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ON

FERTILIZATION

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Charles F. Eckart

CHAIRMAN OF COMMITTEE

SUBMITTED TO THE

Hawaiian Sugar Planters' Association

NOVEMBER, 1901.

HONOLULU:
HAWAIIAN GAZETTE CO.
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Committee on Fertilization:

C. F. ECKART,
C. M. WALTON,
J. T. CRAWLEY,
GEO. ROSS,
JOHN WATT.

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REPORT

ON

FERTILIZATION

(C. F. ECKART, Chairman of Committee)

HONOLULU, H. T., November 18th, 1901.

TO THE PRESIDENT, TRUSTEES, AND MEMBERS OF THE HAWAIIAN
SUGAR PLANTERS' ASSOCIATION,
Honolulu, T. H.

GENTLEMEN:—During the past year, no less than twenty-five thousand tons of commercial fertilizers have been added to our Hawaiian soils to satisfy the demands of the sugar industry.

The initial cost of this large quantity of fertilizing material, added to the cost of distribution and application, makes the subject of fertilization from an economic standpoint one of great importance and worthy of close consideration. The comparative cost of the different manurial compounds, their relative efficacy in meeting the requirements of the cane crop, their proportional liability to waste under given climatic conditions, combined with a knowledge of the soil to which they are to be applied, must constitute the only basis from which any rational and economical system of fertilization can be derived.

The earliest method in use for determining the ability of a soil to furnish the requisite amount of plant food for a given

crop, involved practical tests with small field plats. On a small area, without fertilization, but with due observance of proper tilth and cultivation, a crop was started for purposes of comparison. At the same time other plats were laid off in the same field and received allotments of nitrogen, phosphoric acid, lime, potash, etc., and the effect of each one of these applied elements was carefully noted as regards any increase of the given crop over and above that on the unfertilized area. Not only were these fertilizers added separately on some plats, but in mixtures of varying proportions on others, and valuable conclusions were reached as to the demands of the plant. These practical tests are still carried on to a large extent in some agricultural communities, and results are reached of sufficient value to more than compensate the farmer for time and labor expended.

These plat experiments, however, are found to be open to the following objection: The time necessary to determine the proper quantity and the best balanced proportion of fertilizing ingredients to be added for maximum yields, covers periods of considerable length.

The chemist has endeavored to overcome this objection, and to reach in the laboratory results that have taken the agriculturist months to learn from observation in the field. By an examination of the ash of the particular plant to be grown, he learned the quantities and proportions of the various mineral elements that had been removed from the soil, and used in the development and elaboration of the plant and its products. He digested a small quantity of the soil in hydrochloric acid of a certain specific gravity, and noted the percentages of the different elements in the resulting soil extract. From these analyses, conclusions were drawn as to the fertility of the land in question, and the supply of plant food, from which the crop could draw as needed, was supposed to have been measured.

Unfortunately, discrepancies soon begin to arise between field results with the growing crop and the conclusions reached from chemical analyses, and the chemist found that

his shorter method was not without palpable defects. If an element was lacking in the soil or was present in very small quantity, he felt safe in recommending the application of that element in fertilization, but where an ingredient was present in large amounts, he sometimes found that that self-same element was one to be added in manurial mixtures for satisfactory results. In other words elements can be present in large amounts in the soil, but in a state which renders them unavailable to the plant. Regarding the ordinary agricultural method for determining soil deficiencies, this may be said in its favor: That in some instances it serves as a valuable guide in fertilizer recommendations, when the chemical analysis is supplemented with reliable data as regards the physical condition of the soil, combined with a knowledge of the climatic conditions of the locality from which the sample has been obtained.

In view of the objection which has been mentioned regarding the agricultural method, investigators have endeavored to find an acid more suitable for soil digestion than hydrochloric, and one whose solvent action would be more comparable with the acids of the plant roots. Organic acids were substituted for mineral acids in the experiments, and a long stride was taken towards the solution of this important problem.

ASPARTIC ACID METHOD.—This method of determining the availability of the plant food in the soil, is the one at present in use at the Experiment Station, and a few words may be said in regard to its practicability for Hawaiian conditions. The credit for this system of soil investigation belongs to Dr. Walter Maxwell, the former director of the Experiment Station, and Mr. J. T. Crawley, and is the result of a close and scientific study of conditions obtaining on these islands. A detailed account of the work along this line and the logical conclusions drawn from the same, may be found in an article on "Lavas and Soils of the Hawaiian Islands," published by Dr. Maxwell in 1898, and in this report only a brief reference to the deductions will be made.

The amount of mineral matter being carried into the sea

by waters of discharge from the land was determined with the following results:

Hawaiian Waters.

Lime	0.0013	Per cent
Potash	0.0005	Per cent
Phosphoric acid	0.0001	Per cent

These figures represent the average mineral content of Hawaiian waters collected at many places considered suitable for such observations.

An analysis was made of upland cropped and corresponding virgin soils, the average results being as follows:

UPLANDS.

Elements	Virgin	Cropped	Loss
	Per cent.	Per cent	Per cent.
Lime	0.415	0.248	40.20
Potash	0.324	0.270	16.60
Phosphoric Acid	0.248	0.243	2.02

The term cropping as applied to the above table is used in a very general sense. It includes the action of rain, cultivation, and growing crops in removing plant food from the soil.

Data were obtained which showed that in one case where 7,000 lbs. of lime were removed per acre, only about 15 per cent of this amount had been utilized by the crop itself, and in respect to potash the crop took only one-half of the amount removed by total cropping. "These data show that any system of judging of the depletion or of restoring the fertility of soils, that is based upon a mere calculation of the amounts of the elements that are carried away from the land in crops, is devoid of any approach to the actual facts of the matter." The reason that upland virgin and cropped soils were taken for this comparison, was on account of the washing action of the rains. The makai soil receives a large part of the wash from the mauka lands, and in some instances cropped soils on the lower lands show a higher proportion of given elements than the virgin. The amount of lime removed by cropping is

40.2 per cent, and if this is taken as a standard, applying it also as a basis for the waters of discharge, the relations existing between it and the other elements may be tabulated as below:

Elements Removed from the Soil in Water.			Elements Removed from the Soil by Cropping.		
Lime	Potash	Phosphoric Acid	Lime	Potash	Phosphoric Acid
Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
40.2	15.1	2.80	40.2	16.6	2.02

As Dr. Maxwell has pointed out, these results do not appear so remarkable, when it is considered that the great bulk of matter removed by total cropping is found in the waters of discharge.

With these data at hand, the next step was to find some acid whose solvent action on the soil would remove the essential elements in proportions approximating those of cropping. Many organic acids of different strengths were allowed to act on the soil for varying lengths of time, and it was found that an one per cent solution of aspartic acid, when shaken with the soil at intervals during twenty-four hours, apparently met all requirements. The amounts and proportions of the elements, removed by this acid during twenty-four hours, were approximately the same as were removed by total cropping during a period estimated at twenty years. Dr. Maxwell's conclusions were stated as follows: "An one per cent solution of aspartic acid takes out of Hawaiian soils in twenty-four hours, the same amounts of lime, potash, and phosphoric acid, that are removed during the production of ten crops of cane. Therefore one-tenth of these amounts may be taken as the proportions of lime, potash, and phosphoric acid that are available for the immediate crop of cane." The Aspartic Acid Method, although not perfect, offers a fairly reliable means for determining the amount of available plant food in the soil, and is in fact a better guide in the matter of fertilization on these islands than any other known method, as in its conception, Hawaiian conditions influenced every consideration.

Before considering the subject of fertilization in its more restricted sense, i. e. the application of different manurial compounds to the soil, probably a few words on the average availability of the essential elements in question might prove of interest.

AVAILABILITY OF ELEMENTS.—Considerable data are at hand to give an adequate idea of the amounts of lime, potash, phosphoric acid and nitrogen that are present in the soils of the respective islands, the subjoined table representing average results of about one hundred analyses.

ISLAND	Lime	Potash	Phosphoric Acid	Nitrogen
Oahu	0 380	0 342	0 207	0 176
Kauai	0 418	0 309	0 187	0 227
Maui	0 395	0 357	0 270	0 388
Hawaii	0 185	0 346	0 513	0 540

These results were obtained by the ordinary agricultural method, which was in use at the Experiment Station prior to the adoption of aspartic acid as a soil solvent, and although an absolute analysis would give somewhat larger results, these are comparative to a large extent as showing the proportions of lime, potash, phosphoric acid, and nitrogen present in the island soils.

The amounts of the mineral ingredients which are found to be available are as follows:

ISLAND	Lime	Potash	Phosphoric Acid
	Per cent.	Per cent.	Per cent.
Oahu .....	.01568	.00256	.00012
Kauai .....	.01367	.00249	.00013
Maui .....	.01764	.00312	.00012
Hawaii .....	.00789	.00156	.00014

or reducing these percentages to a more tangible form, we have:

ISLAND	Lime	Potash	Phosphoric Acid
Oahu	549 lbs.	89 lbs.	4.2 lbs.
Kauai	478 "	87 "	4.5 "
Maui	617 "	109 "	4.2 "
Hawaii	276 "	54 "	4.9 "

which quantities represent the amounts of the essential mineral elements, in one acre of soil to a depth of one foot, that are in a condition to be removed through the several actions of total cropping, during the growth of one crop.

It is interesting to note that Kauai stands highest in lime, Maui in potash, and Hawaii in phosphoric acid. The smallest percentage of lime is on Hawaii, while Kauai is lowest in potash and phosphoric acid.

If, however, we consider the availability of these elements instead of the actual amounts in the soil, a somewhat modified order presents itself: Maui and Oahu are both higher in available lime than Kauai, Oahu standing first. Maui with the highest total content of potash has also more of that element in an available form than the other islands. The amounts of available phosphoric acid show little variation, notwithstanding a difference between .187 per cent total phosphoric acid on Kauai, and .513 per cent on Hawaii. This latter ingredient is so closely bound up in iron and aluminic compounds as to be practically insoluble; on Hawaii nine tons of the element per acre scarcely yield five pounds in an assimilable form.

Having considered the method in use for gauging the availability of the mineral elements in question, and having noted the amounts in which they are present in the soils of the respective islands, we will next consider the demands of the crop.

ELEMENTS REMOVED BY THE CROP.—In the report of the Experiment Station for 1900, it was pointed out that where 29,610 lbs. of sugar were produced per acre by Lahaina cane, 6,606 lbs. of mineral matter were extracted from the soil, while with Rose Bamboo, 30,475 lbs. of sugar required 7,662

lbs. of mineral matter. The following table shows the amounts of the various elements including nitrogen, which were required to produce one ton of sugar by the respective varieties:

Varieties	Nitrogen	Phosphoric Acid	Potash	Lime
Lahaina	25.4 lbs.	16.0 lbs.	89.5 lbs.	28.7 lbs.
Rose Bamboo	40.5 "	13.6 "	114.2 "	34.8 "

If we should take five tons of sugar per acre, as the average production for the Hawaiian Islands, and consider for our purpose that the amounts of the essential elements required by the crop for such a yield would be the same as at the Experiment Station, we have:

Nitrogen, Phosphoric Acid, Potash, and Nitrogen Required by the Cane to Produce Five Tons of Sugar

Varieties	Nitrogen	Phosphoric Acid	Potash	Lime
Lahaina	127.0 lbs.	80 lbs.	447.5 lbs.	143.5 lbs.
Rose Bamboo.....	202.5 "	68 "	571.0 "	174.0 "

As it is our present purpose to consider crop requirements in general, and not the special demands made by particular varieties, we will take the mean of the figures presented above, as representing Lahaina and Rose Bamboo needs, and for future consideration say, that a crop to produce five tons of sugar, would require per acre, about:

164.7 lbs. of nitrogen.

74.0 lbs. of phosphoric acid.

509.2 lbs. of potash.

158.7 lbs. of lime.

We will next compare the amounts of available elements in the soils of the respective islands, with the amounts of these elements that would be required by a crop producing five tons of sugar. The nitrogen contents of the lands are not given,

as at the present time we have no reliable method for determining its availability.

ISLAND	Lime in soil	Lime required by crop	Potash in soil	Potash required by crop	Phosphoric Acid in soil	Phosphoric Acid required by crop	Nitrogen required by crop
	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds	Pounds
Oahu	549		89	509.2	4.2		
Kauai	478	164.7	87		4.5	74	32.9
Maui	617		109		4.2		
Hawaii	276		54		4.9		

It will be noticed from the above figures that lime is the only one of the elements that would appear to be present in sufficient quantity for the needs of the crop. But when we consider the statement previously made, concerning the small proportion of lime that is taken up by the crop on some upland soils as compared with the proportion removed by the other factors involved in total cropping, we may see that the average lime content is not so large but what we must consider it very carefully. Maui stands highest in available lime, having 617 lbs. on an average to the acre, but if only 15% of that amount could be utilized by the crop, as in the instance above referred to (which was most likely an extreme case), only 92.55 would go to the crop where 164.7 lbs. were needed. Even if the cane gets on an average 30 per cent of the lime removed, but small margin would be left on Maui, above actual crop requirements, while on Oahu there would be just enough, and on Kauai and Hawaii a marked deficiency.

The potash is found to be very much too low on all the islands for supplying the wants of the cane, and it is readily seen why it was found necessary, during recent years to increase the proportion of that element in fertilizers applied.

Concerning phosphoric acid, the dearth of this element in available quantities in our island soils is very apparent, but we are almost convinced that the aspartic acid method for soil analysis would indicate this ingredient to be lower in availability than it really is.

In the consideration of the amount of plant food taken from

the soil by the growing crop, in order to produce one ton of sugar, we took an average of the quantities removed by Lahaina and Rose Bamboo varieties, as giving a fair idea of the large demands made by the cane upon the soil. However these proportions and amounts are not to be taken as representing the exact requirements of the cane in any locality or under any conditions. At the Experiment Station, the figures in question were reached in a comparative test of thirteen varieties of cane, grown under similar conditions as regards soil, fertilization, and climate, one of the objects being to note their respective drafts on the soil as compared with their value as producers of sugar.

MINERAL MATTER RETURNED TO THE SOIL IN CANE REFUSE.—The last table, although it gives an idea of the amount of plant food that would be required for a crop of such size as was under consideration, does not show the quantities of lime, phosphoric acid, potash and nitrogen, that are taken away from the field. If it did, the application of artificial manures from crop to crop would reach much larger proportions than it really does. As a matter of fact, after the cane is cut for the mill, and the trash and dead canes, etc., are burned, as is most generally the case on plantations, a much larger amount of mineral matter is returned to the soil than is generally supposed. By burning, of course, all the nitrogen is lost with its corresponding manurial value, but the other essential elements remain on the field to be used largely by the succeeding crop.

The following figures indicate the relative amounts of the elements found in the tops, etc., and in the cane, per ton of sugar grown at the Experiment Station.

ELEMENTS REMOVED FROM SOIL PER TON OF SUGAR PRODUCED.

ELEMENT	In tops, leaves, and dead canes.	In cane
Lime	27.9 lbs.	3.7 lbs.
Phosphoric Acid	6.5 "	8.2 "
Potash	66.5 "	35.3 "
Nitrogen	20.2 "	12.7 "

These results show the lime in the tops, etc., to be over seven times that in the cane; the phosphoric acid is more evenly balanced; while the tops, etc., have nearly twice as much potash as the cane. It is thus seen that if only one-half of the mineral matter in the refuse of the field is conserved, a manurial mixture is added to the soil of particular value, which would lessen to a large extent the amount to be applied during regular fertilization.

In regard to the comparative availability of those elements returned to the soil through the burning of the trash, and the same added in ordinary fertilization, there is some difference in favor of the latter. The potash in the ash is chiefly in the form of chloride, with a smaller amount as carbonate and silicate, and the chloride is as assimilable as any that could be added in manurial mixtures. The phosphoric acid is returned to the land as iron and aluminic phosphates with a much smaller amount as phosphate of lime, and phosphate of magnesia. These phosphates are more insoluble than those generally added in fertilizers and are not immediately available to the plant. The lime in the ash is most likely combined with silica, phosphoric acid, and sulphuric acid and is only slightly soluble.

FORMS IN WHICH FERTILIZING INGREDIENTS ARE APPLIED.—The amount of available plant food in the soil and the probable requirements of the crop to be grown are important factors to be considered in any estimation of manurial needs. However, unless these data are supplemented by a knowledge of climatic conditions, and a proper regard shown for their several influences, analytical investigations in respect to the nature of the soil are often of little value.

To the action of the heavy rains of the uplands in washing away the more soluble ingredients of the soil we have already referred. These rains not only leach out material which is gradually being rendered available for plant needs, but also that which is artificially applied in the form of fertilizers. The erosive action on the natural material of the land cannot be controlled, but with a due consideration of the physical and

chemical properties of applied ingredients, we can place in the soil those substances required by the plant, and in a form least liable to waste.

We now come to a consideration of the elements themselves, the relative efficacy of their various combinations, and the conditions that influence their selection as component parts of manurial compounds for different locations.

NITROGEN.—This element is applied to the land in three forms, namely as nitrate of soda, sulphate of ammonia, and organic substances.

Nitrate of soda is the most soluble of these three forms and besides holds its nitrogen in the most assimilable condition. Solubility and availability are not necessarily synonymous expressions as regards nitrogen compounds, although the latter condition is greatly influenced by the former. The solubility of nitrate of soda is influenced by the temperature of the solvent, at 78° Fahr., 100 parts of water dissolve 90.33 parts of nitrate. Added to this extreme solubility is an unfortunate disinclination of the acid part of the salt to become fixed in the soil, which causes its use on some lands to be attended by considerable risk on account of the leaching action of the rains.

A test was conducted at the Experiment Station in 1898 to determine the relative liabilities to waste of nitrogen in the form of nitrate of soda, and the same element in the form of sulphate of ammonia. In one instance 200 grams of nitrogen as nitrate of soda and in another the same amount as sulphate of ammonia were added to corresponding soils draining into a lysimeter. Forty-eight hours after the application of these compounds, a copious irrigation was allowed to over-saturate the soil, and the excess of water was collected in a receiver and analyzed. The loss in nitrogen is seen by the following table:

Forms	Nitrogen Applied	Nitrogen lost in water	
		As Nitrate	As Ammonia
Nitrate of Soda	200 grams	72.56 grams	0.00 grams
Sulphate of Ammonia	200 "	3.08 "	0.44 "

The loss of nitrogen from nitrate is very large. Of the nitrogen from sulphate of ammonia only a minute proportion was found in the receiver, the major part of this small quantity being in the form of nitrate, into which state it had been converted by the nitrifying organisms of the soil.

Mr. J. T. Crawley, of the Committee on Fertilization, conducted a number of interesting experiments during the first part of this year, for the purpose of obtaining data as regards the retentive power of "sandy soils" for fertilizers and water, and his results are of particular value in a consideration of the subject in hand. Four soils varying in their proportions of lime carbonate from 71.25 per cent to 91.07 per cent were placed in iron pipes two feet six inches long and one inch in diameter, the pipes being filled to within six inches of the top. One gram each of ammonium sulphate, nitrate of soda, and muriate of potash were dissolved in a liter of water and 500 cubic centimeters of this solution holding one-half gram each of the salts mentioned were poured upon the soils and allowed to drain through. It was found in regard to the nitrate of soda that practically none was retained by any of the soils, while the other compounds were fixed in an inverse proportion to the lime carbonate content of the medium through which they filtered. In a consideration of the action of sulphate of ammonia and sulphate and muriate of potash when applied to the soil, we shall have occasion to again refer to Mr. Crawley's interesting experiments.

The readiness with which nitrate of soda may be taken up by excessive rains or irrigation and carried from the land is readily seen, but bound up with this question is another of almost equal importance. When the nitrate is lost from the

land through the over-saturation of its soil, not only so much nitrogen is lost, but likewise a large amount of lime. The nitric acid of the nitrate on coming in contact with the lime of the soil, forms lime nitrate, which is almost as easily soluble and as readily washed out as the nitrate of soda.

To observe this action of nitrate on lime, as well as the relative action of different salts in the same particular, tests were made at the Experiment Station in connection with other lysimeter investigations. Nitrate of soda, chloride of potash, ammonium sulphate and sulphate of potash were applied to the rows of cane growing over the lysimeter drains, and forty-eight hours later these rows were irrigated with 102 gallons of water, of which quantity 33 gallons leached out and was analyzed.

Drain	Salt applied	Lime Lost
No. 1	None	1.72 grams
No. 2	Nitrate of Soda	26.52 "
No. 3	Chloride of Potash	23.49 "
No. 4	Sulphate of Ammonia	5.49 "
No. 5	Sulphate of Potash	2.73 "

The lime taken out through the influence of nitrate is seen to be extremely high.

We have spoken at some length concerning the unfavorable characteristics of nitrate of soda when applied to lands of heavy and uncertain rainfall, particularly when such lands are deficient in lime. However, notwithstanding these several draw-backs to its general use in all localities, nitrate of soda has sufficient superior qualities when applied in proper quantities and under suitable conditions to render its use of the highest advantage.

When applied in large amounts and under such conditions as to allow of the fullest effects, nitrate has been observed in many instances to induce an abnormal and undesirable growth, which retarded the ripening of the cane, and resulted in juices of low purity and low sugar content. On the other

hand this self-same stimulating property has been of the greatest service to yellow and "nitrogen-hungry" cane, and with the application of small amounts of this material, wonderful tonic effects have been produced in an extremely short space of time.

In regard to the influence of nitrate on tasseling, Mr. Geo. Renton of Ewa Plantation writes: "My experience in one case with a late application in September of nitrate of soda was that it materially effected tasseling. About one-third only of the stalks flowered. As the application in this instance was made for the express purpose of preventing the tasseling of the cane, these results were gratifying." Mr. Renton further says: "It is my opinion that either excessive or late applications of nitrate of soda will lower the juice purity. The best juice obtained at this mill was from canes upon which nitrate was put on not later than the latter part of April." The experience of Mr. Olding at Kohala has been that "nitrates prevent tasseling in a very marked degree." It was observed last year at the Experiment Station that nitrogenous fertilizers in general prevented tasseling during the flowering period, whereas, unfertilized plats, and plats receiving merely potassic and phosphoric acid fertilizers flowered without exception. On account of the readily available condition of nitrate of soda we should expect small applications of this material to exert a more potent influence in preventing tasseling than would be the case with either sulphate of ammonia, or organic nitrogen.

Some difference of opinion exists as to the amount of nitrate that can be judiciously added to the soil, and reference will be made to that subject later on.

Attention has been called to the fact that where nitrate of soda and chloride of potash are applied to the same land, a chemical reaction might ensue to the detriment of the soil. This supposition is based on the fact that the solium of the nitrate of soda has a strong affinity for chlorine, which forms a part of the chloride of potash, and that the two elements might combine with each other to form common salt. Al-

though this reaction is within the realm of probability we are without the necessary data for a confirmation of this view. However it is better to be on the safe side, and on account of this probable interchange of elements to use potassium sulphate instead of potassium chloride, where nitrate of soda is being used on the land.

Sulphate of ammonia on account of its ready solubility, and small liability to waste as compared with nitrate of soda, is held in much favor as an economical nitrogenous compound. At 15° C. 1.3 parts of water dissolve one part of sulphate of ammonia and it is seen that little difference exists between its solubility and that of nitrate of soda, rendering its diffusion throughout the soil almost as complete as in the case with the latter substance. However it has one very strong advantage over the nitrate of soda, in its ready ability to become fixed in the soil, and on that account alone, its particular suitability for some locations is very apparent. If we refer to the results previously given as to the comparative waste of the two fertilizers under similar conditions, a striking contrast is noted. Of 200 grams of this material added to the land in the lysimeter tests only 3.52 grams of its nitrogen was lost in drainage waters, as compared with 72.56 grams of nitrogen lost from an equal amount of nitrate of soda. Of this small loss, 3.08 grams were in the form of nitrate, into which condition it had been converted by the nitrifying bacteria of the soil as previously mentioned. Only .44 gram of nitrogen escaped in the form of sulphate of ammonia.

To show Mr. Crawley's experience with this salt on "sandy soils," we will give his determinations in full, the conditions of his experiments having been described on page 13.

	1.	2.	3.	4.
Amount of moisture in the original soils...	3.73 p. ct.	2.03 p. ct.	1.08 p. ct.	0.61 p. ct.
Carbonate of lime in the soil.....	71 15 p. ct.	77.37 p. ct.	81.85 p. ct.	91.07 p. ct.
Weight of soil taken..	365 grs.	407 grs.	362 grs.	374 grs.
Time required to penetrate two feet. . . .	55 min.	19 min.	12 min.	8 min.
Total water passing through.....	320 cc.	342 cc.	345 cc.	355 cc.
Time required for the above water to pass through.....	335 min.	180 min.	95 min.	95 min.
Water holding power of the soils.....	49 p. ct.	39 p. ct.	43 p. ct.	38 p. ct.
Moisture in soils after ten days.....	31.5 p. ct.	20.4 p. ct.	18.8 p. ct.	16.6 p. ct.
Sulphate of ammonia lost.....	8 p. ct.	42 p. ct.	59 p. ct.	86 p. ct.
Muriate of potash lost	None.	44 p. ct.	56 p. ct.	65 p. ct.
Sulphate of potash lost.....	None.	8 p. ct.	25 p. ct.	28 p. ct.

“Nitrate of soda practically all was lost, there being little difference in the various soils.” It will be seen that where the lime carbonate of the soil amounts to 71.15% only 8% of the sulphate of ammonia was lost, but the loss increased rapidly in proportion as the content of lime carbonate became larger; a soil of 91.07% of lime carbonate only retaining 14% of the ammonium sulphate applied. These are unusual soils, however, and the proper conditions for holding the salt in question are notably lacking; but they afford us a proper realization of the superior power held by ammonium sulphate to become fixed under the most adverse circumstances. In the last column it is seen that one soil is composed almost entirely of coral or lime-stone, and that other ingredients must be present in very small quantities. As the double silicates in the land are most probably responsible for the fixing of the ammonia radical, it may be easily understood why the coefficient of fixation will be reduced in proportion as the bulk of the soil is taken up with carbonate of lime, and the silicates excluded.

As regards the action of ammonium sulphate as compared with nitrate of soda on the lime of the soil, there is a marked difference in favor of the former. In the lysimeter tests to determine this point, it was found that whereas 26.52 grams of lime were lost through the action of the nitrate of soda applied, only 5.49 grams were removed through the influence of the sulphate of ammonia. In making these comparisons, attention should be drawn to the amount of lime that was carried from the soil by the application of water alone without the addition of the various salts. This amount was 1.72 grams, and should be subtracted from the weights of lime removed, as given in the table on page 14, in order to reach the actual amounts of this soil element that were lost through the influence of the several agencies.

The action of ammonium sulphate in the soil in furnishing nitrogen to the cane, is considerably different from that of the nitrate. The latter substance is in a suitable condition to be absorbed by the plant roots immediately on going into solution in soil water, or in coming in contact with the plant root acids. The ammonia of the ammonium sulphate on the other hand has to be oxidized by soil bacteria and changed into nitric acid before it reaches an assimilable state for the cane. This difference in the immediate availability of the two compounds will explain to a large extent the several differences displayed in their effects upon the crop. The nitrogen as nitrate is so readily absorbed when applied to the land as to act like a stimulant, while the more slowly acting nitrogen of ammonium sulphate is yielded more gradually as a plant food, and forms a longer lasting supply of this material, per given weight of ammonium sulphate added than that from the nitrate of soda.

We now come to a consideration of nitrogen as supplied from organic sources. The chief nitrogenous substances of this order as applied to Hawaiian soils, are dried blood, tankage, and fish scrap or "fish-guano." Of these materials dried blood unquestionably ranks first, both in its high content of nitrogen and the ease with which it is rendered available by

the micro-organisms of the soil. In a perfectly dry state it has been known to run as high as 14 per cent of nitrogen. The samples of this material received at the Experiment Station would indicate an average of about 12 per cent., with a small amount of water.

Tankage, though containing less nitrogen than the blood, is an organic source of nitrogen of no little value. It is composed of scraps and fragments of flesh which have been dried and ground, after the removal of fats by steaming. Tankages have been received at the Experiment Station for analysis which were found to have as high as 10 per cent phosphoric acid in addition to their liberal content of nitrogen, which gives them added value as fertilizing compounds.

Fish scrap, on the average, contains about 8 per cent of nitrogen and 7 per cent of phosphoric acid. It constitutes the ground residue of fish from which the fats and oils have been largely removed, and varies considerably in its value as a manurial substance. Occasionally samples are met with which contain a large amount of fatty matter, and these fats and oils when present in considerable quantity cause the other organic matter to decompose with great difficulty in the soil. Some years ago a sample was received at the Experiment Station laboratory which was found on analysis to contain over 24 per cent of total fats.

In the consideration of organic substances as a source of nitrogen, a distinct difference is manifested between them and the soluble chemical salts which have just been discussed. Nitrate of soda and sulphate of ammonia, on account of their solubility in water, may be readily taken up by that medium and distributed throughout the mass of the soil. The organic material on the other hand can only be applied to the land in spots and needs slight covering to depths varying with the nature of the soil and of the substance used, in order that the most suitable conditions will be reached for thorough decomposition and nitrification.

Nitrification is believed by many authorities to be accomplished through the agency of three kinds of soil bacteria.

One kind changes the nitrogenous material into ammonium compounds, another converts the latter into nitrous acid, and still another completes the work by a conversion from nitrous into nitric acid. These processes are slow and in the course of their operation a gradual distribution of soluble ammonium compounds and nitrates throughout the entire soil very probably takes place. For instance as the ammonia is formed it may be taken up by the water of the soil and carried some little distance before it becomes fixed, and on being oxidized into nitric acid a further dissemination most likely results. The extent of this gradual distribution cannot be measured, but that available nitrogen is carried to parts of the soil remote from the point of contact of the original substance is unquestionable.

POTASH.—This element is usually present as sulphate of potash in Hawaiian fertilizers, although the muriate is also used to some extent. The sulphate on account of its very small effect upon the lime of the soil is favored more than the muriate, and as little difference exists between the prices of the two compounds, the former proves very often the more economical in some localities.

Owing to the rapidity in which potash becomes fixed in loams or soils of a clayey nature, Dr. Stubbs of the Louisiana Experiment Station believes that, in some instances, the more proper time for application would be before planting, in order that the repeated plowing and harrowing might thoroughly distribute the element throughout the soil; otherwise if used as a top dressing it might become entirely fixed in places contingent with the point of application. However, on account of the basic nature of Hawaiian soils, and their smaller content of double silicates as compared with American soils as a rule, potassic fertilizers are much more readily disseminated throughout the soil mass by means of rain or irrigation water. In fact, in the lysimeter tests conducted at the Experiment Station, it was shown that potash was found in the drainage waters where excessive irrigation was followed, and in amounts sufficient to indicate a loss of the potassic fertilizers

which had been applied to the soil. Data are lacking to indicate the relative fixing power of potash in the two salts under consideration, but figures may be found in the table on page 14 to show the influence exerted by each form in removing lime from the land. It is seen that nearly nine times as much lime was removed from the land where muriate was added, than resulted from the application of sulphate. The influence of potassium chloride is evidently almost as potent as that of the nitrate of soda in its depleting action on the lime content.

In Mr. Crawley's investigations with the "sandy soils" previously referred to, some very surprising results were reached as regards the disposition of the respective potassic compounds to become fixed under similar conditions in soils of a highly calcareous nature. By referring to the tabulated results on page 17 it will be noticed that none of the chloride or sulphate of potash was lost in the soil containing the least amount of lime carbonate. In the soil with the highest percentage of lime carbonate, 65 per cent of the chloride was lost and 28 per cent of the sulphate. The absorption of potash by these peculiar soils is influenced chiefly by their content of lime carbonate for several reasons. The higher the percentage of lime carbonate the lower must be that of the double silicates in the respective soils, as was pointed out before in considering sulphate of ammonia, and these silicates are particularly instrumental in holding potash. The mechanical condition of the soils is influenced to a large degree by the quantities of lime carbonate that they contain, and as the mechanical condition varies so will the rapidity with which a solution may filter through them. The time that the solutions of potash were in contact with the earth in the pipes influenced in great measure the extent of the resulting chemical changes.

In the early reports of the Experiment Station it was pointed out that in adding chloride of potash to lands bordering on the sea and which are sometimes abnormally high in salt, there is a liability of increasing the proportion of this deleter-

ious substance, and on that account sulphate of potash was advised as the proper form under such conditions.

PHOSPHORIC ACID.—This element exists in fertilizers in many combinations with varying degrees of solubility. It is usually classed as water-soluble, citrate-soluble, or insoluble. In considering the availability of what have been called the essential elements of the soil, it was noticed that although the lands of the Hawaiian Islands are usually very high in phosphoric acid, that very little of it is rendered assimilable during the growth of the crop. On that account it would seem most natural to apply this element in its most soluble form.

The water-soluble phosphoric acid in the form of super or double super-phosphate is readily taken up by rain or irrigation water and distributed more or less throughout the surrounding soil and is rather thoroughly fixed. This fixation is brought about by the carbonate of lime and by the hydrated ferric oxide and alumina present. In the first case, a more or less insoluble phosphate of calcium, and in the second case a basic phosphate of iron or alumina is produced. Although there are Hawaiian soils with no inconsiderable amount of lime carbonate, the great bulk are either lacking in that compound or else contain it only in very small proportions. The predominating bases are those of iron and alumina, and with them the phosphoric acid is rather quickly united; even where calcic phosphate is formed the indications are that the phosphoric acid of this substance is gradually yielded to form combinations with the former. As nearly all the phosphoric acid in the island soils is already a component part of these basic phosphates, it would seem on first consideration that little or no improvement could be effected by a further addition to these insoluble compounds. However, when the soluble phosphoric acid is taken up by the water in the soil it is distributed thoroughly and coming in contact with the minute particles of iron and alumina, results in compounds which on account of their existence in extremely small grains, and on account of their thorough dissemination throughout the soil

mass, are in a much more available condition than the natural basic phosphates of the land.

Citrate-soluble, or di-calcic phosphate, although insoluble in water, is soluble in a solution of citrate of ammonia, and is readily absorbed by the acids of the plant roots. Owing to its insolubility in water, however, it cannot be so thoroughly incorporated with the soil, as the form previously described and is of corresponding less value.

By insoluble or tri-calcic phosphate is meant that form which exists in natural or untreated phosphate, and is insoluble in water or citrate of ammonia. In the soil it is rendered slowly available through the processes of decay or decomposition, which action is influenced by the amount of organic matter with which it is associated, the fineness of its mechanical division, and also by the moisture content, depth, and temperature of the soil in which it lies. Dr. Maxwell has pointed out that the acidity of a soil also assists materially in this decomposing action, and attributes the greater effect of bone meal on some of the uplands to the higher moisture and acid content of those soils as compared with the lands of a lower elevation.

LIME.—This element is present in nearly all fertilizers containing phosphoric acid, and as calcium phosphate is added in large quantities to Hawaiian soils. In addition to the lime as phosphate a considerable quantity is also present as sulphate or gypsum in treated phosphates such as the form designated as water-soluble or citrate-soluble, and on account of its fine mechanical and chemical condition is of high value as a fertilizing ingredient.

Ground coral and coral sand are also good as well as cheap sources of this element and are used to a considerable extent on these islands, especially where the content of organic matter is low as well as the lime. The percentages of lime in the various compounds are approximately as follows:

Gypsum	32 per cent of lime.
Ground coral	45 per cent of lime.
Coral sand	49 per cent of lime.

The difference in lime content between coral sand and ground coral is due to the admixture of shells in the former, which are composed of almost pure lime carbonate. Slaked as well as quick lime are used in some localities, but owing to the readiness with which these forms of lime attack the nitrogenous material of the soil, they are unsuitable for many lands.

FERTILIZERS USED ON THE DIFFERENT ISLANDS.—The amount of fertilizer to be added to any land involves a consideration of the available constituents of the soil, and the demands of cropping. The form in which its ingredients should exist is influenced by a consideration of their respective properties and the existing climatic conditions of the localities in which they are to be applied.

On the Island of Oahu, the average mixed fertilizer contains its phosphoric acid in the water-soluble and citrate soluble forms; the potash is in the form of sulphate; and the nitrogen is applied in three forms, as nitrate of soda, sulphate of ammonia and organic material.

On Maui, fertilizers are applied to a large extent in the same forms as on Oahu, the water-soluble and the insoluble phosphoric acid being somewhat lower. The three forms of nitrogen are generally used in the same fertilizer, although nitrogen as ammonium sulphate is in excess of the organic and nitric. The total nitrogen is 0.6 per cent higher than on Oahu.

On Hawaii on account of the diversity of conditions, fertilizers are naturally found to vary more in their composition than on the other islands. In the Hilo district owing to the heavy rains, nitrate of soda cannot be used without liability to waste, and potash in the form of chloride is in disfavor owing to its depleting action on the lime content of the soils which are already low in that element. Most of the nitrogen used in the district is derived from organic sources and also in some measure from sulphate of ammonia, although some few fertilizers used during the past year contained nitrate. In Hamakua phosphoric acid is applied mostly in soluble

forms, the nitrogen as a rule being derived from ammonium sulphate and the potash from sulphate.

On Kauai, nitrate of soda and sulphate of ammonia are favored as sources of nitrogen for mixed fertilizers, very little of this element being applied in an organic form. According to the analyses of the Experiment Station laboratory, Kauai fertilizers are higher in nitrogen as a rule than those from any other island.

On account of the wide variations in the composition of fertilizers and the limited number at hand for forming an estimate, it would be impossible to give average formulas for the different islands which would be reliable for purposes of comparison. The following table will give an idea of the wide differences between the lowest and highest percentages of each element applied in mixed fertilizers of which we have data.

ISLAND.	Potash.		Phosphoric Acid.		Nitrogen.	
	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Maui.	4.13	17.24	5.10	14.26	5.04	9.70
Kauai.	4.89	10.10	5.68	9.39	6.66	9.91
Hawaii.	4.03	22.54	5.29	14.61	3.25	10.42
Oahu	8.50	14.66	7.01	15.00	4.70	7.10

TIME AND METHODS OF APPLYING.—Theoretically the various elements should be added to the land in such proportions and at such times as the crop requires them. This would necessitate repeated applications of small quantities of mixed fertilizers with their respective ingredients in ever varying proportions, due consideration being given to their individual inclinations to waste. It would mean the feeding of the plant according to the needs of its fluctuating growth and development, and the multitudinous changes involved in the elaboration of its products. Agricultural science has not advanced so far as to make such nice calculations possible, and if it had, the cost of labor would not permit the close application of such theoretical doctrines.

Most plantations make two applications of mixed fertilizers during the growth of the crop and the times of these applications vary on different plantations. Some incorporate fertilizing material with the soil of the seed bed before planting and others make the first application when the cane is six to eight weeks old or after suckering has actually commenced. Where two applications are made, the first is usually at the end of the suckering period and the second in the fall or in the following spring, depending on the time of the planting season.

The methods followed in applying fertilizers depends largely upon the kind used. Where the ingredients are in soluble forms, on account of labor considerations the practice on many plantations is to merely drop the material in the furrow beside the cane stalks, without covering. This method should give satisfactory results with any but fertilizers containing organic and insoluble forms such as blood, tankage, etc., which latter substances require a slight depth in the soil to meet the proper conditions for nitrification and satisfactory decomposition.

Dr. W. C. Stubbs, ("Sugar Cane," Vol. 1) says, in speaking of practices in Louisiana: "Nitrates and salts of ammonia are always best used as a top dressing—at short intervals, in small quantities. Dried blood requires but little depth, provided moisture necessary for conversion into available plant food be present. Tankage, bones, and fish scrap must be sunk to deeper depths to obtain fermentation necessary to their conversion into soluble plant food. None of the above should be turned too low, especially in stiff soils, since air, moisture, and heat are the factors needed in decomposition."

It was pointed out in the report of the Experiment Station for 1896, that considerable risk is entailed by applying soluble fertilizers in the furrow under the seed where irrigation is practiced. Under such conditions there is a likelihood of the material being washed down and out of the soil before the young cane is in a condition to appropriate any of it. This would not apply, however, to organic sources of nitrogen or

phosphoric acid which are so gradually decomposed, and we understand that such material is giving good results in one locality when applied in such manner.

Mr. Geo. Ross, member of the Committee on Fertilization, writes a very interesting letter on the practices followed on Hakalau Plantation. He says: "At Hakalau I am using almost exclusively a high grade fertilizer of the following average composition. Nitrogen (from sulphate of ammonia and organic ammonia of dissolved bones) 5 to 6%; Phosphoric acid (available) 9 to 10 %; Potash in the form of sulphate of potash, 9 to 10%. This is applied to the plant cane at the rate of 900 lbs per acre in two applications, the first at time of planting and at the rate of 300 lbs. per acre, scattered by hand in the bottom of the furrow, or seed bed, followed by a cultivator to stir it up with the soil. The second application is at the rate of 600 lbs. per acre and just prior to 'hilling up,' or when the cane is too high for further cultivation by mule or horse implements. At this time it is scattered, also by hand, on both sides of the cane row and covered up by small plows which throw the soil in towards the cane, which is afterwards trimmed up by the hoe.

The same grade of fertilizer is applied to all ratoon cane, but usually in one application of about 500 lbs. per acre. It is applied to both sides of the row as is done in the case of the second application to plant cane, and is covered over in the same way by small one horse plows. The usual practice is to apply it to the ratoons as early as possible after the first hoeing.

We have used a fertilizer of this general composition for several years, and although I have experimented to some extent with such special fertilizers as tankage, fish scrap, and bone meal, I have had no results to warrant their continuance. Nitrate of soda on account of its solubility is not adapted to this district, where in the past we have been subject to such heavy rainfall whereby this salt is liable to be lost before being taken up by the plant. Lime always gives satisfactory

results and this is true of all soils in this district. Filter-press cake when passed through a disintegrator and applied in liberal quantity gives excellent and lasting results. The same, of course, is true of stable manure. I might state that the percentage of potash in the mixed fertilizer, above referred to was increased from 5 to 6% up to its present strength about three years ago, and with marked results. This was suggested to me from observing the luxuriant growth produced by ashes from timber burnt in forest clearing."

On some plantations a most commendable system is followed of modifying the composition of fertilizers to suit the requirements of the different fields. Mr. D. C. Lindsay, of Paia Plantation says: "Our regular plant cane mixture is composed of super-phosphate, sulphate of potash, nitrate of soda and sulphate of ammonia. We have each field we plant analyzed and vary the proportions of the above ingredients to suit the analysis, so that as a rule every field has a different fertilizer to suit its requirements.

We sometimes use as a special fertilizer a mixture of nitrate of soda and coral lime in equal quantities and apply about 400 to 500 lbs. per acre. We apply this as late as July and August in the same manner as plant cane mixture.

The difference between our plant cane and ratoon mixture, is, that in the latter we increase the proportion of nitrate of soda and decrease the phosphoric ingredient."

Mr. John Watt of the Committee on Fertilization, in writing concerning the practices followed at Honokaa, says that it is customary to apply from 500 to 800 pounds of mixed fertilizer per acre for the crop. "On poor upper lands we give two applications, on lower lands where soil is rich we give only one. With only one application we distribute the fertilizer in the furrow before the seed is put in, mixing with the soil by a subsoiler or small plow. Where we give two applications the first is given as above and second is given when the cane has about two months' growth, sometimes a little later depending upon the condition of the cane, by distribut-

ing the fertilizer along side of the stool and either hoeing it in or running a cultivator along the furrows."

This year the general composition of mixed fertilizer applied at Honokaa has been as follows:

- 9—10% Phosphoric acid.
- 8% Ammonia from sulphate.
- 5% Potash from sulphate.

Mr. Watt says: "The above is the fertilizer which we have used this year and the weather has been so that we cannot tell what results we may have from it. Last year we used a different mixture on the upper lands with very good results, the analysis of which was as follows:

- 15% Potash from sulphate.
- 5% Ammonia from sulphate.
- 10—12% Phosphoric acid.

"With the above fertilizer the cane came up very well and maintained a vigorous growth until it was checked by the very dry weather during the past five months. When we planted this cane we gave it an application of 700 pounds of the above fertilizer with the seed and about four months later we gave it 700 pounds per acre more."

For some years past Mr. Watt has been very careful in regard to the preserving of all stable manure, which is liberally treated with a dressing of superphosphate to prevent loss of ammonia. Both with this compound and with mud-press cakes which have been passed through a disintegrator he has obtained splendid results.

We are in receipt of a very interesting letter from Mr. J. T. Crawley, who writes of a method in vogue at Kihei Plantation for the distribution of nitrate of soda. On account of its bearing so strongly on the question of labor economy the letter is given in full.

HONOLULU, T. H., Sept. 24, 1901.

CHAS. F. ECKART,

Chairman, Committee on Fertilization.

DEAR SIR:—I wish to include in the report on fertilization a method of applying nitrate of soda devised and used by Manager W. F. Pogue of Kihei Plantation, and communicated to me in a letter from him dated July 26. Mr. Pogue says: "Lacking labor sufficient to apply nitrate of soda with ground coral, I have just finished fertilizing some 600 odd acres with nitrate dissolved in water and applied in the irrigation. The form of application was as follows: Dilute one bag of nitrate of soda in one barrel containing 50 gallons of water, one pail of this solution is added to 4 pails of water, or in that proportion; in another barrel a hose bibb in the bottom of the last barrel discharges the diluted solution into a tub which is kept filled to a given mark, from the tub the mixture flows in an exact amount all day into the main irrigation ditch. The outlet of the tub is fixed, and cannot be opened or closed by the laborer doing the work. Strainers are used on the tub and diluting barrel. In this way one man can easily apply 100 lbs. per acre of nitrate to 60 acres in six days, two men will do three or four times as much. In applying I have put on 75 lbs. of nitrate to an irrigation, then skip one or two irrigations and apply the same amount again.

The fields thus treated have started from short joint sticks to very long joint sticks which means a very rank growth.

It seems to me that any soluble fertilizers can be applied much more evenly and certainly very much cheaper than in the ordinary method.

It also seems to me that if the applications could be made in small doses as the cane needs it, it would be the correct method, exactly as we would feed a horse or a cow."

Again in a letter of Sept. 20, Mr. Pogue says that he is applying 50 pounds nitrate per acre. To quote his words: "We have with my method applied 50 pounds to the acre with

one ordinary Jap to as high as 26 acres in one day, that is, 5,250 pounds were applied to 105 acres (one field) in four days by one Jap. The cane began showing the effects on the fifth day, by the seventh day after application, the cane roots had fully gotten hold of the stimulant, from a greenish yellow the leaves were turned a dark green.

We apply 50 lbs. nitrate every other irrigation, or say every 18 days. Cane shows the want of stimulant in from 20 to 30 days, according to nature of soil, after first application, and 30 to 40 days after the second application with this amount of 50 lbs. per acre. Later on, I can give you results of further experiments on these same lines."

The idea of dissolving the nitrate of soda in the water of irrigation was suggested by the scarcity of labor, and Mr. Pogue saw the added advantage of applying this very soluble fertilizer in very small quantities and frequently, rather than in one or two large doses. The only objection that I can see to this method is that there will be loss in the ditches through which the water passes before it reaches the rows of cane, and this loss will depend upon the nature of the soil that compose the bottoms and sides of the ditches. Mr. Pogue states that in the red soils where he is using the method the loss of water is very small. Again, if the part of the row where the water is entering takes up more water than the far end it will likewise take up more nitrate of soda.

The main advantage, aside from the labor question, to my mind is the advantage of applying only so much nitrate as the cane needs at the time, and to be able to apply it in small and frequent doses.

With as fugitive a substance as nitrate of soda this is a great consideration indeed. Whatever of this substance as is not taken up by the cane, can be washed away either by a heavy rain or by a heavy irrigation, and the least amount that is in the soil at any one time the less is the danger of loss.

Very truly yours,

J. T. CRAWLEY.

This method for the distribution of nitrate of soda, as adopted by Mr. Pogue, apparently has much to commend it, both as regards the saving of labor and the added advantage of being able to apply small quantities of the material as the cane seems to demand it. As the barrel from which the nitrate solution is discharged into the main ditch is kept at a constant level, an even pressure and discharge is obtained which would guarantee a regular and unchanging admixture of nitrate solution and irrigation water. Mr. Crawley's observation as regards probable loss of nitrate during the passage of the water through the irrigation ditches is well taken, though this loss may probably be small and of little consequence as compared with the saving of labor and other advantages to be derived from a following of this method. However this loss is a factor which will be considered later on in a special reference to the use of nitrate on plantations.

A curious point manifests itself in this method of applying nitrate of soda, which would be particularly striking where the cane is planted in long rows receiving their water direct from the main ditch, and less so in proportion as lateral trenches are used and the cane rows shortened. In the former instance the ends of the rows next to the ditch necessarily receive more water than the other extremities and consequently they will receive more nitrate. When this material is distributed in the usual way by hand, each part of the field has approximately the same amount applied to it, and loses it in proportion to the amount of water added providing a point above saturation is reached. At the ditch end of the furrow, according to Mr. Pogue's method a larger quantity of nitrate comes in contact with the cane roots, while in the ordinary method that point is marked by the greatest loss.

Mr. Pogue speaks of the probable advisability of applying all soluble fertilizers in this way on irrigating plantations and the plan certainly presents many favorable points for consideration. However, the question would arise whether the saving of labor and the advantage of small and frequent applications would off-set the loss of soluble high grade fertilizers

in the irrigation ditches, which is influenced by the area and nature of the exposed soil. This is a point which must be studied out very carefully before any radical change in the system of applying fertilizers is introduced, and I believe this point may be fully determined by a method which will shortly be presented for consideration.

It has been pointed out that the ends of the furrows next the ditches receive more water than other points along the cane row. Under ordinary conditions the soil at these furrow ends, where long rows are the rule, will soon become saturated and lose a larger quantity of their available plant food than other points, through the leaching action of the excess of water. With that water will go a certain percentage of the fertilizer in solution it is true, but the dissolved elements which leave the irrigation water to become fixed in the soil, would doubtless be more than sufficient to replace the same elements that had been removed from the soil itself. In other words the largest amount of fertilizing material would be added to the points suffering most from ordinary irrigation, on account of the resultant leaching action.

NITRATE OF SODA.

Owing to the differences of opinion held by plantation managers concerning the efficacy of this substance as a fertilizing compound, I wish to give a consideration of this subject some prominence in this report on fertilization, as I believe that the reasons for this difference of opinion can be largely explained.

In the early reports of the Experiment Station, the readiness with which nitrate of soda is taken up by the cane and its corresponding stimulating action on the plant were referred to at some length. We may quote from the Report of 1895, page 29, where Dr. Maxwell says: "Excepting in locations where the water supply is so small as to retard its quick operation, nitrate of soda is not a safe and normal fertilizer—it is not a good ordinary diet for comparatively slow growing plants. Under the average conditions of moisture and warmth, the plant takes it too greedily, and the result often is

abnormal growth. The results of this abnormal growth in cane are bulk, which includes an excess of water and unelaborated products of assimilation, and comparatively less sugar, with low purity of the juice. In wheat and oats the result is lots of straw and little grain. In one case where the manager of a plantation called my attention to a piece of cane, which he called 'very coarse and rank, and would never get real ripe,' I found that 350 pounds of nitrate had been added all at once, and the weather had been such as to allow of the fullest effects. I do not advise nitrate of soda as a regular diet in any situations excepting those of extremely small water supply. I advise nitrate of soda only as a tonic and immediate source of nitrogen in a crisis of a crop, and only in locations of moderate or small rainfall, but never where the rainfall is constant or heavy."

The views of Dr. Maxwell on this subject are clearly set forth, and the advices of the Experiment Station in regard to the use of this material have been largely influenced by his practical observations of field effects following the application of nitrate on plantations.

During the last few months, my attention has been called to the fact that a number of plantations are applying nitrate far in excess of amounts considered safe by the Experiment Station for the normal growth and development of the cane, and reports from these plantations indicate that the cane is doing well. These cases certainly need careful consideration, and a study of the conditions under which nitrate is applied in these instances must necessarily throw considerable light on this important and apparently perplexing problem. Reference has been made to a case where 350 pounds of nitrate, per application per acre, were seen to produce a rank and frothy growth on one plantation where conditions allowed its complete appropriation by the cane. In other instances of more recent observation it is found that 500 pounds, per application per acre, leaves nothing to be desired, the cane presenting not only a vigorous, but a perfectly sound and healthy growth. This apparent inconsistency, I believe may be fully explained,

and the explanation will involve a factor of greater economical significance than the nitrate itself, namely that of water supply.

The properties of nitrate of soda have already been discussed, and its ready solubility and disinclination to become fixed in the soil have received special attention. It was noted in the lysimeter tests referred to on page 13 that the loss of nitrate of soda from over-irrigation reached extremely large proportions and those data will now be of particular value in considering the subject in hand. If a plantation were to use say 500 or 600 lbs. of nitrate, per application per acre, also applying more water to the fields than the soil will hold, the excess of water which drains off is necessarily going to carry from the land, a large percentage of the nitrate of soda, and the nitrate remaining in the soil after irrigation is concluded might be easily reduced to such a quantity that a harmful influence could not be exerted on the crop. In other words the cane would not get all of the nitrate applied and a large percentage of this material together with a large amount of water would be going to waste.

It is seen that such a condition of affairs is possible, and with the light of further data it will be seen to be probable. Where a plantation is using large amounts of nitrate without any signs of an injurious action, and where the water of irrigation is practically free from salt, a view that over-irrigation is practiced can only be based on the non-deleterious action of the nitrate of soda; at the present time sufficient data for a thorough confirmation of this opinion are lacking. But if we take a plantation that is using nitrate of soda in large quantities and is irrigating with water of high salt content, sufficient evidence is at hand to show that a large part of that nitrate is being wasted, and in proportion to the amount of water used over and above what is necessary to saturate the soil. This leads us into a consideration of the salt content of irrigation water and of Hawaiian soils, which subject has a particular bearing on the question before us.

In Bulletin No. 90, U. S. Department of Agriculture, en-

titled "Irrigation in Hawaii," is given a table showing the percentages of salt that have been found in Hawaiian soils, and the resulting condition of cane growing on those lands. The tabulated results are given in full.

SALT FOUND IN HAWAIIAN SUGAR LANDS, AND ITS EFFECT UPON SUGAR CANE.

Sample of Soil	Location.	Salt in Soil. Per Cent.	Condition of Cane.
1....	Highlands .....	.061	Normal.
2....	" .....	.063	Normal.
3....	" .....	.050	Normal.
4....	" .....	.059	Normal.
5....	Lowlands .....	.129	Not wholly healthy.
6....	" .....	.130	Not wholly healthy.
7....	" .....	.155	Quite healthy and normal.
8....	" .....	.181	Yellow in color.
9....	" .....	.181	Yellow in color.
10....	" .....	.460	Small, yellow, stunted.
11....	" .....	.832	Cane white and dying.
12....	Sea bluff land .....	.223	Leaves bleached, cane small.

Another table gives the effect of salt upon the growth of cane, on "three parts of one field which contained different amounts of salt in the soil, the soil in other respects being identical."

FIELD.	Salt in Soil. Per Cent.	Yield of sugar per acre. Tons.
First part.....	0.10	6.0
Second part.....	0.45	1.5
Third part.....	1.00	0.0

It is noticed from the first table that where the salt content of the soil reaches over 0.1 per cent an injurious effect is produced on the cane, soil sample No. 7 with 0.155 per cent being an exception.

We will now consider the amount of salt that is found in some of our irrigation waters and take for an example, the

water of a plantation which is using 1,000 pounds of nitrate of soda per acre, making two applications of 500 pounds each. The manager of this plantation estimates that he is using about 2,500,000 gallons of water per acre for the crop, and this water is found on analysis to contain over 125 grains of salt per U. S. gallon. If 2,500,000 gallons of water are being applied to the acre, with it go 44.642 pounds of salt, during the growth of one crop. If the land in question were not irrigated to a point above saturation practically none of this water would drain off and the salt would remain in the soil. The weight of an acre of soil to a depth of 12 inches is approximately 3,500,000 pounds, and 44.642 lbs. of salt are practically 1.27 per cent of this amount. This would mean that at the end of five or six irrigations the cane would likely sicken and turn yellow. A certain amount of salt is taken up by the cane itself without apparent bad effects, and the percentage remaining in the soil would consequently be lessened but only to a very small degree and not enough to alter these figures to any appreciable extent.

However the cane on this plantation is doing well and the salty water is having no apparent effect, which would indicate that the salt from the water is not reaching a harmful accumulation in the soil. An undue concentration of salt could only have been prevented by an occasional very heavy rain or by an excessive amount of water used in irrigation. For instance let us say that only so much water was added during five irrigations as the soil would take up and hold. Then this water would evaporate from the surface of the soil and be dissipated into the air through the leaves of the cane, leaving the salt behind, and in quantities sufficient to weaken the growth of the cane. If, however, for the sixth irrigation, double the amount should be used as was applied during any of the previous irrigations, the accumulation of salt would be dissolved up and removed in large measure in the drainage from the land.

The soil would then be freed from its injurious amount of

salt and again be suitable for the growth of the cane. This occasional flushing of the land to such an extent is not likely to occur, however, on an irrigating plantation; the chances are in favor of an excess being applied at each watering, and that the amount that drains off from the land during every irrigation is what keeps the salt down below a harmful proportion. The manager of this plantation did not feel that he was using an excess of water, because if he decreased the amount applied, the cane soon showed it. Now on cutting that water down did the cane suffer from too little water or too much salt? To my mind it was more likely the salt which produced the sickening of the cane, because conditions were then made more favorable for an accumulation of that material.

If a soil were irrigated with saline water below a point of saturation, for a number of times, it has been pointed out that the salt solution in the soil necessarily becomes more concentrated and contains a higher percentage of salt than the irrigation water. Providing that the drainage from the land is good and an excess of water can find an outlet through underground or other channels, the more water that is put on in excess of the amount that the soil will hold, the more dilute will become the salt solution in the soil, until a point is reached in which the solution in the soil is practically of the same density as the irrigation water. The more dilute this salt solution is rendered, naturally the more suitable it is for the growth of the cane. But as soils have a high absorptive power for water varying on these islands between 30 and 87 per cent., it is readily seen that after any irrigation where there is much salt in the water, a considerable quantity of that material must necessarily be left behind in the land no matter how much water is applied. When the next application of water is made, the concentrated solution of the soil is added in large measure to the irrigation applied, and the salt percentage of the latter is increased as it passes into the soil, until an amount is added sufficient to leach through the soil and drain off, when the dilution will set in according to the

excess of water applied after that point is reached. It can readily be seen what may happen when the irrigation is cut down in some instances and particularly when it is cut down to such a degree as to allow of no drain from the land whatever. If the supply of water were decreased gradually it is not too much to suppose that before a point is reached at which the cane will suffer from too little water, it will suffer from too much salt.

It has been established as a principle in soil physics that if a continuous and rather heavy rain falls evenly upon the surface of a homogeneous soil, a column of water is formed in the soil which will as it descends displace a salty solution without mixing with it to an appreciable extent. If the drainage of the land were good, the salt solution would be forced out of the soil into the natural outlet. In irrigation as practiced on these islands, however, I believe that the diffusive or diluting action of the applied water would be a more potent factor in removing salt from the land, if the soil were deep and of high absorptive power, than that of mere pressure. This is caused by the water having to be distributed throughout the soil from fewer points of application as compared with rain water, and also by the fact that the salt or salt solution in the hills between the furrows where it is carried by capillarity, could not be forced out by any column of water descending from the cane furrow. However, the question of pressure cannot be omitted entirely in a consideration of the manner in which salt is removed from the lands of irrigating plantations, as its importance will increase with the shallowness of the soil and its inability to hold much water.

We have now seen that a plantation which is using very salty water for irrigation purposes must have a well drained soil, and irrigate quite frequently above saturation, in order that the cane may produce a healthy and normal growth, and we now come to the point upon which this question of irrigation bears from a fertilizing standpoint. Under such conditions what becomes of the nitrate of soda that is applied in such large quantities to the land? As nitrate of soda is an

extremely soluble material and is but slightly fixed in the soil, large amounts must be leached from the land and lost through the excess of irrigation water used under the existing conditions, and it is not unreasonable to suppose that the amount of nitrate remaining in the soil is decreased to such an extent, that the effects of this material on the crop do not correspond with the effects of the same material added in like quantities, but under conditions where the cane may appropriate the full amount.

These points in regard to the use of salty water on our cane lands open up a new field for investigation along the line of irrigation, but a consideration of that matter must necessarily be left out of a report of this nature.

On a plantation where nitrate of soda is being added to the land in considerable quantities at each application, and where the irrigation water contains in solution only a very small amount of salt, we cannot say positively that over-irrigation is practiced, as at the present time data are lacking to substantiate such a view. The fact that such land is able to stand more nitrate than other lands where irrigation is not practiced, but where the full effects of the nitrate are unquestionably obtained, points to the conclusion that an excess of water may in large measure account for this apparent inconsistency. The original nitrogen content of the soils and the size of the crop are naturally factors to be taken into consideration, but they are not sufficient to account for such variations in the behavior of nitrate as we have found in some instances. Unfortunately over-irrigation is not always manifested in a visible drainage from the land. An excess of water in some instances can sink down into a deep soil below a point from which capillarity can raise it, and find an outlet into an underground reservoir, or along impervious strata into the sea.

The necessity of determining the probable loss of nitrate on a plantation such as we have just described would seem to be of more importance than in the case which has already been considered. Not only is there a likelihood of so much nitrate

being lost, but with it is bound up the question of water which, economically, is a matter of greater concern. Where irrigation with brackish water is practiced, more water would necessarily have to be used, than would be the case if the water were "sweet," as an occasional over-irrigation is required. However, in both instances a loss of nitrate and a corresponding loss of water are conditions capable of amelioration, although the degree of conservation of brackish water would vary with its percentage of salt.

On one plantation where nitrate is used in large amounts, the manager informs me that directions are always given to use less water for the first irrigation following an application of nitrate of soda, and this certainly is a good precaution to observe, as in a measure it constitutes a safe guard against the immediate loss of the nitrate. But if we look into this matter more closely, it can be seen that this practice does not insure completely against a considerable loss of this soluble material, although a certain saving would take place, providing of course, that we assume that over-irrigation is the rule, which still remains to be proven. For instance, let us say that 500 pounds of nitrate are applied, and one-half of the water ordinarily used, is applied at the first irrigation following. Then we may feel reasonably certain that none of the nitrate is lost from the land during that irrigation; but the question arises: Can the cane appropriate all of that 500 pounds of nitrate between the time it is applied and the second irrigation following? Such a period we might say would probably cover ten or twelve days at the most, and we may feel sure that all the nitrate could not possibly be assimilated by the cane in that time. What is not assimilated is then liable to waste during the second irrigation and those following.

Although this report is concerned primarily with fertilization, owing to the manner in which soluble fertilizing material may be washed out of the land and lost, the question of over-irrigation must needs be bound up quite closely in an economic consideration of this subject. Through the examination of many soils from various plantations, a wide variation

was found to exist as regards their capacities to take up and hold water, and consequently irrigation requirements were seen to vary within very wide limits in different localities. A comparison of the amounts of water used per pound of sugar produced at the Experiment Station and on several plantations, showed a variation between 859 lbs. at the Experiment Station and five and six times this amount on the plantations ("Irrigation in Hawaii," Maxwell). Such results would seem to indicate that a superfluous amount of water had been used and probably still is being used on many plantations. This question from an economic standpoint is certainly one of the highest importance, and although at the present time we have data that point quite significantly to the fact that there must be a waste in many instances, the amount of irrigation water that can be applied to Hawaiian soils, without waste, has never been determined. The importance of the subject would require that a definite conclusion be reached in every case where the conservation of water is a vital consideration, and I believe that this may be accomplished in a practical manner and on the field to which the water is being applied.

In a deep soil where the drainage is evidently through some underground and invisible outlet, any method for the determination of loss of water must be based on the water absorptive power of the soil. If on such a land we can trace the downward movement of the water, and show that a penetration is reached below a point from which capillarity can raise it, the question of loss is fully solved. When water is applied to the land, it is only when the minute capillary pores of the surface are filled, that those immediately below can take up water, and on becoming saturated allow the water to proceed to depths below them. The downward movement of water in a soil is then characterized by an increasing layer of saturated soil which gradually extends toward the lower levels until an outlet is reached and percolation ensues from hydrostatic pressure. Now if we can follow the extension of this saturated layer and note the time in which it comes in contact with a stratum or suitable medium for drainage, we can say pos-

itively that any water applied after such time is bound to waste from the land.

By the adaptation of an electrical instrument, termed a soil hygrometer, devised by the Division of Soils, U. S. Department of Agriculture, for determining the moisture content of soils, I believe the point referred to above may be fully determined. In describing this soil hygrometer we will quote from an article of Lyman J. Briggs, Department of Agriculture. "This method depends upon the principle that the resistance offered to the passage of an electric current from one carbon plate to another buried in the soil depends upon the amount of moisture present in the soil between the carbon plates and electrodes. This resistance is measured by a suitable instrument designed for this purpose.

The electrical resistance of the soil between the carbon electrodes depends not only upon the amount of water present in the soil, but also upon the quantity of soluble salts dissolved in the water, and upon the temperature. For soils in which the amount of water soluble material is not sufficiently great to interfere with plant development, field experiments appear to show that for any given water content, the amount of salts in solution remains very approximately the same in any given soil. The determinations made by this method rest consequently upon the assumption that the salt content does not change independently of the moisture content. Wherever we have a translocation of salts due to excessive evaporation or seepage, this assumption will not hold. In such cases the fact that a translocation of salts has taken place is shown by gravimetric moisture determinations which should be occasionally made for this purpose; and if the departure from the previous conditions is not great, the error may be easily corrected.

The effect of the change in the soil resistance due to temperature is eliminated by comparing the soil resistance with the resistance of a small cell containing a solution whose electrical resistance changes with temperature at exactly the same

rate as the soil resistance, and which is buried in the soil near the electrode so as to possess always the same temperature as the soil.

The comparison of these resistances is made by an instrument which is a modified form of the well-known Wheatstone bridge method of measuring electrical resistance. The soil resistance and the temperature cell resistance occupy adjacent arms of the bridge, and any change in temperature affects both resistances to the same extent, and so does not change the reading of the instrument."

"The moisture record obtained, consequently deals with the variation in moisture content of the same portion of the soil. This is one of the advantages of the method since it has been shown that the moisture content of a seemingly uniform soil may vary as much as 4 per cent within an area of one square rod. Consequently in order to obtain a consistent record of the change in water content, it is necessary to deal with the same sample of soil, which can only be done by this electrical method."

"We thus see that the electrical method has the advantage of working always with the same portion of soil and furnishes a direct and rapid method of determining the water content after having once been installed."

From the above description an idea may be gained as to the principle of this method for making moisture determinations of the soil in place. In adapting it to meet the requirements of an investigation in respect to the loss of water from the land, these electrodes can be sunk to varying depths in the soil and the movement of water can be traced.

I believe that a number of extremely important facts may be learned from its use on Hawaiian plantations which could not be learned in any other practical way. For instance the amount of water that is lost in irrigation ditches might be determined by noting the depth of soil saturation and the extent of the exposed area. The amount of nitrate of soda that would be held by this amount of water, where that material

is applied as at Kihei, could be calculated with fairly reliable results.

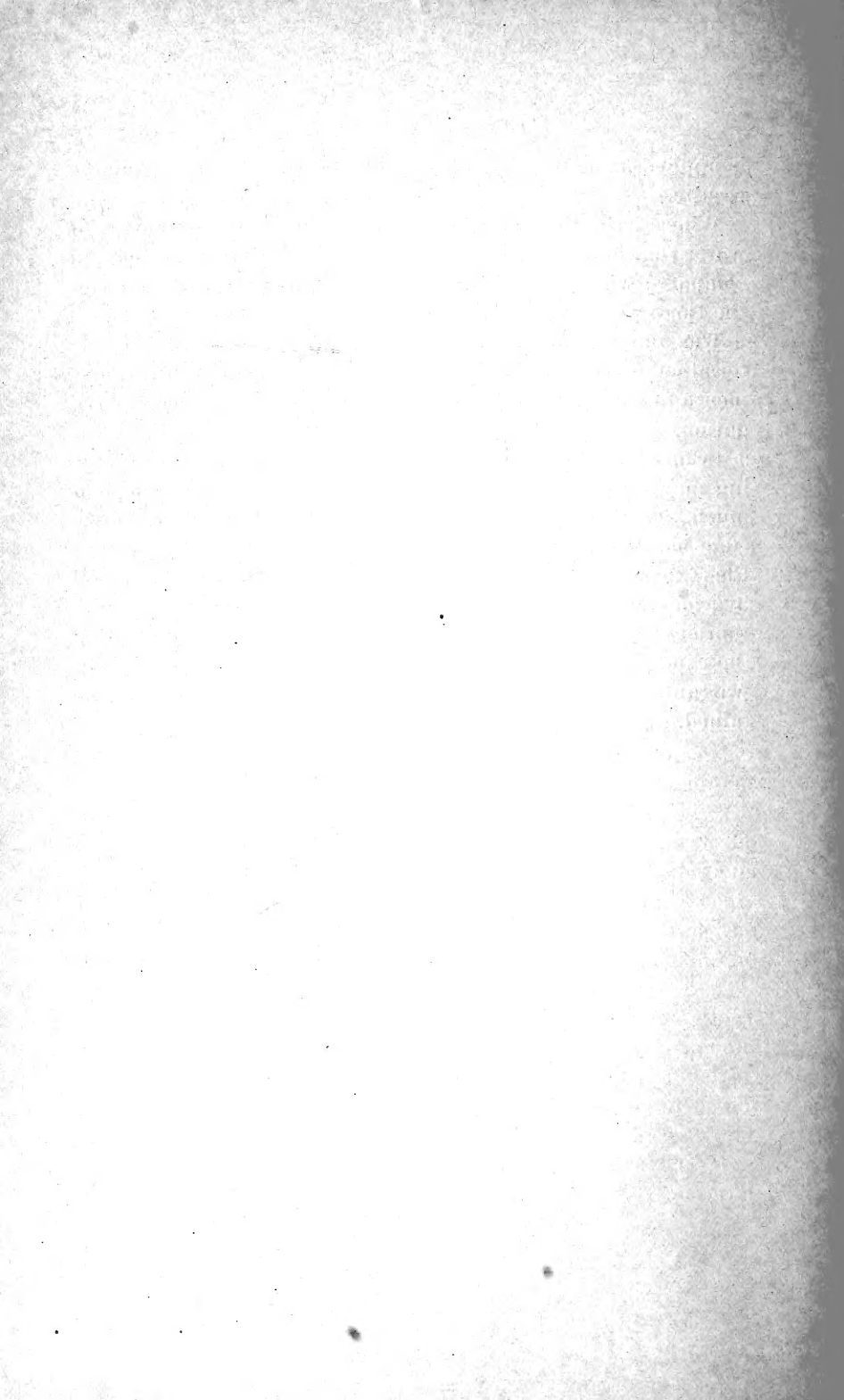
Where irrigation with long rows is the rule, the amount of water that is taken up at the ditch end could be measured and compared with the amount absorbed at the other extremity of the furrow.

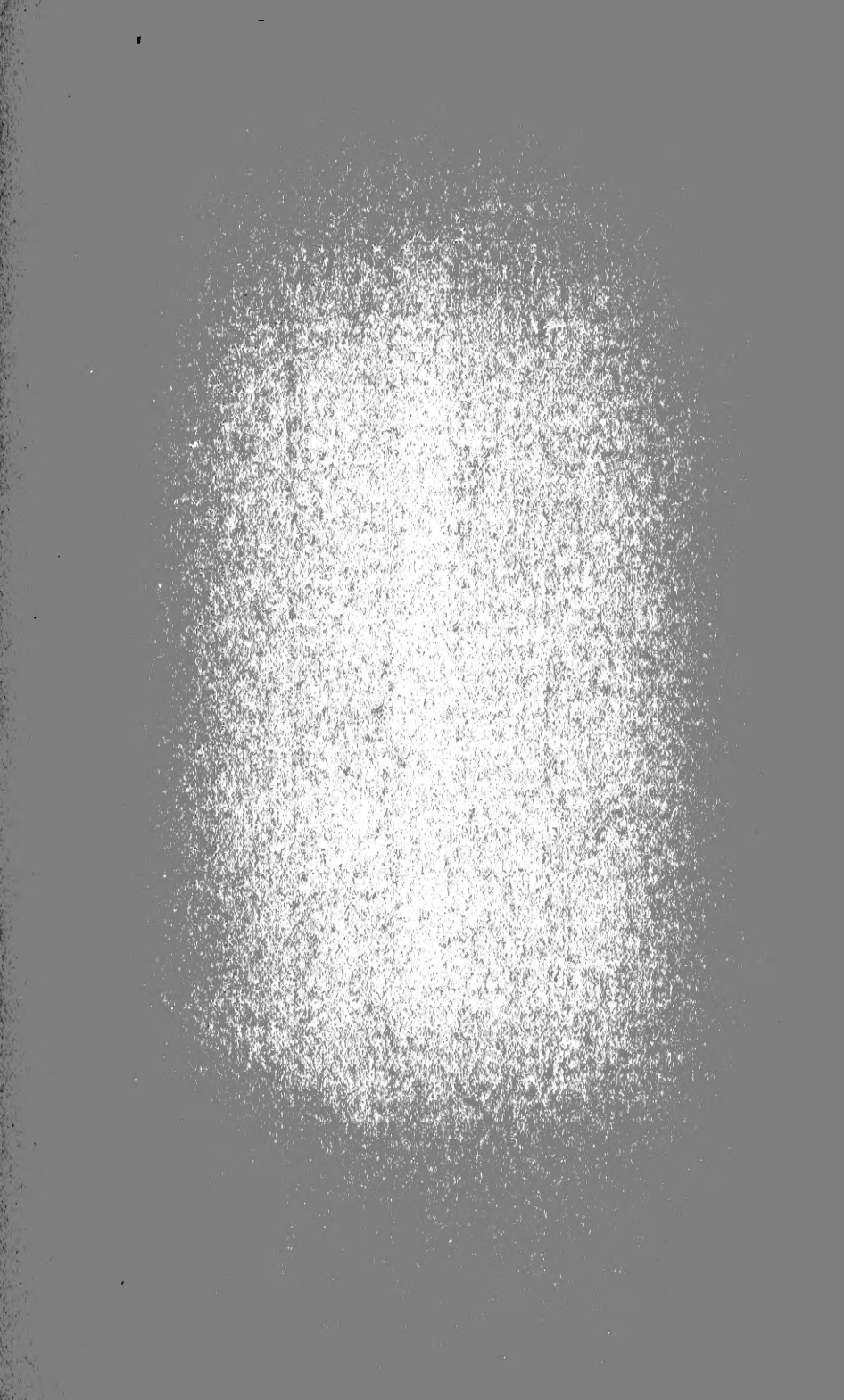
The amount of salt dissolved in waters may also be determined by this method and an insight gained as to the movements of common salt where brackish water is used in irrigation.

In fact, this method would seem to present a means of solving many problems that have heretofore been the subject of much theoretical speculation, but of which our exact knowledge has been rather limited. In conclusion I will say that the Experiment Station is about to procure one of these soil hygrometers and after a thorough trial in the Experiment Station field I would suggest that investigations be conducted on the cane fields of various plantations where conditions would warrant the expectation that valuable results might be obtained.

Respectfully submitted

C. F. ECKART,
Chairman of Committee.





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