obviously be out of place here to attempt giving a detailed account of all these terms, and strict scientific accuracy will have to be sacrificed to brevity and conciseness.

By the term "salt" which is so much used in this bulletin, the chemist designates a substance which may be considered as consisting of two components in a very firm combination. One of these components is usually some metal, as for instance sodium, potassium, calcium, magnesium, iron, aluminium, etc., and the other component is either a non-metalic element, as for instance chlorine, or a combination of such a non-metalic element with the element oxygen. The metals which are the elements characteristic of basic substances, like caustic soda or quick lime, are in this bulletin termed "basic radicles", and the other radicles which are characteristic of acids like carbonic, sulfuric, hydrochloric, etc., are called "acid radicles". The combinations of basic and acid radicles are called salts, like sodium sulfate, calcium chloride, etc. One acid and one base may form several salts by combining in different well defined proportions. Thus sodium bicarbonate contains only one carbonic acid radicle for one of sodium, whereas sodium carbonate has one for two of sodium. In chemical analysis it is necessary to determine the acid radicles by themselves and the basic radicles by themselves, and their sum total gives the total quantity of salts present, which may exist there in a number of combinations. Thus, if we find in a given salt solution, sodium and potassium on the one hand, and sulfuric and hydrocholoric acids on the other, we would have in the solution the four salts: sodium chloride, sodium sulfate, potassium chloride and potassium sulfate, in certain proportions.

In our analyses we give only the different radicles found without paying attention to their possible combinations which do not concern us much. These few words on the subject will probably suffice to give to those readers who are not familiar with chemistry, the necessary explanations.

The writer is indebted, besides Mr. Crawley, to the following gentlemen who have rendered him assistance in this investigation; Mr. J. C. Howells, Irrigation Engineer; Mr. J. R. Johnston, Pathologist of this Station; Mr. E. E. Olding, formely manager of Central Cambalache; Mr. H. Shapley, Chemist of Central Plazuela; Mr. W. E. Hess, of the Agricultural Experiment Station at Mayaguez; Mr. Santiago Sifre, Administrator of Central Plazuela; and Mr. Justiniano Santiago, Administrator of the Tiburones lands, managed by the Plazuela Sugar Company. The writer wishes to express his thanks to all these gentlemen, whose help is greatly appreciated by him.

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THE SALT MARSHES ON THE NORTH COAST OF PORTO RICO

INTRODUCTION.

With the ever increasing population in nearly all parts of the globe the demand for food stuffs is constantly rising and even the adoption of more intensive methods of cultivation has not been able to keep pace with it. Consequently, large stretches of land, which had formerly been thought to be unfit for the production of crops, have in recent times been taken into cultivation. Immense areas of slight rainfall in the western United States have been reclaimed for agricultural purposes, simply by providing them with drainage and irrigation. In northern Europe people found themselves obliged long ago to utilize marsh and moor lands which presented the most difficult problems in their reclamation. In late years attention has been called to lands of a similar nature in the United States, especially in Wisconsin, Indiana, and in the Atlantic and Gulf States. It is true that in some of these cases, as for instance in Connecticut and New Jersey, the principal reason for the drying of these marsh areas was the fact that millions of mosquitoes annually breed in them, rendering all the surrounding country uninhabitable; but even there the gain in arable land is no small item.

The island of Porto Rico has, in proportion to its size, a considerable area of swamp and marsh lands. The good land which may be used profitably for the growing of sugar cane is practically all under cultivation now; prices of land are constantly rising, and thus the question has recently arisen as to whether the extended marshes, commonly called "poyales", which are found along the coast, may be made to produce cane at a profit. A beginning at reclamation has already been made in one of these marshes, and the studies reported on in this bulletin, have mainly been upon that particular marsh.

There are several swamp areas of considerable extent on the north coast, and the one just mentioned is the largest of them all. It extends from the vicinity of Arecibo to the west to within a small distance of Barceloneta to the east, and is usually called the "Caño de Tiburones" or "Laguna de Tiburones". The other marsh areas are from west to east:

		Acreage
1)	Laguna de Tortuguero and surrounding marshes, acreage unknown.	....
2)	Marshlands controlled by the San Vicente Sugar Company	....
3)	Palmas—Cienaga de la Mar, mangrove lands and marshes	705 acres
4)	Pueblo Viejo Abajo—Marsh lands bordering on the Bay of San Juan and the San Fernando Canal to the north: on Finca Canejas to the south: on Ensenada de la Criolla, Rio Puerto Nuevo and Quebrada Margarita to the east; and on the San Fernando Canal to the west; acreage unknown.	....
5)	Mangrove lands of Ensenada de Pueblo Viejo and Martín Peña Canal	726 "
6)	Hoyo Mulas—Mangrove land on the west side of the Laguna de Mata Redonda, or Torrecilla	111 "
7)	Mangrove lands of the Laguna San José, as far as the city limit of San Juan	127 "
8)	Mangrove lands of Boca Cangrejos	125 "
9)	Cangrejos Arriba—Mangrove lands of the Laguna Mata Redonda and the San José Canal	356 "
10)	Mangrove lands of the Laguna Piñones and the Hoyo Mulas Canal	898 "
11)	Mangrove lands of the Laguna Mata Redonda or Torrecilla, Hoyo Mulas and Cangrejos canal	1252 "
12)	Barrio Cabezas—Mangrove lands and marshes	150 "

The foregoing list was furnished by the Department of the Interior of the Insular Government, and comprises the mangrove lands and marshes belonging to the People of Porto Rico, and situated along the north coast of the island, according to the data found in the archives of the Department. Only the lands under No. 2 were added to this list by the writer, they having passed into private ownership.

All these marsh and swamp lands are located only a short distance from the sea shore and separated from it usually by low sand bars or coral reefs. Some of them are still, directly or indirectly, connected with the sea, while others are completely isolated. In their natural state they are either covered with water or the ground water is quite near the surface.

The native vegetation of these marshes consists mainly of the following plants, which Mr. J. R. Johnston, Pathologist of this Station and Mr. W. E. Hess, of the Agricultural Experiment Station at Mayagüez, have identified. In the Caño de Tiburones there were found, Melanthera aspera — Compositae; Andropogon sp. — Gramineae; Conocarpus erectus—Combretaceae; Lippia nodiflora—Verbenaceae; Polygala panniculata—Polygalaceae: Hydrocotyle sp.—Umbelliferae; and one of the Cyperaceae (Johnston.) In the vicinity of the Laguna de San José the vegetation consisted of mangrove, polypodium and typical salt land sedges and rushes, (Hess).

CHARACTER OF SOIL, AND ITS BEARING ON POSSIBLE METHODS OF AMELIORATION.

The soils of these marshes are of a very peculiar nature, and it was with the object of learning something definite about their physical and chemical characteristics, that the present investigation was undertaken; the ultimate object being, of course, to obtain data as to the best methods of improving them and of increasing their crop-producing power. The soil consists of two principal strata. The upper layer is a grayish black to black mass, formed of the debris of decaying vegetable matter. In some places the forms of decayed roots and other plant parts may be seen with the naked eye; in others a more complete decomposition has taken place and the soil presents the appearance of a fine humous mass. It is very porous and when partly dry feels quite elastic when stepped upon . Its depth in most places is at least several feet; only in a few locations is it as little as four inches. The amount of moisture in the soils in their natural state is exceedingly high, as is to be expected under the circumstances. The average moisture of 23 samples was found to be 83%, with a minimum of 77% and a maximum of 91%. The vegetable origin of the soil is evident from its appearance and from its chemical composition. The agricultural analyses of six samples, by the methods of the Association of Official Agricultural Chemists, gave the following figures:

TABLE I.

	(1)	(2)	(3)	(4)
Moisture, in fresh state........	88.86%	77.01%	91 20%	78.66%
Moisture, air dry	17.82	17.23	11.78	16.56
Insoluble residue	.71	8.94	24.06	3.75
Volatile matter....	87.06	81.64	56.96	81.88
Oxide of iron and alumina......	1.61	4.39	4.53	2.65
Lime....	5.58	3.30	12 63	8.53
Magnesia...............	1.70	0.65	0.59	0.85
Potash.................... ..	0.09	0.20	0.21	0.21
Phosphoric acid..	0.05	0.05	0.06	0.24
Calcium carbonate.............	3.45%	2.65%		7.78%
Lime, not in form of carbonate..	3.65	1.82		4.18
Total nitrogen....	2 09	1.92		2.82
Humus.	34.38	37.82		30.73
Humus nitrogen.....	.91	1.82		1.65
" " % of humus	2.65	4.81		5.38

	(5)	(6)	Average
Moisture, in fresh state........	82.41%	85.01%	83.86%
" air dry........... .	12.96	15.37	15.79
Insoluble residue	16.16	4.53	9.69
Volatile matter	60.85	77.05	72.57
Oxide of iron and alumina......	9.38	4.69	4.54
Lime, ...	11.22	10.63	8.65
Magnesia...........	0.52	0.51	0.80
Potash......................	0.23	0.25	0.20
Phosphoric acid......	0.13	0.11	0.11
Calcium carbonate...	12.55%	12.58%	7.80%
Lime not in form of carbonate..	3.19	2.59	3.09
Total nitrogen.....	1.63	2.69	2.27
Humus.	25.42	30.79	31.83
Humus nitrogen....	1.00	1.75	1.43
" " % of humus	3.93	5.68	4.49

These samples came from the following locations:

No. 1 Caño de Tiburones, Colonia A, Pieza 1, to 12 in. depth.

No. 2 San Vicente, Guarico, Surface soil.

No. 3 Tortuguero, Surface soil.

No. 4 Caño de Tiburones, Cambalache property, Pieza 2, to 2ft depth.

No. 5 Caño de Tiburones, Cambalache property, Pieza 4, to 2ft. depth.

No. 6 Caño de Tiburones, Cambalache property, Pieza 5, to 2ft. depth.

The average moisture content of the six samples in their natural state is almost 84%, and even when air dry they still retain 15.79% of moisture; it is quite probable though that part of this loss of weight on drying is due to decomposition of the organic matter. Almost three fourths (72.57%) of the perfectly dry substance volatilizes upon ignition. Most of this volatile matter is of an organic nature, since the loss due to the presence of hydrated silicates, oxide of iron and alumina, and that due to carbon dioxide, cannot be very high. Thus the soils are by their chemical analysis also characterized as of vegetable origin. No. 1 is typical of these soils. The residue insoluble in hydrochloric acid amounts to less than 1%, and the rest of the inorganic material is principally calcium and magnesium carbonate. The soils are well provided with carbonate of lime and the quantity of magnesia is quite small as compared with that of lime. As regards the other plant food ingredients, we find the percentage of potash and of phosphoric acid to be rather small, while the nitrogen is exceedingly high. This we would naturally expect to be the case in a soil of this character. However, the actual percentages calculated on the perfectly dry soils would be entirely misleading, should we base any conclusions on them regarding their crop producing power. In the tropics, 0.2% of potash and 0.1% of phosphoric acid would, in an otherwise good mineral soil, be considered quite sufficient. But if we calculate the actual quantity of plant food per acre foot of this vegetable soil, we find that the quantities of potash and phosphoric acid are exceedingly small, as may be seen from the following consideration. The volume weight of the soil, i. e., the weight per unit volume in its natural state, in five samples, was found to be 1.06 on the average, therefore the weight per acre foot amounts to a little less than 3,000,000 pounds. Since 100 parts of soil contain only 16.14 parts of solid material, the total weight of solid material per acre foot is roughly 500,000 pounds. One tenth of one per cent of this is equal to 500 pounds, and we thus find that the soil contains on an average only 500 pounds of phosphoric acid and 1,000 pounds of potash per acre foot, and all of this is probably not immediately available for the crop. The nitrogen, however, amounts to 11,000 pounds per acre foot, and 7,000 pounds of this are found in the humus matter alone. According to Hilgard, the nitrogen that is not found existing in the humus, is of practically no value to growing crops, only the humus nitrogen being used in nitrification. Hilgard also maintains that the percentage of nitrogen in the humus should not be below 4%, as otherwise the soil may become "nitrogen hungry". Whether this is true in the case of these soils, remains to be seen; at all events the average percentage of nitrogen in the humus is above 4%, and moreover, the actual quantity of humus nitrogen per acre foot in our soil is higher than in 63 out of 72 soils quoted by Hilgard.

The subsoil of this marsh is a white or yellow mass of loamy consistency, and has the following composition:

TABLE II

	(1)	(2)	(3)	(4)
Moisture, in fresh state	58.80%	55.73	42.21	66.38
Moisture, air dry	2.69	1.88	2.62	3.72
Insoluble residue	0.33	0.27	1.88	0.26
Carbon dioxide	41.78	39.41	38.19	37.01
Volatile matter not carbon dioxide	3.38	9.00	10.43	15.53
Oxide of iron and alumina	0.85	0.61	1.26	0.14
Lime	51.22	48.41	45.50	44.14
Magnesia	1.40	1.25	2.22	2.12
Potash	0.07	0.07	0.06	0.06
Phosphoric acid	0.03	0.01	0.02	0.02
Total nitrogen	0.19	0.50	0.66	0.48
Humus	1.52	1.32	2.24	2.56
Humus nitrogen	0.10	0.12	0.23	0.08
» » % of humus	6.49	9.19	10.25	7.22

The samples were collected in the following places:

No. 1 Caño de Tiburones, Colonia A, Pieza 3, 4 to 12 in.

No. 2 San Vicente, Guarico, Subsoil.

No. 3 Caño de Tiburones, Colonia A, Pieza 1, second foot.

No. 4 Caño de Tiburones, Colonia A, Pieza 3, second foot.

It appears from the analyses that this subsoil is a limestone, more or less mixed with organic material. The moisture is quite high in these samples in their fresh state, but they retain very little of it after drying. The principal constituent is calcium carbonate with a small amount of magnesium carbonate. The insoluble residue, the oxide of iron and alumina, are insignificant, and the volatile matter is practically all of an organic nature, with the exception of the carbon dioxide in combination with lime and magnesia. Where the organic matter rises to from 9 to 15%, the nitrogen is accordingly higher than in No. 1, where the respective figures are only 3.38% of organic matter and .19% of nitrogen. Potash and phosphoric acid are extremely low. It will not be necessary to discuss at length the agricultural conditions of this subsoil except in so far as it exerts an influence on the surface stratum, for the simple reason that in most places the black layer is so thick that the cane roots do not come in contact with the lime subsoil. The interesting point in the composition of this subsoil is the fact that its calcareous nature explains the high percentage of calcium carbonate in the black soil, and the non-acidity of the same. If the subsoil consisted of material devoid of calcium carbonate, the black soil would certainly be highly acid, and any attempt at reclamation would be practically prohibitive or at least very expensive. Where the lime appears near the surface there is some danger of having too much lime present for the growing of cane. But this difficulty could be overcome by incorporating with it some of the black vegetable mould and thus reducing the danger arising from an excess of lime. Such a mixing has been partially effected in Colonia A, Field No. 1; here the lime is near the surface, and the material resulting from the digging of the ditches was thrown on top of the black soil and mixed with it. The composition of the soil formed in this way was the following:

Moisture, in fresh state	62.20%
Moisture, air dry	6.70%
Insoluble residue	2.61%
Volatile matter	60.58%
Oxide of iron and alumina	1.19%
Lime	33.02%
Magnesia	1.98%
Potash	0.10%
Phosphoric acid	0.07%
Total Nitrogen	1.91%
Humus	12.06%
Humus nitrogen	0.78%
Humus nitrogen % of humus	6.43%

This is substantially the composition that we would expect to find in a mixture of the black soil and of the marl.

From the general character of these soils we might conclude that they should after reclamation, and with judicious fertilization and cultural methods be able to produce good crops. Unfortunately there is too little known about tropical soils of this character, to make any offhand recomendations in that direction. British Guiana has large stretches of peaty soils, but there the layer of peat is, according to Noel Deerr, not very thick, and the subsoil consists of a gray clay, poor in lime and with an excess of magnesia over lime. It seems that so far there has been very little need in the tropics of utilizing marsh lands for the cultivation of dry land crops. Most of the experience gained on marsh soils has been gathered in the temperate zone, and we cannot directly apply the results obtained there to our case. A large part of the marsh soils in northern Europe and in the United States is of an acid character, and in their reclamation it is necessary to apply liberal quantities of lime, usually in the form of carbonate, with three purposes in view. In the first place, the calcium carbonate neutralizes the free acids present in the soil; second, it causes a rapid decomposition of the partly decayed plant remnants, thus bringing about rapid humification; and in the third place, it favors the growth of nitrifying organisms and makes the nitrogen available which would otherwise be inert.

In a number of places the marsh soils themselves contain sufficient lime to render a further addition of this substance unnecessary. Such is the case in some marsh soils in northern Europe, in Ontario, in certain areas in Wisconsin, and as we have already seen, in the majority of the marsh soils of Porto Rico. Extensive studies of marsh soils have been made by the University of Wisconsin and the most important conclusions that were arrived are as follows(1):

"Through proper drainage and soil management much of this land can by made very productive and will add greatly to the farm area of the state. The chemical composition and the possibility of thorough drainage are the chief factors which determine the value of marsh lands for cultivation. The drainage of marshes is the first step toward improvement. On large marshes the organization of drainage districts and the cooperation of a number of adjoining land owners is necessary, but thousands of farms include some land which can be readily drained by the owners without legal difficulties. Proper tillage of marsh lands is of the utmost importance. Heavy rolling by packing the loose peat soil, produces a firmer seed bed which is better adapted to cultvated crops, especially small grains. Fertilization of the marsh soils is important on account of the unbalanced condition of the elements which they contain. Marsh soils are excessively rich in nitrogen, but are frequently deficient in phosphorus and potash While barn yard manure will supply the last two elements, these can be supplied in commercial fertililizers, allowing the use of barn yard manure on upland soils where its nitrogen as well as its mineral elements are needed Under such special conditions it is profitable to use commercial fertilizers supplementing the manure of the farm. The crops best adapted to marsh lands nclude corn........"

Some of the results of special experiments in the non-acid marshes of Wisconsin may be of interest in this connection. It was found that:

"Owing to the presence of lime carbonate and hence to the «sweet» character of these soils, there is no dificulty in securing the necessary decomposition of the soil to supply an abundance of nitrogen where good drainage is developed. As a rule, the amount of nitrogen in these soils is so large that it is unnecessary to use fertilizers that contain this element so that barn yard manure, the most important element of which is nitrogen may be used on upland soils which require it, using only mineral fertilizers on the marsh soils as needed.

There seem to be two effects of the presence of lime carbonate on the phosphorus supply of these marsh soils: first that it carries with it a somewhat larger amount of phosphorus than is found in other marsh soils, and even more important than this, seems to render what is there more available than it is in acid marsh soils. In Wisconsin so far as these marsh soils in the southeastern part of the state have been cropped they have not shown a special need for phosphate fertilizers However, it is quite probable that after some years of cropping they will be found to need some supply of phosphorus, as do all other soils.

The only marked need for special treatment which the marsh soils of this portion of the state, when properly drained ordinarily show within the first few years after reclamation, is for potash. Quite frequently these marshes when planted to corn or other crop, show patches of from a few rods to several acres in extent on which the seed germinates well, but the crop turns yellow at an early stage and fails to develop. It frequently happens that corn will grow to a height of only one or two feet during the whole season and produce no grain whatever. Where this occurs, so far as our experience goes, it is due either to the lack of sufficient drainage or the lack of a supply of available potash. For some reason not yet fully understood, the potash present in the soil is not available and some fertilizer must be used.

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(1) Wisconsin Agric. Expt. Sta., Bull. 205, pp. 2 and 16 to 17; 1911.

In many cases experiments during the past ten years, on soils of different character in this portion of the state, have shown increases in yield all the way from two to five or six times, by the application of potash fertilizers only."

To what extent these conclusions will hold true in the case of the Porto Rican marshes, remains to be seen. They give, however, some indications as to what field experiments are apt to give good results. The first and paramount necessity in the reclamation of all marsh lands, is sufficient drainage, and this is especially so in the marsh soils of Porto Rico. The reasons for this latter statement will be fully explained in the following chapters of this bulletin. As far as fertilization goes, we may expect, on the basis of the studies reported and of the analyses of the Porto Rican marsh soils made in this laboratory, that they will be benefitted by the application of potash and phosphoric fertilizers, but that nitrogen may not have much effect, owing to its presence in large amounts in the soils themselves. It is, however, possible that the humus nitrogen may not be so available as it has been found to be in other countries. The only way to decide the question of fertilizer requirements is by actual experiments in the field where the three elements are applied alone or in mixtures of various proportions, in different forms, and in varying quantities. Only such a practical test will disclose what fertilizers will bring the greatest pecuniary profits.

The administrator who was in charge of the Tiburones lands last year, made a small test with potassium sulfate alone, applying it in some of the worst lands. The cane soon improved visibly, and the result of this small test demonstrates the value of such experiments. However, in order to get results of permanent value, it will be necessary to make the experiments in a systematic way so that the influences of other factors than fertilizers may be excluded as much as is practicable.

THE SALT CONTENT OF THE MARSH SOILS, AND ITS RELATION TO THE PRODUCTION OF CANE.

In an ordinary marsh, drainage is provided with the main object of removing the surplus water, and of reducing the moisture to such an extent that the physical, chemical, and biological processes, without which the soil cannot support the growth of cultivated plants, may take place normally. But in two other large classes of soils, namely, the marine saline lands, and the alkali lands, the establishment of a good drainage system is necessary for another most important reason. While these two soil groups show certain differences in their nature and origin, the soluble salts which are characteristic of both, are qualitatively identical, and the object of reclamation is essentially the same in both cases. The dominant feature of these soils is the comparatively high quantity of soluble salts found in them. The most common of these salts is sodium chloride, but besides this we may find, and often do find, the chlorides of calcium, potassium and magnesium, and the sulfates, bicarbonates and carbonates of these four metals. We hardly ever find only one salt present in any one soil, but usually most or all of them in varying proportions.

Most cultivated plants are unable to grow in soils that are heavily charged with salts. The injury produced is due to direct as well as indirect causes. There is a direct corrosive action on the roots; and there are also produced, through the salts that are taken up by the plant, certain disturbances of the natural biological processes. Among the indirect effects of alkali one of the most important probably is that on nitrification. Lipman [1] has found that nitrification does not proceed normally when the concentration of sodium carbonate in the soil reaches 0.025%. Sodium chloride is less toxic, and nitrification is quite normal up to a concentration of 0.1% of this salt, while the quantity of sodium sulfate may reach even 0.35% without ill effects. The effect of salts on ammonification is of a different order, sodium chloride being the most toxic and sodium carbonate the least. These results are most important and they may partly explain the favorable effect of lime salts in salt lands. They counteract the influence of the other salts with the result that nitrification may proceed normally, which it could not do in the presence of the other salts by themselves.

If it is intended to use salt lands for agricultural purposes, the salts must be partly or wholly removed. In some cases certain measures will produce a considerable improvement, for instance the application of calcium sulfate which counteracts the effects of other salts and converts sodium carbonate into the less toxic sulfate, under the formation, at the same time, of insoluble calcium carbonate. But such measures as these will be effective in rare cases only. There is only one method which will absolutely and permanently reclaim the better of these lands, and this is an efficient system of drainage in connection with irrigation to leach out the salts.

There exist great differences in the tolerance of plants for different salts, and in that of different plants for the same salt. The limits of salt content also vary with the character of the soil. In general it may be said that sodium carbonate is the most toxic of all salts; the upper limit tolerated, for instance, by cereals in a sandy loam soil, is about 0.1%: sodium chloride, sodium bicarbonate and magnesium chloride are less toxic, and the maximum for sodium chloride is, under the above conditions, 0.25%. Sodium sulfate and magnesium sulfate are still less harmful than the former, the limit of sodium sulfate being about 0.45 to 0.5% (1). Calcium salts are the least toxic of all and rather large

(1) Centr. Bakt. Parasitenk., II. Abt., Vol. 33, pp. 305-313.

(2) Hilgard, "Soils", p. 464.

quantities of these salts are readily tolerated. For other plants and in other soils these figures may vary to a greater or less extent.

The conditions are much more complicated where we find mixtures of the different salts in the same soil. If the effect of the different salts were simply additive, then we could easily calculate what their total effect would be. But the effect of one salt not only does not intensify the action of others, but on the contrary there are certain salts which will counteract the effect of others. Thus sulfates in general will mitigate the effects of carbonates, bicarbonates and chlorides, and calcium salts in general will counteract sodium and magnesium salts. For this reason it is sometimes very difficult to interpret the results of analyses of soluble salts contained in a given soil.

While some plants are quite resistant to the effect of soluble salts, others are easily harmed by even small amounts. There are certain grasses and other plants that grow well only in places highly impregnated with salt. But they are very few. Among cultivated plants, beets, barley and asparagus are most resistant. Another important point is, that plants usually are much less resistant when young than after they have fully developed and are naturally stronger. Thus the salt content of a soil may, during the growth of a plant decidedly increase, without detriment to the plant, and finally reach a concentration which would have killed the plant in the earlier stages of its growth. A good example of this behavior is alfalfa which shows little resistance to salts when young, but which will stand enormous amounts in subsequent years without showing signs of injury.

The character of the soil is also very important in this connection. In stiff soils the tolerance for salts is usually much less than in light soils which can be more easily cultivated, thus helping the plant in its attempt to resist the effect of the salts. In soils high in carbonate of lime the different salts are less injurious than in those devoid of lime, because, as we have already seen, lime salts counteract the effect of sodium and magnesium salts. A high nitrogen content in soils is also helpful against the bad effect of salts in the soil.

Having thus reviewed the effects of salts in soils in a general way we shall now turn to the sugar cane in particular which is the natural crop for the coast lands of Porto Rico. As the cane is not grown for its total weight but for the sugar contained in it, we have to make a distinction between the influence of salts on the growth of the cane and that of its composition.

There is an apparent difference of opinion among authors concerning the effect of salt on the growth of the cane. Some say that cane will thrive on soils impregnated with salt (1). In Jamaica, Barbados, Trinidad

(1) Journal d' Agriculture Tropicale, Vol. 1, p. 145.

and Demerara it has been found that an occasional flooding with sea water or the application of sodium chloride in certain fields is quite beneficial. This fact is explained by Prinsen Geerligs ([1]) on the ground that a treatment with sodium chloride renders the potash, lime and magnesia contained in the soil more available, as was proven by experiments made by himself and also by studies made, independently, by Eckart ([2]). It is also a well known fact of plant and animal physiology that certain substances when applied in large doses, are toxic to plants and animals, but have, when used in small quantities, quite the opposite effect and rather act as stimulants. While it is thus true that sodium chloride in small quantities may be quite beneficial in soils with low chlorine content and with small percentages of available potash and lime, it is equally true that there is a certain limit above which sodium chloride becomes detrimental to the growth of cane. On the basis of many analyses Maxwell arrived at the conclusion that in ordinary soils percentages of sodium chloride exceeding 0.15% (0.09% of chlorine) will prevent the normal growth of cane ([3]). In soils which are well provided with nitrogen the chlorine content may go higher than 0.15% of sodium chloride without causing any harm. If the chlorine is combined mainly with calcium it may also reach higher figures than 0.09%. Eckart concludes from the analyses of several Hawaiian soils that "where the salt content of the soil reaches over 0.1% (0.06% of chlorine) an injurious effect is produced on the cane." ([4]). Figures on the tolerance of cane for other salts, like sulfates, carbonates and bicarbonates are still lacking and carefully controlled experiments will have to be made to find out how much of the different salts, by themselves and in mixtures, the cane will stand without harmful effects. In the meantime we shall have to content ourselves with observations made with soils and canes in the field. A beginning in this direction has already been made at this Station and these studies are being continued. From the results obtained so far it seems that the limit of endurance for sodium chloride in our mineral soils is about the same as that found by Maxwell and Eckart in Hawaii; but it also appears that cane in its later stages of growth may stand much higher quantities of salt without visible injury.

It has been said above that not only the growth of the cane is affected by the presence of salts but that its composition is also largely influenced by it. This is well shown by the results of field experiments made at the Experiment Station of the Hawaiian Sugar Planters' Association. A comparison of two plots, one of them irrigated with fresh water and the other with salt water containing 200 grains of salt

[1] Intern. Sugar Journal, 1905.
[2] Expt. Sta. of Hawaiian Sugar Planters' Assn., Report for 1902.
[3] Office of Expt. Stations. Bull 90, p. 17.
[4] Expt. Sta. of Hawaiian Sugar Planters' Assn. Special Bull. B, p. 51.

per U. S. gallon (3428 parts per million), gave the following results (1):

TABLE III.

Nº	Quality of water	Brix	Sucrose	Glucose	Purity	Salt, grs per gallon.	Tons cane.	Sucrose in cane.	Sugar per acre, Tons
1	Fresh	20.3	18.9	0.31	93.2	16.17	76	16.9	12.8
2	Salt	15.9	13.8	0.28	86.8	173.67	15	12.35	1.86

Similar results were obtained in comparing two plats which received an occasional heavy irrigation, as may be seen from table IV (1).

TABLE IV.

Nº	Quality of water	Brix	Sucrose	Glucose	Purity	Salt, grs per gallón	Tons cane	Sucrose in cane	Sugar per acre Tons
3	Fresh	20.0	18.7	0.29	93.4	14.24	91.5	16.7	15.3
4	Salt	16.1	14.0	0.27	87.1	180.6	31.25	12.5	3.9

It appears from these two tables that salt accumulated in the soil, besides preventing the normal growth of the cane, also affects its composition in a most deleterious manner.

It was further shown in the experiments just mentioned that lime applied to soil which is impregnated with salt will help much toward saving the crop; while the growth of the cane is still greatly impeded, its composition becomes normal. The application of nitrogen in the form of dried blood had the same effect as lime.

Some analyses made in this laboratory also tend to show that a high salt content in the soil depresses the sucrose content and purity of the juice in the cane. The analyses of the respective soils and canes follow:

[1] Expt. Sta. of H. S. P. A., Bulletin 11.

TABLE V.

Series I. Central "Mercedita".

	Soil Nº 1.	Soil Nº 2.
Carbonic acid, (Co 3)	.007%	.006%
Bicarbonic acid, as(HCO 3) 2	.101	.110
Chlorine	.125	.015
Sulfuric acid, as SO 4	.082	.036
Calcium	059	.041
Magnesium	.006	.004
Potassium	.007	.005
Sodium	.080	.015
	.467%	.232%

	Cane Nº 1.	Cane Nº 2
Variety	Blanca	Blanca
Number of stalks	2.	2.
Weight per stalk in pounds	3.1	2.8
Extraction	60.6	59.3
Brix	19.3	21.0
Sucrose	15.5	18.3
Glucose	2.5	1.3
Purity	80.3	87.1
Glucose Ratio	16.1	7.1
Non Sugars	1.3	1.4
Non Sugar Ratio	8.4	7.7
Potassium Chloride	0.331%	0.138%
Potassium Sulfate	0.109%	0.135%
Pottassium Chloride plus Sulfate	0.440%	0.273%

Series II, Central "Cortada."

	Soil Nº 1.	Soil Nº 2.
Carbonic acido as, (Co 3)	.002%	.006%
Bicarbonic acid as, (HCO 3)2	.087	.055
Chlorine	.114	.006
Sulfuric acid as, (SO 4)	.033	.005
Calcium	.011	.016
Magnesium	.005	.004
Potassium	.005	.004
Sodium	.099	.004
	.356%	.103%

	Cane Nº 1.	Cane Nº 2
Variety	Cristalina	Cristalina
Number of stalks	5.	5.
Weight per stalk in pounds	2.1	2 2
Extraction	45.9	42.9
Brix	17.9	18.3
Sucrose	13.7	15.3
Glucose	2.1	1.5
Purity	76.5	83.6
Glucose Ratio	15.3	9 8
Non-Sugars	2.1	1 5
Non-Sugar Ratio	15.3	9.8
Potassium Chloride	0.337%	0.312%
Potassium Sulfate	0.075%	0.091%
Potassium Chloride plus Sulfate	0.412%	0.403%

Maxwell gives some further figures [1] on the influence of the salt content of the soil on the yield of sugar. They show clearly that the sugar production decreases with a rising salt content of the soil:

TABLE VI.

A.

Condition of irrigation water	Salt in water	Salt in cane juice	Condition of cane
Slightly brackish	.125%	.470%	Growing
Highly brackish	.223%	.714%	Dying

B.

Part of field.	Salt in soil %.	Yield of sugar per acre. Tons.
1	0.10	6.0
2	0.45	1.5
3	1.00	0.0

(1) "Office of Experiment Stations, Bul. 90, p. 17."

The actual factory yield is even smaller than would appear from the sucrose content and purity of the juices, because cane from salt land contains more chlorine than that from soil free from chlorides (See tables III to VI), and it is a well known fact that a high salt content in the cane depresses the quantity of available sugar and causes an increase in the amount of molasses obtained.

CANO DE TIBURONES

FIRST SERIES OF ANALYSES.

After the brief review of the literature on the effect of salts upon the growth and composition of the cane, given in the preceding chapters, we shall now take up the specific problem of the marsh soils on the north coast of this island. As has been remarked above, the Caño de Tiburones was chosen for these studies because it is the largest of these marsh areas, being fairly representative of all of them, and also because the work of reclamation was already in active progress when this investigation was begun, thus requiring immediate attention. Two large canals had already been dug; one on the north side near the edge of the swamp and running about parallel with its longer axis, and another parallel to the first, but along the south side of the swamp, and toward the hills. Both canals unite at a place some distance from the outlet into the Arecibo River and discharge their drainage waters into this river near its mouth.

In order to get a general idea of the conditions in the whole district, as far as the salt content of the soils and its influence on the cane is concerned, a number of soil samples (8) were taken by Mr. Howells, engineer in charge of irrigation investigations of the Plazuela Sugar Company by which corporation these estates are managed; and at the same time the cane growing in the same places was examined by Mr. J. R.Johnston, Pathologist of this Station. Some more samples were collected by the writer, and these, in combination with those taken by Mr. Howells, comprise pretty well all the soil types of the estate, including the best loam lands down to the marsh itself. The results of this first investigation, which were partly incorporated in a report made jointly by Mr. Johnston and the writer, are discussed on pages 21-31 of this bulletin.

At many places on the estate a white incrustation may be seen on the surface of the soil which is evidently formed by evaporation of the soil solution. A sample of such an incrustation adhering to the soil was taken in the low lands of "Paja", and analysed with the following results. The air dry substance contained per cent:

Carbonic acid, as (Co 3)	0.000%
Bicarbonic acid, as (HCO 3)2	0.164%
Chlorine	1.162%
Sulfuric acid (SO 4)	0.119%
Calcium	0.090%
Magnesium	0.031%
Potassium	0.058%
Sodium	0.683%
	2.307%

The percentage composition of the incrustation as calculated from this analysis, is as follows:

Carbonic acid as (CO 3)	0.00%
Bicarbonic acid (HCO 3)2	7.08%
Chlorine	50.36%
Sulfuric acid (SO 4)	5.17%
Calcium	3.90%
Magnesium	1.37%
Potassium	2.51%
Sodium	29.59%
	100.00%

It is readily seen that the main constituent of this incrustation, commonly called "potasa" in that neighborhood, is sodium chloride, which is mixed with small amounts of the bicarbonates and sulfates of calcium, magnesium and potassium.

Knowing the nature of the incrustation, it was desirable to find out, in what quantities the salts found were present in the different parts of the estate, and whether they are present to such an extent as to influence the cane as regards growth, diseases and insects.

Mr. Howells collected at each place a sample of the soil itself, and besides a subsoil sample at the depth of five feet. Notes were taken on the yield of the cane, the level of the ground water, the number of years during which the field had been under cultivation, and on the use of fertilizers. Mr. Shapley, Chemist of Plazuela, kindly furnished us with analyses of the ground water at the different places where the samples were taken. The first of these was collected at the part of the estate which is situated towards the Caño de Tiburones, about 2800 meters west of the central factory, and the other samples at about equidistant points in the direction towards the Central, that is east, and then from there, at a right angle, going south, towards the hills. Table VII gives the definite locations where the samples were collected, and the other data obtained with the exception of the analyses of the gound water which are given in table IX, (page 26).

TABLA VII.

Nº	Distance from Central meters	Water level below surface.	Yield of cane in tons Plant cane	1910 Crop	Time in cane, years	Time fertilizer have been used
1	2800, W.	1.5 ft.	22.80		6	—
2	2200, W.	2.0 "	37.10	23.25(3)	40 to 50	—
3	1600, W.	3.0 "	53.15	27.75(3)	40 to 50	—
4	650, W.	3.0 "	21.30	—	40 to 50	5 years
5	0	4.0 "	42.25	27.00(1)	40 to 50	5 "
6	700, S.	9.0 "	22.00	15.00(2)	40 to 50	5 "
7	1500, S.	12.0 "	37.00	29.80(1)	40 to 50	—
8	2400, S.	14.0 "	—	— —	30	—

Note (1) Second ratoon.
» (2) Third "
» (3) Fifth "

On examiation of the general condition of the cane and of the amount of infestation by diseases and insects, Mr. Johnston reported the following facts:

No. 1. Very small amount of root disease and very few insects. No root grubs. A good root system developed, but many of the roots dead.

No. 2. Good deal of root fungus. Roots well developed. Root hairs in pretty good shape. Cane about fair.

No. 3. Much root fungus. Root system only fair, root hairs in poor condition; many dead and dry shoots, probably due to soil conditions.

No. 4. Worse than No. 3. Great deal of root disease. Well developed root system, but many dead roots. Root hairs scarce.

No. 5. Some root disease. Root system fairly good, plenty of root hairs.

No. 6. Very small amount of root disease. Very good root system and root hairs.

No. 7. No signs of root disease. Roots and root hairs in excellent condition.

No. 8. Some root fungus. But roots well developed and root hairs in good condition.

The condition of the root system is considered of more importance than the presence or absence of root fungi or insects. The abundance of root hairs in good condition determines the ability of the plant to assimilate sufficient water for its needs.

The other samples mentioned on page 21, and taken by the writer, comprised the following:

No. 9. In Colonia A, field No. 1; about 12000 meters from the central factory; the soils from this place are typical marsh soils and their agricultural analyses have been given in the preceding chapter. The first of the 3 samples represents the surface stratum, about four inches thick, and consists of a mixture of the black vegetable mould and the white marl. Its agricultural analysis is given on page (12). The next sample is the black vegetable mould itself, found in the same place, from four to twelve inches depth; it is the soil whose analysis is found on page (9), table I, under No. 1. The ground water in this place is about 18 inches below the surface. The last of the three samples is the white marl, the agricultural analysis of which may be seen on page (11), table II, under No. 3.

The cane in this field absolutely refused to grow in some places, and in others the little cane there was, showed a very stunted growth and a yellowish appearance.

No. 10. is situated in "Paja", tablon 3, about 2500 meters from the factory. The cane at this place was not very vigorous, yielding only about 20 tons per acre; it was evidently suffering, in spite of the fine composition of the soil itself which has 1.51% of lime, 0.42% of potash, 0.17% of phosphoric acid and 0.38% of nitrogen. The surface soil was six inches deep, and the subsoil was sampled to the depth of eighteen inches.

No. 11 is the Experimental Field near the factory between the two places where samples Nos. 5 & 6 were collected. The cane is quite healthy here, but the yields are not very good. The soil was sampled to the depth of twelve inches, the subsoil from twelve to twenty four inches.

All the soil samples described were, in the fresh state, analysed for moisture, carbonates, bicarbonates, chlorides and sulfates, and the results are given in table VIII. None of the samples showed any alkaline carbonates; but they have a slight alkalinity due to the presence of bicarbonates which are, in a strictly chemical sense, acid salts, however salts of a very strong base and a very weak acid, so that the character of the former predominates.

TABLE VIII.

Water soluble constituents in Plazuela soils, on moisture free basis, in per cent.

SERIE I.

		Bicarbonates. $(HCO_3)_2$	Clorine Cl_2	Sulfates. SO_4
Nº 1	Soil	.149	.137	.015
Nº 1	Subsoil	.215	.180	.033
Nº 2	Soil	.084	.043	.014
Nº 2	Subsoil	.090	.354	.035
Nº 3	Soil	.077	.114	.007
Nº 3	Subsoil	.098	.126	.020
Nº 4	Soil	.069	.119	.009
Nº 4	Subsoil	.040	.111	.010
Nº 5	Soil	.049	.026	.011
Nº 5	Subsoil	.042	.125	.015
Nº 6	Soil	.065	.014	Trace
Nº 6	Subsoil	.026	.021	Trace
Nº 7	Soil	.021	.016	Trace
Nº 7	Subsoil	.032	.013	Trace
Nº 8	Soil	.022	.011	Trace
Nº 8	Subsoil	.020	.013	Trace
Nº 9	Soil, 0 to 4 in.	.318	.186	.138
Nº 9	" 4 to 12 "	.199	1.674	.462
Nº 9	Subsoil	.211	.248	.149
Nº 10	Soil	.097	.164	.042
Nº 10	Subsoil	.090	.212	.047
Nº 11	Soil	.022	.017	.032
Nº 11	Subsoil	.032	.029	.030

The following table, No. IX, gives the composition of the water in the drainage ditches, sampled near the places where the soil samples were taken.

TABLE IX.

Parts per millon

Nº	Total Solids	Chlorine	Sulfates, SO 3
1	1040.8	380	51.1
2	1804.0	727	68.3
3	2162.0	740	205.7
4	1740.0	610	trace
5	2180.0	758	163.0
6	440.0	70	25.2
7	320.0	28	trace
8	238.0	25	trace
9	2193.2	835.0	187.8
10	2353.6	1010	107.1
Branch of Canal near Nº 1	1040.8	340	68.3
North Canal, near center	2100.0	880	172.1
North Canal, at last bridge	909.6	745	126.0
Mouth of Canals near Arecibo River	2644.0	1085	171.6

(At location No. 11 a sample of the drainage water could not be taken, as the ditches were dry.)

All these analyses, with the exception of Nos. 9 and 10, were made by Mr. Shapley, Chemist at Plazuela.

We have seen before that when a given sample of soil contains not one but several salts simultaneously, the injurious action of these salts is not directly additive. On the contrary, any salt when present in a soil in mixture with other salts, is less harmful than would be the case were it present by itself. However, when the salts contained in several samples are present in about the same proportions in each one, then the total quantity of salts found in each sample will be representative of the relative amount of injury caused by the salts in that sample. Such is the case in our soils, and therefore, in discussing the results of our analyses, we shall consider the sum of the acid radicles, as given in the above tables. The higher we find the total quantity of salts, the more injury we may expect.

We shall first try to determine if there is any regularity in the general distribution of the salts over the estates controlled by the Plazuela Sugar Company. With this purpose in view we shall arrange in tabular form the average figures for the total acid radicles of each soil and its corresponding subsoil, as being indicative of the "saltness" of the place, i.e. of the total amount of salts present, in the order of the different locations, beginning at the marsh and going in the direction to the factory, and from there towards the mountains. These figures are compiled in table X.

TABLE X.

Location	Distance from Factory.			Total acid radicales
9	12,000	m.	W.	1.190%
1	2800	"	"	.365
10	2500	"	"	.326
2	2200	"	"	.311
3	1600	"	"	.222
4	650	"	"	.179
5	0			.134
11	300	m	S.	.081
6	700	"	"	.063
7	1500	"	"	.041
8	2400	"	"	.032

(It must be remarked here, that there is a fresh water spring near location 1, which dilutes the soil solution, as may also be seen from the analysis of the drainage water at this particular point (See page 26). The normal salt content would therefore be much larger than is indicated by the figure in the above table.)

It is readily seen that the total amount of salts gradually diminishes in the direction from the marsh to the factory and from there to the hills. There is quite a drop from the marsh soil to the first mineral soil, but from there on the differences are more regular.

If we now ask what relation exists between the salt content of the soil and the condition of the cane as regards root system, diseases and insects, we cannot base any conclusions solely on the figures given in table X, but we must consider that the cane is a shallow feeder, the roots being comparatively short. Therefore, we must in this discussion pay particular attention to the surface soil in which the cane actually grows. For this reason we have compiled, in table XI, the figures for total acid radicles, and also for chlorine alone, present in the *surface soils,* again in the same sequence as in table X.

TABLE XI.

Location	Total acid radicles	Chlorine
9	1.771%	1.178%
1	.301	.137
10	.326	.188
2	.142	.043
3	.198	.114
4	.198	.119
5	.085	.026
11	.071	.017
6	.079	.014
7	.037	.016
8	.033	.011

We find that here the figures for total acid radicles are not as regular as in table X, but these discrepancies are only apparent, and, in fact, help to explain the condition of the came from the respective places.

In the discussion which follows we shall take up each location separately, and study the relation between the salt content of the soil and the condition of the cane. The dscription of the condition of the cane in the different places is due to Mr. Johnston.

9.—In this location cane had been planted for the first time, and it was either dead or dying. There is no doubt that the high percentage of salts was largely responsible for this (1.178% of chlorine and 1.771% of total acid radicles.)

1.—Here the plant crop for 1910 produced only 27.8 tons per acre, notwithstanding the land had been in cultivation only 6 years. Fertilizer had never been applied. In the adjacent field of old cane there was a small amount of root disease, and very few insects. Some stools showed absolutely no root disease, while in others it was confined entirely to a few small dead shoots. The root system was well developed but many of the roots were dead indicating either injurious parasites or a bad condition of the soil as to constitution or texture. Parasites were not present in sufficient amount to account for any injury to the cane. It must be noted here that the soil was comparatively shallow and that the subsoil with its high chlorine content of 0.18% came in contact with the lower part of the root system. As the amount of the salts present increases and decreases at any given point according to the rise and fall of the water level it will be readily seen how a good root system may have developed but subsequently beame injured. The soil was apparently rich in plant food but of rather close consistency. Altogether the physical condition of the soil may have had a small part in preventing a big crop of cane, but the matter of fungus or insect enemies may be entirely eliminated, leaving the majority of the blame to the salt content which amounted to a total of .301% acid radicles, .137% being chlorine.

It has been stated on page (27) that the salt content at this place would be higher if there were not a fresh water spring right near. It is for this reason that the chlorine and also the total acid radicles are lower here than at the next location, 10, while we would expect the opposite to be the case. But even with only 0.137% of chlorine and 0.301% of total acid radicles the cane would probably have suffered more, were it not for the high nitrogen content of this soil, which tends to neutralize the injurious effects of the salts.

10.—Here the yield was also small, about 20 tons per acre. There was a considerable amount of small cane found, and it did not have a normal appearance. The trouble is evidently due to the high salt content (.326% total acid radicles, and .188% chlorine), and would certainly have been more pronounced yet, if the soil did not, like at 1, contain a large percentage of nitrogen (0.38%), and, besides, 1.5% of lime.

2.—About this station the land had been in cultivation for from 40 to 50 years. The crop of 1910 produced only 22.8 tons for the fifth ratoon while the first crop of the same planting produced 37.1 tons. The root system of the cane was in good condition, well developed with plenty of good root hairs, notwithstanding a large amount of root fungus present. The texture of the soil at this station was loose, and consequently the drainage good. The soil was dark, and apparently rich in plant food. There was nothing in the texture of the soil to warrant the presence of so much root fungus. Probably the cane was weakened from some other cause and thus allowed the fungus free play on the cane, for it seems to be a fact that the root fungus on vigorous cane does little damage, while on weak cane it seriously accentuates the trouble.

The salt content in this soil was found exceptionally low, for this particular place, only .142% of total acid radicles, and but .043% of chlorine, when we should expect a much higher figure. But this is easily explained. This soil is very porous, and the subsoil begins at a much lower level than in sample 1. Otherwise the soils and subsoils of the two places are very similar. This place, 2, evidently had a good rain shortly before the samples were taken, as may be seen from the figures for moisture in the fresh samples, 46% and 70% respectively. The result naturally is that the salt which might have accumulated in the soil was washed down into the subsoil where it actually appears in a concentration of 0.35% of chlorine, but out of reach of the bulk of the roots of the cane.

3.—This section has been in cane for from 40 to 50 years. No fertilizer had ever been used here. The tonnage shows a rather remarkable decrease from 53.1 tons of the plant crop to 27.7 tons for the fifth ratoon cut in 1910. The cane shows much root fungus together with a root system in very poor condition, a large number of roots being dead. The soil is a heavy clay and apparently not very rich. The chlorine content of this soil is .114%, the total acid radicles amounting to .198%.

4.—In cultivation for 40 to 50 years with fertilizer used during 5 years. The plant crop cut in 1910 amounted to only 21.3 tons. There was much root disease and the roots were in very poor shape. The soil was a very heavy clay. The chlorine content here was .119% (.198% total acid radicles), a little higher than in 3. Both of these soils are stiff clays, very different in structure from 1, 10 and 2, which are open dark soils rich in humus.

5.—Here we enter a region where the chlorine content of the soil is getting slight, even though there be still quite a quantity of it present in the subsoil. This area, 5, had been in cultivation also for 40 to 50 years, and fertilizer had been used for five years. The tonnage of the plant crop was 42.25 tons while that of the second ratoon of the same planting was 27.00 tons. There was some root disease but the root system was in good condition. The chlorine content of the soil was only 0.026% (total acid radicles 0.085%), much less than at No. 4. The soil is a rather heavy clay.

11 and 6.—These two locations do not materially differ from each other. The land here had been in cultivation for 40 to 50 years, and had been fertilized for five years. The plant crop from No. 6 gave only 22 tons, and the third ratoon cut in 1910 gave but 15 tons. The cane showed a very small amount of root disease and a good root system. The chlorine in the soil was only 0.014 to 0.017% (total acid radicles 0.071 to 0.079%.) Evidently the chlorine cannot, in this case, be made responsible for the small production, but some other factor, possibly lack of fertility, must be the cause of it.

7.—In cultivation for 40 to 50 years, but no fertilizer used. The plant crop gave 37 tons, but the second ratoon crop in 1910 gave only 29.8 There was no root disease present and the root system was in excellent condition. The chlorine was low, 0.016%, the total acid radicles 0.037%.

8.—This area had been in cultivation for about 30 years and no fertilizer had ever been used. It is said to produce 60 tons of cane, but actual records are not available. Some root fungus was found, but the root system was good. The chlorine here was only 0.011% (total acid radicles 0.033%).

If we now compare all of the results obtained we see at once that there exists a very striking relation between the salt content of the soils and the general condition of the cane grown in them. Taking a vigorous, healthy root system as the predominating factor in determining the condition of the cane, we find that where the chlorine content is found to be from 0.014 to 0.043%, and the total acid radicles from 0.033 to 0.142%, the cane is in good condition, and where the chlorine is above 0.114% (total acid radicles above 0.198%), the cane is not normal. There was no salt content found between 0.142 and 0.198% of total acid radicles, and between 0.043 and 0.114% of chlorine, so that we cannot say where the exact limit lies, above which the cane will be injured by chlorides and other salts. But it is somewhere between the figures just given. It is possible that all the figures for chlorine, etc., were a little higher than the average for a growing season, as the samples were taken at the end of a dry spell. Heavy rains would have reduced the salt to some extent, at least for a time.

While it is evident that the general condition of the cane is greatly influenced by the salt content of the soil, there is no direct relation between this latter and the actual amount of disease present. In places where the salt content is very low, considerable root disease may be present, and in others, where the salt is high, root disease may not be found. This fact is strikingly shown at location No. 1, where the conditions of moisture etc. seem to be excellent for the development of the root fungus. But it is more than probable that the salt content of that soil is too high for the proper development of the fungus.

From the first series of analyses reported on in the preceding pages we may conclude that in the ordinary mineral soils of the region investigated the danger point for chlorine is between 0.043 and 0.114% (0.142 and 0.198% of total acid radicles), and that it is probably quite near that fixed for Hawaiian conditions by Maxwell at 0.09% (0.15% of sodium chloride), and by Eckart at 0.06% chlorine (0.1% of sodium chloride).

SECOND SERIES OF ANALYSES.

Having thus made a general survey of the conditions obtaining on the estates controlled by the Plazuela Sugar Company, so far as the salt content of the soils is concerned, and having established the limit of chlorine that the cane will stand in the ordinary soil types, attention was now centered on the marsh itself. The general working plan was the same as in the first investigation: a number of locations were carefully selected, soil samples taken and the condition of the cane noted at the same time. The area studied in this second investigation lies along a branch of the plantation railroad which runs across the Caño de Tiburones at a point between kilometers 12 and 13 of the main line of the same railroad, from north to south, crossing both drainage canals. This part of the estate had only recently been planted to cane for the first time (Spring 1911; samples taken in June 1911). Samples of soil were taken at five different points along the branch line, collecting separately the samples of the surface foot and that of the underlying second foot. At the same time notes were taken on the condition of the cane and on the height of the water level at each place, during high tide.

All of the soil in this entire field is the very moist black vegetable mould already fully described. The exact depth of this material was not ascertained, but the underlying stratum most probably consists of the same white marl which crops out at the surface in Colonia A, at the edge of the swamp and at some distance from the field under investigation. The agricultural analyses of these soils have been given on previous pages of this bulletin. We have seen that the black material is very rich in humus, and that even the marl underneath to the depth of two two feet is well supplied with it. In accordance with this the nitrogen content of the black material is very high, exceeding two per cent of the dry soil, decreasing in the lower layers. The subsoil consists of almost pure calcium carbonate, and even the black material contains on the average 8.65% of lime. The magnesia is .8% in the soil and 1.75% in the subsoil. Potash and phosphoric acid are low, .2 and .1% respectively in the soil, and .065 and .02% in the subsoil.

If we now compare the nature of the injurious soil constituents existing in the first series of soils with that of those contained in this series, we find some very remarkable and important differences. Generally speaking, the soils used in the first investigation are very different in character from those which we are to discuss now. All samples but one of the first series were collected within a radius of 2,800 meters from the central factory and represented regular mineral soil types. In the present series, however, we have to deal with vegetable moulds, formed in a medium impregnated with salts. In the first as well as in the second area we find white incrustations on the surface of the land, but in their composition the incrustations from the two places are entirely different. In the first area the crust was found to consist mainly of sodium chloride, with small amounts of the sulfates and bicarbonates of calcium magnesium and potassium. The incrustation that is found in enormous quantities in the swamp area of the Caño de Tiburones, on the other hand, is for the most part insoluble in water and consists principally of calcium carbonate. The water soluble part of this incrustation amounts to less than one half per cent of the total, and is made up of about equal parts of bicarbonates, chlorides and sulfates. The analyses of this incrustation follow here:

COMPLETE ANALYSIS

Moisture	2.50%
Insoluble residue	0.78%
Carbon dioxide and volatile matter	45.79%
Iron oxide and alumina	0.94%
Lime	48.37%
Magnesia	1.23%
Potash	0.04%
Soda	0.18%
	99.83%

WATER SOLUBLE CONSTITUENTS.

Carbonates	0.000%
Bicarbonates, $(HCO_3)_2$	0.112 "
Chlorine, Cl_2	0.084 "
Sulfates, (SO_4)	0.114 "

The formation of this incrustation is easily explained. As the soil contains a large percentage of calcium carbonate, considerable quantities are dissolved during wet weather, by the combined action of water and of the carbon dioxide dissolved in it. In dry weather this solution of calcium bicarbonate rises to the surface and dries up, losing a part of its carbonic acid, and being redeposited as normal calcium carbonate. Naturally, chlorides and sulfates are mixed with it, having risen to the surface through the same forces as the calcium bicarbonate.

It is important to note that in the incrustation of the first type, the sulfuric acid radicle, SO_4, amounts to less than 9% of the total water soluble acid radicles, whereas in that of the second type its quantity is 37% of the total. Again, in the different soil samples of the first series, the same relation ranges from 6 to 9%, and in those of the second from 21 to as much as 78%, as we shall see from the analyses given further on.

Having pointed out these important differences in the characteristics of the areas investigated, we shall now examine in detail the results of the study of the Tiburones swamp lands.

As before, we shall again give the results of the field investigations in tabular form. We have stated above that the samples were taken along a cross section of the swamp, at a right angle with its longitudinal axis, beginning at the north border of the swamp and proceeding south to its south border. Towards the two sides the land is higher than towards the center of the marsh, as may be judged from the water levels given in table XII. Column 1 of this indicates the distance of each location from the edge of the field lying next to the north border of the swamp; column 2 gives the height of the water level, and column 3 the condition of the cane growing at the point where the sample was taken.

TABLE XII.

Nº	1 Distance from North end	2 Water level	3 Condition of cane, and remarks
1	57 meters	2.5 ft.	Good cane, dark green foliage; 7 monts old, 6 ft. high.
2	410 "	2.0 ft.	Medium fair cane, not as gren as Nº 1; leaves at base dried up; 5 mo. old, 4.5 ft. high.
3	783 "	15 in.	Weak, sickly cane, leaves yellow; 3 to 4 mo. old, 18 in. high; surface incrustation.
4	1025 "	15 in.	Cane dying; leaves yelow; 3 to 4 mo. old, 15 in. high; surface incrustation.
5	1410 "	18 in.	Better cane, leaves green; 5 mo old 2.5 to 3 feet high.

In table XIII are given the results of the analyses of the two samples, representing the first and scond foot respectively, of each location. The average figures for the entire depth of two feet are also given, as in this loose soil the roots of the cane will penetrate beyond the first foot. The first column of table XIII indicates bicarbonates calculated as bicarbonic acid ion, $(HCO3)\ 2$, as has been done before; column 2 gives the chlorine $(Cl2)$, the third the sulfuric acid ion $(SO4)$, the fourth the sum total of acid radicles, and the fifth the sum of bicarbonic acid and chlorine. The reason for this arrangement will soon be apparent.

TABLE XIII.
WATER SOLUBLE CONSTITUENTS IN TIBURONES SOILS, ON MOISTURE FREE BASIS, IN %;

SERIES II.

	(HCO 3) 2	Cl 2	SO 4	Total Acid Rad.	(HCO 3)2 + Cl 2
Nº 1 1 foot	.088	.112	.980	1.179	.200
,, ,, 2 feet	.080	.189	.658	.927	.269
Average	.084	.150	.819	1.063	.234
Nº 2, 1 foot	.121	.244	.511	.876	.365
,, ,, 2 feet	.134	.400	.844	1.379	.534
Average	.128	.322	.678	1.127	.450
Nº 3, 1 foot	.587	.054	.347	.988	.641
,, ,, 2 feet	.211	.157	.150	.518	.367
Average	.399	.105	.249	.753	.504
Nº 4, 1 foot	.472	.125	.198	.794	.597
,, 2, 2 feet	.512	.213	.161	.886	.725
Average	.492	.169	.179	.840	.661
Nº 5, 1 foot	.309	.060	.116	.486	.369
,, ,, 2 feet	.159	.057	.047	.264	.216
Average	.234	.059	.082	.375	.293

Note:—None of the samples contained normal carbonates.

In discussing the analytical results of the first series of soil samples, the amount of injury to the cane to be expected could be estimated on the basis of the total amount of salts present, chlorine and bicarbonates being the chief factors, since sulfates were found in small quantities only, from 6 to 9% of the total. This manner of interpretation could be used there, since, as stated before, the salts contained in the several samples were present in about the same proportion in each. If in the present series of analyses we should consider the total amount of salts to be indicative of the injury to be expected, we would arrive at entirely erroneous conclusions. In such a case No. 2 would be expected to grow the worst cane, following nos. 1, 4, 3, and 5. The facts show that such is not the case. Nor can the chlorine content alone be used as a criterion. Sample No. 3 had .1% of chlorine, and the cane was dying; No. 1 had .15% of chlorine, and the cane there was vigorous and healthy.

A further examination of the table shows that the proportion of bicarbonate to chlorine and to sulfate in any one sample is quite different from that in the other samples so that we cannot draw conclusions in the same way as we did in the first series of analyses.

How are we then to interpret the figures of the table? Returning again to what was said in the discussion of the first series of analyses, chlorides and bicarbonates are about equally injurious while sulfates are much less so. In fact, sulfates are not only less injurious, but, in mixtures with other salts, even exert a protective effect, so that the other salts in the presence of sulfates are less injurious. A good illustration of this phenomenon is afforded by a case cited by Hilgard, concerning the growth of sugar beets in salt land (Hilgard's "Soils", page 466): Beets were "good" where the sulfate (Glauber's salt) ranged up to 0.8%, with .1 to .2% of common salt; but so soon as the latter rose above .2%, the beets were poor despite the low percentage of Glauber's salt; then became "good" again so soon as the common salt fell below 0.2%, although the Glauber's salt increased. Investigations by Cameron have also shown that sulfates, and more especially calcium sulfate counteract the injurious effect of sodium and other soluble salts. As in the soils under investigation lime is present in considerable quantities, the sulfuric acid found in the samples must first be combined with lime, forming calcium sulfate. We shall see how markedly the protective influence of calcium sulfate is shown in our samples.

Beginning with No. 1, we found a vigorous, healthy cane with a dark green foliage which in seven months had attained a height of six feet. The average sum of chlorine and bicarbonic acid is lower than in any other sample, viz. .234%, and the sulfuric acid, representing the protective influence, is highest, .819%.

At the next station the sum of bicarbonic acid and chlorine has reached .45% and the sulfuric acid is slightly lower than in the first, .678%. Corespondingly the cane was not as good as in No. 1. The leaves were still green, and the cane had made a good growth in five months, attaining a height of four and a half feet, but the basal leaves were somewhat burned, thus exhibiting the injurious action of the salts present.

At location No. 3 the cane was weak and sickly looking, the leaves being yellow and drying up. The total height of the cane after three to four months growth was only 18 inches. We are therefore not surprised to find .504% of bicarbonic acid and chlorine, with .641% in the first foot alone; while the sulfuric acid radicle amounts to only .249%, which is not more than one half of the other radicles, while in Nos. 1 and 2 the sulfuric acid radicles was largely in excess.

Location No. 4 presented about the same appearance as the foregoing; the cane was possibly somewhat worse than at No. 3, having grown to only 15 inches in three months and being practically in a dying condition. Correspondingly we find here the highest quantity of bicarbonic acid and chlorine, viz. .661%, with .597% in the first foot; and at the same time the sulfuric acid is quite low, only .179%.

No. 5 had better cane. This had grown to a height of 2.5 to 3 feet in three months, and looked much healthier then than the cane at locations 3 and 4. In accordance with these findings we have much less bicarbonic acid and chlorine, only .293%. From this we might expect even better cane than at station No. 2, but there we have a large quantity of sulfate present, whereas in No. 5 it amounts to only .082%.

There is another factor yet which must be considered in the interpretation of the results, namely the height of the water level. In a large part of the field the ground water comes quite near to the roots of the cane, and the water alone will damage the cane, even if it be not salty.

While the condition of the cane at the different stations can easily be accounted for relatively, by the proportions of the salts present, the absolute amount of chlorine and of bicarbonic acid that will permit the cane to grow, is much higher than that found in the mineral soils discussed before. We find that the cane at this place will grow well where the chlorine content is .15%, the sum of bicarbonic acid and chlorine amounting to .234%; and that it even grows comparatively well at a place where the chlorine is as high as .322%, and the sum of this and of bicarbonic acid .45%. In the other area we had found the limit of chlorine that the cane will endure to be between 0.04 and 0.11%. In the present case there are evidently several factors at work which raise the endurance limit of the cane towards salts beyond the point we had found before. These factors have already been discussed at length, and we shall only briefly recapitulate them here. The first of them is the protective influence of sulfates against the injurious effects of other salts. The second is the fact that calcium salts in general, and especially the sulfate, are not only less harmful by themselves, but act as antidotes to the salts of sodium and magnesium. The third reason why the cane will at this place stand more salt than at others, is the high nitrogen content of the black vegetable mould.

THIRD SERIES OF ANALYSES.

In order to get more data on the subject which might enable us to fix numerically the limit of tolerance for salts in these marsh lands, another series of samples was taken in the Caño de Tiburones, in April 1912. The area investigated at this time was situated in that part of the marsh which is controlled by Central Cambalache. It is located in the south-west quarter of the marsh, near the railroad station Santana. Here cane had been planted one season before, and the crop had been cut and allowed to ratoon wherever the condition of the cane warranted this policy. In other parts it had been left standing without cutting.

Sample No. 1 was taken in field No. 2. The cane here was ratoon cane, quite vigorous and healthy, and had attained a height of from seven to eight feet.

No. 2 came from field No. 4, also in ratoon cane. The cane here was apparently healthy, but it was not as good as in location No. 1, having grown to a height of only five feet.

At location No. 3, also in field 4, the cane had likewise been cut and allowed to ratoon. But it was only about three feet high and showed marked signs of suffering.

In place No. 4, located in field No. 8, the cane, when first planted, had germinated, but most of it subsequently died.

In location No. 5, in field 5, the cane did not even germinate.

It is important to note here that in locations No. 1, 2 and 3 the ground water was low enough to be out of reach of the cane roots, whereas in Nos. 4 and 5 it was quite near the surface.

Table No. XIV gives the analyses of the soils from the 5 places, to the depth of two feet.

TABLE XIV.

WATER SOLUBLE CONSTITUENTS IN TIBURONES SOILS, ON MOISTURE FREE BASIS, IN %

SERIE III.

	1	2	3	4	5
(HCO 3) 2	.284	.417	.465	.430	.566
Cl 2	.124	.126	.125	.199	.297
So 4	.237	.204	.278	.201	.358
Total acid radicles	.645	.747	.868	.830	1.221
Calcium	.153	.172	.190	.140	.247
Magnesium	.035	.042	.048	.043	.057
Alkali (Sodium)	.058	.057	.080	.145	.186
Total basic radicles	.246	.271	.318	.328	.490
Acid radicles	.645	.747	.868	.830	1.221
Basic radicales	.246	.271	.318	.328	.490
Total Salts	.891	1.018	1.186	1.158	1.710
(HCO 3) 2+Cl 2	.408	.543	.590	.628	.862
SO 4	.237	.204	.278	.201	.358

It appears from the analyses that the conditions in this area of the marsh are less complicated than in the second series reported on before, inasmuch as the proportion of the sulfates to the sum of bicarbonates and chlorides is more uniform than it was there. While in the second series the quantity of sulfates, expressed in per cent of the sum of bicarbonates and chlorides, ranged from 28% to 356%, it varies here only between 31% and 59%. The amount of sulfates is throughout much smaller than that of the sum of bicarbonates and chlorides, and the influence of the sulfates is not only slight, but also about proportional.

If we now compare the condition of the cane and the salt content of the soils we find that the cane is the better, the smaller the quantity of chlorides plus bicarbonates, and that the cane gradually becomes worse, as that quantity increases. With .408% of bicarbonic acid plus chlorine the cane is quite normal, and even with .543% it still makes a pretty good showing.

Combining these results with those of the second series of analyses, we reach the final conclusion that cane in these marsh lands grows well where the sum of bicarbonic acid ion and of chlorine does not exceed 0.4%, always provided that the level of the ground water is low enough to prevent the cane roots from coming in contact with it. If the sum of bicarbonic acid and chlorine rises above 0.4 to 0.5%, the cane begins to suffer visibly, even though it be not growing in standing water.

These figures can, of course, not be considered as a standard in all cases, because a number of other factors influence their magnitude to a greater or lesser extent. Thus the proportion of chlorine to bicarbonic acid may in practice vary within wide limits. Then the influence of the sulfates has to be taken into account, as is so well shown in the study of the second series of analyses. Moreover, the soil of the marsh is not uniform throughout, and its texture and other physical properties and its chemical composition may largely affect the relation between the salt content and the growth of the cane. But it would be virtually impossible to find all these conditions represented in the field in such a way that each factor may be studied by itself to the exclusion of all other factors. We must therefore be content with such indications as are afforded by the data given in this report; and in order to study all of the points just mentioned, it will be necessary to carry out experiments with all conditions under perfect control so that each factor may be studied separately. Such investigations will necessarily have to be made in tubs.

For all practical purposes we may conclude that, at least in this marsh, and in such places where the ground water is sufficiently low, to be out of the reach of the cane roots, the sum of bicarbonic acid and of chlorine may safely rise to 0.4%, but must be lower where that condition is not fulfilled.

OTHER MARSH AREAS.

A few samples of soil were collected in other marshes on the north coast, and it was found that some of them are extremely salty. The analyses are compiled in table XV.

TABLE XV.

	1	2	3	4	5
Carbonic acid, as (CO_3)	.000	.000	.000	.000	,000
Bicarbonic, acid,as(HCO_3)2	.843	trace	trace	.105	.147
Chlorine	.142	1.758	1.194	.115	.081
Sulfuric acid (SO_4)	–	–	–	.061	.033
(HCO_3) 2+Cl 2	.985	1.758	1.194	.220	.228

Sample No. 1 is from the Tortuguero, near Manatí, and was collected by Mr. Howells.

Nos. 2 and 3 were taken in the marsh surrounding the Laguna de San José.

Nos. 4 and 5 are samples from a marsh belonging to the estate controlled by the San Vicente Sugar Company. The general formation of this marsh is the same as that of the Caño de Tiburones; it consists of the characteristic black surface soil and the white calcareous subsoil. Here, according to Mr. Crawley, the water is very near the surface so that the cane roots are in contact with it.

We find that in samples Nos. 1 to 3 the salt content is exceedingly high, and so far only typical salt plants grow in these soils.

Nos. 4 and 5 are interesting samples inasmuch as they bear out our conclusion arrived at above, that the cane will in marsh lands stand much less salt when it is growing in standing water than when its roots are not in contact with the ground water. In fact, the cane at that place is not growing well.

RECLAMATION OF THE MARSHES.

In the preceding chapters we have ascertained the trouble that prevents the cane from growing normally in these salt marshes and have found out under which conditions it will grow well. We now come to the question as to how these conditions may in practice be arrived at with the least possible expense. The first necessity is, as we have seen, the lowering of the water level. This would be indispensable, even if the water did not contain salt, since, as is well known, cane is a plant that requires excellent drainage. However, as the water in this marsh, is not fresh water, but, on the contrary, highly charged with salts, drainage becomes absolutely imperative. We have seen that around the center of the swamp, about stations 3 and 4 of Series 2, the salt content is exceedingly high, and the counteracting sulfates are low. By dropping the water level sufficiently the trouble can be remedied, and regular floods which at present are a great danger to the cane in wet weather, will thus be avoided. After good drainage has been provided the excess of salt must be washed out, by the natural rainfall, and, if necessary, by the aid of irrigation, until the concentration of the salts falls below the danger point as indicated by the results of our investigations. But before an attempt is made to leach out the salts, an excellent drainage system must first be installed. Unless this be done, always forcing the water to move in a downward direction, it will dissolve the salts out of the lower soil strata, then rise by capillary action, and on evaporation will leave more salts in the surface layer than there were before. It will be well to quote Maxwell's own words in this connection (1). "The salt content of the soil and its action upon the growing crop can be modified by the amount and quality of the water used in irrigation. 'Sweet' water can carry the salt down out of reach of the cane roots, but if there is no outlet for the water through the subsoil, it will come up again by evaporation to the surface, bringing with it a greater excess of salt to deposit near the roots."

(1).—O. E ·S. Bull. 90, p. 17.

A very good beginning towards the final reclamation of the Caño de Tiburones has already been made. The ditches are quite close together and generally deep enough to carry off the water into the canals. It would perhaps have been better and more profitable to first completely reclaim the land before commencing to plant cane, in consideration of the fact that, under the conditions obtaining, the operations of planting, cultivation and harvesting are extremely expensive and would pay only if the yield of suger per acre were very high. The preparation of the land, planting and cultivation had, on account of the very nature of the soil, to be done entirely by hand and with the greatest care. And, with all this expense, the quantity of sugar produced per acre was exceedingly small. We must further consider that the cane, already weakened by the effect of the salt, is much more liable to suffer from the attacks of insects and diseases than healthy cane growing in a good soil. In fact, some of the ratoon cane in the marsh is very heavily infested by the moth stalk borer.

While, for the reasons alluded to, it would probably have been more advantageous not to plant cane until the land was in a condition for growing it successfully, a large area of the swamp, about 2000 acres, has already been planted to cane, and the reclamation work has to be carried on simultaneously with the cane cultivation. Since the summer of 1911 good progress has been made in this direction, and the water level has fallen about six to eight inches. Even this improvement has been accompanied by excellent results. The ratoon cane this year presents a much better appearance than the plant cane, although the salt content, according to some analyses made lately, is on the average about the same as last year. But the natural limit in lowering the water level has now about been reached. At the present time the entire difference in level between the center of the swamp and its outlet at the Arecibo River, is only 1.20 meters, or only 10 centimeters per kilometer. This slight grade will hardly be sufficient to quickly drain the marsh. It must, moreover, be considered that the black soil shrinks very much on drying, so that the surface of the soil sinks, thus again raising the water level. It follows that a more effective system of drainage must be installed, as for instance by dikes and pumps.

With an efficient system of drainage it will be easy to get rid of the salts. It is quite probable that the rains may be sufficient to accomplish this. If the year, should, however, be dry, then irrigation may have to be resorted to.

After the soil has finally and definitely settled, it may be found advantageous to replace the open ditches by a system of tile drains in order to avoid all the difficulties arising from the close proximity of the ditches; this always provided that the character of the soil permit the use of tiles.

In the meantime it would be well to carry out some experiments on fertilization, in order to find out what fertilizers will bring the largest returns. This question has already been discussed at length on pages (10-14), to which we refer the reader.

It is sincerely to be hoped and it seems now quite certain that these marsh lands after being thoroughly reclaimed and when cultivated according to the best known methods of agricultural practice, will finally produce good crops of cane, and thus contribute their share to the wealth of this beautiful island.